TEXAS WATER COMMISSION

BULLETIN 6306

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE RED RIVER, SULPHUR RIVER, AND CYPRESS CREEK BASINS, TEXAS

By

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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 Red River, Sulphur River, and Cypress Creek 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

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RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE RED RIVER, SULPHUR RIVER, AND CYPRESS CREEK BASINS, TEXAS

ABSTRACT

The Red River, Sulphur River, and Cypress Creek Basins, Texas, comprise an area of 31,116 square miles and include all or parts of 54 counties in the northern part of the State from the New Mexico State line to the Arkansas and Louisiana State lines. About 760,000 people reside in the area.

The economy is dependent largely upon the availability and quality of ground water for agriculture and industry. Irrigation is practiced throughout the area as an implement for successful farming on the High Plains and much of the Osage Plains, where the climate is dry-subhumid to semiarid, but chiefly on a supplemental basis in the humid to moist-subhumid eastern region of the West Gulf Coastal Plain. A large part of the industrial development is associated closely with areas of agricultural production and with the production of petroleum and natural gas.

The area ranges in elevation from about 4,500 to about 180 feet and is characterized by the nearly flat elevated surface of the High Plains, the dissected area of low relief of the adjoining Osage Plains, and the gently rolling hills and alluvial lowlands of the West Gulf Coastal Plain. Rocks cropping out range in age from Pennsylvanian to Quaternary and consist of thousands of feet of clastic, carbonate, and evaporite sediments. Deposits of sand, gravel, anhydrite, and gypsum form the aquifers of the area.

Primary aquifers are the Trinity Group, Woodbine Formation, and Wilcox Formation and Carrizo Sand, undifferentiated, in the West Gulf Coastal Plain; the Blaine Gypsum and the Quaternary alluvium in the Osage Plains; and the Ogallala Formation in the High Plains. Included as secondary aquifers are the Blossom Sand, Nacatoch Sand, Mount Selman Formation and Sparta Sand, undifferentiated, and Quaternary alluvium in the West Gulf Coastal Plain; the Cisco and Wichita Groups, undifferentiated, Pease River Group (except for the Blaine Gypsum), and Whitehorse Group of the Osage Plains; and the Dockum Group of the High Plains.

Fresh to slightly saline water is available from all aquifers with the exception of the Blaine Gypsum, which generally contains slightly to moderately saline water. In the other primary aquifers, most of the water in the fresh to slightly saline water-zone is fresh. Secondary aquifers, containing large amounts of slightly saline water, include the Cisco and Wichita Groups, Pease River Group (except for the Blaine Gypsum), Whitehorse Group, and Dockum Group of the Osage Plains and High Plains, and the Blossom Sand of the West Gulf Coastal Plain. The base of the fresh to slightly saline water varies with each aquifer, but is deeper generally in the primary artesian aquifers of the West Gulf Coastal Plain.

About 970,000,000 gallons per day or about 1,100,000 acre-feet of ground water was used in the Red River, Sulphur River, and Cypress Creek Basins in 1959. Of this amount, 93 percent was for irrigation, 4 percent for public supply, and 1 percent for industry. About 2 percent was withdrawn for domestic, livestock, and miscellaneous purposes. The largest withdrawal was from the Ogallala Formation in the heavily irrigated High Plains. In the Osage Plains, large amounts of irrigation water was supplied by the Quaternary alluvium and the Blaine Gypsum. In the West Gulf Coastal Plain, most ground water is supplied by the Carrizo Sand and Wilcox Formation, undifferentiated, the Woodbine Formation, and the Trinity Group, chiefly for public supply and industry.

Water levels are declining in areas of heavy development. The amount of decline varies among aquifers and within aquifers as a result of large withdrawals of water. Discharge of ground water exceeds recharge in the Ogallala Formation of the High Plains, where the aquifer is being dewatered in places as much as 5 feet per year. Declines are less in the Blaine Gypsum and the Quaternary alluvium in the Osage Plains, where, even though large quantities of water are pumped, effective natural recharge partly replenishes the aquifers. Declining artesian pressures rather than dewatering of the aquifers are characteristic of the heavily pumped aquifers of the West Gulf Coastal Plain. Water levels are declining in heavily pumped areas as much as 6-1/2 feet per year in the Trinity Group, 12 feet per year in the Woodbine Formation, and 3.3 feet per year in the Wilcox Formation and Carrizo Sand, undifferentiated. Water levels are declining significantly also in the Blossom and Nacatoch Sands in places of heavy pumpage. In areas remote from heavy pumpage, levels in the artesian aquifers have not declined significantly.

To compute the potential quantity of ground water available in the primary artesian aquifers in the West Gulf Coastal Plain, many assumptions are necessary, chiefly because of the lack of sufficient hydrologic data. One of the assumptions is that water levels would be lowered to a maximum depth of 400 feet along a line of discharge. Based on this and other assumptions, the amount of fresh to slightly saline ground water perennially available from the Trinity Group would be about 6,800 acre-feet and the amount of water released from storage as the water level was lowered to 400 feet would be about 29,400 acre-feet. The amount of fresh to slightly saline ground water perennially available from the Woodbine Formation would be about 11,700 acre-feet, and about 9,000 acre-feet of water would be released from storage as the water level was lowered to 400 feet. About 18,000 acre-feet would be perennially available from the Carrizo Sand and Wilcox Formation, undifferentiated, and the amount of water released from storage as the water level was lowered to 400 feet would be about 27,000 acre-feet.

In the Osage Plains, the amount of ground water pumped from the Blaine Gypsum and Quaternary Alluvium in 1959 was 40,000 and 43,000 acre-feet, respectively. These quantities may be considered perennially available because indications are that discharge probably does not exceed recharge during periods of normal rainfall. In addition, about 5,400,000 acre-feet of ground water in storage in the Quaternary Alluvium was available to wells in 1959. The amount of ground water stored in the Blaine Gypsum is not known.

In the High Plains, about 63,000,000 acre-feet of ground water in storage was available to wells in 1958.

The problem common to almost every aquifer of primary and secondary importance is declining water levels; in some aquifers the declines are regional, in others they are local. In the Ogallala Formation, even though considerable quantities of ground water are still available, the remaining ground-water supply is being depleted at a relatively rapid rate. Large pressure declines in the artesian aquifers of the West Gulf Coastal Plain have lowered water levels to an extent that some wells have stopped flowing and pumps are continually being lowered in wells in some areas, resulting in higher lifting costs and decreases in the efficiency of the wells. Lack of sufficient data in much of the area does not permit a complete appraisal of many of the aquifers. More data need to be gathered and analyzed to ascertain more correctly the ground-water reserves and availability for future development.

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE RED RIVER, SULPHUR RIVER, AND CYPRESS CREEK 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-planning division within the Texas Board of Water Engineers (name changed to Texas Water Commission, January 1962). The act directed that the Board submit a statewide report on the water resources of the State and 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 December 1958. The report states (Texas Board of 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, a cooperative project between the Texas Board of Water Engineers (Commission) and the U. S. Geological Survey was begun in September 1959. The project was titled, "Reconnaissance ground-water investigations in Texas." The Planning Division of the Texas Board of Water Engineers based its approach to water-resource 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 is reporting on the Red, Sulphur, Cypress, Brazos, Upper and Lower Rio Grande, Guadalupe, Nueces, and San Antonio Basins, and on the Gulf Coast region. The Texas Water Commission is reporting on the Canadian, Sabine, Neches, Trinity, Colorado, and Middle Rio Grande Basins. All the reports are scheduled for completion in 1962, except for the Canadian Basin report, which was completed in 1960 (Texas Board of Water Engineers, 1960), the Gulf Coast region report completed in 1961 (Texas Water Commission, 1963), and a report on the Guadalupe, Nueces, and San Antonio Basins, which will be completed in 1963.

The studies of the river basins were to have their principal emphasis on the following items (Texas Board of 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 Red River, Sulphur River, and Cypress Creek Basins in Texas comprise an area of 31,116 square miles, including all or parts of 54 counties in the northern part of the State. The area is bordered on the west by New Mexico, on the north by the Canadian River Basin, Oklahoma and Arkansas, on the east by Arkansas and Louisiana, and on the south by the Brazos, Trinity, and Sabine River Basins. The Red River forms most of its northern border. The area is irregular, ranging in width from about 160 miles to less than 1 mile and averaging about 50 miles. Most of the area is between latitude 32° and 36° north and longitude 94° and 103° west (Figure 1).

Economic Development and Cultural Features

The Red River, Sulphur River, and Cypress Creek Basins constitute 12 percent of the area of Texas and have 8 percent of the State's population, or 760,000. Most of the population is urban. Among the larger centers of population, all or partly in the basins, cities having more than 10,000 population (1960 census) are Amarillo, 137,969, in the western part of the area; Wichita Falls, 101,724; Sherman, 24,988; Denison, 22,748; and Vernon, 12,141, in the central part; and Texarkana, Texas, 30,218; Marshall, 23,846; and Paris, 20,977, in the eastern part. Most of the cities and towns obtain their water from wells.

Agriculture has contributed substantially to the economy. Farming, livestock raising, and dairying are successful because of the fertile soils, and for the most part, a favorable climate. The availability of ground water has been largely responsible for the success of farming in many areas, especially in the drier western part, where irrigation is necessary to sustain crops. In the eastern part, where rainfall is greater, only supplemental irrigation is practiced, thus insuring and maintaining good crop yields. The raising of beef cattle, prevalent in parts of the western half of the area where irrigation is not being practiced, is important to the economy. Dairying is common in the eastern half of the area.

Ground water for irrigation was largely responsible for the economic development of much of the area. In the 1930's and 1940's, cattle raising and dry-land farming gave way to large-scale irrigation farming in parts of the High Plains. Irrigation increased in the High Plains during the drought of the early

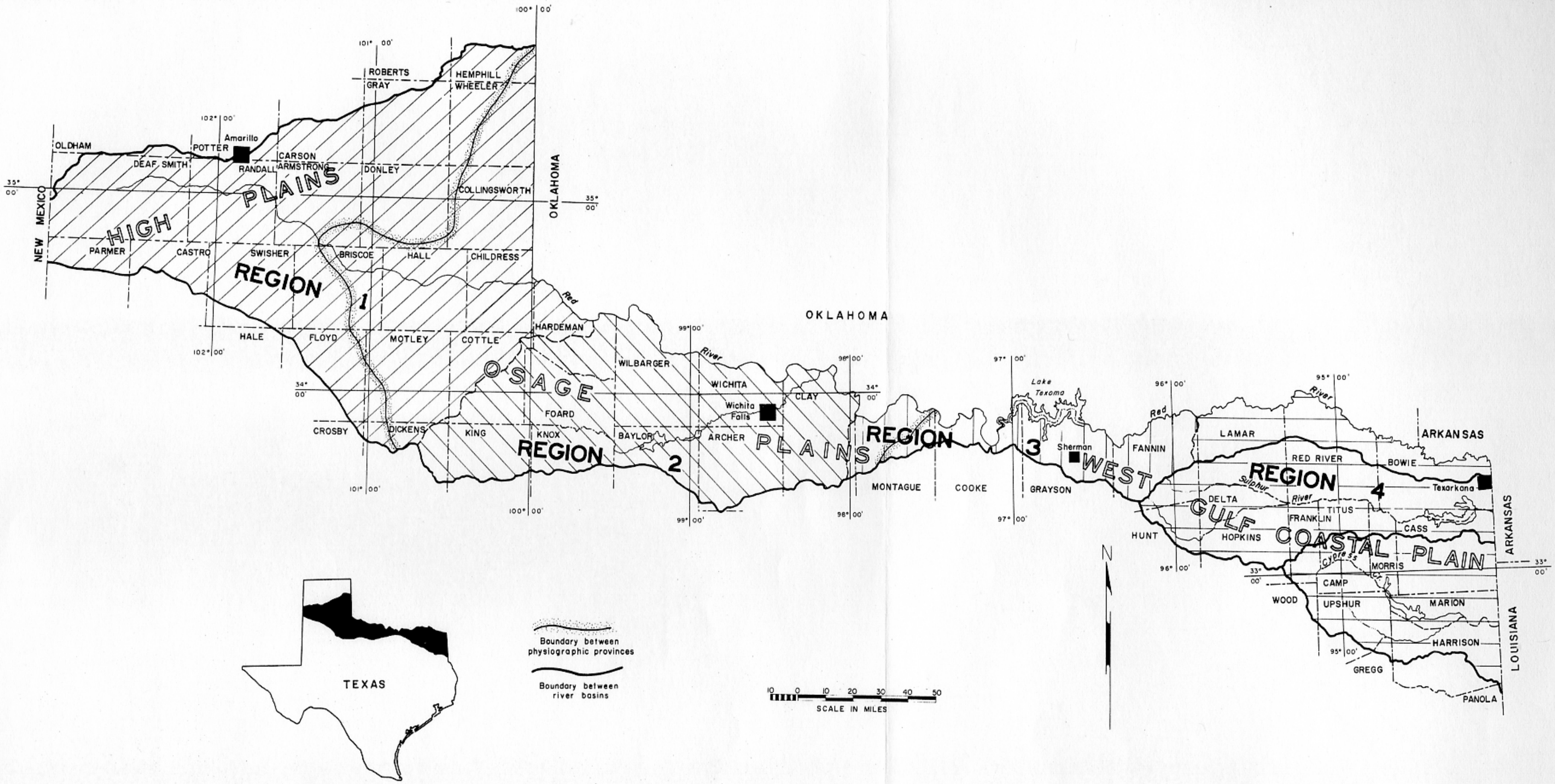

Figure 1

Map of the Red River, Sulphur River, and Cypress Creek Basins Showing Physiographic Provinces

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

1950's, and as of 1962 the High Plains is one of the largest intensively cultivated regions of the State. Irrigation spread throughout the rest of the Red River, Sulphur River, and Cypress Creek Basins as a result of the drought of the 1950's. Large irrigation centers were developed in the west-central part of the area where suitable ground water was available. In the eastern part, where dryland farming is successful, irrigation is used chiefly as a supplement to the usually adequate rainfall. Cotton, grain sorghums, and wheat are the principal crops in the western part, and cotton, corn, and vegetables predominate in the eastern part. According to the Extension Service of Texas A. & M. College (Keese, 1959, p. 1-16), about 1,650,000 acres was under irrigation in the Red River, Sulphur River, and Cypress Creek Basins in Texas in 1959, 98 percent being irrigated by ground water.

Industry in the area is diversified and consumes substantial amounts of ground water. Much of the industrial development is related to the production of oil and gas, and the development of irrigation in places has been facilitated greatly by the abundant supply of natural gas, a cheap fuel. According to the Texas Railroad Commission, about 76 million barrels of crude oil and about 4 million Mc.f. (thousand cubic feet) of gas was produced in 1958, or 8 percent and 3 percent, respectively, of the total for the State. Industries in the area depending on the production of oil and gas include synthetic rubber, carbon black, refineries, petrochemicals, and pipeline companies. A large part of the manufacturing has been closely associated with the areas of agricultural production, and many of the largest manufacturers process local farm products. Several manufacturers are producing food and food products. Other industries include lumber mills and plants related to timber production, power plants, manufacturers of cotton goods and apparel, machinery, furniture, and miscellaneous products.

The report area is served by several rail, air, and bus lines and by many hundreds of miles of paved Federal and State highways and secondary roads.

Methods of Investigation

Fieldwork in the Red River, Sulphur River, and Cypress Creek Basins was done from September 1, 1959, to December 31, 1960. Basic data were collected and assembled by C. A. Armstrong, E. T. Baker, Jr., A. T. Long, Jr., R. D. Reeves, and P. L. Rettman of the U. S. Geological Survey. The basic data included primarily an inventory of the major wells throughout the area. For the purpose of this report, major wells include public-supply, industrial, and irrigation wells having a pumping capacity of 50 gpm (gallons per minute), or more. All public-supply wells were included, regardless of capacity. Total ground-water pumpage was tabulated from the well inventory. Records for other types of wells--domestic, livestock, and miscellaneous--were obtained in selected areas for quality-of-water studies or for use as geologic or hydrologic control points. Other hydrologic data included the chemical analyses of more than 100 water samples collected during the investigation in addition to several hundred analyses of water samples previously collected. The analyses were used in delineating areas of usable water and as a guide in interpreting quality of water from electric logs. Records of changes in ground-water 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 top and bottom of formations, saturated-thickness-of-sand maps, depth-to-water maps, and water-table maps. These maps were prepared from thousands of electric and drillers' logs of wells and water-level measurements, and served as a basis for evaluating the availability of water, water problems, and overall potential of the aquifers.

Well-Numbering System

The numbers assigned to wells and springs in this 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 numbered with 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 a 1-digit number. 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 in 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 54 counties that are all or partly in the Red, Sulphur, and Cypress Basins are as follows:

County	Prefix	County	Prefix	County	Prefix
Archer	AJ	Donley	JA	Marion	SX
Armstrong	AK	Fannin	JS	Montague	TR
Baylor	AU	Floyd	JW	Morris	TU
Bowie	BD	Foard	JX	Motley	TW
Briscoe	BL	Franklin	JZ	Oldham	UH
Camp	BZ	Gray	KS	Panola	UL
Carson	DA	Grayson	KT	Parmer	UR
Cass	DB	Gregg	KU	Potter	UU
Castro	DD	Hale	KY	Randall	UY
Childress	DK	Hall	KZ	Red River	WB
Clay	DL	Hardeman	LD	Roberts	WJ
Collingsworth	DU	Harrison	LK	Swisher	XT
Cooke	HA	Hemphill	LS	Titus	YA
Cottle	HP	Hopkins	LZ	Upshur	YK
Crosby	HK	Hunt	PH	Wheeler	ZB
Deaf Smith	HT	King	RL	Wichita	ZD
Delta	HU	Knox	RS	Wilbarger	ZH
Dickens	HY	Lamar	RT	Wood	ZS

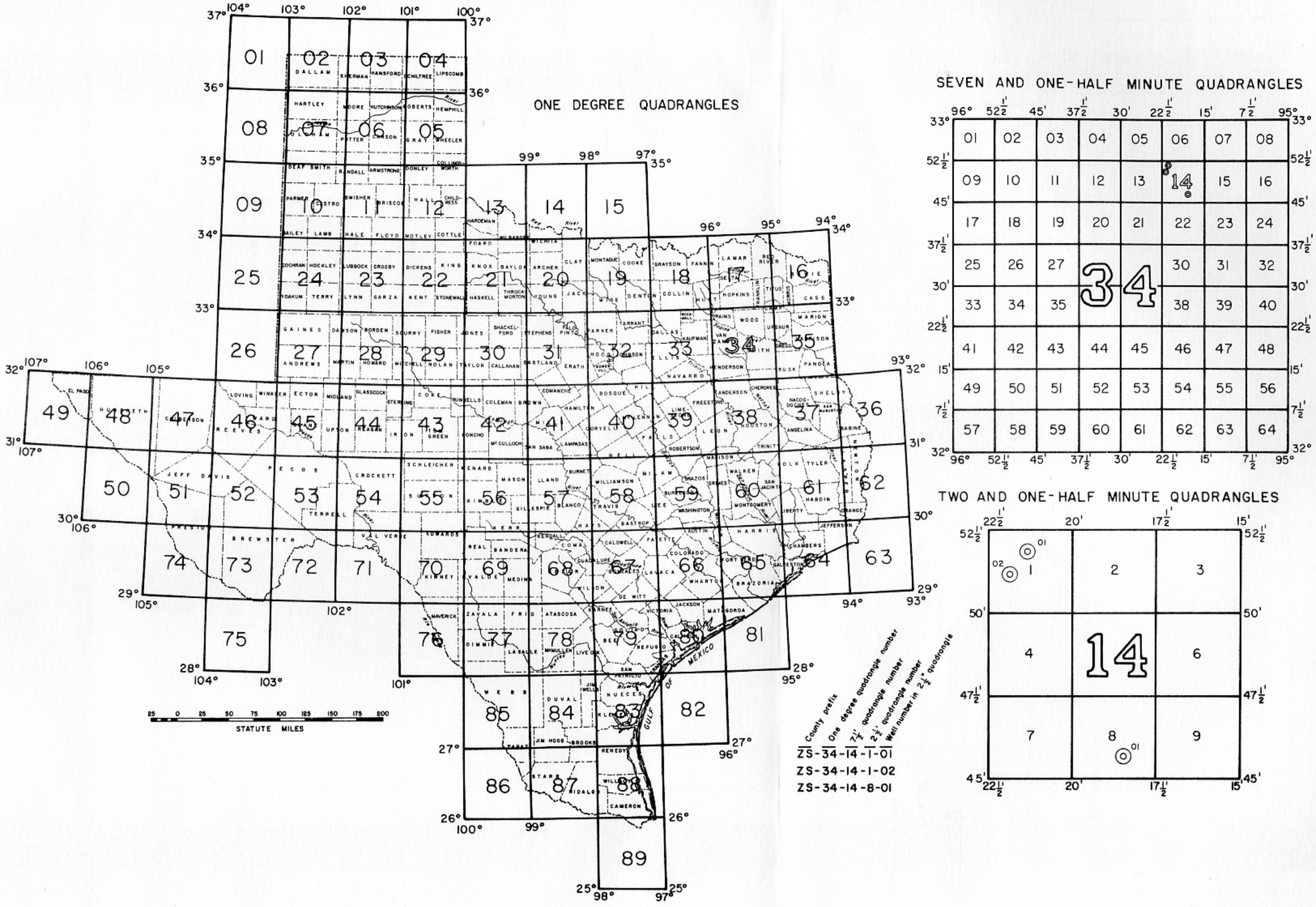

Figure 2

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

In this report only the degrees of latitude and longitude are shown on 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 easily located by identifying the 1-degree quadrangle from Figure 2 and using the degree lines on the individual well maps. Similarly, a well located on a map can be approximately identified by dividing a 1-degree quadrangle into 7-1/2 minute quadrangles.

Previous Investigations

The ground-water resources of much of the Red River, Sulphur River, and Cypress Creek Basins in Texas have been discussed in various reports. (See Selected References.) Among the earliest ground-water studies were those by Taff (1892), Taff and Leverett (1893), Hill (1901), Johnson (1901, 1902), Gould (1906, 1907), Veatch (1906), Gordon (1911, 1913), and Baker (1915). Most of the early ground-water reports were generalized, discussing large areas of several counties. Many, however, served as a basis for later, more detailed reports. During the period 1936-46, 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, included counties in much of the report area. The records of wells, drillers' logs, water analyses, and maps showing locations of wells serve as guides to landowners, officials of industrial plants, well drillers, and others who need basic information regarding wells, the depth to ground water, and the quantity and quality of water yielded by the wells.

Periodic measurements of water levels are made in wells in the principal aquifers of the State through an observation-well program of the Texas Water Commission to evaluate effects of ground-water development in relation to available supply. Records of such measurements in hundreds of wells in many of the counties in the western part of the Red River Basin are available for the period 1936 to 1962. The records, by counties, are published periodically by the Texas Water Commission. Water levels in some observation wells also are published in annual reports of the U. S. Geological Survey on water levels and artesian pressures in the United States.

Numerous other reports on ground water in the area have been published. A series of reports beginning in 1945 give summarized descriptions of the public-water supplies in Texas. Reports on eastern, north-central, and western Texas describe the entire area of the Red River, Sulphur River, and Cypress Creek Basins. Much of the High Plains has been described since 1936 in a series of progress reports on the occurrence of ground water. Many reports discussing local areas smaller than counties have not been published but are in the open files of the U. S. Geological Survey and Texas Water Commission. Recent detailed investigations of the geology and occurrence of ground water in the report area include those for Grayson County (Baker, 1960), Carson and Gray Counties (Long, 1961), and the Southern High Plains of Texas, (Cronin, 1961).

Acknowledgments

The collection of basic data was greatly facilitated by the cooperation of the well owners, well drillers, and personnel of oil companies and ground-water

conservation districts, who gave their time in supplying the necessary records essential to this report. The writers express their appreciation.

GEOGRAPHY

The Red River, Sulphur River, and Cypress Creek Basins are in three physiographic sections--the High Plains section of the Great Plains province, the Osage Plains section of the Central Lowland province, and the West Gulf Coastal Plain section of the Coastal Plain province (Figure 1). The Red River Basin includes all three sections. The Sulphur River and Cypress Creek Basins lie within the West Gulf Coastal Plain section only.

The High Plains section within the Red River Basin is characterized by a nearly flat surface sloping gently southeastward about 10 feet per mile. Among the few and generally insignificant features of relief are saucerlike depressions, ranging in diameter from several tens of feet to about a mile and in depth from a few inches to about 60 feet. The eastern margin of the High Plains is marked by a prominent escarpment, or "breaks of the plains."

The Osage Plains section within the Red River Basin adjoins the High Plains and has as its eastern boundary the westward margin of the gulfward-dipping Cretaceous rocks of the West Gulf Coastal Plain. The Osage Plains section is, for the most part, a gently eastward-sloping plain dissected by prominent systems of drainage. The valleys are wide and are bounded by abrupt escarpments, and the rivers flow in broad, shallow channels. Much of the surface of the area has a definite reddish color.

The West Gulf Coastal Plain section adjoins the Osage Plains and extends eastward throughout the rest of the report area. Low relief and the gentle gulfward slope of the land surface characterize this section. Local topographic features are irregular, rolling, and hilly uplands and flat flood plains and terraces. The streams have wide, nearly flat flood plains bounded by a series of terraces, which may be more than 100 feet higher than the stream channel.

The Red River is formed by the junction of several streams in the southeastern part of the Panhandle of Texas. Tierra Blanca Creek, which drains a large area on the High Plains and is, therefore, considered the continuation of the main stream, has its beginning in the extreme western part of Deaf Smith County and adjacent part of New Mexico at an approximate elevation of 4,500 feet. From this source the stream takes a general southeastward course of about 200 miles across the High Plains and Osage Plains and flows to a point on the east side of Childress County, where it intersects the Oklahoma boundary. Thence, it flows along this boundary about 440 miles and along the Arkansas boundary 40 miles to the northeast corner of Texas.

In its upper drainage across the High Plains, the Red River is little more than a dry channel, which in places is poorly defined and flows only during times of heavy precipitation. Its first perennial flow is in Randall, Armstrong, and Brisco Counties--derived from springs in Palo Duro and other canyons, which are cut to a depth of several hundred feet. East of Grayson County, the river passes through a timbered country of relatively heavy precipitation, and the flow of the stream is augmented by many tributaries. Where it leaves Texas, the flow averages about 9,400,000 acre-feet per year. The principal tributaries of the river in Texas include the Sulphur, Wichita, and Pease Rivers, Cypress Creek, and Salt and North Forks of Red River.

The Sulphur River is formed at the extreme eastern tip of Delta County by the junction of the North and South Sulphur Rivers. The South Sulphur River has its source in south-central Fannin County and flows southeastward and eastward about 60 miles to its junction with North Sulphur River. North Sulphur River has its source in southeastern Fannin County and flows eastward about 50 miles to its junction with South Sulphur River. The Sulphur River, thus formed, flows eastward about 75 miles through heavily timbered country and crosses the Arkansas boundary at the Bowie-Cass County line, joining the Red River in Arkansas about 15 miles to the southeast.

Cypress Creek (Big Cypress Creek) has its source in southeastern Hopkins County and flows eastward and southeastward about 100 miles through heavily timbered country, emptying into Caddo Lake at the Louisiana boundary. Its principal tributary, Little Cypress Creek, has its source in northeastern Wood and southwestern Camp County and flows eastward about 65 miles, joining Cypress Creek about 12 miles west of the Texas State line. Cypress Creek, partly forming the boundary of Marion and Harrison Counties, joins the Red River at Shreveport, Louisiana.

CLIMATE

The climate of the Red River, Sulphur River, and Cypress Creek Basins in Texas ranges from humid to semiarid (Thornthwaite, 1952, p. 32). According to Thornthwaite's classification, which is based on a moisture index, the potential evapotranspiration is compared with the precipitation. Where precipitation is exactly the same as potential evapotranspiration and water is available just as needed, water is neither deficient nor in excess, and the climate is neither moist nor dry. 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.

East of a north-south line near the Cooke-Montague County line, the area of the Red River, Sulphur River, and Cypress Creek Basins has surplus moisture and is characterized by a moist-subhumid to humid climate. West of this line the area is deficient in moisture and is characterized by a dry-subhumid to semiarid climate.

Precipitation ranges widely from an annual mean of about 16 inches in the semiarid western region to about 48 inches in the humid eastern region (Figure 3). The average monthly precipitation at Amarillo, Iowa Park, Denison Dam, and Clarksville are shown in Figure 4. In general, precipitation is greatest during the spring and summer and least during the winter. However, in the eastern part, precipitation tends to be more evenly distributed throughout the year than in the western part. At Amarillo, for example, May, the wettest month, has five times the precipitation of January, the driest. Most of the precipitation is during the growing season, although in much of the semiarid and subhumid region, the amount and distribution of rainfall is usually inadequate to insure good crop yields; successful farming is thus implemented by irrigation. In the moist subhumid to humid regions, precipitation generally is

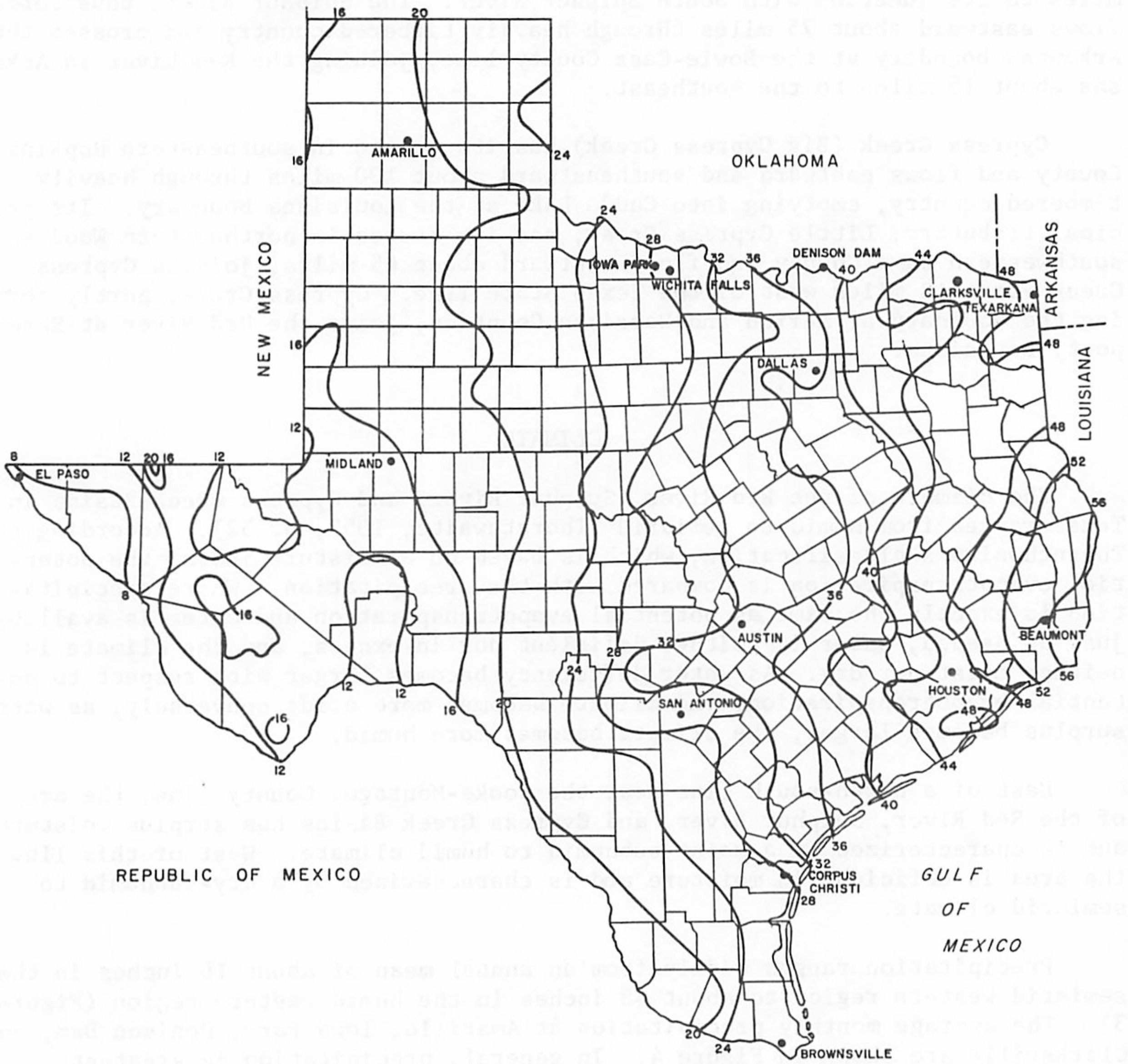

Figure 3

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

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

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

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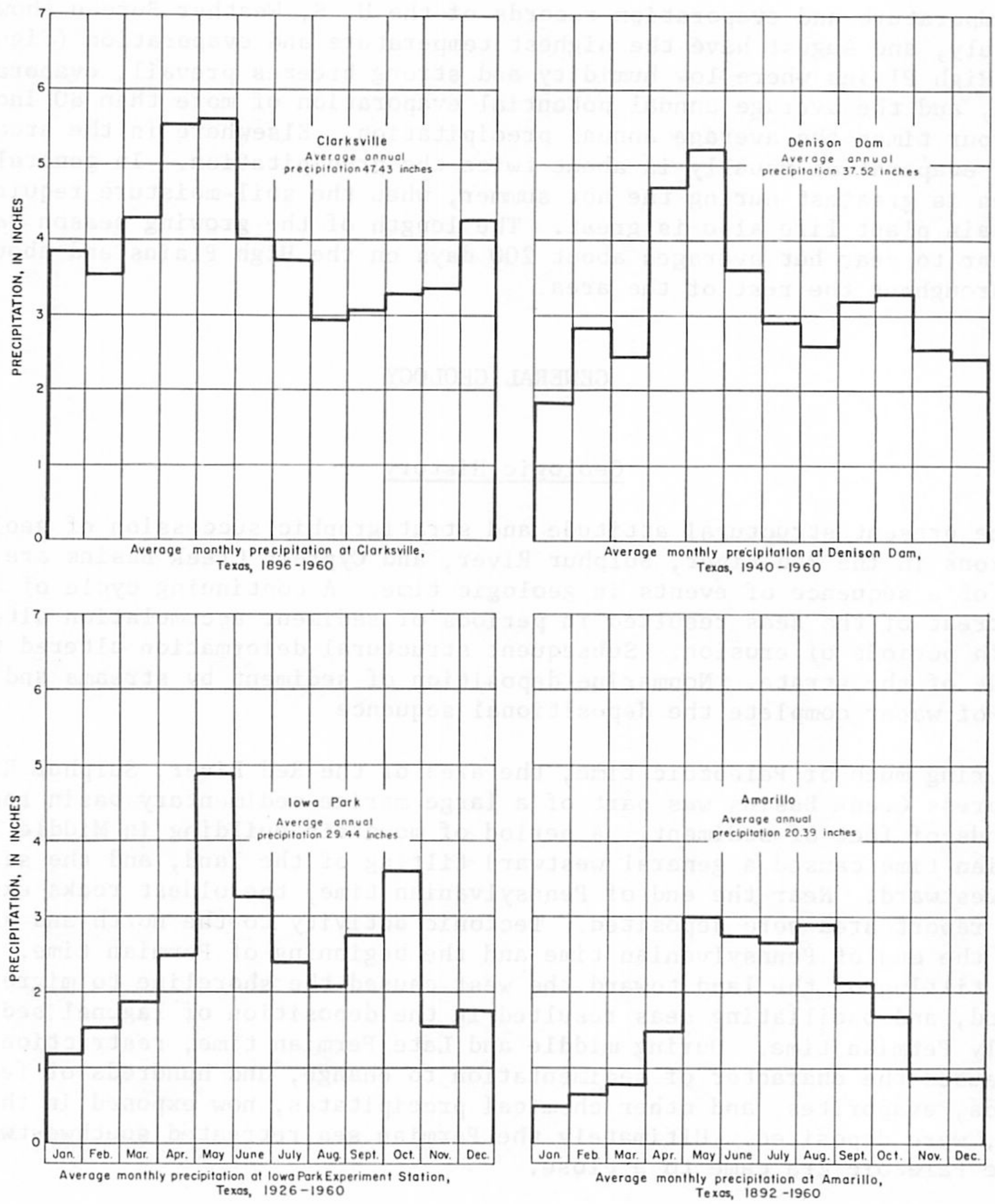

Figure 4

Average Monthly Precipitation at Amarillo, Iowa Park, Denison Dam, and Clarksville

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

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

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sufficient for most dryland farming, although during periods of below-normal rainfall, irrigation is practiced in some areas to prevent the loss of crops.

Temperature and evaporation records of the U. S. Weather Bureau show that June, July, and August have the highest temperature and evaporation (Figure 5). On the High Plains where low humidity and strong breezes prevail, evaporation is high, and the average annual potential evaporation of more than 80 inches is about four times the average annual precipitation. Elsewhere in the area, potential evaporation usually is about twice the precipitation. In general, evaporation is greatest during the hot summer, when the soil-moisture requirement to sustain plant life also is great. The length of the growing season varies from year to year but averages about 200 days on the High Plains and about 228 days throughout the rest of the area.

GENERAL GEOLOGY

Geologic History

The present structural attitude and stratigraphic succession of geologic formations in the Red River, Sulphur River, and Cypress Creek Basins are the result of a sequence of events in geologic time. A continuing cycle of advance and retreat of the seas resulted in periods of sediment accumulation alternating with periods of erosion. Subsequent structural deformation altered the attitude of the strata. Nonmarine deposition of sediment by streams and other bodies of water complete the depositional sequence.

During much of Paleozoic time, the area of the Red River, Sulphur River, and Cypress Creek Basins was part of a large marine sedimentary basin receiving thousands of feet of sediment. A period of mountain building in Middle Pennsylvanian time caused a general westward tilting of the land, and the seas moved westward. Near the end of Pennsylvanian time, the oldest rocks exposed in the report area were deposited. Tectonic activity to the north and south marked the end of Pennsylvanian time and the beginning of Permian time. Continued tilting of the land toward the west caused the shoreline to migrate lowly westward, and oscillating seas resulted in the deposition of lagunal sediments in Early Permian time. During middle and Late Permian time, restriction of the seas caused the character of sedimentation to change, and hundreds of feet of red beds, evaporites, and other chemical precipitates, now exposed in the Osage Plains, were deposited. Ultimately the Permian sea retreated southwestward, and the Palezoic Era came to a close.

The area was a land region at the beginning of the Mesozoic Era and remained above sea level throughout Triassic time. The area probably was exposed to erosion during Early and Middle Triassic time; however, during Late Triassic time, continental sediments several hundreds of feet thick were deposited on the eroded surface of the Permian rocks, their source presumably being the ancestral mountains of southern Colorado. Much of the area remained above sea level in Jurassic time. While the western part of the area was being eroded, northeastern Texas was inundated by Jurassic seas, and several thousand feet of sediments consisting of evaporites, carbonates, and clastics were deposited before the sea retreated gulfward. Although the absence of Jurassic rocks in

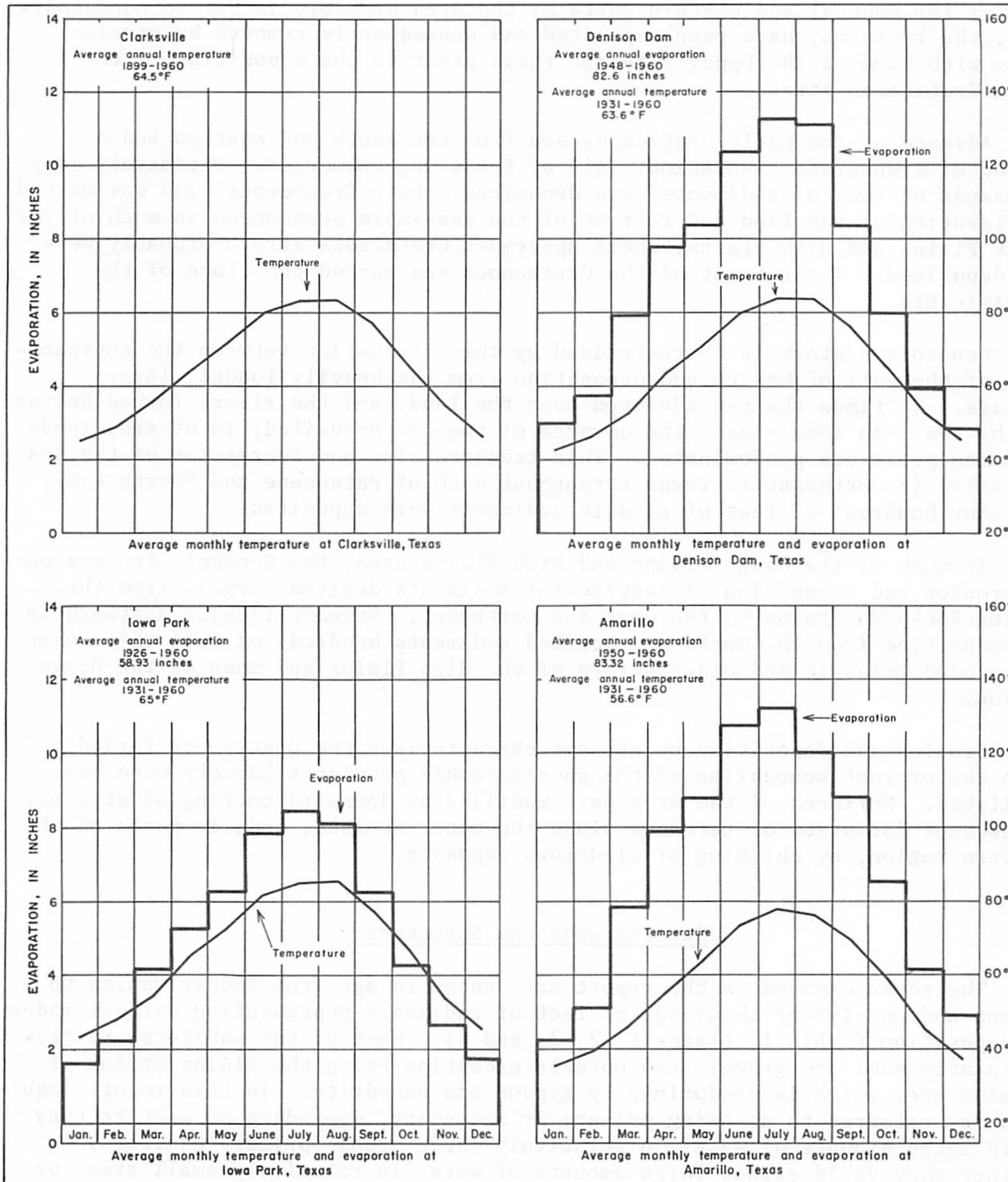

Figure 5

Average Monthly Temperature at Amarillo, Iowa Park, Denison Dam, and Clarksville, and Average Monthly Evaporation at Amarillo, Iowa Park, and Denison Dam

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

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much of the central and western parts of the area probably is due to nondeposition, the rocks may have been deposited and subsequently removed by erosion along with some of the Upper Triassic rocks prior to the deposition of the Lower Cretaceous strata.

Advance of the Early Cretaceous sea from the south and east marked a period of widespread inundation. All of Texas was submerged. Ultimately many thousands of feet of sediments were deposited. Late Cretaceous time was marked by elevation of the land and retreat of the sea--more pronounced in much of the Osage Plains and High Plains, where uppermost Cretaceous strata probably were not deposited. The retreat of the Cretaceous sea marked the close of the Mesozoic Era.

Cenozoic history is characterized by the alternation between the encroachment of the Gulf of Mexico and deposition from the heavily loaded, large streams. At times the sea advanced over the land, and the rivers formed deltas in the sea. In some epochs the advance of the sea prevailed; in others, land-building processes predominated. This transgression and regression of the sea prevailed in northeastern Texas throughout much of Paleocene and Eocene time, and many hundreds of feet of clastic sediments were deposited.

In much of the Osage Plains and High Plains area, the Cenozoic Era was one of erosion and deposition of continental sediments derived largely from the rising Rocky Mountains to the west and northwest. Streams flowing eastward in Pliocene time from the Rockies deposited sediments hundreds of feet thick over the eroded Triassic and older strata of the High Plains and much of the Osage Plains.

Erosion and deposition by streams characterized the Quaternary Period, when the present boundaries of the physiographic provinces largely were established. Surfaces of the area were modified by downward cutting of streams, subsequent formation of terraces along the water courses, and, in parts of the western region, by shifting of windblown deposits.

Stratigraphy and Structure

The rocks exposed in the report area range in age from Pennsylvanian to Recent and consist of thousands of feet of sediments representing various modes of deposition (Table 1, Plates 1, 2, 3, and 4). Most of the aquifers are predominantly sand and gravel, the notable exception being the Blaine Gypsum of Permian age, which is predominantly gypsum and anhydrite. In this report, aquifers are referred to as being 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).

Osage Plains

Rocks ranging in age from Pennsylvanian to Recent are exposed in the Osage Plains, the systems of rocks including Pennsylvanian, Permian, Triassic, and Quaternary. The Pennsylvanian rocks lie on older Paleozoic rocks consisting chiefly of more than 14,000 feet of shale, limestone, dolomite, sandstone, and evaporites. These older rocks do not yield potable water. Of the Pennsylvanian rocks, only the uppermost group, the Cisco, crops out in the report area. The Cisco Group consists of about 1,000 feet of shale, sandstone, fossiliferous limestone, and conglomerate. The Cisco Group does not readily yield water and is a secondary aquifer.

The Permian rocks, nearly 6,000 feet thick, consist, in ascending order, of the Wichita, Clear Fork, Pease River, and Whitehorse Groups and are by far the most widespread strata in the Osage Plains. The Wichita and Clear Fork Groups represent the near-shore and off-shore facies of the Permian sea and consist of about 3,600 feet of shale, sandstone, limestone, dolomite, and evaporites. Of the two groups, only the Wichita is considered to be a significant aquifer. The Pease River Group overlies the Clear Fork Group and consists of about 900 feet of shale, anhydrite, gypsum, limestone, dolomite, and sandstone. The gypsum and anhydrite in the Blaine Gypsum forms a primary aquifer in the Pease River Group. The Whitehorse, which is the uppermost group of the Permian in this area, consists of about 1,200 feet of sandstone, evaporites, shale, and dolomite. The Whitehorse yields small to moderate quantities of water and is a secondary aquifer.

The Quaternary alluvium, including the Seymour Formation of Pleistocene age, consists of sand, silt, clay, and gravel and in places is more than 340 feet thick. It constitutes a primary aquifer in parts of the Osage Plains. Included in the Quaternary alluvium are channel fillings of ancestral streams, terraces, flood plains associated with present-day drainage, and sheets of windblown material.

The regional dip of the Upper Pennsylvanian and Permian strata in the Osage Plains is, in general, toward the west (Plates 5, 6, and 7) about 40 feet per mile. The Quaternary deposits and Triassic strata dip toward the southeast about 15 feet per mile. Although the strata include unconformities, small-scale faults, and local structural features, they have not been affected by any deformation of large magnitude. Among the large structural features of the Osage Plains are the Red River uplift (Figure 6) underlying parts of Foard, Wilbarger, Wichita, Clay, and Montague Counties, and the eastward projection of the Amarillo uplift in parts of Wheeler and Collingsworth Counties.

High Plains

Rocks ranging in age from late Tertiary to Quaternary constitute the surface of the High Plains (Plates 1 and 5). The Ogallala Formation of Pliocene age covers by far the largest area and has a maximum thickness of about 900 feet. The Ogallala, which consists of sand, clay, silt, gravel and caliche, is a primary aquifer. Quaternary deposits of various types and thicknesses overlie a small part of the surface of the Ogallala, chiefly along the eastern margin near the escarpment, and in places they extend into the Osage Plains. The deposits are principally stream-channel fillings, sheets of windblown material, and sand dunes. The thickness of the deposits probably averages 40 to 60 feet. The Quaternary deposits generally are above the water table in the High Plains; they are hydrologically significant in that they serve as a recharge facility to the underlying Ogallala Formation.

Table 1.--Stratigraphic units and their water-bearing properties, Red River, Sulphur River, and Cypress Creek Basins

Era	System	Series	Group	Formation	Occurrence	Thickness (ft.)	Lithology	Water-bearing properties
Cenozoic	Quaternary	Recent and Pleistocene, undifferentiated		Alluvium in Red River Valley, channel fills, sand dunes, and Seymour Formation	Alluvium exposed in regions I, II, III, and IV. Seymour exposed in region I and II.	0- 340+	Stratified sand, silt, clay, and gravel.	Yields small to large quantities of water. Water in Seymour Formation and in alluvium of Red River Valley used chiefly for irrigation. Sand dunes form major areas of local natural recharge.
	Tertiary	Pliocene		Ogallala Formation	Exposed in region I.	0- 900	Sand, clay, silt, gravel, and caliche.	Principle source of water in High Plains. Yields large quantities of fresh to slightly saline water to irrigation, industrial, and public-supply wells.
		Eocene	Claiborne	Sparta Sand	Exposed in region IV.	0- 50±	Stratified sand and clay.	Yields small quantities of water to domestic and livestock wells in Sulphur and Cypress Basins. Not an extensive aquifer in northeastern Texas.
				Mount Selman Formation	Exposed and in subsurface in region IV.	0- 400	Sand, clay, glauconite, lignite, and ironstone.	Yields small to moderate quantities of water chiefly to domestic and livestock wells. Water is typically high in iron content.
				Carrizo Sand	do	0- 100±	Fine to coarse sand in lower part; silt and clay in upper part.	Yields small to moderate quantites of water to wells where sands are thick.
				Wilcox Formation	Exposed and in subsurface in region IV.	0- 800	Fine to medium cross-bedded sand, clay, and lignite.	Principal source of water in eastern part of West Gulf Coastal Plain. Yields small to moderate quantities of water to public supply, industrial, and irrigation wells in large area.
		Paleocene	Midway		do	0- 900	Calcareous clay and limestone and some thin beds of fine sand or silt in upper part.	Not known to yield water to wells.
Mesozoic	Cretaceous	Gulf	Navarro		do	0- 300	Fossiliferous clay and hard limy marl.	Do.
					Nacatoch Sand; do	0- 450	Fine sand and marl; fossiliferous. Sand beds thickest near top; marl predominates near base.	Yields small to moderate quantities of water to public-supply, industrial, and irrigation wells.
				Rocks of Taylor age	do	0- 750	Marl, hard chalk, and sandy marl.	Hard chalk beds yield small quantities of water to shallow dug wells.
				Rocks of Austin age	Exposed in region III and IV. In subsurface in region IV.	0- 400?	Hard fossiliferous chalk and marl.	Hard chalk beds yield small quantities of water to shallow dug wells.
					Exposed and in subsurface in region IV. Blossom Sand	0- 400	Fine to medium fossiliferous sand, marl, and chalky marl. West of central Fannin County the Blossom Sand grades laterally into marl and chalk.	Yields small to moderate quantities of water to public-supply, domestic, and livestock wells on outcrop and short distances downdip. Not an aquifer west of central Fannin County.

(Continued on next page)

Table 1.--Stratigraphic units and their water-bearing properties, Red River, Sulphur River, and Cypress Creek Basins--Continued

Era	System	Series	Group	Formation	Occurrence	Thickness (ft.)	Lithology	Water-bearing properties
Mesozoic	Cretaceous	Gulf		Rocks of Austin age	Exposed in region III and IV. In subsurface in regions III and IV.	0- 400?	Hard fossiliferous chalk and marl.	Hard chalk beds yield small quantities of water to shallow dug wells chiefly in Grayson County.
				Eagle Ford Shale	do	0- 675+	Gypsiferous shale; thin beds of limestone and sand near top.	Yields small quantities of water to domestic wells from upper sands.
				Woodbine Formation	do	0- 600	Medium to coarse cross-bedded furruginous tuffaceous sand, clay, and lignite. More massive beds of sand near base.	Principal source of water in central part of West Gulf Coastal Plain. Yields moderate quantities of water to public-supply, industrial, and irrigation wells.
		Comanche	Washita and Fredericksburg, undifferentiated		Exposed in region III. In subsurface in region III and IV.	0- 925+	Fossiliferous limestone, marl, and clay. Some sand beds near top.	Sand beds near top yield small quantities of water to shallow domestic wells. Limestone beds yield small quantities of water to dug wells.
			Trinity	Paluxy Sand	Trinity Group not differentiated west of Fannin County. Paluxy Sand differentiated in subsurface in regions III and IV.	300?-700?	Fine to medium sand, clay, and some limestone. Sand predominates in upper part.	West of Fannin County, upper part of the Trinity Group, undifferentiated, yields moderate quantities of water to public-supply, industrial and irrigation wells in region III. In Red River County Paluxy Sand yields moderate quantities of water to irrigation wells.
				Glen Rose Limestone	In subsurface in regions III and IV.	0-2,800	Alternating series of fossiliferous limestone, marl, and some sand. Anhydrite beds near middle of formation. West of Fannin County, Trinity Group is predominantly sand and Glen Rose Limestone is not differentiated.	Glen Rose Limestone not known to yield water to wells.
				Travis Peak	Trinity Group not differentiated west of Fannin County. Travis Peak Formation differentiated in subsurface in regions III and IV.	200±-1,800±	Fine to coarse sand, clay, and basal gravel and conglomerate.	West of Fannin County lower part of Trinity Group, undifferentiated, yields moderate quantities of fresh to slightly saline water to public-supply and industrial wells. East of Grayson County no wells are known to tap the Travis Peak Formation.
	Jurassic				In subsurface of region IV.	0-3,500+	Sandstone, shale, limestone or dolomite, and salt.	Not known to yield water to wells.
	Triassic		Dockum		Exposed and in subsurface of region I.	0-1,400+	Shale and sandy shale, crossbedded sandstone, and conglomerate.	Yields small to moderate quantities of water to wells.
Paleozoic	Permian	Guadalupe	Whitehorse		Exposed and in subsurface of regions I and II.	0-1,200+	Fine sandstone, gypsum and anhydrite, shale, and dolomite.	Yields small to moderate quantities of fresh to moderately saline water to public-supply and irrigation wells.
			Pease River	Dog Creek Shale	do	0- 250±	Shale, anhydrite and gypsum, and dolomite. Anhydrite and gypsum commonly cavernous.	Yields small to moderate quantities of slightly to moderately saline water to irrigation wells locally.
				Blaine Gypsum	do	0- 250±	Anhydrite and gypsum, shale, and dolomite. Anhydrite and gypsum commonly cavernous.	Yields moderate to large quantities of slightly to moderately saline water to irrigation wells.
				Flowerpot Shale and San Angelo Sandstone, undifferentiated	Exposed in region II. In subsurface in regions I and II.	0- 400±	Shale, anhydrite, and gypsum. Sandstone, shale, and some gypsum in lower part.	Yields small to moderate quantities of water to wells. Most wells yield slightly to moderately saline water although some fresh water is obtained locally.
		Leonard	Clear Fork		do	0-1,800	Dolomite, limestone, and shale. Some thin beds of anhydrite, gypsum, and sandstone.	Yields small quantities of fresh to moderately saline water to wells.
		Wolfcamp	Wichita		Exposed in regions II and III. In subsurface in regions I and II.	0-1,800±	Shale, sandstone, and fossiliferous limestone. Near outcrop, sandstone is more abundant in lower part than in upper part.	Yields small quantities of water to domestic and public-supply wells. Fresh to slightly saline water extends to greater depths in eastern part of outcrop in Montague County than in western part.
	Pennsylvanian	Upper	Cisco		Exposed in regions II and III. In subsurface in regions I, II, and III. Not known to underlie region IV.	0-1,000±	Shale, sandstone, fossiliferous limestone, and conglomerate.	Yields small quantities of water to domestic and public-supply wells.
		Paleozoic Rocks, undifferentiated			Underlies all of Red River Basin	14,000+	Shale, limestone, dolomite, sandstone, and evaporites.	Not known to yield water to wells.

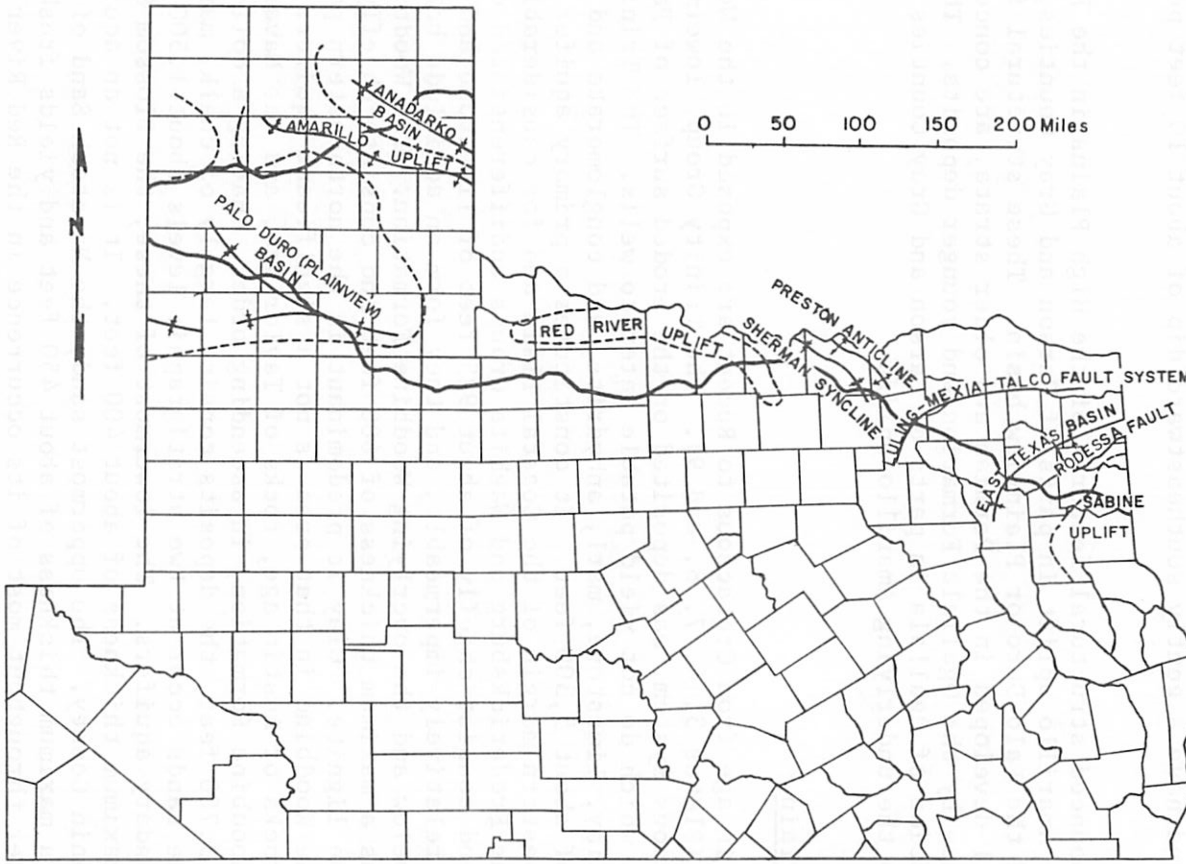

Figure 6

Map of Northern Texas Showing the Major Structural Features of the Red River, Sulphur River, and Cypress Creek Basins

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The Upper Triassic rocks represented by the Dockum Group overlie the Permian strata on the High Plains. They consist principally of about 1,400 feet of shale, sandstone, and conglomerate. Only a small part of the Triassic section is exposed, most of it being covered by Pliocene deposits of the High Plains. The Dockum Group yields small to moderate quantities of water and is a secondary aquifer.

The Cenozoic deposits of the High Plains show no significant structural deformation. They were deposited on an irregular erosional surface of Triassic and Permian rocks and have a gently southeastward dip of about 10 feet per mile (Plate 5).

The most pronounced structural features of the High Plains in the Red River Basin are the Amarillo uplift in parts of Carson and Gray Counties, the Anadarko basin, and the Palo Duro or Plainview basin. These structural features, although well developed in the Permian and older strata, are concealed mostly at the surface by the Ogallala Formation and younger deposits. The relatively thin section of Ogallala in parts of Carson and Gray Counties probably is related to the underlying Amarillo uplift.

West Gulf Coastal Plain

Rocks ranging in age from Cretaceous to Recent are exposed in the West Gulf Coastal Plain (Plates 3, 4, 7, 8, and 9). The Trinity Group, lowermost group of the Cretaceous System, was deposited on the eroded surface of Paleozoic and Jurassic rocks, which do not yield potable water to wells. The Trinity consists of sand, clay, limestone, marl, anhydrite, and conglomerate and has a maximum thickness of about 5,300 feet. It constitutes a primary aquifer in its outcrop along the western margin of the Coastal Plain and for considerable distances downdip. The Fredericksburg and Washita Groups undifferentiated overlie the Trinity Group and consist chiefly of about 925 feet of limestone and marl. These deposits are relatively impermeable, and they form an aquiclude between the Trinity Group below and the overlying Woodbine Formation. The Woodbine, a primary aquifer, has a maximum thickness of 600 feet and consists chiefly of sand, clay, and some lignite. Clay is predominant in the northeastern part of the outcrop, and the Woodbine in that area is not a significant aquifer. The Eagle Ford Shale, rocks of Austin age, rocks of Taylor age, and the Navarro Group overlie the Woodbine Formation, in ascending order. Having a collective thickness of about 3,700 feet, the deposits consist largely of chalk, marl, clay, and sand. The sands occur at two stratigraphic levels about 1,500 feet apart and form secondary aquifers. The lowermost of these, the Blossom Sand of Austin age, has a maximum thickness of about 400 feet. It is not an aquifer west of central Fannin County. The uppermost sand, the Nacatoch Sand of the Navarro Group, has a maximum thickness of about 450 feet and yields fresh to slightly saline water throughout most of its occurrence in the Red River Basin and in a part of the Sulphur River Basin.

The Tertiary rocks in the West Gulf Coastal Plain are, in ascending order, the Midway Group, Wilcox Formation, and Claiborne Group. With the exception of the Midway Group, which consists mostly of clay and is about 900 feet thick, the Tertiary sediments are largely sand. The Carrizo Sand and Wilcox Formation together form a primary aquifer. The Carrizo and Wilcox have a maximum thickness of about 900 feet and consist of sand and subordinate amounts of clay.

The Mount Selman Formation and Sparta Sand, the youngest deposits of Tertiary age, have a maximum thickness of about 450 feet and consist chiefly of sand and clay. The deposits as a unit constitute a secondary aquifer.

Quaternary deposits of the West Gulf Coastal Plain include flood-plain and terrace material consisting of sand, silt, and clay associated with the Red River and to a lesser extent with the Sulphur River. Flood plains and lower terrace deposits along the Red River, although isolated in places, are secondary aquifers. Their maximum thickness may be more than 100 feet in places.

The Cretaceous and Tertiary strata exposed in the West Gulf Coastal Plain show effects of moderate structural deformation. Regionally these strata dip eastward and southward, the dip decreasing from an average of about 75 feet in the Trinity Group to about 25 feet in the Wilcox Formation. The principal structural features of the area are the East Texas basin, Sabine uplift, Preston anticline, Sherman syncline, the Luling-Mexia-Talco fault system, and the Rodessa fault. Noteworthy among the buried structural features affecting primarily the Paleozoic rocks is the eastward extension of the Red River uplift.

The East Texas basin trends northeast-southwest, the axis passing through Cass, Morris, Upshur, and Wood Counties. The basin is bordered on the southeast by the Sabine uplift, the northwestern part of the uplift extending into parts of Marion and Harrison Counties. The structural features interrupt the normal gulfward dip of the Cretaceous and Tertiary strata causing reversals of dip to the north and west on the flank of the Sabine uplift. Uplift and erosion during the early growth stages of the Sabine uplift have caused the removal of hundreds of feet of Lower and Upper Cretaceous strata in the basin. Occasional uplifts since, accompanied by continued downwarping of the basin contemporaneous with deposition, have caused thinning and thickening of much of the Cretaceous and Tertiary strata in the area.

In Grayson and Fannin Counties, the Preston anticline and Sherman syncline, plunging southeastward, have deflected the Cretaceous strata sharply to the southeast. The structural features were factors that created local problems of ground-water quality in the area.

The Luling-Mexia-Talco fault system, trending along the Cretaceous-Tertiary contact, acts as a barrier to the normal gulfward movement of ground water in many of the aquifers of Cretaceous age. The faults, having displacements commonly of 300 to 500 feet, mark the southward limit of fresh to slightly saline water in the Nacatoch Sand. The Rodessa fault on the northwest flank of the Sabine uplift and the part of the Luling-Mexia-Talco fault system that cuts the aquifer of the Carrizo and Wilcox on the surface probably act as a partial barrier to the movement of water.

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 Red River, Sulphur River, and Cypress Creek 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 and evaporite rocks, such as limestone and gypsum deposits--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 and 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.

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 en route 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

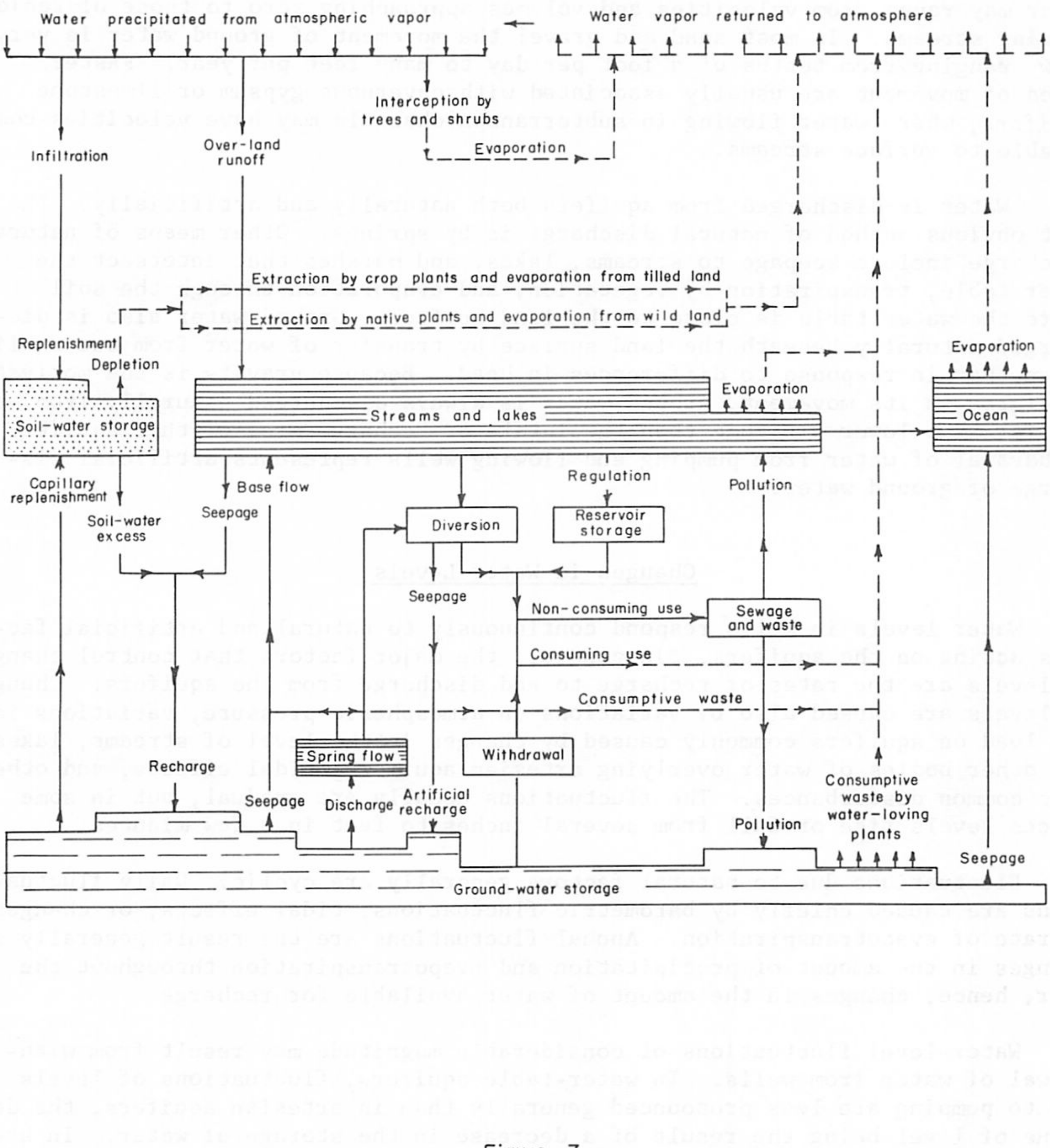

Figure 7

The Hydrologic Cycle in the Red River, Sulphur River, and Cypress Creek Basins

(Modified from Piper, 1953, p. 9)

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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 are usually associated with cavernous gypsum or 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 obvious 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.

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 8 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 ft. 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.

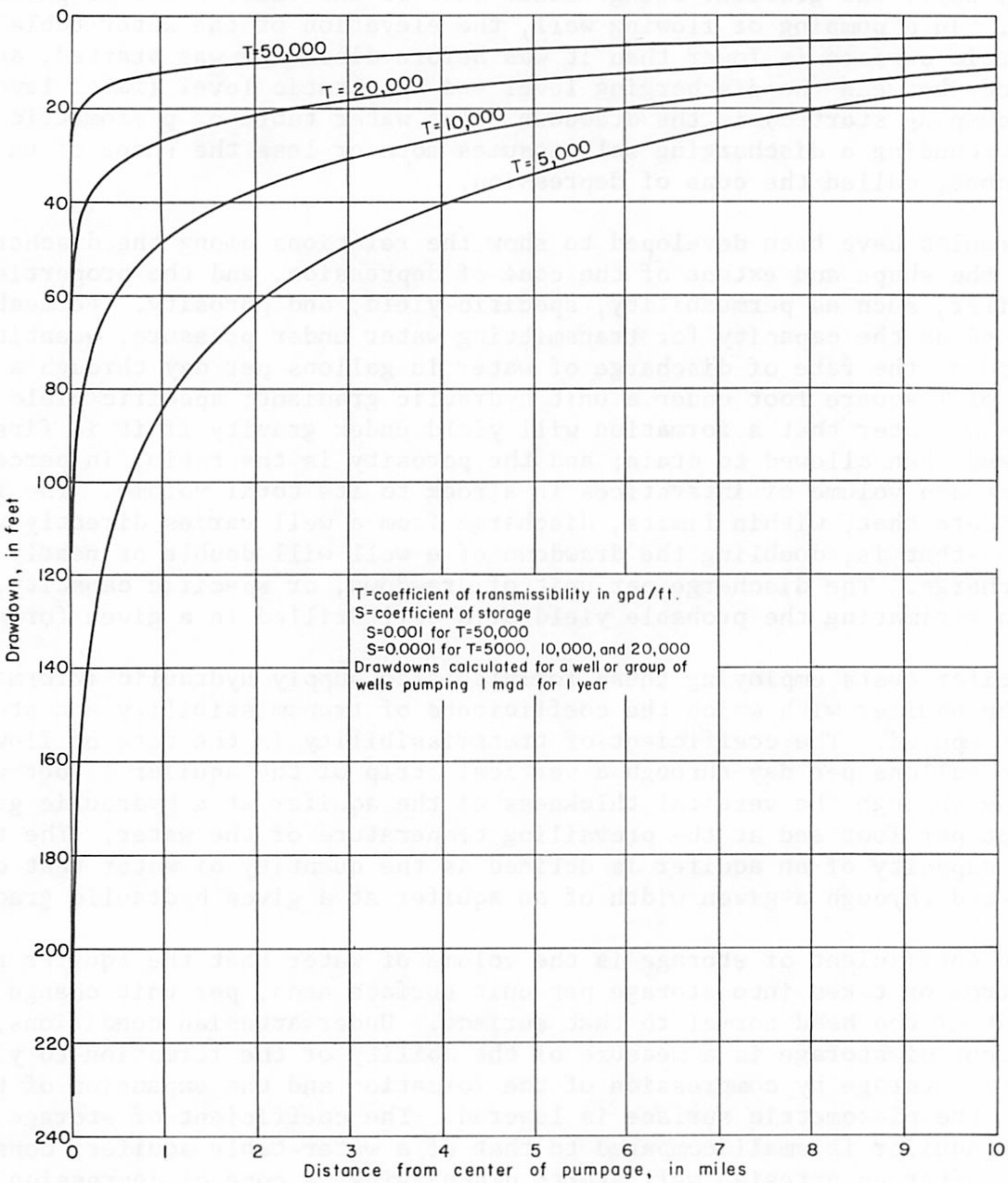

Figure 8

Graph Showing Relation of Drawdown to Transmissibility

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Figure 9 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 time-drawdown relation when a line source of recharge is 20 miles from the point of discharge.

Figure 10 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 aquifer because of the larger coefficient of storage, other factors being 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.

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 contemplated 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

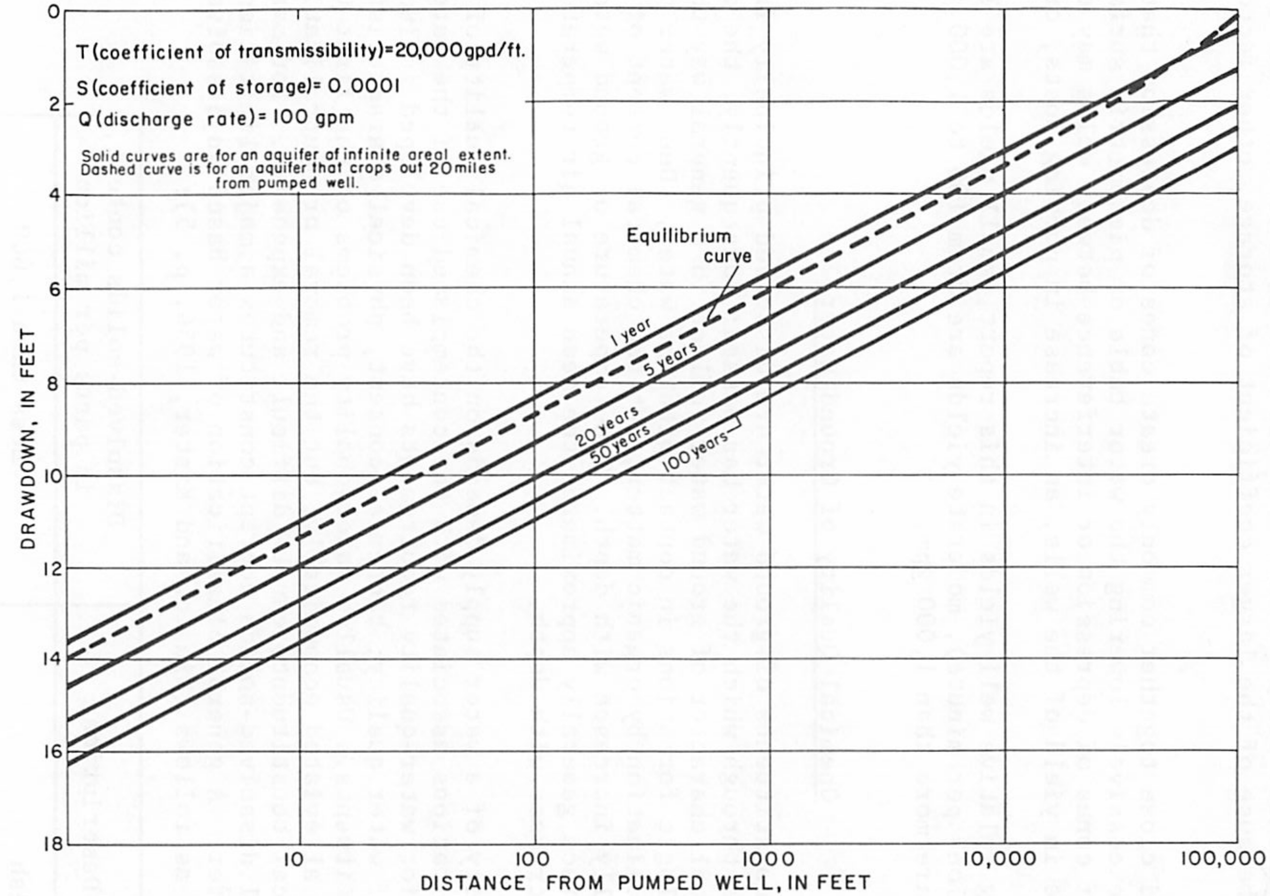

Figure 9

Graph Showing Relation of Drawdown to Time in an Artesian Aquifer

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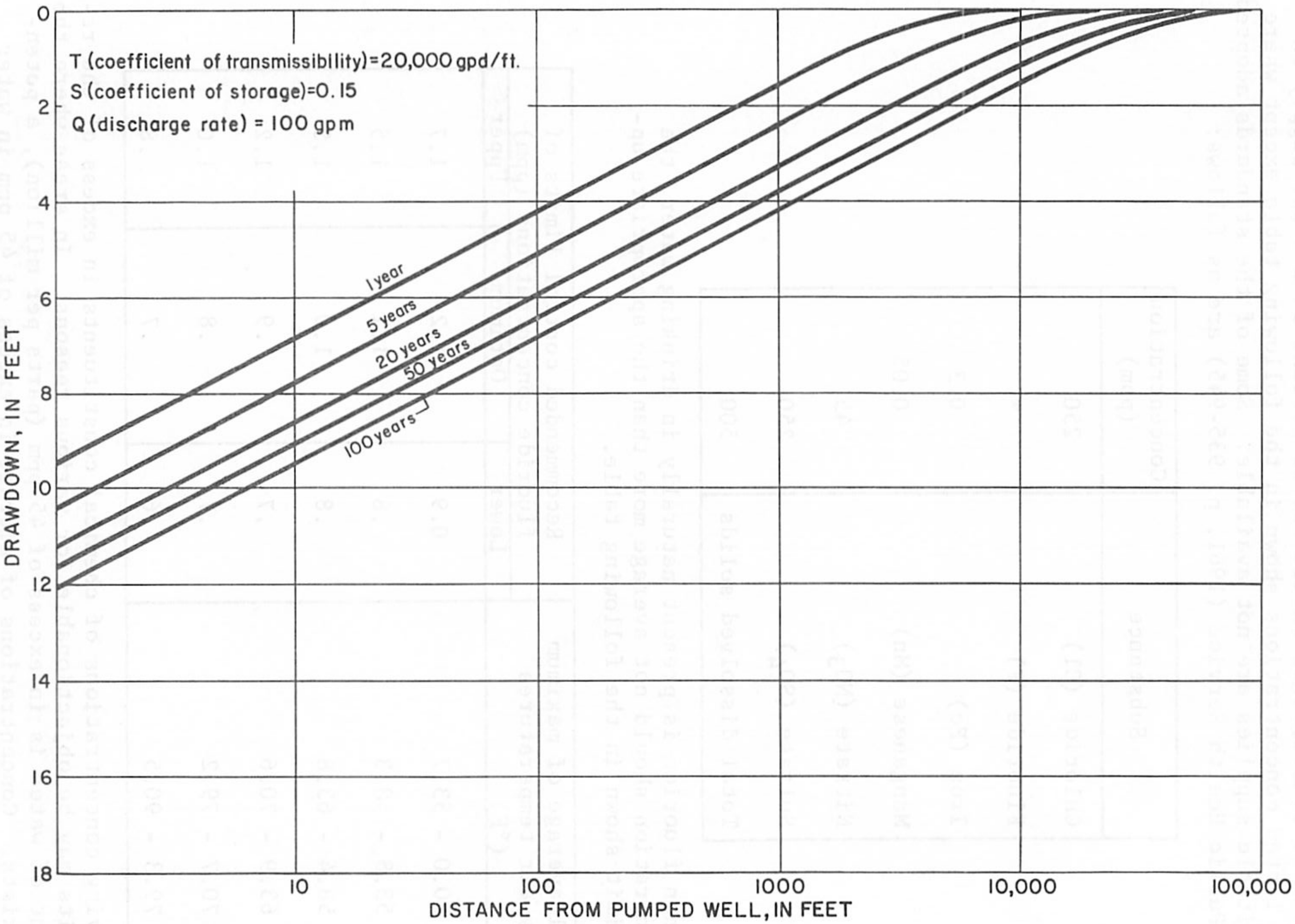

Figure 10

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

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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 (1961, p. 935-945) are as follows:

Substance	Concentration (ppm)
Chloride (Cl)	250
Fluoride (F)	*
Iron (Fe)	0.3
Manganese (Mn)	0.05
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 (methemoglobinemia or "blue baby" disease), a reduction of the oxygen content in the blood constituting a form of asphyxia (Maxcy, 1950, p. 271). High concentrations of nitrate may be an indication of pollution from organic matter, commonly sewage. 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 adversely affect 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, especially 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 a 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 sodium-adsorption ratio (SAR). This classification of irrigation water is diagrammed in Figure 11.

Wilcox (1955, p. 15) stated that the system of classification used by the Salinity Laboratory Staff "...is not directly applicable to supplemental waters used in areas of relatively high rainfall." Thus, in the eastern part of the Red River Basin and in all of the Sulphur River and Cypress Creek Basins, the system probably is not directly applicable.

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. His suggested permissible limits of boron for irrigation waters are shown in the following table:

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

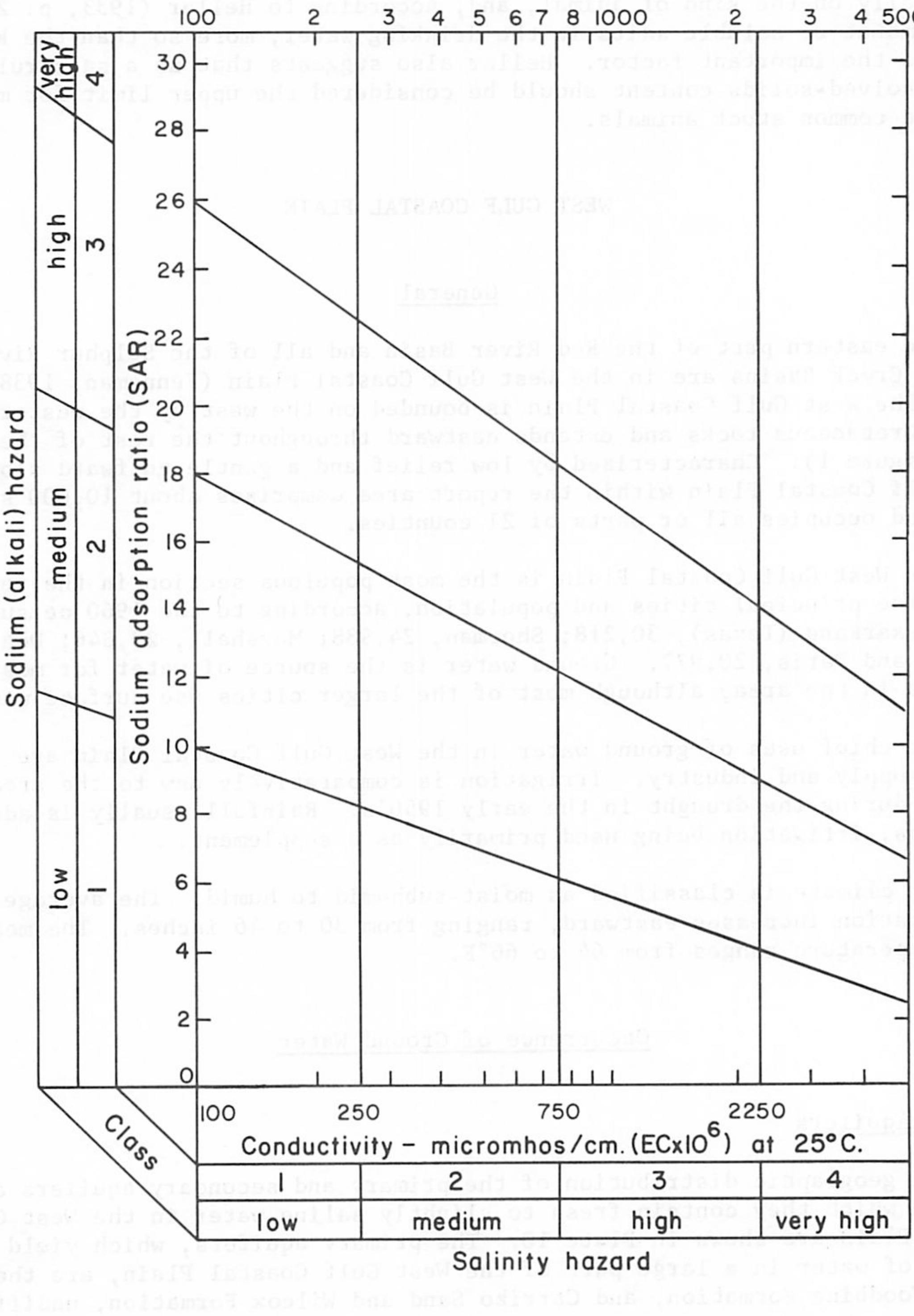

Figure 11

Diagram for the Classification of Irrigation Waters

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

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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.

WEST GULF COASTAL PLAIN

General

The eastern part of the Red River Basin and all of the Sulphur River and Cypress Creek Basins are in the West Gulf Coastal Plain (Fenneman, 1938, p.100-120). The West Gulf Coastal Plain is bounded on the west by the western margin of the Cretaceous rocks and extends eastward throughout the rest of the report area (Figure 1). Characterized by low relief and a gentle gulfward slope, the West Gulf Coastal Plain within the report area comprises about 10,000 square miles and occupies all or parts of 21 counties.

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 Texarkana (Texas), 30,218; Sherman, 24,988; Marshall, 23,846; Denison, 22,748; and Paris, 20,977. Ground water is the source of water for most public supplies in the area, although most of the larger cities use surface water.

The chief uses of ground water in the West Gulf Coastal Plain are for public supply and industry. Irrigation is comparatively new to the area, beginning during the drought in the early 1950's. Rainfall usually is adequate for crops, irrigation being used primarily as a supplement.

The climate is classified as moist-subhumid to humid. The average annual precipitation increases eastward, ranging from 30 to 46 inches. The mean annual temperature ranges from 64 to 66°F.

Occurrence of Ground Water

Primary Aquifers

The geographic distribution of the primary and secondary aquifers and the areas in which they contain fresh to slightly saline water in the West Gulf Coastal Plain are shown in Plate 10. The primary aquifers, which yield moderate amounts of water in a large part of the West Gulf Coastal Plain, are the Trinity Group, Woodbine Formation, and Carrizo Sand and Wilcox Formation, undifferentiated.

Trinity Group

Physical Description

The Trinity Group crops out in the Red River Basin in Texas, principally in eastern Montague County and western Cooke County, and in places in northern Grayson County along the Preston anticline, where it has been exposed by uplift (Plate 3 and Figure 6). Much of the northernmost outcrop, trending east and west, is in Oklahoma and Arkansas. South and east of its outcrop where water-table conditions prevail, the Trinity Group dips beneath younger rocks and is present throughout the subsurface as an artesian aquifer.

The Trinity Group is divided into the Paluxy Sand, Glen Rose Limestone, and Travis Peak Formation, in descending order. The division applies only to the area south and east of a northeast trending line representing the updip limit of the Glen Rose Limestone through central Fannin County. North and west of the line, the Trinity Group is almost all interbedded sand and clay and is, therefore, not divided into formations (Plate 7). Most of the fresh to slightly saline water is in this part of the Trinity Group.

The undivided Trinity Group, as defined above, consists of basal conglomerate and gravel overlain predominantly by fine to coarse white to light-grayish poorly consolidated massive crossbedded sand interbedded with red, purple, and gray clay. The beds of clay generally are in the form of lenses that are neither continuous nor extensive over large areas and, thus, are not effective barriers to the movement of ground water except perhaps locally. The thickness of the undivided Trinity Group ranges from about 450 feet near the outcrop in Cooke County to about 1,000 feet near the updip limit of the Glen Rose Limestone in Fannin County (Plate 7).

The Paluxy Sand underlies the area south and east from the updip limit of the Glen Rose Limestone. It does not crop out in the report area, but is exposed a few miles north of the Red River in Oklahoma and Arkansas. The Paluxy Sand on the outcrop consists of reddish-brown to light-gray and white rounded well-sorted unconsolidated crossbedded sand interbedded with thin lenses of gray clay. In the subsurface in Texas, the sand generally is light gray to red and fine to medium. The more massive sand beds are in the upper part of the formation. Near the base, the sands are less dominant, and some limestone beds are present. The thickness of the Paluxy Sand changes rapidly in a distance of a few miles. In much of the area, the thickness ranges from 300 to 700 feet, although in places the Paluxy Sand may be less than 300 or more than 700 feet thick.

The Glen Rose Limestone, consisting of alternating beds of limestone, marl, anhydrite, and some sand, and the Travis Peak Formation, consisting of fine to coarse sand, clay, basal conglomerate, and gravel, do not crop out in the report area; but they are present in the subsurface south and east of central Fannin County, where they have a maximum aggregate thickness of about 4,600 feet. Neither the Glen Rose Limestone nor the Travis Peak Formation contain significant amounts of fresh or slightly saline water.

The Trinity Group dips east and south, the magnitude of dip ranging widely (Plates 11 and 12). Generally, however, in areas of undistrubed rocks, the dip ranges from 45 feet per mile to the east in Cooke and Grayson Counties to 100 feet per mile to the south from Fannin to Bowie Counties (Plates 7, 8, and 9). Locally, in parts of Grayson County on the south flank of the Preston anticline, the Trinity Group dips southward in excess of 300 feet per mile. In the northern part of Hunt County, where the Trinity Group contains its deepest fresh to slightly saline water, the depth to the top of the formation is about 3,700 feet.

Recharge, Movement, and Discharge of Ground Water

The Trinity Group is recharged primarily by precipitation on the outcrop. The outcrop, about 15 miles wide in Cooke and Montague Counties and about 10 miles wide in Oklahoma and Arkansas, is chiefly a loose, friable sand affording favorable conditions for infiltration of rainfall. The average annual precipitation along the outcrop ranges from 34 to 48 inches, but only a small fraction of this amount becomes recharge.

The Red River crosses the outcrop of the Trinity Group in Cooke County, and Lake Texoma is in contact with the group in Grayson County. In Cooke County, the Red River probably is effluent--that is, the Trinity is discharging to the river. Similar conditions existed in Grayson County prior to the formation of Lake Texoma; however, since the impounding of water in the lake in 1943, water from the lake is recharging the sands of the Trinity Group, and has saturated about 80 feet of previously dry material (Baker, 1960, p. 40).

The movement of ground water in the Trinity Group has two horizontal components of direction. From the recharge areas in Montague and Cooke Counties, ground water is moving eastward through Cooke and Grayson Counties. From the recharge areas in the outcrop in Oklahoma and Arkansas, the water moves generally southward. Locally, in northern Grayson County, where water from Lake Texoma enters the Trinity, the movement is southward toward the heavily pumped Sherman area. The present rate of movement in the Trinity Group in Grayson County was estimated to be 1 to 2 feet per year (Baker, 1960, p. 37). The presence of fresh to slightly saline ground water in the Paluxy Sand south of a wedge of more highly mineralized water in Fannin, Lamar, and Red River Counties (Plates 8, 9, and 10) suggests that water probably is moving from the outcrop in Oklahoma and Arkansas southwestward along zones of higher permeability outlined by the area of fresh to slightly saline water. The movement of ground water presumably is impeded to a large degree by low permeabilities of the Paluxy Sand in the wedge of highly mineralized water. The wedge of highly mineralized water extends into McCurtain County, Oklahoma, where, according to Davis (1960, p. 29, 79), a part of the water in the Paluxy Sand, including that in the outcrop, is saline.

Pumpage from wells constitutes the principal discharge from the Trinity Group. In 1959, about 3,000 acre-feet was pumped from the Trinity Group in the Red River Basin in Texas.

Ground water is discharged from the Trinity Group naturally by seeps and springs, probably in the valley of the Red River in Cooke County. Some upward migration of water along or across fault planes in the Luling-Mexia-Talco fault system is probable, although most of the water in the Trinity at the fault system is highly mineralized. In Montague County and parts of Cooke County, the presence of fresh or slightly saline water in the Wichita and Cisco Groups beneath the Trinity probably is due to discharge from the Trinity.

Chemical Quality

The area of occurrence of fresh to slightly saline water in the Trinity Group is shown in Plate 10. The area is mostly in the Red River Basin, although a rather large part is in the northwestern part of the Sulphur River Basin. Most of the water in the zone of fresh to slightly saline water is fresh, containing dissolved solids of less than 1,000 ppm. The slightly saline water is confined mainly to the basal part of the zone, except perhaps in the area south of the wedge of highly mineralized water in Fannin, Lamar, and Red River Counties, where much of the water in the Paluxy Sand probably is slightly saline. A zone of highly mineralized water below the base of fresh to slightly saline water begins at the base of the Trinity Group in central Cooke County and extends eastward, increasing in thickness with depth, until it occupies the whole of the Trinity Group (Plates 7 and 8). In northern Grayson County and northwestern Fannin County along the crest of the Preston anticline, the zone of highly mineralized water occupies almost all the Trinity Group. Wells drilled too deeply are thus likely to encounter the highly mineralized water. The thickness of fresh to slightly saline water sands in the Trinity Group is shown in Plates 13 and 14.

An abundant supply of ground water of good to excellent quality suitable for many uses is available from the Trinity Group. Table 2 shows chemical analyses of water from selected wells in the Trinity Group. The locations of the wells are shown by means of bars over the well symbols on the well maps (Plates 3 and 4). 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 Trinity Group at the general depth and vicinity of the wells.

The chemical analyses indicate that the softer but more mineralized water normally occurs at greater depth and that most of the fresh to slightly saline water is high in sodium bicarbonate content. The hardness of 40 samples ranged from 1 to 426 ppm; however, it exceeded 60 ppm in only 7 samples. The dissolved-solids content in 19 samples ranged from 242 to 1,830 ppm, exceeding 500 ppm in all but 1 sample. However, in only 4 did it exceed 1,000 ppm. The total iron content in 19 samples ranged from 0.00 to 7.8 ppm. In 7 of the samples, the content exceeded 0.3 ppm; however, in most places the iron content is not a serious problem. The fluoride content in 14 samples ranged from 0.2 to 6.2 ppm, exceeding 1.5 ppm in 5 samples. Most of the ground water is alkaline (pH greater than 7.0). The chemical analyses used here for comparison are from wells mostly more than 1,000 feet deep and should not be used as an indication of quality at shallower depths, where mineralization generally is less.

The quality of water in much of the Trinity Group is suitable for public supply. Generally, the ground water nearer the outcrop is less mineralized, and concentrations of chemical constituents in most places will not exceed the limits established by the U. S. Public Health Service. Deeper water in the Trinity Group generally exceeds 500 ppm in dissolved-solids content, although in many places it is less than 1,000 ppm.

Table 2.--Chemical analyses of water from selected wells in the Trinity Group, Red 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.)	Silica (SiO_2)	Iron (Fe) (Total)	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
HA-19-23-502	943	12	b/ 0.00	1.2	0.2	218	0.9	459	43	34	0.2	1.2	1.2	540	4	99	47	885	8.5
19-16-801	885	13	--	1.8	.4	c/ 220		472	31	45	--	.2	--	548	6	99	39	913	8.4
KT-18-17-901	940	13	.20	1.4	.5	279	1.0	600	93	22	1.2	2.0	1.2	709	6	99	52	1,130	8.7
18-10-702	1,518	13	.08	1.9	1.0	232	1.3	426	46	82	.3	1.8	.03	588	8	98	35	994	8.3
18-20-701	2,176	16	.04	4.8	2.0	446	3.0	466	111	362	1.0	.0	.59	1,180	20	98	43	2,020	8.2
18-20-719	2,295	16	.05	2.1	.8	308	1.5	515	93	105	1.0	.0	.50	781	8	98	46	1,290	8.4
d/ 18-28-107	2,460	20	b/ .07	1.8	--	c/ 285		554	87	56	--	--	--	740	6	99	51	1,140	8.5
18-29-302	1,700	14	.05	1.8	.4	364	.6	762	91	44	2.2	.0	--	893	6	99	65	1,410	8.2
WB-17-07-402	406	11	7.8	48	7.8	26	3.2	188	17	30	.2	.0	--	242	152	27	.9	420	7.0
17-23-902	1,818	16	.59	9.5	2.3	c/ 729		776	5.4	680	6.2	.0	2.2	1,830	33	98	55	3,180	7.6
17-23-801	1,808	15	.60	2.8	1.1	c/ 451		822	153	105	4.0	.0	1.8	1,140	112	99	57	1,810	7.8
17-31-201	2,058	17	.06	4.0	1.6	c/ 508		778	140	230	5.2	.0	1.7	1,290	16	99	55	2,110	8.0

a/ Includes the equivalent of any carbonate (CO_3) present.
b/ In solution.
c/ Sodium and potassium calculated as sodium (Na).
d/ Analyses by Curtis Laboratories.

Ground water from the Trinity Group may be used for many industrial purposes. Vast amounts of typically soft water are available, but high concentrations of sodium bicarbonate may make it undesirable as boiler-feed water and for use in laundries. Most industries requiring cooling water obtain their supply from shallow wells near the outcrop, as the temperature of the water in the Trinity Group ranges from about 65°F, the mean annual air temperature on the outcrop, to more than 90°F in wells 2,500 feet deep.

Analyses of water from sands below 500 to 600 feet indicate that generally the sodium and salinity hazards are medium to very high, according to standards established by the U. S. Salinity Laboratory Staff (Figure 11). The most favorable areas where water of suitable quality for irrigation may be obtained are on or near the outcrop in Montague and Cooke Counties and in places in extreme northern Red River County and adjoining the counties on the west, where the Trinity Group is closer to the surface.

Utilization and Present Development

Table 3 shows the amount of ground water pumped from the Trinity Group for public supply and industrial and irrigation use in 1959. Pumpage for domestic, livestock, and miscellaneous purposes from the Trinity Group was not calculated, but it is probably relatively small because of the deep position of the aquifer in most of the area and the accessibility of shallower aquifers.

In 1959, 2.7 mgd (million gallons per day), or about 3,000 acre-feet, of ground water was pumped from the Trinity Group from about 17 major wells. All major pumpage was from region III in the Red River Basin. More than half the total major pumpage was from major subdivision RE-38, which includes the Sherman area in Grayson County. The remainder of the pumpage was about equally distributed in major subdivisions RE-35 and RE-37 in parts of Montague, Cooke, and Grayson Counties (Plate 3).

Public-supply systems pumped 85 percent or 2.3 mgd of the ground water withdrawn from the Trinity Group in 1959, and about 65 percent was withdrawn in the Sherman area. Other municipalities using water from the Trinity include Gainesville in Cooke County and Whitesboro, Bells, and Gordonville in Grayson County. About 13 major public-supply wells in the Trinity Group were in use at the end of 1959.

Industry used 15 percent or 0.41 mgd of ground water from the Trinity Group in 1959. Most of this was from three major wells in Cooke and Grayson Counties. The water is used chiefly for cooling at gasoline refineries and natural gas processing plants. Relatively minor amounts of slightly saline water is withdrawn from the Trinity Group (Paluxy Sand) in western Red River County, where the water is produced in association with oil in two small oil fields (Plate 4, and wells WB-17-23-902, WB-17-23-801, and WB-17-31-201 in Table 2).

The amount of ground water pumped from the Trinity Group for irrigation is insignificant. Water from only one well in Grayson County was used in 1959 as a supplement to rainfall. Three irrigation wells tap the Trinity Group (Paluxy Sand) in extreme northern Red River County but were not used during 1959. The wells are capable of flowing several hundred gallons per minute but are capped when not in use.

Table 3.--Pumpage from major wells tapping the Trinity Group, 1959

Major subdivision	Public supply		Industrial		Irrigation		Total*	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
RE-35	0.61	684	0.05	56	--	--	0.66	740
RE-37	.22	246	.36	403	--	--	.58	650
RE-38	1.43	1,600	--	--	--	--	1.4	1,600
Total*	2.3	2,500	0.41	460	--	--	2.7	3,000

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

Changes in Water Levels

Reported water levels in the early part of the 20th century prior to large development of wells indicate the water level or piezometric surface of the Trinity Group was close to or above land surface in parts of Grayson and Cooke Counties. Levels declined steadily in places in the artesian part of the aquifer after wells were drilled. From 1909 to 1958, levels in wells in the Trinity at Sherman declined at least 180 feet, or 3.5 feet per year. However, increased withdrawal of water at Sherman for public supply after World War II accelerated the rate of decline to 6.5 feet per year. Levels declined also in the western part of Grayson County in the vicinity of Whitesboro, where during the period 1935-57, levels in the Trinity declined 72 feet, an average of almost 3.5 feet per year. Some of the decline may have been caused by heavy pumping at Sherman and Gainesville.

Where pumping has caused a decline in water levels, the decline usually reflects a decrease in artesian pressure rather than a reduction in storage. At Sherman, for example, the level of the Trinity is still about 1,300 feet above the top of the aquifer and levels fluctuate in response to pressure changes. However, at Gainesville, a short distance downdip from the outcrop of the Trinity, where levels have declined in some wells more than 80 feet from 1946 to 1960, the pressure had been reduced to such an extent that the level in 1960 was at or below the top of the aquifer. Pumping below this level will cause a dewatering of the sands.

A significant rise in water levels in the aquifer of the Trinity has been recorded in northern Grayson County. Almost 80 feet of saturation has been added to the aquifer, where it is in contact with Lake Texoma, since the formation of the lake in 1943. Levels in wells adjacent to the lake now fluctuate in response to changes in lake level.

Artesian pressures in the Trinity Group east of Sherman probably have remained high, as ground-water withdrawal is insignificant in the area.

Short-term records of water levels in the Sherman area (Figure 12, wells KT-18-20-719 and KT-18-20-721) show artesian pressures are lowest in August and September, generally the months of heaviest pumping. The hydrograph of well HA-19-14-801, which is in the outcrop of the Trinity Group, shows fluctuations of the water table in response to recharge from precipitation on the outcrop of the aquifer. The highest level of the water table for the length of record was in May 1958 when rainfall was great.

Availability and Potential Development

The coefficient of transmissibility of the Trinity Group in the Red River Basin generally is small in comparison to most of the major aquifers in Texas. The coefficient of transmissibility determined from pumping tests of 5 wells that tap the Trinity in Grayson County ranged from 300 to 4,700 gpd per foot and averaged about 2,800 gpd per foot (Baker, 1960, p. 48). The coefficient of storage ranged from 0.00002 to 0.00008 and averaged 0.00003.

Because of the low transmissibility of the Trinity Group, the specific capacities of the wells are also low. In 11 wells that tap the Trinity in

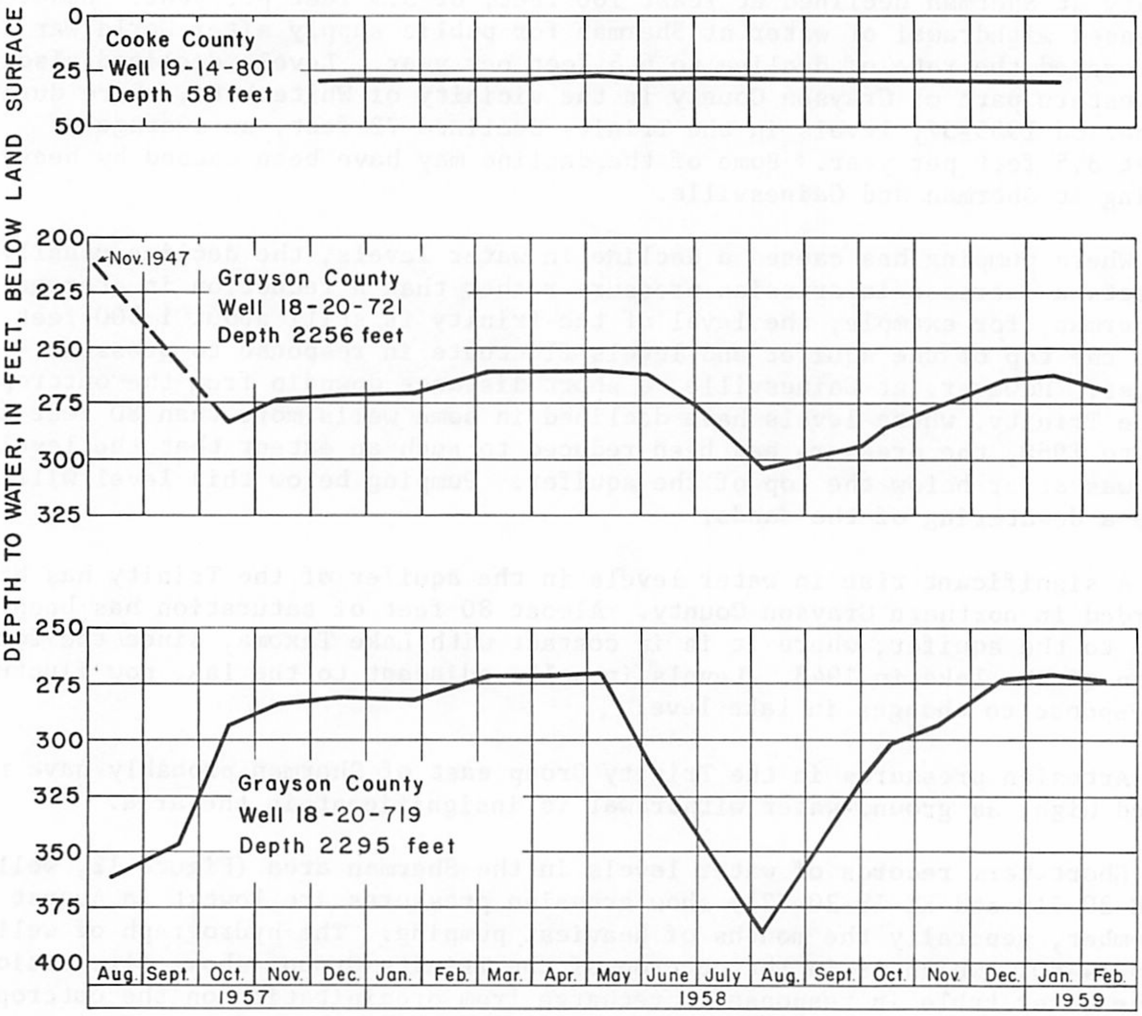

Figure 12

Changes in Water Levels in Wells in the Trinity Group

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

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Grayson County, the specific capacity ranged from 0.57 to 4.2 gpm per foot and averaged 2.25 gpm per foot (Baker, 1960, p. 46). The average well that taps the Trinity would have about 100 feet of drawdown for each 225 gpm pumped, although 1 well in the city of Sherman was reported to pump 602 gpm with only 170 feet of drawdown (Baker, 1960, p. 82). The wells having the largest yields, highest coefficients of transmissibility, and largest specific capacities generally penetrate the full thickness of the fresh water-bearing part of the Trinity Group and are screened opposite all the water-bearing sands.

Where it contains fresh to slightly saline water, the top of the Trinity ranges from more than 600 feet above sea level in the outcrop to more than 3,000 feet below sea level in Hunt County, or from land surface to more than 3,600 feet below land surface. The top of the fresh to slightly saline water sands in southeastern Fannin, northeastern Hunt, and in Delta, Lamar, and Red River Counties is from 1,500 to more than 3,600 feet in depth and has not been tapped by water wells (Plate 12).

The saturated thickness of the fresh to slightly saline water sands in the Trinity Group ranges from 0 to 500 feet in the Red and Sulphur River Basins (Plates 13 and 14). A zero isopach line encloses a large area in northeastern Fannin, north-central Lamar, and northwestern Red River Counties. The 500-foot isopach line encloses two small areas in south-central Grayson County. The saturated thickness in the outcrop of the Trinity Group in the Red River Basin in Texas generally is less than 300 feet.

The volume of fresh to slightly saline water stored in the sands in the Trinity Group in the Red and Sulphur River Basins in Texas is estimated to be 90,000,000 acre-feet. However, only a very small fraction of the water stored in the sands is recoverable by known methods at present costs. The amount of water stored in the aquifer was determined by planimetering the areas of equal saturated thickness (Plates 13 and 14) and computing the volume of saturated sand. This figure was multiplied by 30 percent, which is the estimated porosity.

To compute the amount of water available from the Trinity Group for comparison, several assumptions were made. A line of discharge was postulated more or less parallel to the outcrop in regions III and IV. The line of discharge in region III was 39 miles long, extending from a point on the boundary of the Red River Basin 8 miles southwest of Sherman to a point on the zero saturated-thickness line about 13 miles northeast of Bonham. The line averages 38 miles from the assumed line source of recharge. The discharge line in region IV was 84 miles long between a point in Hunt County on the boundary of the Sulphur River Basin 19 miles northwest of Commerce and a point on the Red River 14 miles northeast of Clarksville. The discharge line averages 32 miles from the assumed line source of recharge. The transmission capacity of the aquifer from the outcrop to each line of discharge was computed, using the following assumptions:

1. Water levels will be lowered to a maximum depth of 400 feet along the line of discharge.

2. No water moves downward into the aquifer except in the outcrop area, 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. The altitude of the water levels is the same and remains the same at all points along the center line of the outcrop (assumed effective line source of recharge); the altitude of the water levels is the same at all points along the salt-water interface; and the altitude of the water levels is the same at all points along the line of discharge.

4. The slope of the water surface will be constant after drawdown to 400 feet at the line of discharge.

5. The hydraulic gradient is a straight-line slope from the water level at the line source of recharge to the water level along the line of discharge.

6. All the sands between the line source of recharge and the line of discharge transmit water from the outcrop area to the line of discharge. The assumed average coefficient of transmissibility of the Trinity Group is 4,000 gpd per foot.

7. Where recharge is considered, the amount of recharge along the line source is sufficient to supply the water that can be transmitted to the line of discharge at the assumed gradients.

8. The rate of transmission of water through the aquifer is the average of the rate based on the present hydraulic gradient and the rate based on the maximum hydraulic gradient that can be attained with a water level of 400 feet at the line of discharge.

9. The only increment to the water moving toward the line of discharge from the downdip side is that water released from storage as a result of lowering water levels.

The transmission capacity of the Trinity Group from the assumed line source to the assumed line of discharge in region III would be about 1,200 acre-feet per year at the average hydraulic gradient during the time that the water level was being lowered to 400 feet. The transmission capacity at the maximum hydraulic gradient would be about 2,000 acre-feet per year. The amount of water withdrawn from artesian storage as the water level was lowered to 400 feet would be about 9,400 acre-feet. At the present discharge rate of the wells tapping the Trinity Group in region III, the water level could be lowered to 400 feet along the assumed line of discharge in about 5 years. The present rate of withdrawal is about 3,000 acre-feet a year which is the equivalent discharge of about 19 wells equally spaced along the assumed discharge line and each pumping 100 gpm continuously. By moving the line of discharge to only half the distance to the outcrop, the hydraulic gradient would be steepened, so that the transmission capacity at the average hydraulic gradient would be about 2,200 acre-feet per year, and at the maximum gradient would be about 3,900 acre-feet per year. Most of the withdrawal from the Trinity Group is in the vicinity of Sherman which, although just 5 miles northeast of the assumed line of discharge, is only about 15 miles from the nearest outcrop of the Trinity in Lake Texoma because of the irregularity of the strike of the Trinity outcrop in region III.

The amount of recharge on the outcrop necessary to replace the water moving downdip at the maximum transmission capacity (2,000 acre-feet per year) would be 0.05 inch per year. The conditions are suitable for recharge of several times that amount.

The transmission capacity of the Trinity Group to the assumed line of discharge in region IV would be about 2,400 acre-feet per year at the average hydraulic gradient during the time that the water level was being lowered to 400 feet. The transmission capacity at the maximum hydraulic gradient would be about 4,800 acre-feet per year. About 20,000 acre-feet of water would be released from storage as the water level was lowered to 400 feet. Although there is no significant withdrawal from the Trinity in region IV, a withdrawal rate of 6,000 acre-feet per year, which is the equivalent of 38 wells pumping 100 gpm continuously equally spaced along the 84 miles of the assumed discharge line, would lower the water level to approximately 400 feet in 5.5 years at the transmission capacity at the average gradient. The assumed line of discharge is near the center of the area of occurrence of fresh to slightly saline water in the Trinity in region IV; if the line were moved closer to the outcrop, it would be near or in the area of salty water. No wells tap the Trinity in the area except for a few oil wells near Clarksville so that the transmissibility and storage coefficients are unknown. The coefficients may be considerably lower than those used which were assumed from information in region III.

The amount of recharge on the outcrop of the part of the Trinity Group parallel to the assumed line of discharge in region IV necessary to replace the amount of water moving downdip at the maximum transmission capacity (4,800 acre-feet per year) would be about 0.10 inch per year. Conditions are such that adequate recharge is available to maintain water levels in the outcrop at that rate of recharge.

Problems

The decline of artesian pressure in areas of large ground-water withdrawals is one of the most serious problems associated with the Trinity Group. Continuing declines of water levels in some areas--particularly near Sherman, where 1.4 mgd is pumped from the Trinity--have resulted in the costly process of lowering pumps in wells, installing larger motors, and thereby increasing the overall lifting costs. Wells drilled into the Trinity Group in recent years have deep pump settings to accommodate anticipated declines.

Evidence of encroachment of salt water has caused concern in some areas. Salt-water contamination in the heavily pumped Sherman area has caused an increase in chloride content in several of the public-supply wells during the several years prior to 1960. The source of this contamination is not well known; however, some wells are screened in fresh-water sands short distances above the highly mineralized basal water of the Trinity Group, and it is probable that "coneing up" of the saline water is occurring during the pumping operation, thus increasing the salinity of the water pumped. Another possible source of contamination is from improperly cased, cemented, or plugged oil tests. The repressuring of oil fields also could cause salt water to rise in abandoned casings and invade the fresh-water zones.

The presence of large amounts of salt water in the Trinity Group on the Preston anticline in northern Grayson County and its movement southward creates a problem; however, this situation poses little threat to the Sherman area in the foreseeable future because of the low permeability of the sands and consequent slow rate of movement of the water.

Additional information is needed in region IV in Fannin, Hunt, Delta, Lamar, and Red River Counties to appraise more accurately the availability of water in the Paluxy Sand. Little is known about the Paluxy Sand regarding permeability, water levels, movement of water, or quality. Chemical analyses from a few oil tests and water wells indicate that the water in much of the Paluxy Sand in this area is fresh to slightly saline; however, the scarcity of electric logs and the absence of water wells in the Paluxy Sand in much of the area makes evaluation difficult. Also, more information is needed concerning the source and movement of the very saline ground water (in excess of 10,000 ppm dissolved-solids content) which saturates part of the Paluxy Sand, including the outcrop in eastern McCurtain County, Oklahoma. The movement presumably is southward into Texas and could be a major source of contamination to the Paluxy in Red River, Lamar, and Fannin Counties.

Woodbine Formation

Physical Description

The Woodbine Formation crops out in the Red River Basin in Texas, principally in the eastern part of Cooke County and western and northern parts of Grayson County, and in places in northwestern Fannin and extreme northern Lamar and Red River Counties (Plates 3, 4, and 10). Much of the northernmost outcrop is in Oklahoma and Arkansas, trending east and west. South and east of the outcrop, where water-table conditions prevail, the Woodbine Formation dips beneath younger rocks and becomes an artesian aquifer.

The Woodbine Formation consists of brownish-red to light-gray medium to coarse crossbedded unconsolidated ferruginous tuffaceous sand and laminated shaly clay interbedded with layers of lignite and gypsiferous clay. Beds of hard siliceous sandstone are scattered throughout the formation; locally, the outcrop is covered with residual boulders of this siliceous material. Many of the sands are highly lenticular and grade laterally into clay within short distances. Neither the hard siliceous sandstones nor the lenticular layers of clay retard the movement of water in the formation, except perhaps in local areas. In most places, the thickest and more massive sand beds are at or near the base of the formation. Thick accumulations of sand are common also in the upper one-third of the formation. The separation of the upper and lower sand strata becomes more pronounced in parts of Fannin and Hunt Counties. Farther to the east, the proportion of clay gradually increases, and the sand content decreases until in parts of Lamar and Red River Counties the formation is almost totally composed of clay and the Woodbine ceases to be a primary aquifer.

The thickness of the Woodbine Formation ranges from about 410 feet near the outcrop in western Grayson County to about 600 feet in southeastern Fannin County near the downdip limit of fresh to slightly saline water. Eastward from Fannin County, the thickness gradually decreases until in parts of Bowie County the Woodbine is less than 200 feet thick. Where the formation is a primary aquifer, however, its thickness is rarely less than 400 feet.

The Woodbine dips south and east, ranging from 45 feet per mile eastward in parts of Grayson County to 70 feet per mile southward in Red River County (Plates 7, 8, 15, and 16). Locally in central and northern Grayson County, the

Woodbine Formation on the south flank of the Preston anticline dips southward more than 300 feet per mile. In the north-central part of Hunt County, where the deepest fresh to slightly saline water occurs in the Woodbine, the depth to the top of the formation is about 1,900 feet.

Recharge, Movement, and Discharge of Ground Water

Rainfall on the outcrop is the principal source of recharge to the Woodbine Formation. The outcrop, ranging in width from about 10 miles in western Grayson County and eastern Cooke County to about 5 miles along much of its east-west outcrop, is typically sandy, affording favorable conditions for infiltration of rain. The average annual precipitation along the outcrop is from 37 to 48 inches, but only a small fraction of this amount reaches the water table. The Red River, which flows on the outcrop of the Woodbine Formation in places in Fannin, Lamar, and Red River Counties, is probably effluent throughout its course. No recharge is taking place from Lake Texoma, which is impounded in part of the Woodbine Formation in northwestern Grayson County.

Water in the Woodbine Formation moves eastward from the recharge area in western Grayson County and eastern Cooke County and southward from the recharge areas along the east-west trending outcrop in northern Grayson, Fannin, and Lamar Counties. From these two components of direction in Grayson County, the resultant direction is southeastward. Areas of heavy pumping interrupt the general downdip direction of movement of ground water in the Woodbine--for example, at Sherman ground water moves toward the discharge area from all sides.

The rate of movement in the Woodbine Formation in Grayson County was estimated to be 10 to 20 feet per year. Although most of the sands in the Woodbine are hydrologically connected, the greatest circulation and movement of ground water probably is in the thick basal sands, which generally contain fresher water than the upper more lenticular sands.

Pumpage from wells constitutes the principal discharge from the Woodbine Formation. In 1959, about 4,500 acre-feet was pumped from the Woodbine by major wells in the Red and Sulphur River Basins in Texas. Flowing wells on the shore of Lake Texoma discharge water continuously. The amount of the waste water is small, however, probably less than 0.02 mgd. Ground water is discharged naturally from the Woodbine Formation by springs and seeps into streams crossing the outcrop. This type of discharge may be considered rejected recharge--that is, the formation is full at the outcrop and the discharge represents an overflow from the outcrop area. The amount of ground water discharged by the Woodbine Formation to the Red River where it crosses the outcrop is unknown but probably is large. Phreatophytes, abundant in much of the outcrop of the Woodbine especially along many of the streams, consume substantial amounts of ground water. Ground water in the Woodbine probably is discharged along or across fault planes into other formations in the area of the Luling-Mexia-Talco fault system; however, the water in the Woodbine at the fault zone is highly mineralized.

Chemical Quality

The area of occurrence of fresh to slightly saline water in the Woodbine Formation is shown in Plate 10. Most of the water is in the Red River Basin, probably less than 10 percent being in the Sulphur River Basin in Fannin, Hunt, and Lamar Counties. Chemical analyses show that most of the fresh to slightly saline water has less than 1,000 ppm dissolved-solids content and is, thus, classified as fresh. The slightly saline water in the Woodbine Formation is confined for the most part to the fringes of the southward and eastward limit of the fresh to slightly saline water in Hunt, Fannin, and Lamar Counties. Ground water in the outcrop of the Woodbine Formation is less abundant and more mineralized east of north-central Lamar County, primarily because of the gradual decrease in sand content. In Red River County, the Woodbine ceases to be significant as an aquifer. The thickness of sand containing fresh to slightly saline water in the Woodbine Formation is shown on Plates 17 and 18.

Table 4 shows chemical analyses of water from selected wells in the Woodbine Formation. The locations of the wells are shown on the well-location maps (Plates 3 and 4) by means of a bar over the well symbols. The analyses shown are only a few of the total number of analyses on record, but may be considered representative of the quality of ground water in the Woodbine Formation at the general depth and vicinity of the wells.

Ground water of good to excellent quality suitable for most uses is available from the Woodbine Formation. The hardness of 114 samples ranged from 0 to 1,120 ppm and exceeded 60 ppm in 38 samples. The dissolved-solids content in 35 samples ranged from 114 to 1,750 ppm, exceeding 500 ppm in 16 samples. However, in only 4 samples did it exceed 1,000 ppm. The total iron content in 24 samples ranged from 0.02 to 7.2 ppm; in 13 samples the content exceeded 0.3 ppm. The fluoride content in 29 samples ranged from 0.1 to 2.5 ppm, exceeding 1.5 ppm in only 5 samples. In general, water in the Woodbine Formation is characterized by a high sodium bicarbonate content and is rather high in iron; normally the softer but more mineralized water is at greater depths.

Water in the Woodbine Formation generally is suitable for public supply. Water from relatively shallow wells in or near the outcrop is high in iron content, usually exceeding the limits established by the U. S. Public Health Service. The high iron content seems to be the only serious quality problem, and this can be solved by inexpensive treatment. Much of the deeper water in the Woodbine conforms to U. S. Public Health Service standards, although, because mineralization increases with depth, the dissolved-solids content generally is in excess of the recommended limit of 500 ppm.

Ground water in the Woodbine Formation is acceptable for many industrial purposes. The abundance of very soft water makes it desirable for boiler use and laundries, although some of the water is excessively high in sodium bicarbonate. Ground water in or near the outcrop is unacceptable for certain types of industry that require low concentrations of iron. Water in the outcrop, however, is more effective for cooling, the temperature being about 65°F, whereas at depths of 800 feet, the temperature is about 80°F.

Ground water in the outcrop of the Woodbine Formation is acceptable for irrigation and can be used on almost all soils where leaching is at least moderate; the relatively high rainfall probably is adequate for the necessary

Table 4.--Chemical analyses of water from selected wells in the Woodbine Formation, Red River and Sulphur 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.)	Silica (SiO_2)	Iron (Fe) (Total)	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
KT-18-09-901	180	13	7.2	23	8.7	25	1.8	115	27	18	0.2	0.0	0.04	174	93	36	1.1	298	6.5
18-10-402	180	17	2.2	42	18	14	1.4	189	40	7.5	.2	.0	.00	233	179	14	.5	389	6.9
18-10-801	345	12	2.5	26	11	55	2.9	193	43	22	.4	.2	.03	276	110	51	2.3	468	6.9
18-11-801	443	14	1.1	12	4.1	72	2.4	188	31	12	.4	.5	.22	243	47	76	4.6	401	7.7
18-19-304	620	14	b/ .02	1.7	.2	c/ 139		209	104	18	.6	.2	--	381	5	98	27	605	8.4
18-20-702	955	14	.30	.9	.1	94	.8	199	32	10	.5	.0	.23	253	3	98	26	414	7.7
18-20-718	736	15	.03	1.0	.3	152	.5	270	67	34	.5	.0	.32	404	4	99	35	668	8.8
d/ 18-28-106	1,023	18	b/ .07	1.0	.3	c/ 174		354	62	18	--	--	--	461	4	99	38	686	8.1
18-28-702	1,069	13	.05	1.2	.7	367	1.5	751	118	33	1.4	3.0	.20	909	6	99	65	1,450	8.6
18-29-701	1,180	14	.04	1.1	.5	359	1.2	632	99	104	1.6	1.0	.24	893	4	99	74	1,470	8.5
18-29-901	1,189	15	b/ .01	1.3	.2	c/ 279		505	108	56	1.4	2.0	--	743	4	99	61	1,160	8.4
18-29-301	709	12	.05	.4	.2	153	.6	327	39	14	.7	1.2	.09	388	2	99	47	634	8.1
JS-18-30-102	528	16	b/ .07	1.2	.2	200	1.4	395	75	26	.9	.8	--	532	4	99	43	860	8.4
18-30-602	461	12	b/ .14	2.8	.4	375	1.0	822	74	46	2.5	2.8	--	932	8	99	58	1,500	8.6
18-14-907	280	13	--	2.0	.9	c/ 472		1,000	125	57	--	3.5	--	1,170	8	99	73	1,850	8.5
18-31-503	1,288	18	b/ .02	2.0	.3	319	3.6	473	199	76	1.2	.0	--	861	6	99	57	1,400	8.4
18-39-501	1,595	17	b/ .04	1.0	.0	312	1.4	477	199	62	1.5	.2	2.6	841	2	99	96	1,310	8.2
18-32-501	1,640	15	b/ .05	1.0	.1	355	1.6	485	250	76	1.4	.0	--	951	3	99	89	1,500	8.0
17-25-401	1,691	16	b/ .03	1.0	.2	382	1.8	493	280	94	1.4	.0	--	1,020	4	99	83	1,600	7.8
17-25-302	1,673	17	b/ .07	2.8	.2	345	2.0	515	212	79	1.8	2.5	--	941	8	99	53	1,530	8.6

a/ Includes the equivalent of any carbonate (CO_3) present.
b/ In solution.
c/ Sodium and potassium calculated as sodium (Na).
d/ Analyses by Curtis Laboratories.

leaching. All the irrigation wells in the Woodbine are on the outcrop of the formation. Water from depths between 500 and 1,000 feet generally has a medium salinity hazard, but a very high sodium hazard (Figure 11). Such water should not be used for continuous irrigation but possibly can be used supplementally and when soil conditioners such as gypsum are added. Water in the Woodbine Formation below 1,000 feet is, for the most part, unsatisfactory for irrigation.

Utilization and Present Development

Table 5 shows the amount of water pumped from the Woodbine Formation for public supply and industrial and irrigation uses. Pumpage from the Woodbine for domestic, livestock, and miscellaneous purposes was not calculated, but probably is less than 15 percent of the total for all uses. About 4,500 acre-feet, or 4.0 mgd, of water was pumped by major wells in 1959 from the Woodbine Formation in the Red and Sulphur River Basins in Texas, almost all of which was from the Red River Basin in region III. Almost 45 percent of the total pumpage was from major subdivision RE-38, which includes the Sherman area. The rest of the pumpage was divided among major subdivisions RE-37 in western Grayson County and RE-39 in Fannin County (Plate 3).

About 2.5 mgd of water was pumped from the Woodbine for public supply in 1959, about 63 percent of the total major pumpage from the Woodbine Formation. About 35 percent of the total water pumped for public supply was for the city of Sherman; most of the remainder was in major subdivision RE-39, where the city of Bonham is the largest user. In addition to Sherman and Bonham, 11 other municipalities in Fannin and Grayson Counties depend on the Woodbine Formation for water. About 25 public-supply wells in the Woodbine Formation were in use at the end of 1959 in the Red and Sulphur River Basins.

Water for industry constituted about 35 percent, or 1.4 mgd, of the total major pumpage from the Woodbine Formation in 1959. All the industrial pumpage was in Grayson County within an 8-mile radius of Sherman. The water is used for processing and cooling and in boilers.

The amount of water pumped from the Woodbine Formation for irrigation is relatively small, about 2 percent of the total, 0.07 mgd being withdrawn in 1959. The production is from five wells in western Grayson County, all the wells being on the outcrop of the Woodbine Formation. The wells range in depth from 180 to 345 feet and yield as much as 260 gpm; the water is used chiefly to supplement rainfall.

Changes in Water Levels

Water levels in the Woodbine Formation have declined significantly in a few areas in the Red and Sulphur River Basins since the development of wells in the early part of the century. All the declines have been in the artesian part of the aquifer, and they represent, for the most part, a decline in pressure rather than a decrease in storage or dewatering of the sands.

The larger declines in the Woodbine Formation have been at centers of heavy pumping such as at Sherman, where about 1,000 acre-feet of water is withdrawn per year. During the 49-year period from 1909 to 1958, levels in the

Table 5.--Pumpage from major wells tapping the Woodbine Formation, 1959

Major subdivision	Public supply		Industrial		Irrigation		Total*	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
RE-37	0.22	246	0.61	684	0.07	79	0.90	1,000
RE-38	1.03	1,150	.78	875	--	--	1.8	2,000
RE-39	1.25	1,400	--	--	--	--	1.3	1,400
SU- 1	.01	6	--	--	--	--	.01	6
Total*	2.5	2,800	1.4	1,600	0.07	79	4.0	4,500

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

Woodbine at Sherman have declined about 240 feet, or about 5 feet per year; however, most of the decline has been since 1945 at a rate of 12 feet per year. In some of the Sherman municipal wells, levels are at or below the top of the Woodbine Formation, indicating local overdraft and dewatering of the sands. The hydrographs of wells KT-18-20-710 and KT-18-20-718 (Figure 13) at Sherman show the decline in levels and fluctuations due to seasonal pumping, the heaviest withdrawals and consequently the deepest water levels being in August.

Water levels have declined substantially at Perrin Air Force Base 6 miles northwest of Sherman. Since the drilling of the first well in the Perrin well field, the level declined 72 feet during the period 1941-57, an average of 4.5 feet per year; most of the decline was from 1953 to 1957 at a rate of 9 feet per year. The decline diminishes with distance from the center of pumping (Figure 8). The level in the public-supply well in the town of Pottsboro, 3 miles north of Perrin Air Force Base, declined an average of 6.5 feet per year from 1952 to 1958.

In Fannin County, artesian pressures have declined around centers of local pumping. At the city of Bonham, the largest user of ground water in the county, levels have declined 180 feet, from 120 feet in 1911 to 300 feet in 1960, a decline of almost 4 feet per year.

Water levels in or near the outcrop of the Woodbine Formation probably have not been seriously affected by the large withdrawal downdip. Wells on the outcrop of the Woodbine Formation in an area 15 miles northwest of Sherman flowed in 1901 (Hill, 1901, p. 624) and were still flowing in 1961 with little apparent loss of head. Furthermore, in places along the outcrop of the Woodbine Formation, recharge is being rejected by springflow and seepage, indicating the aquifer at places is completely saturated. The hydrograph of a typical well on the outcrop of the Woodbine Formation (Figure 13, well KT-18-18-401) shows fluctuations of the water level in response to recharge from rainfall, the highest water levels reflecting periods of heaviest rainfall.

Availability and Potential Development

The coefficient of transmissibility of the Woodbine Formation is small compared to that of most of the major aquifers in Texas. The coefficient of transmissibility, determined from tests of 9 wells tapping the Woodbine in Grayson County, averaged about 3,200 gpd per foot (Baker, 1960, p. 54). Although the transmissibility ranged from 1,400 to 12,500 gpd per foot, all but 3 of the tests indicated a transmissibility between 2,100 and 2,700 gpd per foot. The coefficient of storage ranged between 0.00002 and 0.0002 and averaged 0.0001. A short recovery test on a well in Fannin County indicated a coefficient of transmissibility of 9,900 gpd per foot.

The specific capacities of wells tapping the Woodbine Formation are correspondingly low, ranging from 0.36 to 6.0 gpm per foot in 12 wells in Grayson County (Baker, 1960, p. 53). The average specific capacity was 2.9 gpm per foot. In the vicinity of Sherman the combination of low specific capacities and moderate to large yields has lowered the pumping levels in some of the wells tapping the Woodbine below the top of the sand after prolonged periods of pumping. In other areas the pumping levels at moderate yields are above the top of the sand except in and near the outcrop.

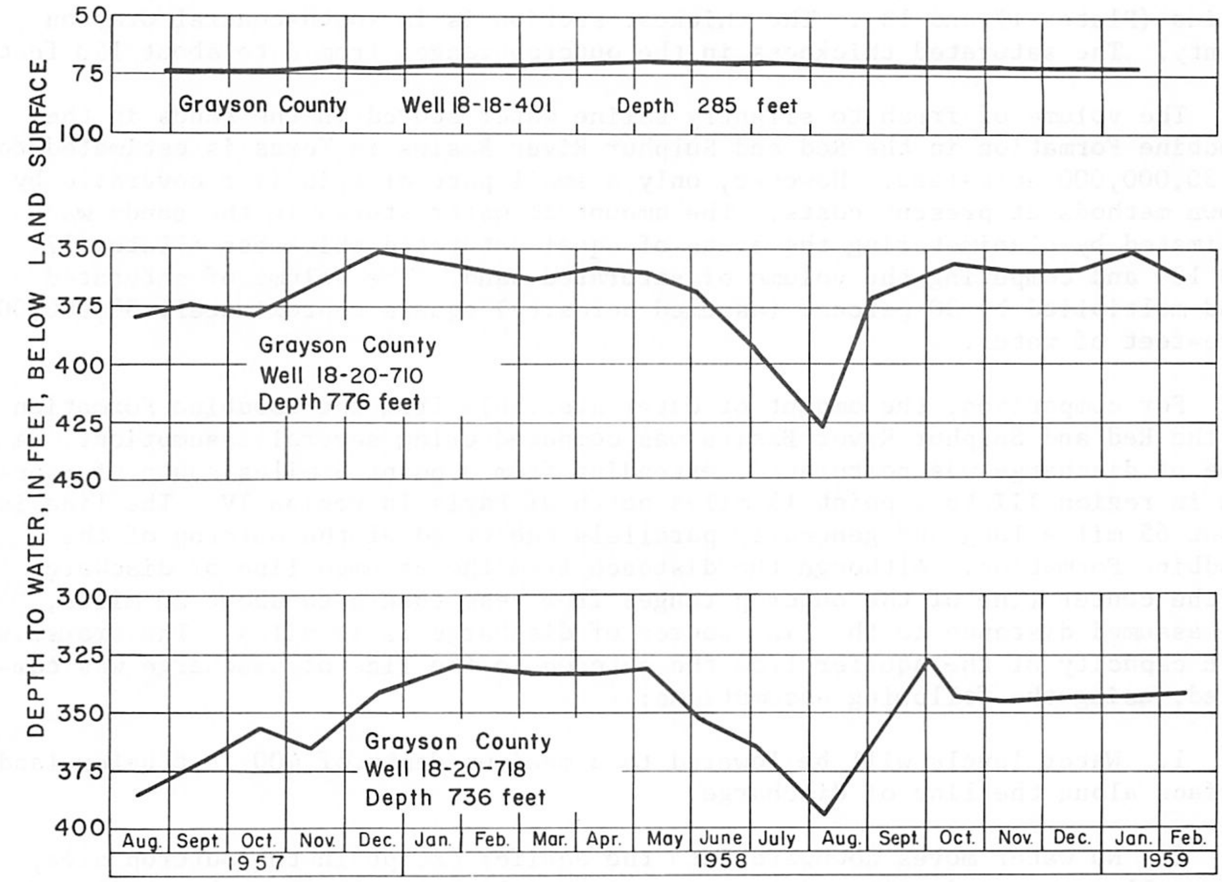

Figure 13

Changes in Water Levels in Wells in the Woodbine Formation

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

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The altitude of the top of the fresh to slightly saline water sands in the Woodbine ranges from more than 600 feet above sea level in and near the outcrop in Grayson and northwestern Fannin County to more than 1,200 feet below sea level in southeastern Fannin and northeastern Hunt Counties. The depth to the top of the Woodbine in northeastern Hunt County northwest of the zero thickness line of fresh to slightly saline water (Plates 15 and 16) is about 1,800 feet.

The saturated thickness of the fresh to slightly saline water sands in the Woodbine Formation ranges from 0 to about 250 feet in the Red and Sulphur River Basins (Plates 17 and 18). The thickest section is in south-central Grayson County. The saturated thickness in the outcrop ranges from 0 to about 150 feet.

The volume of fresh to slightly saline water stored in the sands in the Woodbine Formation in the Red and Sulphur River Basins in Texas is estimated to be 30,000,000 acre-feet. However, only a small part of this is recoverable by known methods at present costs. The amount of water stored in the sands was estimated by planimetering the areas of equal saturated thickness (Plates 17 and 18) and computing the volume of saturated sand. The volume of saturated sand multiplied by 30 percent (assumed porosity) equals approximately 30,000,000 acre-feet of water.

For comparison, the amount of water available from the Woodbine Formation in the Red and Sulphur River Basins was computed using several assumptions. A line of discharge was postulated, extending from a point 8 miles south of Sherman in region III to a point 15 miles north of Paris in region IV. The line is about 65 miles long and generally parallels the trend of the outcrop of the Woodbine Formation. Although the distance from the assumed line of discharge to the center line of the outcrop ranges from less than 5 to about 20 miles, the assumed distance to the line source of discharge is 10 miles. The transmission capacity of the aquifer from the outcrop to the line of discharge was computed, using the following assumptions:

1. Water levels will be lowered to a maximum depth of 400 feet below land surface along the line of discharge.

2. No water moves downward into the aquifer except in the outcrop area, 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. The altitude of the water levels is the same and remains the same at all points along the center line of the outcrop (assumed effective line source of recharge); the altitude of the water levels is the same at all points along the salt-water interface; and the altitude of the water levels is the same at all points along the line of discharge.

4. The slope of the water surface will be constant after drawdown to 400 feet at the line of discharge.

5. The hydraulic gradient is a straight-line slope from the water level at the line source of recharge to the water level along the line of discharge.

6. All the sands between the line source of recharge and the line of discharge transmit water from the outcrop area to the line of discharge. The assumed average coefficient of transmissibility of the Woodbine Formation is 4,000 gpd per foot.

7. Where recharge is considered, the amount of recharge along the line source is sufficient to supply the water that can be transmitted to the line of discharge at the assumed gradients.

8. The rate of transmission of water through the aquifer is the average of the rate based on 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.

9. The only increment to the water moving toward the line of discharge from the downdip side is water released from storage as a result of lowering water levels.

The transmission capacity of the Woodbine Formation from the assumed line source to the assumed line of discharge at the average hydraulic gradient during the time the water level is being lowered to 400 feet would be about 8,500 acre-feet per year. The transmission capacity at the maximum hydraulic gradient would be about 11,700 acre-feet per year. The amount of water withdrawn from artesian storage as the water level was lowered to 400 feet would be about 9,000 acre-feet. If the 1959 discharge (4 mgd or 4,500 acre-feet per year) were continuously maintained by wells evenly spaced along the assumed line of discharge, the water levels would not be lowered to 400 feet. However, if pumpage were increased to 10 mgd or 11,200 acre-feet per year from wells evenly spaced along the assumed line of discharge, the water level could be lowered to 400 feet in about 3 years at the average gradient. The transmission capacity at the maximum gradient after the water level had been lowered to 400 feet below the land surface would be slightly greater than the 10 mgd withdrawal rate.

The amount of recharge on the outcrop necessary to replace the water moving downdip at the maximum transmission capacity (11,700 acre-feet per year) would be about 0.28 inch per year. This probably is well below the potential in this area.

The concentrated withdrawal from the Woodbine in the vicinity of Sherman already has lowered pumping levels to more than 500 feet below land surface during periods of heavy pumping. The computations indicate that if the withdrawal was evenly distributed along the 65-mile long assumed line of discharge, the water levels would be less than 400 feet below land surface. However, owing to local variations in saturated-sand thicknesses, coefficients of transmissibility, distances from outcrop, and other factors, the concept of the assumed line of discharge is valid for order-of-magnitude comparisons only.

Problems

The decline of artesian pressure is the most serious problem concerned with ground-water development from the Woodbine Formation. The problem is most acute around centers of heavy withdrawal of ground water; however, the cones of depression from the heavy pumping affects areas of many square miles, lowering water levels in domestic and other wells within the area of influence. This situation has resulted in the necessity of lowering pumps in many of the affected wells.

At Sherman, where water levels have declined below the top of the Woodbine Formation in many wells, the water is being taken from storage or "mined." Further declines will cause a noticeable reduction in pumping rates and efficiency of the wells. Steps are being taken in the Sherman area to check the problem by spacing new wells to be drilled to the Woodbine over wider areas and by limiting increases in pumpage.

Carrizo Sand and Wilcox Formation, Undifferentiated

Physical Description

The Carrizo Sand and Wilcox Formation, undifferentiated, crop out principally in the eastern and southern parts of the Sulphur River Basin and northwestern and southeastern parts of the Cypress Creek Basin. Two inliers of small extent are in east-central Upshur County (Plates 4 and 10). In the general region between the major outcrops, the Carrizo Sand and Wilcox Formation, undifferentiated, dip beneath the Mount Selman Formation, and artesian conditions prevail.

The Carrizo Sand and Wilcox Formation, although treated as a hydrologic unit in this report, may be distinguished lithologically. The Wilcox Formation is more important hydrologically than the Carrizo Sand, chiefly because of its greater thickness. The Wilcox consists principally of reddish-brown to light-gray unconsolidated ferruginous crossbedded fine-to-medium sand, interbedded with light to dark-gray clay, lignite, and silt. The upper and lower parts of the formation have a larger percentage of sand than the middle, and some massive beds 100 feet or more in thickness are made up entirely of medium sand. Individual sand beds are lenticular and may grade laterally into clay, lignite, or silt in short distances. However, the lenticularity of the strata generally does not isolate water in one sand from that in another. The total thickness of the Wilcox Formation ranges from about 450 to 800 feet.

The Carrizo Sand overlying the Wilcox Formation consists of light brownish-gray to reddish-brown unconsolidated crossbedded, fine-to-medium sand and an interbedded sequence of fine sand, silt, and clay generally near the top of the formation. The thickness of the Carrizo Sand is highly variable, ranging from 0 to not more than 100 feet.

The maximum combined thickness of the Carrizo Sand and Wilcox Formation is about 900 feet, the thickest sections being along the axis of the East Texas basin in parts of Cass, Morris, Camp, Upshur, and Wood Counties.

The dip of the Carrizo Sand and Wilcox Formation, undifferentiated, is both southeastward and northwestward into the East Texas basin (Plate 12). From its northern outcrop, which trends southwestward from the Arkansas State line to Hopkins County, Texas, the dip of the beds averages about 15 feet per mile to the southeast. In the eastern part of Marion and Harrison Counties on the Sabine uplift, the unit dips northwestward from 20 to 50 feet per mile. The greatest dips in the Carrizo and Wilcox are in areas of structural deformation in northeastern Marion County on the downthrown south side of the Rodessa fault and in an uplift in western Upshur and eastern Wood Counties. The depth to the top of the Carrizo and Wilcox exceeds 500 feet in only a few places; the unit is deepest in northwestern Marion and southwestern Cass Counties.

Recharge, Movement, and Discharge of Ground Water

The principal source of recharge to the Carrizo Sand and Wilcox Formation, undifferentiated, is precipitation on the outcrop. The northern outcrop, about 15 miles wide in most places, and the southern outcrop, occupying much of Marion and Harrison Counties, is covered by loose porous sand offering ideal conditions for the infiltration of precipitation, the annual average of which ranges from about 40 to 48 inches. Only a small percentage of the annual precipitation, however, is added to the ground water in storage. The presence of numerous springs, seeps, and marshes in much of the outcrop suggests that recharge is being rejected, indicating complete or nearly complete saturation of the sand in the outcrop. The Sulphur River, which flows diagonally across the northern outcrop of the Carrizo and Wilcox into Lake Texarkana, and Big and Little Cypress Creeks, crossing the southern outcrop of the Sabine uplift and flowing into Caddo Lake, are effluent throughout their courses. Probably no recharge to the Carrizo and Wilcox occurs from either Lake Texarkana or Caddo Lake.

Movement of ground water in the Carrizo Sand and Wilcox Formation, undifferentiated, has several components of direction due chiefly to the geologic structure of the area. However, three principal components of direction predominate. One component is southeastward from the northern outcrop and another is northwestward from the southern outcrop on the Sabine uplift. Water from these two source areas meet along the axis of the East Texas basin, thence takes a northeastward course and moves downdip along the trough of the basin in the general direction of southern Arkansas and northern Louisiana.

The effect of the Rodessa fault (Figure 6) on water moving northwestward from the Sabine uplift is not clearly known. The Carrizo and Wilcox are not completely displaced by the fault, and water probably is moving across the fault--providing the fault plane is not effectively sealed. However, an abnormal amount of slightly saline water near the base of the Carrizo and Wilcox in places south of the fault may indicate that the fault functions as a partial barrier, restricting the normal circulation of ground water.

Structural uplift within the trough of the East Texas basin in western Upshur County, where the Carrizo and Wilcox are exposed (Plates 4 and 12), probably forms a ground-water divide that affects a considerable area. The area possibly is the highest structurally in the entire East Texas basin, and it probably forms a divide between an eastward and westward movement of ground water in the trough of the East Texas basin.

Considerable amounts of ground water are discharged from the Carrizo Sand and Wilcox Formation, undifferentiated, by artificial and natural means. Pumping from wells constitutes a principal discharge. In 1959, about 5,400 acre-feet was discharged from the Carrizo and Wilcox by major wells in the Sulphur River and Cypress Creek Basins.

Significant amounts of ground water also are discharged naturally by springs and seeps on the outcrop. Much of the southern part of the Sulphur River Basin and almost all the Cypress Creek Basin is thickly timbered and vegetated. The amounts of ground water transpired by such thick plant growth probably is a large part of the total water discharged by the Carrizo and Wilcox.

Chemical Quality

The area where fresh to slightly saline water may be obtained from the Carrizo Sand and Wilcox Formation, undifferentiated, is shown in Plate 10. Probably less than 10 percent of the fresh to slightly saline water in the Carrizo and Wilcox is available from the southern part of the Sulphur River Basin where the unit crops out. The remainder underlies the Cypress Creek Basin, and fresh to slightly saline water may be obtained anywhere in the basin. As a rule, although there are minor exceptions, the base of the Carrizo and Wilcox marks the base of the zone of fresh to slightly saline water (Plate 8). Chemical analyses show that most of the water is fresh; the slightly saline water is confined for the most part to the lower part of the Carrizo and Wilcox. The thickness of sand containing fresh to slightly saline water in the unit is shown in Plate 14.

Chemical analyses of water from selected wells in the Carrizo Sand and Wilcox Formation, undifferentiated, are shown in Table 6. The locations of the wells indicated by the identifying numbers in the table are shown on the well map (Plate 4) by means of a bar over the well symbols. The analyses shown are only a few of the total number of analyses on record, but may be considered representative of the quality of ground water in the Carrizo and Wilcox at the general depth and vicinity of the wells.

The chemical analyses indicate that ground water from the Carrizo and Wilcox is suitable for a wide range of uses. A combination of good circulation of ground water, recharge areas to the north and south receiving abundant rainfall, and the fact that the aquifer does not attain great depths are largely responsible for the good quality of the ground water. The water is characterized by high sodium bicarbonate content, a low dissolved-solids content, and the water is soft throughout the formation. The hardness of 18 samples ranged from 5 to 59 ppm. The dissolved-solids content in 18 samples ranged from 99 to 698 ppm, exceeding 500 ppm in only 4 samples, all the samples having less than 700 ppm. The iron content in 12 samples ranged from 0.00 to 10 ppm; in 4 of the samples, the content exceeded 0.3 ppm. The fluoride content in 14 samples ranged from 0 to 1.4 ppm.

The quality of water in the Carrizo and Wilcox is excellent for public supply. The concentrations of chemical constituents generally are within the recommended limits established for drinking water by the U. S. Public Health Service. Concentrations of iron in excess of 0.3 ppm may be expected in some places, generally on or near the outcrop, and treatment may be necessary. The dissolved-solids content normally increases with depth in the Carrizo and Wilcox, but because the aquifer is relatively shallow in the Sulphur River and Cypress Creek Basins, in most places the concentration is less than 500 ppm.

The water in the Carrizo and Wilcox generally is suitable for most industrial needs, although reduction of iron concentration for some uses may be necessary. In or near the outcrop, acidic ground water may require treatment to prevent corrosion. The ground water should be soft enough to use in boilers; however, some of the water has medium to high concentrations of silica. The temperature of ground water in the Carrizo and Wilcox should range from about 65°F in the outcrop to more than about 70°F at depths in excess of 400 feet.

Ground water in the Carrizo and Wilcox is acceptable for irrigation in most of the area. The salinity hazard of most of the water is medium, and even

Table 6.--Chemical analyses of water from selected wells in the Carrizo Sand and Wilcox Formation, undifferentiated, Sulphur River and Cypress Creek Basins

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

Well	Depth of well (ft.)	Silica (SiO_2)	Iron (Fe) (Total)	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 $CaCO_3$	Percent sodium	Sodium adsorp-tion ratio (SAR)	Specific conduct-ance (micromhos at 25°C)	pH
LZ-17-50-701	710	22	b/ 0.03	1.4	0.4	c/ 220		472	41	38	0.1	0.0	--	555	5	99	43	--	8.9
JZ-17-55-405	80	87	2.2	1.7	1.1	c/ 22		48	2.6	5.0	.4	7.5	--	198	9	84	3.2	--	7.0
17-63-501	440	13	b/ .05	1.5	.4	101	1.1	240	.2	18	.2	.2	0.28	254	5	97	20	417	7.9
BD-16-43-201	15	62	b/ .00	3.0	1.1	24	.6	10	32	10	.0	.5	--	138	12	80	3.0	144	4.8
16-46-402	275	44	b/ .13	7.5	1.5	38	1.8	96	4.2	18	.2	.0	.02	162	25	75	3.3	215	6.4
BZ-35-01-803	475	12	--	3.0	.9	113	2.0	275	12	12	.3	2.8	--	302	11	95	15	485	7.8
LK-35-22-706	316	12	--	1.0	.1	c/ 146		235	28	18	.2	.0	--	402	3	99	37	651	8.1
35-31-704	792	15	--	16	4.7	83	3.3	221	23	24	.2	3.0	--	281	59	74	4.7	464	7.4
DB-16-63-203	844	20	b/ .07	2.6	.8	c/ 215		382	2	115	--	.2	--	545	10	98	30	--	8.4
16-62-701	825	20	b/ .08	3.0	1.2	c/ 279		440	3	174	--	.0	--	698	12	98	34	--	--
16-59-902	477	13	10	14	5.6	c/ 18		86	17	6.0	--	.5	--	117	58	40	1.0	--	--
TU-16-59-701	654	29	b/ .08	8.0	3.2	6.3	6.0	23	24	7.0	.2	.2	--	99	33	--	.5	141	7.3
16-51-401	260	--	--	8.8	2.2	c/ 21		6.0	17	22	.0	30.0	--	104	31	--	1.6	--	5.4
16-51-502	450	20	b/ .47	3.0	.8	225	3.6	411	1.4	114	1.4	.2	--	578	11	--	29	--	8.3
BZ-35-01-105	466	12	.40	8.7	2.1	c/ 92		180	65	9.0	--	2.0	--	289	30	87	7.3	--	--
YK-35-17-202	554	13	b/ .04	3.0	.7	102	3.4	213	33	18	.2	2.2	--	281	10	--	14	478	7.2
DB-35-04-801	380	--	--	6.4	1.2	c/ 38		98	15	6.0	.3	--	--	115	22	80	3.5	--	--

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

though the percentage of sodium generally is high, the sodium-adsorption ratio (SAR) or sodium hazard is low to medium because of the low dissolved-solids content of the water. Because the salinity hazard generally is medium, SAR as much as 20 may be allowed in water used for supplemental irrigation. Good drainage, adequate leaching, which can be expected from the relatively high rainfall, and the use of chemical additives generally will counteract much of the harmful effects of using water of borderline quality. The better irrigation water in the Carrizo and Wilcox occurs at shallow depths in or near the outcrop.

Utilization and Present Development

Table 7 shows the amount of ground water pumped from the Carrizo Sand and Wilcox Formation, undifferentiated, for public-supply, industrial, and irrigation use. Pumpage from the Carrizo and Wilcox for domestic, livestock, and miscellaneous use was not calculated, but probably is less than the major pumpage. About 5,400 acre-feet, or 4.8 mgd, of ground water was pumped from 106 major wells in the Carrizo and Wilcox in the Sulphur River and Cypress Creek Basins in 1959; about 90 percent of the pumpage was in the Cypress Creek Basin. Almost 40 percent of the total pumpage from the Carrizo and Wilcox was from major subdivision CY-6 in eastern Harrison, Marion, and Cass Counties (Plate 4).

About 3.1 mgd of ground water was used for public supply in 1959; this represents about 65 percent of the total major pumpage from the Carrizo and Wilcox in 1959. About 30 percent of the water for public supply was from wells in the eastern part of the Cypress Creek Basin in major subdivision CY-6, where the city of Atlanta is the largest consumer. Forty-eight municipal wells in 20 municipalities were in use at the end of 1959.

Industrial pumpage accounted for 1.6 mgd, or 33 percent, of the total major ground-water pumpage from the Carrizo and Wilcox in 1959. About 51 percent of the industrial pumpage was in major subdivision CY-6 in the eastern part of the Cypress Creek Basin, the water being used for cooling and boiler feed. More than half the remaining industrial pumpage was from 8 wells in southern Franklin County, where the water was used for waterflooding in oil fields, cooling, and boiler feed. Forty-one industrial wells producing from the Carrizo and Wilcox were in use at the end of 1959.

About 0.12 mgd was pumped for irrigation in 1959. This is about 3 percent of the total ground water pumped from the Carrizo and Wilcox in 1959. The production was from 13 wells in the Cypress Creek Basin. About 75 percent of the water pumped for irrigation was from 5 wells in eastern Harrison County in major subdivision CY-6. Most of the irrigation in the Cypress Creek Basin is used to supplement the usually adequate rainfall. Frequently the rainfall is distributed evenly throughout the year and the irrigation wells commonly are shut down for several months to more than a year.

Changes in Water Levels

Water levels have declined in the Carrizo and Wilcox since the early development of public-supply wells. The more significant declines have been restricted, for the most part, to the artesian part of the aquifer, and they

Table 7.--Pumpage from major wells tapping the Carrizo Sand and Wilcox Formation, undifferentiated, 1959

Major subdivision	Public supply		Industrial		Irrigation		Total*	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
SU-6	0.01	11	0.03	34	--	--	0.04	45
SU-7	.12	134	--	--	--	--	.12	140
SU-8	.24	269	--	--	0.01	11	.25	280
SU-9	.03	34	.07	78	--	--	.10	110
CY-1	.21	235	.57	638	--	--	.78	870
CY-2	.56	627	--	--	.02	22	.58	650
CY-3	.51	571	.12	134	--	--	.63	710
CY-4	.49	549	--	--	--	--	.49	550
CY-5	.00	2	.00	3	--	--	--	5
CY-6	.92	1,030	.82	918	.09	101	1.80	2,000
Total*	3.1	3,500	1.6	1,800	0.12	130	4.8	5,400

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

represent chiefly a decline in pressure rather than a decrease in the volume of water in storage.

The areas of large withdrawals of ground water have had the greatest declines of water levels. In eastern Cass County in the city of Atlanta, which pumps about 0.56 mgd, levels declined about 80 feet during the period 1936-60, a decline of about 3.3 feet per year. However, the static level in 1960 remained about 50 feet above the top of the aquifer. Levels declined about 55 feet in northern Morris County at the city of Naples, 12 miles north of Daingerfield, during the period 1943-60, the decline being about 3.2 feet per year. The sands are being dewatered at Naples, as the level is below the top of the aquifer. A municipal well in the city of Jefferson in Marion County flowed 50 gpm when drilled in 1926. The artesian pressure declined, and in 1937 the flow ceased; in 1960 the level was below the land surface.

In general, water levels tend to fluctuate in wells in response to rainfall on the outcrop of the Carrizo and Wilcox and to seasonal pumping in the cites. The highest levels may be expected in the winter, and the lowest during the summer, when pumpage is greatest. Heavy withdrawal of ground water in the artesian part of the aquifer has not caused general declines in levels in the outcrop, which in most places is nearly saturated.

Availability and Potential Development

The average coefficient of transmissibility of the Carrizo Sand and Wilcox Formation, undifferentiated, in the Sulphur River and Cypress Creek Basins is about 10,000 gpd per foot. The coefficient of transmissibility, determined from pumping tests of 3 wells tapping the Carrizo and Wilcox in the report area, was less than 1,000 gpd per foot, and in 3 others it ranged from 7,000 to 14,000 gpd per foot. No coefficients of storage were obtained during the tests, and in most wells only part of the total sand thickness was tapped.

Specific capacities of 7 wells tapping the Carrizo and Wilcox ranged from less than 0.5 to about 19 gpm per foot of drawdown, and in 3 wells they were less than 1 gpm per foot. An analysis of reported yields of 60 public-supply, industrial, and irrigation wells tapping the Carrizo and Wilcox in Hopkins, Marion, Morris, Titus, Camp, Harrison, Franklin, and Cass Counties shows that 40 percent yielded less than 100 gpm, 70 percent less than 200 gpm, and 90 percent less than 300 gpm. Only 2 of the 60 wells yielded more than 500 gpm. However, in much of the area, wells capable of yielding 500 gpm or more could be constructed by screening opposite more of the sand beds in the Carrizo and Wilcox. Many of the wells are screened opposite only one or two sand beds.

The altitude of the top of the Carrizo Sand and Wilcox Formation, undifferentiated, where the unit is overlain by the Mount Selman Formation in the Sulphur and Cypress Creek Basins, ranges from more than 500 feet in soucheastern Hopkins and southwestern Franklin Counties to slightly below sea level in the East Texas basin in Cass and Marion Counties (Plate 12). The altitude of the outcrop north of the East Texas basin ranges from about 600 feet in southeastern Hopkins County to less than 200 feet at the Sulphur River at the Louisiana State line south of Texarkana. The altitude of the outcrop in Marion and Harrison Counties ranges from about 400 feet to 180 feet in Caddo Lake. The greatest depth below land surface to the top of the Carrizo and Wilcox is about 500 feet in the vicinity of the Marion-Cass County line northwest of Jefferson.

The saturated thickness of the fresh to slightly saline water sands in the Carrizo Sand and Wilcox Formation, undifferentiated, ranges from about 100 to 550 feet except in the outcrop where it ranges from 0 to 400 feet (Plate 14). The greatest thickness of saturated sand is near both the east and west ends of the Camp-Upshur County line

The volume of fresh to slightly saline water stored in the sands in the Carrizo Sand and Wilcox Formation, undifferentiated, in the Sulphur River and Cypress Creek Basins in Texas is estimated to be 230,000,000 acre-feet, assuming a porosity of 30 percent. However, only a small fraction of the water is recoverable by known methods at present costs.

For comparison, the amount of water available from the unit from the Sulphur River and Cypress Creek Basins was computed using several assumptions. A line of discharge was postulated extending from a point on the basis boundary south of Gilmer to a point on the Texas-Louisiana State line east of Linden, about 12.5 miles north of the Cass-Marion County line. The line is about 60 miles long and generally parallels the trend of the outcrops. The distance from the assumed line of discharge to the center lines of the outcrops ranges from about 10 to 35 miles; however, the assumed distance from both line sources is 30 miles and the line of discharge is assumed to be equidistant from both. The transmission capacity of the aquifer from the outcrops to the line of discharge was computed using the following assumptions:

1. Water levels will be lowered to a maximum depth of 400 feet below land surface along the line of discharge.

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

3. The altitude of the water levels is the same and remains the same at all points along the center line of each outcrop (assumed effective line sources of recharge); and the altitude of the water levels is the same at all points along the line of discharge.

4. The slope of the water surface will be constant from both line sources after drawdown to 400 feet at the line of discharge.

5. The hydraulic gradient is the slope of a straight line from the water level at each line source of recharge to the water level along the line of discharge.

6. All the sands between each line source of recharge and the line of discharge transmit water from the outcrop areas to the line of discharge. The assumed average coefficient of transmissibility of the Carrizo and Wilcox is 10,000 gpd per foot.

7. Where recharge is considered, the amount of recharge along each line source is sufficient to supply the water that can be transmitted to the line of discharge as the assumed gradients.

8. The rate of transmission of water through the aquifer is the average of the rate based on 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.

The transmission capacity of the Carrizo and Wilcox from each assumed line source to the assumed line of discharge at the average hydraulic gradient during the time that the water level is being lowered to 400 feet would be about 6,350 acre-feet per year or a total of 12,700 acre-feet per year from both line sources. The total transmission capacity at the maximum hydraulic gradient from both line sources would be about 18,000 acre-feet per year. The amount of water that could be withdrawn from artesian storage as the water level is lowered to 400 feet along the line of discharge would be about 27,000 acre-feet, assuming no dewatering. However, along part of the line of discharge some of the upper sand beds would be dewatered if the water level were lowered to 400 feet below land surface. If the 1959 discharge rate (4.9 mgd or 5,400 acre-feet) were continuously withdrawn from wells evenly spaced along the assumed line of discharge, the water levels would not be lowered to 400 feet. However, if the pumpage rate were increased to 15 mgd (16,800 acre-feet per year) from wells evenly spaced along the assumed line of discharge, the water level could be lowered to 400 feet in about 7 years at the average gradient. The transmission capacity at the maximum gradient after the water level had been lowered to 400 feet below land surface would be about 1 mgd greater than the 15 mgd withdrawal rate. Also, the proper distribution of pumpage thoughout the area, leakage from overlying formations, locally much larger coefficients of transmissibility, and other factors probably would increase the perennial discharge rate by a factor of from 3 to 10 times the 1959 rate.

The amount of recharge on the outcrop necessary to replace the water moving downdip at the maximum transmission capacity (18,000 acre-feet per year) would be about 0.14 inch of rainfall per year, or less than 0.5 percent of the annual rainfall.

Problems

The continuing decline of artesian pressure is a cause for concern in areas of heavy withdrawal. Water levels in most places in the artesian part of the aquifer, however, are still many feet above the top of the aquifer. As artesian pressures continue to decline, the problem will become more common.

Data are insufficient to permit a complete evaluation of the potential of the aquifer of the Carrizo and Wilcox. More information is needed on hydraulic characteristics to determine more accurately the rate and direction of movement of water in the aquifer and the ability of the sands to transmit and yield water to wells. Also, periodic measurements of water levels in selected observation wells are needed to evaluate the effects of ground-water development on available supply.

Secondary Aquifers

Secondary aquifers in the West Gulf Coastal Plain, which yield either moderate amounts of water in relatively small areas or small amounts of water in relatively large areas are the Blossom Sand, Nacatoch Sand, Mount Selman Formation and Sparta Sand, undifferentiated, and Quaternary alluvium.

Blossom Sand

The Blossom Sand of Austin age crops out in the Red and Sulphur River Basins in central Fannin, Lamar, and Red River Counties and in extreme northwestern Bowie County. The Blossom is not differentiated from other rocks of Austin age on the geologic maps, and only the undifferentiated rocks are shown (Plates 3 and 4). In Red River and Bowie Counties much of the outcrop is covered by high-level alluvial terrace deposits. The outcrop trends east and west and is terminated on the west in central Fannin County near the city of Bonham, where the Blossom Sand merges laterally into marl and chalk. South of its outcrop, the Blossom underlies younger deposits in the Red River, Sulphur River, and Cypress Creek Basins, where it is an artesian aquifer. However, the Blossom contains fresh to slightly saline water only in the Red River Basin and the northern part of the Sulphur River Basin; in the rest of the area the water is more saline.

The Blossom Sand consists of brownish to light-grayish unconsolidated ferruginous glauconitic fine to medium sand interbedded with light to dark sandy marl and chalky marl. Individual beds for the most part, extend over a few square miles and do not tend to change lithology in short distances, although facies changes in greater distances of perhaps a few tens of miles are common. Most of the Blossom Sand is relatively impermeable sandy clay or marl and chalk; the net sand thickness constitutes about 25 percent of the formation and the overall percentage of sand decreases westward. Generally, the thicker accumulations of sand, in places 40 to 50 feet thick, are at the base and near the top of the formation, and, because of the thick intervening relatively impermeable section, probably are not hydrologically connected.

The Blossom Sand thickens southward downdip and eastward along the strike. The total thickness ranges from 0, where the formation merges into marl in central Fannin County, to about 400 feet in southern Red River County.

The dip of the Blossom Sand is southward throughout the area in which it contains fresh to slightly saline water, the magnitude of dip averaging about 85 feet per mile. No major structural features interrupt the dip of the aquifer. The depth to the top of the aquifer along the southward limit of fresh to slightly saline water is, in most places, less than 350 feet, and the maximum depth to the base of the fresh to slightly saline water is about 750 feet, a few miles south of Clarksville in central Red River County.

The principal source of recharge to the Blossom Sand is precipitation on the outcrop, which ranges in width from about 1 mile near its western end in central Fannin County to about 5 miles in central Red River County. Much of the outcrop in Red River County is covered by a mantle of thin high-level terrace deposits, which in places forms an excellent recharge facility for the Blossom Sand. Thick saturated deposits of alluvium along the Red River probably supply considerable water to the underlying Blossom Sand in extreme northwestern Bowie County.

Water moves southward in the Blossom Sand from the recharge areas on the outcrop to points of discharge. The rate of movement is not known, but probably is very slow. Water is discharged from the Blossom by pumping from wells and by natural means, such as transpiration by plants on the outcrop and by seepage into other formations in the subsurface, especially along the Luling-Mexia-Talco fault system.

Fresh to slightly saline water may be obtained from the Blossom Sand in the area shown in Plate 10. The area is divided about equally between the Red and Sulphur River Basins. The irregularity of the southern limit of the fresh to slightly saline water is related primarily to the distribution and amount of sands in the formation. Thick sand beds in eastern and central Red River County gradually merge into marl toward the west, as indicated by the narrowing of the outcrop and the subsurface extent of fresh to slightly saline water.

Chemical analyses of water from selected wells in the Blossom Sand are shown in Table 8. The locations of the wells are shown on the well map (Plate 4) by a bar over the well symbols. The analyses shown may be considered representative of the quality of ground water in the Blossom at the general depth and vicinity of the wells. In general, ground water from the Blossom Sand is high in sodium bicarbonate, high in dissolved-solids content, and is soft. The hardness of 5 samples ranged from 8 to 30 ppm. The dissolved-solids content in 5 samples ranged from 501 to 2,030 ppm, all exceeding the 500 ppm limit recommended by the U. S. Public Health Service. The fluoride content ranged from 0.4 to 2.6 ppm, exceeding 1.5 ppm in 1 sample.

The quality of water in the Blossom Sand is acceptable for public supply in small areas mostly close to the outcrop in the eastern half of Red River County. The dissolved-solids and chloride contents commonly exceed the recommended limits for drinking water.

The acceptability of water from the Blossom for industrial use is dependent on the type of use. Although the water is soft, the high concentration of sodium bicarbonate and high dissolved-solids content makes it undesirable for boiler feed. The temperature of the water should range from 65°F in the outcrop to 73°F at a depth of 600 feet.

Ground water in the Blossom Sand generally is unsatisfactory for irrigation. Most of the water, even from relatively shallow wells, is high in salinity and sodium hazards; however, where soils have good drainage and leaching is adequate, the water of better quality in the Blossom might be used on a supplementary basis without damage.

Table 19 shows that about 336 acre-feet, or 0.30 mgd, of water was pumped from the Blossom Sand by major wells in 1959, all of the water being used for public supply. All the pumpage was in Red River County in major subdivision SU-4 from 2 public-supply wells at Clarksville. The amount of water used from the Blossom Sand for domestic, livestock, and miscellaneous purposes is not known, but probably is about 25 percent of the major pumpage. A large part of the total discharge for domestic, livestock, and miscellaneous purposes is from 5 flowing wells in Lamar County near Paris where 0.03 mgd flows for livestock use.

Table 8.--Chemical analyses of water from selected wells in the Blossom and Nacatoch Sands, West Gulf Coastal Plain

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

Well	Depth of well (ft.)	Silica (SiO_2)	Iron (Fe) (Total)	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
Blossom Sand, Sulphur River Basin																			
RT-17-21-702	90	11	--	7.8	2.7	c/ 365		540	148	158	1.4	0.0	--	960	30	96	29	1,590	7.8
17-21-801	90	11	--	8.8	2.1	c/ 183		314	81	59	1.0	1.2	--	501	30	93	15	836	7.6
WB-17-23-901	350-380	9.8	b/ 0.00	3.2	.8	748	3.4	682	458	412	2.6	4.2	--	1,980	12	99	94	3,180	8.0
17-32-201	602	15	b/ .04	5.3	1.0	384	4.8	437	201	204	.4	2.0	--	1,030	17	97	41	1,790	8.4
16-25-101	640	13	--	2.0	.6	c/ 813		784	51	762	1.2	3.2	--	2,030	8	100	125	3,590	8.0
Nacatoch Sand, Red and Sulphur River Basins																			
RT-17-38-401	20	28	0.03	116	5.6	c/ 40		334	30	40	0.2	47	--	487	312	22	1.0	757	6.6
WB-17-39-506	167	16	b/ .00	3.8	.7	210	1.2	533	.0	24	.3	3.2	0.90	522	12	97	26	834	8.5
16-34-503	348	13	--	1.4	.2	272	1.4	543	45	82	--	.2	1.9	684	4	99	56	1,130	8.8
BD-16-35-901	780	13	--	1.5	.1	c/ 328		622	26	128	--	.0	--	822	4	99	71	1,350	8.3
16-37-301	500	11	--	2.5	.4	c/ 412		560	.4	310	2.1	1.2	--	1,010	8	99	63	1,790	8.0
16-32-701	430	13	--	2.5	.1	c/ 273		450	1.6	160	1.2	.0	--	672	6	99	48	1,170	8.6
PH-17-49-304	440	12	1.7	.8	.3	175	.9	374	45	19	.6	3.0	.36	442	3	99	44	703	8.8
17-49-305	453	12	.20	.6	.4	185	.9	396	45	22	.7	.5	.28	464	3	99	46	737	8.9
WB-17-39-901	408	15	b/ .05	2.8	1.0	c/ 413		544	2	326	.3	.2	--	1,030	11	99	54	--	--
PH-17-41-902	580	14	b/ .03	2.7	.5	256	10	474	73	80	.5	.8	--	678	8	96	39	1,180	9.0
17-41-903	433	10	b/ .03	2.9	.4	266	6.4	471	91	80	.3	.5	--	694	8	97	41	1,180	8.8

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

Water levels in the Blossom Sand have declined since the start of development in the early part of the 20th century; however, the decline has been small and is restricted to the artesian part of the aquifer and is a decline in pressure rather than a dewatering of the sand. Since the drilling of the first well in the city of Clarksville in 1905, levels have declined from 144 to 170 feet below land surface in 1960, about 0.5 foot per year. The static level in 1960 was near the top of the aquifer; however, most of the wells are screened in the lower sands several hundred feet below the top of the aquifer and the danger of dewatering is small.

Insufficient data preclude a quantitative hydrologic evaluation of the Blossom Sand; however, north and east of Clarksville, where water levels are probably high, large quantities of sand in the Blossom probably contain water of good quality. A pumping test of a well in Clarksville indicated coefficients of transmissibility and storage to be 3,800 gpd per foot and 0.00004, respectively, and the specific capacity to be 1.8 gpm per foot. Yields of wells in the Blossom Sand should be 650 gpm or more in areas of optimum sand thickness. Additional information is needed regarding the changes in quality of the ground water from place to place as well as an accurate determination of sand thicknesses throughout the extent of fresh to slightly saline water in the aquifer.

Nacatoch Sand

The Nacatoch Sand crops out in the Sulphur and Red River Basins in Hunt, Delta, Hopkins, Franklin, Lamar, Red River, and Bowie Counties (Plate 10). The outcrop, which trends northeastward, is almost entirely within the Sulphur River Basin. Only the part in northern Bowie County is in the Red River Basin. From Red River County eastward, much of the outcrop is covered by a thin mantle of high-level terrace deposits, and thick deposits of alluvium in the Red River Valley conceal the outcrop where it crosses the Red River. The Nacatoch Sand is not separated from other rocks of the Navarro Group on the geologic map (Plate 4); hence only the undifferentiated Navarro Group is shown. In the outcrop, water-table conditions prevail, whereas to the south the Nacatoch Sand underlies younger deposits and is an artesian aquifer.

The Nacatoch Sand consists of light gray unconsolidated massive glauconitic calcareous sand and marl. Some layers of sand are indurated, forming hard calcareous concretionary masses. Although some sand beds, especially near the top, are persistent in a wide area of several counties, other sand beds, particularly in the middle part of the formation, may grade into marl within a few miles. The ratio of sand to marl in the Nacatoch varies from place to place, but in general the formation consists of about 50 percent sand. In the eastern part of the outcrop and in the subsurface in Bowie County, the lower part of the Nacatoch Sand is predominantly marl. The lower marly part of the aquifer decreases in thickness westward until, in much of the area west of Bowie County, sandy beds mark the base of the aquifer.

The thickness of the Nacatoch Sand ranges from about 500 feet in parts of Bowie County, decreasing westward along the strike, to about 350 feet in parts of Delta and Hunt Counties. The thickness does not change significantly downdip from the outcrop within the area of extent of fresh to slightly saline water.

The Nacatoch Sand dips southward at about 80 feet per mile. In the western part of the outcrop in Delta, Hopkins, and Franklin Counties, the formation is cut by numerous faults of the Luling-Mexia-Talco fault system (Plates 8 and 9). The system also displaces the formation in the subsurface in Red River and Bowie Counties. At the southward extent of fresh to slightly saline water near the Red River-Bowie County line, the depth to the top of the Nacatoch is about 800 feet.

Precipitation on the outcrop is the chief source of recharge to the Nacatoch Sand. The outcrop, ranging in width from 1 mile in Hunt County to 6 miles in Bowie County, is covered by a mantle of high-level terrace deposits in much of its area in Red River and Bowie Counties, but is generally at the surface in Hunt, Delta, and Hopkins Counties. A significant amount of recharge probably is being continuously derived from the overlying terrace deposits, which are saturated in many places.

Movement of ground water in the Nacatoch Sand is southward in the direction of dip. The rate of movement is not known, but it is probably slow because of the fine sand size and the discontinuity of the sand beds.

Ground water from the Nacatoch Sand is discharged by pumping and flowing wells and by natural means. The relation between the Nacatoch Sand and the South and North Sulphur Rivers, which flow for several miles on the outcrop, is not known completely; however, based on a few water levels in the outcrop of the Nacatoch Sand, the streams probably are effluent. Numerous faults in the Luling-Mexia-Talco fault system, which displace the Nacatoch, probably are conduits through which the water moves from the Nacatoch to other formations.

Fresh to slightly saline water may be obtained from the Nacatoch Sand in the area shown in Plate 10. About 80 percent of the area is in the Sulphur River Basin, the rest being mostly in northern Bowie County in the Red River Basin. The southern extent of the fresh to slightly saline water is controlled in large measure by the Luling-Mexia-Talco fault system, the northernmost fault or series of faults marking the southern limit in the subsurface in western Bowie County, Red River County, and eastern Hunt County. South of the faults, the water is, for the most part, highly mineralized (Plates 8 and 9). In Delta and Hopkins Counties the fault system cuts the outcrop of the Nacatoch Sand, largely restricting the area of fresh to slightly saline water to the outcrop.

Chemical analyses of ground water from selected wells in the Nacatoch Sand are shown in Table 8. The locations of the wells are shown on the well map (Plate 4) by a bar over the well symbols. The analyses shown may be considered representative of the quality of ground water in the Nacatoch Sand at the general depth and vicinity of the wells. In general, the ground water is highly alkaline, high in sodium bicarbonate content, and soft. The hardness of 11 samples ranged from 3 to 312 ppm, exceeding 60 ppm in only 1 sample. The dissolved-solids content in 11 samples ranged from 442 to 1,030 ppm, exceeding 500 ppm in 9 samples and 1,000 ppm in 2 samples. The iron content in 7 samples ranged from 0.00 to 1.7 ppm, exceeding 0.3 ppm in only 1 sample. The fluoride content in 9 samples ranged from 0.2 to 2.1 ppm, exceeding 1.5 ppm in only 1 sample.

The quality of water in the Nacatoch Sand generally is good for public supply. Excessive concentrations of chloride and dissolved solids are, for the most part, associated with the deeper water near faulted areas. Ground water from the outcrop and short distances downdip generally conform to the recommended standards for drinking water.

Ground water from the Nacatoch Sand is suitable for many types of industrial uses, but high sodium bicarbonate waters usually are objectionable in high-pressure steam boilers, laundries, and textile plants. Ground water at or near the outcrop is more efficient for cooling, the temperature of the ground water ranging from the average annual air temperature of 65°F at the outcrop to 80°F at a depth of 800 feet.

Ground water from the Nacatoch Sand is, in most places, generally unacceptable for irrigation. The water is high to very high in sodium hazard and high in salinity hazard. However, where soils are well drained and sandy, water from the Nacatoch at shallow depths on or near the outcrop may be used as a supplement to rainfall without damage to the soil.

The quantity of water withdrawn in 1959 from the Nacatoch Sand by major wells for public supply, industry, and irrigation is shown in Table 19. In 1959, about 1,500 acre-feet, or 1.2 mgd, was pumped for all uses from the Nacatoch in the Red and Sulphur River Basins, about 86 percent being withdrawn from the Sulphur River Basin. Withdrawal for public supply was 1.16 mgd, or about 83 percent of the total. About 79 percent of the total public-supply pumpage was from 6 wells at the city of Commerce and adjoining area in major subdivision SU-1. Other municipalities using water from the Nacatoch include DeKalb in Bowie County, Bogata in Red River County, and Talco in Titus County. Industry used 0.15 mgd, almost 11 percent of the total ground water withdrawn from the Nacatoch Sand in 1959. All industrial pumpage was from 3 major wells in southwestern Red River County in major subdivisions SU-3 and SU-5. Most of the water was used for cooling and boiler feed. About 0.07 mgd from the Nacatoch Sand was used for irrigation, representing about 5 percent of the total water withdrawn from the aquifer. All pumpage was from 3 wells in northwestern Bowie County in major subdivision RE-42. The amount of water withdrawn from the Nacatoch for domestic, livestock, and miscellaneous purposes has not been estimated, but is probably relatively small. Eighteen flowing wells in southeastern Red River County and eastern Bowie County discharged about 0.13 mgd, or about 9 percent, of the total major ground-water pumpage in 1959. Although some of the flow is being used, most of it is wasted.

Water levels in the Nacatoch Sand have declined steadily in places where withdrawal is heavy. Since the drilling of the first municipal well in Commerce in 1914, levels have declined about 180 feet during a 47-year period, an average of about 4 feet per year. Levels were at or below the top of the aquifer at Commerce in 1961, indicating a dewatering of the sand in that area. Withdrawal of about 0.2 mgd for public supply and industrial use in a small area in southwestern Red River County has caused rapid declines of levels, as much as 16 feet per year from 1957 to 1961. As a result, a municipal well in the area, which flowed 23 gpm in 1942, stopped flowing, and in 1959 had a level 40 feet below land surface.

Lack of sufficient data precludes an accurate evaluation of the potential development of the Nacatoch Sand. However, in general, yields as much as 500 gpm may be obtained in areas of optimum sand thickness and where water levels are high enough to permit sufficient drawdowns without dewatering the sands.

Water levels are high in much of southeastern Red River County and southwestern Bowie County, where flowing wells are common, and the depth to the top of the aquifer is several hundred feet, providing sufficient drawdown for large yields. Specific capacities of 6 wells ranged from about 0.50 to about 14.0 gpm per foot, being greatest in parts of western Bowie County and in Hunt County. A pumping test about 6 miles northwest of Texarkana indicated the coefficient of transmissibility to be 2,200 gpd per foot. The well tested had a specific capacity of 1.3 gpm per foot.

Much information is needed regarding sand thickness in the aquifer and the ability of the aquifer to transmit water before the availability of water from the Nacatoch Sand may be determined accurately.

The most serious problem concerning water in the Nacatoch Sand is the declining levels. In areas of relatively heavy pumping, static water levels are below the top of the aquifer, and in some wells the pumping levels are dangerously close to the screened part of the aquifer. Continued declines will result in a reduction of the yield and an overall decrease in efficiency of the wells.

Mount Selman Formation and Sparta Sand, Undifferentiated

The Mount Selman Formation and Sparta Sand, undifferentiated, crop out in the Sulphur River and Cypress Creek Basins (Plates 4 and 10), where they overlie the Carrizo Sand and Wilcox Formation, undifferentiated. The Mount Selman Formation and Sparta Sand, undifferentiated, are present only in the southeastern part of the Sulphur River Basin, the greater extent of this map unit occupying about 90 percent of the Cypress Creek Basin. The only parts of the Cypress Creek Basin not underlain by the unit are on the Sabine uplift and in the extreme northwestern part of the basin.

The Mount Selman Formation and Sparta Sand, undifferentiated, consist of light gray to brownish-gray unconsolidated ferruginous crossbedded fine to medium sand interbedded with light to dark-gray carbonaceous clay, glauconite, lignite, and ironstone. Iron staining imparts a decidedly reddish color to much of the weathered outcrop. Fine to medium sand in massive beds as much as 50 feet thick is common in many places. The Mount Selman Formation may be separated into members--Reklaw, Queen City Sand, and Weches Greensand, in ascending order. However, because of the predominance of sand in the Mount Selman Formation, the fact that most of the sand beds are hydrologically connected, and because the Sparta Sand overlying the Mount Selman is sandy and relatively thin, the two formations are undifferentiated and may be considered a composite hydrologic unit or aquifer in the report area. Water-table conditions prevail in most of the aquifer; however, locally ground water may be confined under artesian pressure by thick beds of clay generally near the base of the aquifer.

The thickness of the aquifer ranges from 0 at its contact with older rocks at the surface to about 500 feet. The thicker sections are in the trough of the East Texas basin in areas of highest altitudes (Plate 8).

The dip of the Mount Selman Formation and Sparta Sand, undifferentiated, is predominantly southeastward and northwestward toward the synclinal axis of the East Texas basin, the magnitude of dip ranging from about 15 feet per mile southeastward to about 50 feet per mile northwestward. The greatest dips are in areas of structural deformation in northeastern Marion County adjacent to the Rodessa fault and around the uplift in western Upshur and eastern Wood Counties.

The principal source of recharge to the Mount Selman Formation and Sparta Sand,,undifferentiated, is precipitation on the outcrop. The aquifer crops out in parts of 10 counties and receives an average of 40 to 48 inches annually; however, only a small part of the rainfall may be considered recharge. Streams flowing across the outcrop, particularly Big and Little Cypress Creeks, are probably effluent throughout much of their courses.

Water has several components of movement in the aquifer. In general, it is moving downward to the water table, thence laterally from higher to lower elevations; thus, much of the movement is northeastward in the direction of southern Arkansas and northern Louisiana. The rate of movement is not known.

Water is discharged from the aquifer by wells and natural means. Pumpage from major wells was 152 acre-feet, or 0.14 mgd, in 1959. Most of the pumpage is from several hundred domestic, livestock, and miscellaneous wells. Spring-flow and seepage into streams and transpiration by the thick vegetation, which covers much of the outcrop, account for substantial amounts of discharge from the aquifer. Water from the Mount Selman Formation and Sparta Sand, undifferentiated, may be discharging into the underlying aquifer of the Carrizo and Wilcox in areas where the artesian pressure in the Carrizo and Wilcox is low.

Fresh to slightly saline water may be obtained from almost any part of the aquifer (Plate 10). Most of the water is fresh, typically low in dissolved-solids content, and generally soft. Chemical analyses of water from selected wells in the Mount Selman Formation and Spartan Sand, undifferentiated, are shown in Table 9. The locations of the wells are shown on the well map (Plate 4) by a bar over the well symbols. The analyses shown are only a few of the total number on record, but they may be considered representative of the quality of water in the aquifer at the general depth and vicinity of the wells. The hardness of 43 samples ranged from 6 to 295 ppm, exceeding 60 ppm in only 8 samples. The dissolved-solids content in 43 samples ranged from 12 to 549 ppm, exceeding 500 ppm in only 1 sample. The iron content in 5 samples ranged from 0.18 to 6.6 ppm, exceeding 0.3 ppm in 4 samples. The fluoride content in 11 samples ranged from 0 to 0.4 ppm. Most of the water is acidic.

The quality of the water in the aquifer generally is acceptable for public supply. Concentrations of most chemical constituents are typically low and meet the standards for drinking water as recommended by the U. S. Public Health Service. However, concentrations of iron in excess of 0.3 ppm are common and treatment may be necessary. Concentrations of nitrate generally are high, exceeding 45 ppm in places. The high nitrate content may be an indication of contamination by sewage, and water having high nitrate content should be tested for bacterial content.

Water in the aquifer is suitable for many kinds of industrial uses. The softness of the water and absence of alkalinity is desirable for boiler feed, but the acidity of the water may have a corrosive effect on metals. Industry requiring low concentrations of iron may need to treat the water to reduce the iron content. The temperature of much of the ground water should be about 65°F or slightly higher.

Table 9.--Chemical analyses of water from selected wells in the Mount Selman Formation and Sparta Sand, undifferentiated, and Quaternary alluvium, West Gulf Coastal Plain

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

Well	Depth of well (ft.)	Silica (SiO_2)	Iron (Fe) (Total)	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 $CaCO_3$	Percent sodium	Sodium adsorp-tion ratio (SAR)	Specifc conduct-ance (micromhos at 25°C)	pH
Mount Selman Formation and Sparta Sand, undifferentiated, Sulphur River and Cypress Creek Basins																			
BZ-35-02-501	23	62	0.18	6.0	4.9	[c] 11		0	55	22	0.2	0.8	--	163	35	27	0.8	213	4.3
DB-16-60-901	60	23	.31	14	.5	3.8	1.1	48	.4	3.0	.0	3.2	--	73	37	18	.3	103	5.9
35-06-201	46	9.1	6.6	2.5	.8	.8	.4	18	2.4	1.8	.0	.8	--	29	10	9	.1	43	5.9
SX-35-20-302	28	22	1.9	2.0	1.1	3.4	.4	4	.0	9.0	.1	1.2	--	41	10	43	.5	44	4.7
LK-35-20-501	30	17	.48	15	3.7	4.2	1.4	34	.0	8.2	.1	29	--	96	53	14	.3	142	5.7
Quaternary alluvium, Red River Basin																			
KT-18-12-601	58	23	[b] 0.10	94	8.0	[c] 37		393	16	3.5	0.4	4.3	--	389	268	23	1.0	628	7.7
JS-18-14-909	45	24	[b] .07	92	42	30	1.5	517	41	5.0	--	2.2	0.25	492	402	14	.7	799	7.4
18-23-102	49	20	--	15	3.6	5.3	.6	36	6.8	5.0	.0	26	--	100	52	18	.3	139	6.4
18-23-801	55	20	--	78	4.9	[c] 47		285	7.8	38	--	26	--	362	214	32	1.4	595	6.8
17-09-504	22	19	.10	2.5	1.6	5.7	.3	16	5.2	2.1	.1	5.1	--	50	13	48	.7	59	5.4
RT-17-14-101	30	25	.02	81	16	[c] 22		263	56	16	.2	24	--	369	268	15	.6	564	6.8
WB-17-07-405	30	16	.46	24	7.2	[c] 12		98	11	11	.2	8.4	--	138	90	22	.5	230	6.0
BD-16-19-901	58	30	.01	17	2.7	5.6	.8	69	.0	4.8	.1	4.0	--	99	54	18	.3	146	6.0
16-32-702	48	17	--	197	49	[c] 87		646	93	180	--	2.2	.22	943	693	21	1.4	1,570	6.5

[a] Includes the equivalent of any carbonate (CO_3) present.
[b] In solution.
[c] Sodium and potassium calculated as sodium (Na).

The quality of the water for irrigation is excellent. Low salinity and sodium hazards indicate that it can be used on almost all soils and crops with little danger.

Table 19 shows that about 160 acre-feet of water, or 0.14 mgd, was pumped from the aquifer by major wells in 1959. All the pumpage was in eastern Cass County from major subdivision CY-6, the water being used in industry and for irrigation. The quantity of water pumped for domestic use and livestock was not calculated, but it probably is large compared to the withdrawal for industry and irrigation.

Water levels in the Mount Selman Formation and Sparta Sand, undifferentiated, fluctuate chiefly in response to rainfall. Levels in wells rise during wet periods and decline during drought. However, a comparison of levels measured in 58 wells in December 1941 and January and March 1942 with those measured in the same wells in August, September, and October 1960, show that the levels declined in 46 wells and rose in only 12, even though rainfall was 2.5 inches greater in the measuring period in 1960 than it was in 1941 and 1942. The declines ranged from less than 1 to almost 10 feet, averaging about 2.5 feet, and the rises ranged from less than 1 to about 5 feet, averaging about 2 feet. Water levels in the aquifer range from slightly above land surface to as much 75 feet below the surface.

The Mount Selman Formation and Sparta Sand, undifferentiated, are, for the most part, undeveloped as an aquifer. Yields of 200 gpm or more could be obtained in areas of optimum sand thickness, generally along the axis of the East Texas basin, where the aquifer generally is thickest and high water levels allow for relatively large drawdowns. However, data are insufficient to permit a complete evaluation of the aquifer. More information is needed concerning the areas of greatest sand thickness and the ability of the aquifer to yield water to wells.

Quaternary Alluvium

Quaternary alluvium is exposed in the West Gulf Coastal Plain from Montague County eastward for about 170 miles to the northeast corner of Texas. Although the Quaternary alluvium is present along many of the streams in the area, the deposits that may be considered as aquifers are restricted to the Red River Valley and are, thus, wholly within the Red River Basin.

The alluvial deposits along the Red River are in the form of terraces formed at different stages of the river. Consequently, the highest terrace is the oldest, and the lowest (the present flood plain) is the youngest. The older terraces commonly are dissected by erosion and are about 100 feet above the present level of the Red River. These high-level dissected deposits generally contain only minor amounts of ground water and are, for the most part, relatively poor aquifers. However, in parts of Bowie and Fannin Counties and possibly in a few other places, these upland terraces, though not shown on the geologic maps, are thick enough to contain sufficient ground water for irrigation. In this report, only the flood-plain deposits and low-level comparatively undissected terraces are treated as significant aquifers (Plates 3, 4, and 10).

The Quaternary alluvium consists of light-grayish to reddish-brown unconsolidated crossbedded very fine to very coarse sand interbedded with dark-colored clay, silt, and gravel. The gravel, ranging in size from pebbles to cobbles, generally is near the base of the deposit. Most of the sediments constituting the alluvial deposits may grade laterally and vertically into sediments of different character; however, this condition is local and does not materially restrict the movement of water.

The Quaternary alluvial deposits in the Red River Valley are highly irregular in thickness and areal extent, the thickest and most widespread deposits generally occupying the concave side of bends in the Red River. In places the sediments may overlie level surfaces of bedrock or fill irregular depressions in the bedrock surface. Buried stream channels of the ancestral Red River undoubtedly are present in places beneath the alluvium. The thickness of the Quaternary alluvium ranges from 0 at its contact on the surface with older rocks to 100 feet or more in places in northeastern Bowie County. The maximum thickness is largely conjectural, as no wells of that depth are known to tap the alluvium; however, Davis (1960, p. 49) reports a maximum thickness of 110 feet along the Red River in McCurtain County, Oklahoma, opposite parts of Red River and Bowie Counties. In general, the alluvial deposits thicken eastward with a corresponding increase in flow of the Red River.

The dip of the Quaternary alluvial deposits is, in general, eastward in the direction of slope of the land surface, although locally they may dip in other directions, depending on the direction of the flow of the stream. From the exposure near the Montague-Cooke County line at an altitude of about 750 feet, the alluvial deposits decrease in altitude until at the northeast corner of the State in Bowie County, they are at an altitude of about 250 feet, a dip of approximately 2-1/2 feet per mile.

Recharge to the Quaternary alluvium principally is from precipitation on the outcrop or as runoff from adjacent slopes. The flood plain and lowermost terraces range in width from less than 1 to more than 5 miles and receive an annual average precipitation of 36 inches in Montague County to 48 inches in Bowie County. A part of the precipitation infiltrates the typically sandy surface and is added to the water in storage. Many of the older high-level dissected terraces, although relatively poor aquifers, are favorable recharge areas for underlying bedrock aquifers. The Quaternary deposits adjacent to the Red River are recharged in places during high water or flood stages on the river, when significant amounts of water in the stream moves into the deposits to be held as bank storage. However, much of the water drains back into the stream after the high-river stages subside. Heavy withdrawals of water from the alluvium by pumping from wells near the river may induce recharge by diverting part of the streamflow into the alluvium.

The movement of ground water in the Quaternary alluvium principally is toward the Red River. In no areas in the West Gulf Coastal Plain, as far as could be determined, is the reverse situation true during normal flow of the river; thus, for parts of the Red River having a relatively straight east-west course, the slope of the water table in the adjacent alluvial deposits is toward the river and slightly downstream. The rate of movement is not known; however, Davis (1960, p. 49) determined the slope or hydraulic gradient of the water table in alluvial deposits along the Red River in McCurtain County, Oklahoma, opposite parts of Red River and Bowie County, to be from 2 to 5 feet per mile southeastward.

Discharge of ground water from the alluvium is by pumping from wells and natural means. About 320 acre-feet of ground water was discharged by pumping wells from the alluvium in 1959. Large amounts of ground water also are discharged by numerous springs and seeps along the banks of the Red River and in places where relatively impermeable beds are exposed between terrace levels. Other natural means of discharge include transpiration by vegetation--which is abundant in places, especially near the banks of the Red River--and probably seepage into underlying permeable formations.

The areas where fresh to slightly saline water may be obtained from the Quaternary alluvial deposits of the flood plain and low-level terrace deposits are shown in Plate 10. Most of the fresh to slightly saline water in the alluvium is fresh, high in calcium and magnesium bicarbonate, and generally the water is moderately hard to very hard. Chemical analyses of water from selected wells in the Quaternary alluvium are shown in Table 9. The locations of the wells are shown on the well maps (Plates 3 and 4) by means of a bar over the well symbols. The analyses shown may be considered representative of the quality of ground water in the Quaternary alluvium at the general depth and vicinity of the wells. The hardness of 9 samples ranged from 13 to 693 ppm, exceeding 60 ppm in 6 samples. The dissolved-solids content in 9 samples ranged from 50 to 943 ppm, and exceeded 500 ppm in 1 sample. The total iron content in 6 samples ranged from 0.01 to 0.46 ppm, exceeding 0.3 ppm in only 1 sample. The fluoride content in 6 samples ranged from 0 to 0.4 ppm. The pH of 9 samples ranged from 5.4 to 7.7, exceeding 7.0 in 2 samples, indicating the water to be mostly acidic.

The quality of the water in the Quaternary alluvium is suitable for public supply. Only rarely does the concentration of chemical constituents exceed the recommended limits for drinking-water standards. Most of the water is, however, moderately hard to very hard, and, although hardness is not a criteria for suitability of drinking water, it is important in general domestic use. Nitrate in the water sampled was high but not excessive; where high it may be contaminated by sewage and should be tested for bacterial content.

The suitability of water in the Quaternary alluvium for industry depends on the use. Most of the ground water, being hard and relatively high in silica, will cause the formation of scale in boilers, especially those operating at high pressures. Thus, treatment may be necessary to reduce the hardness. The temperature of the water should be about 65°F.

Ground water in the Quaternary alluvium is excellent for irrigation in most places. Because the water is low in dissolved-solids content, the salinity hazard is low to medium and the sodium hazard is low, indicating that the water may be used on almost any soil without danger. Also, boron concentrations appear to be low, less than 1 ppm, which is permissible for irrigating most boron-sensitive crops.

Table 19 shows the amount of ground water pumped from the Quaternary alluvium by major wells, all of the pumpage in the West Gulf Coastal Plain being from the Red River Basin. In 1959 about 310 acre-feet, or 0.27 mgd, was pumped from the alluvium by 33 irrigation wells and 1 industrial well, the quantity pumped by industry being relatively small. About 47 percent of the pumpage for irrigation, or 0.12 mgd, was in major subdivision RE-38, the most concentrated withdrawal being in a small area about 12 miles northwest of Bonham in Fannin

County, where 14 irrigation wells are in use. Other areas of pump irrigation are in Bowie County in subdivision RE-42, 42 percent of the total pumpage, and Fannin County in subdivision RE-39, about 11 percent.

Water levels in the Quaternary alluvium fluctuate in response to changes in ground-water storage. During periods of rainfall, when irrigation wells are not being used, levels rise. During drought or when withdrawal of ground water for irrigation is large, levels decline. Because of the relatively high rainfall along the outcrop, levels have remained comparatively high, within 10 to 20 feet of the surface. In some of the upland terraces, levels are lower, as much as 45 feet below the surface in some places. No long-term records of levels in the alluvium are available; however, little or no declines in levels have been reported, although most of the irrigation wells were drilled in the middle 1950's.

Ground water in the Quaternary alluvium in the Red River Valley is only partly developed. Moderate to large supplies of fresh ground water are available in areas where sands are thick and water levels are high. These conditions are most likely in the more extensive deposits immediately adjacent to the Red River. Yields of 500 gpm or more are possible under optimum conditions. A pumping test on a well in the Quaternary alluvium 6 miles northwest of Texarkana indicated a transmissibility of about 22,000 gpd per foot and a specific capacity of 15.3 gpm per foot.

Insufficient data preclude a complete appraisal of the ground-water potential of the Quaternary alluvium. Boundaries of the alluvial deposits and thicknesses need to be more accurately mapped to determine the vertical and areal extent of the deposits. Hydraulic characteristics largely are unknown, and long-term records of water-level fluctuations are lacking.

OSAGE PLAINS

General

The central part of the Red River Basin in Texas is in the Osage Plains province. The Osage Plains (Figure 1) is an area of low relief, and in this report is defined as extending from the eastern escarpment of the High Plains (Plate 1) to the western limit of the Cretaceous rocks (Plate 3). Where the escarpment is not present, the western boundary is defined as the eastern margin of the Ogallala Formation. The area of about 15,000 square miles occupies all or parts of 23 counties and is the largest physiographic region within the Red River Basin.

The 1960 census showed the population of the principal cities in the Osage Plains part of the Red River Basin to be Wichita Falls, 101,724; Vernon, 12,141; Burkburnett, 7,621; and Childress, 6,399.

Most of the public water-supply systems in the Osage Plains use ground water. However, probably not more than 35 percent of the urban population is supplied by ground water because several of the larger public-supply systems, including that of Wichita Falls, use surface water.

Prior to 1950, only a few scattered irrigation wells were in use in the Osage Plains. The drought of the 1950's gave impetus to the development of irrigation, practically all the wells having been drilled since 1950. The irrigation development was concentrated where water of suitable quality was available at shallow depths in the Blaine Gypsum or Quaternary alluvium. The areas of concentrated irrigation from the alluvium are in Wilbarger and Foard Counties, Baylor and Knox Counties, and Hall, Motley, Briscoe, and Dickens Counties (Plates 1 and 2). The greatest concentration of irrigation wells tapping the Blaine Gypsum is in Childress, Collingsworth, Hardeman, and Cottle Counties.

The climate of the Osage Plains in the Red River Basin is dry-subhumid. The average annual precipitation ranges from 20 inches in the western part to 36 inches in the eastern part. The average annual temperature ranges from 57°F in the northwest to 64°F in the east.

Occurrence of Ground Water

Primary Aquifers

The primary aquifers in the Red River Basin are the Blaine Gypsum and the Quaternary alluvium.

Blaine Gypsum

Physical Description

The Blaine Gypsum, included in the outcrop of the Pease River Group (Plates 1 and 2), crops out in eastern Hardeman and western Foard Counties, the outcrop trending southwest and south through the eastern parts of Cottle and King Counties. The Blaine also crops out in Knox County but "...Very small quantities of water are produced from the Blaine in Knox County," according to Ogilbee and Osborne (1961, p. 25). The outcrop probably is as much as 20 miles wide in the northern part, where the westward dip is slight. In the southern part, where the rocks dip 25 to 30 feet per mile to the west, the outcrop of the Blaine probably is less than 10 miles wide. The dip also is westward in Foard County and eastern Childress County; however, farther west the dip is reversed, and the Blaine crops out in northwestern Childress County and southwestern Collingsworth County because of a local structural high (Plate 5).

The Blaine Gypsum consists of anhydrite, gypsum, shale, and dolomite. The soft shales form the gentle, rolling plains, whereas the harder dolomite forms mesas or buttes. The gypsum is eroded easily by chemical weathering, and the beds containing gypsum generally are cavernous. Collapsed caverns are common in some areas, particularly in Collingsworth County, where sinkholes may be observed. Some of the sinkholes have formed in recent years, indicating that solution of the gypsum is progressing today. The cavities formed in the beds of gypsum result in the secondary permeability typical of water-soluble rocks.

The observed thickness of the Blaine Gypsum ranges from 0 to about 250 feet in the outcrop; in the subsurface the minimum thickness is about 200 feet

(Plate 5). The saturated thickness of the Blaine is indicated at three points in section A-A' (Plate 5), where the depths to water in the wells in 1958 are shown. The saturated thickness probably changes greatly from one place to another, and the entire Blaine probably is saturated at some distance downdip from the outcrop. The maximum depth to which irrigation wells have been drilled in the Blaine is 375 feet.

The Blaine Gypsum is overlain by the Dog Creek Shale, which consists of shale, anhydrite, gypsum, and dolomite. Although the anhydrite and gypsum are cavernous and may be considered aquifers in some places, the Dog Creek Shale is an aquiclude in most places, confining the water in the Blaine. The Flowerpot Shale, which underlies the Blaine, consists of shale, anhydrite, and gypsum. The Flowerpot also is an aquiclude, although small quantities of water are obtained from the gypsum beds.

Recharge, Movement, and Discharge of Ground Water

The source of recharge to the Blaine is precipitation on the outcrop. Precipitation enters the ground-water reservoir by direct infiltration and by percolation from streams that are above the water table. The solution openings and fractures in the gypsum offer easy access for the water where the rocks are exposed. The Blaine also may receive some of its recharge from the overlying Dog Creek Shale.

The water moves slowly in the direction of the hydraulic gradient from areas of recharge toward areas of discharge. Water is discharged from the Blaine in low places in or near stream valleys where the water table intersects the land surface. In one of the areas, about 5 miles northwest of Quanah in Hardeman County (Plate 1), a spring flows 50 to 60 gpm. The principal artificial discharge is from wells in the heavily irrigated areas (Plates 1 and 2).

Chemical Quality

The chemical analyses of samples of water from 10 selected wells tapping the Blaine Gypsum are shown in Table 10. 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 water in the Blaine Gypsum at the general depth and vicinity of the wells. The analyses show that the principal mineral constituent is calcium sulfate (gypsum). Generally, the sulfate content ranges from 1,000 to 2,000 ppm, although in some samples the content exceeds 2,000 ppm. The chloride content ranges from 20 to more than 1,000 ppm.

Water from the Blaine Gypsum is not suitable for public supply; the sulfate content and, in some wells the chloride content as well, exceeds the 250 ppm limit recommended by the U. S. Public Health Service.

The water from the Blaine is not suitable for many industrial uses; however, it may be acceptable for cooling and washing.

The suitability of water from the Blaine Gypsum for irrigation is dependent upon its classification in regard to salinity and sodium hazards and the

Table 10.--Chemical analyses of water from selected wells in the Blaine Gypsum, Red 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.)	Silica (SiO_2)	Iron (Fe) (Total)	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
DU-05-63-101	80	23	--	602	43	29	1.8	203	1,460	20	0.4	39	0.13	2,320	1,680	4	0.3	2,520	6.7
05-62-602	112	23	--	618	102	[b] 55		278	1,620	83	.3	59	--	2,700	1,960	6	.5	2,910	6.7
12-14-102	180	19	--	572	112	29	3.7	123	1,720	34	.9	1.0	.66	2,550	1,890	3	.3	2,700	7.0
DK-12-24-208	176	18	--	606	73	[b] 50		236	1,580	55	--	31	.41	2,530	1,810	6	.5	2,740	7.4
12-23-603	177	18	--	604	151	[b] 260		162	1,950	380	--	3.2	1.2	3,450	2,130	21	2.5	4,030	7.5
12-24-702	153	17	--	602	139	[b] 240		190	1,890	360	--	4.6	.93	3,350	2,070	20	2.3	3,890	7.4
12-40-404	270	16	--	620	232	[b] 730		220	2,400	1,040	--	.2	4.7	5,150	2,500	39	6.3	6,490	7.5
LD-13-33-404	105	17	--	--	--	134	6.5	163	1,770	186	--	.5	1.0	3,170	1,930	13	4.2	3,310	8.1
13-34-401	158	15	--	598	83	53	4.9	193	1,640	80	--	9.5	.31	2,580	1,830	6	.5	2,860	7.9
13-41-501	129	15	--	609	123	188	6.9	212	1,820	280	.4	11	.92	3,160	2,030	17	1.8	3,770	7.6

[a] Includes the equivalent of any carbonate (CO_3) present.
[b] Sodium and potassium calculated as sodium (Na).

type of soil and crops grown. The SAR, as given for 7 of the samples in Table 10, shows that the sodium hazard is not excessive for use on well-drained soils. However, the salinity hazard for all 10 samples was excessive, and the water should be used where soils are permeable, drainage adequate, excess leaching water is applied, and salt-tolerant crops are grown. The fact that water from the Blaine has been used successfully for several years to irrigate crops is an indication that the quality of the water meets the irrigation requirements under special circumstances, at least on a temporary basis. The results of irrigating with water of this quality for an extended period of time must be left to the future.

Utilization and Present Development

Table 11 shows that 40,000 acre-feet (about 36 mgd) of water was pumped from the Blaine Gypsum in the Red River Basin in 1959. Practically all the water was used for irrigation and was pumped from about 550 wells in Childress, Hardeman, Cottle, Collingsworth, Wheeler, and King Counties.

Changes in Water Levels

Water levels in wells in the Blaine Gypsum ranged in depth from slightly above land surface in two flowing wells in Collingsworth County to 215 feet below land surface in a well in Cottle County. Figure 14 shows the changes in levels in three wells in the Blaine during the period 1953-61. The declines noted in several wells in 1957 probably resulted from increased pumping and decreased recharge because of the low rainfall in 1956, when precipitation was at least 10 inches below normal at both Iowa Park and Amarillo (Figure 4). Levels in most wells rose in 1957 in response to increased recharge and decreased pumping after drought-breaking rains in the spring of 1957. The declines in levels in some wells in 1958 and 1959 probably resulted from increased pumping, as irrigation development spread. Continued declines, particularly after periods of deficient rainfall, should be expected in the heavily pumped areas.

Availability and Potential Development

Aquifers containing water-soluble rocks characteristically have a wide range in water-transmission properties. The Blaine Gypsum locally is very permeable, and high yields are obtained in some places, such as in western Hardeman and in parts of Collingsworth and Childress Counties. However, even in areas where yields are generally high, yields of particular wells may be low. Records of abandoned wells may indicate that the yields were insufficient for irrigation. Yields of wells in Hardeman, Foard, Cottle, Childress, and Collingsworth Counties ranged from 80 to 1,650 gpm.

The specific capacities of wells in the Blaine Gypsum ranged widely. Specific capacities in 4 wells in Collingsworth County were 7.5, 8.7, 12.5, and 19.6 gpm per foot of drawdown. Specific capacities of 7 wells in Childress County ranged from 7 to 136 gpm per foot and averaged 47 gpm per foot.

Because of a lack of sufficient data, it is impossible to estimate quantitatively the potential development of water from the Blaine in the Red River

Table 11.--Pumpage from major wells tapping the Blaine Gypsum, 1959

Major subdivision	Public supply		Industrial		Irrigation		Total*	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
RE-11	--	--	--	--	8.9	10,000	8.9	10,000
RE-13	--	--	--	--	10.7	12,000	10.7	12,000
RE-15	--	--	--	--	1.9	2,100	1.9	2,100
RE-18	--	--	--	--	1.4	1,600	1.4	1,600
RE-21	--	--	--	--	.27	300	.27	300
RE-24	--	--	--	--	.06	65	.06	65
RE-25	--	--	--	--	.89	1,000	.89	1,000
RE-27	--	--	--	--	11.6	13,000	12.0	13,000
Total*	--	--	--	--	36	40,000	36	40,000

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

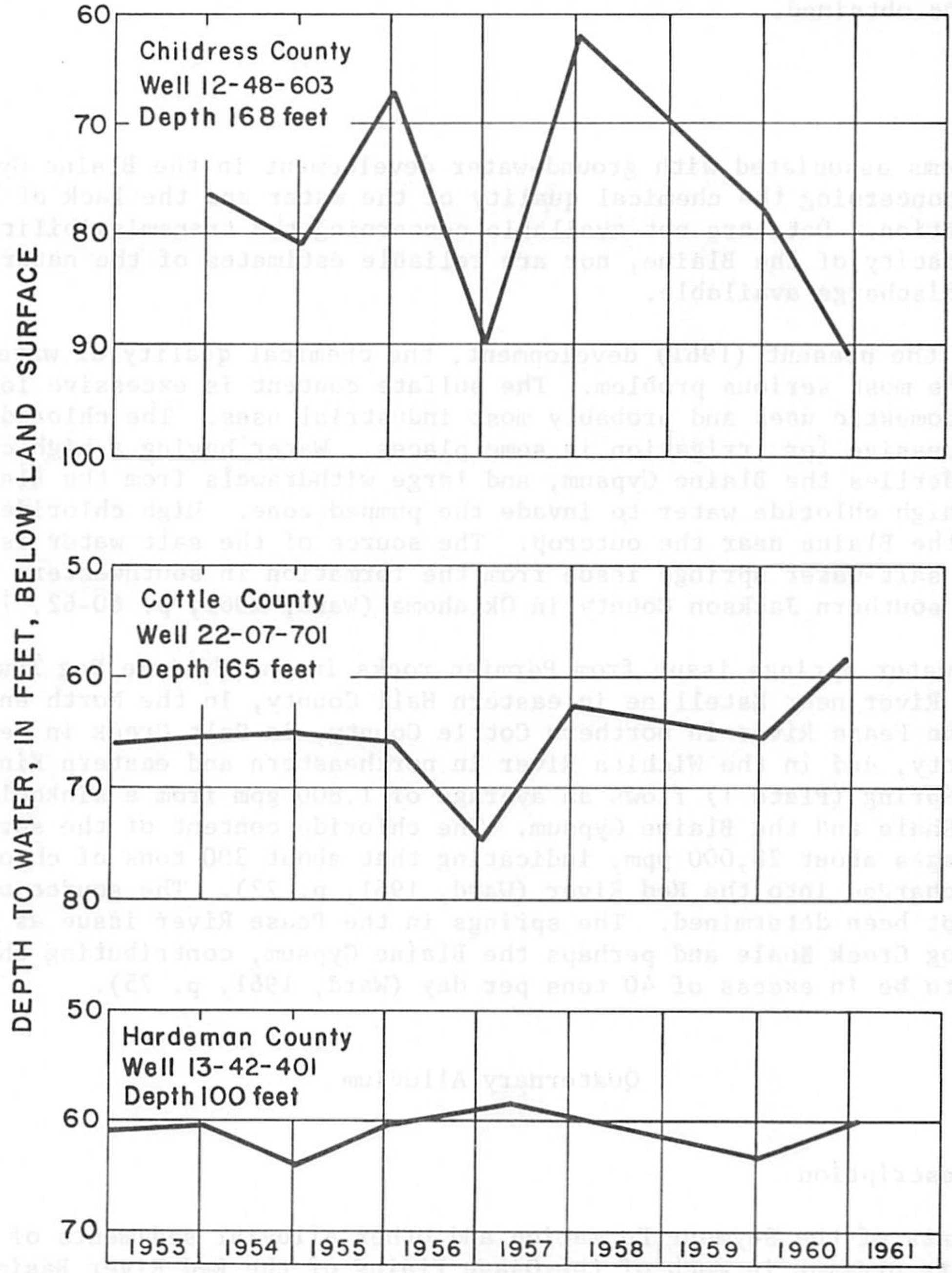

Figure 14
Changes in Water Levels in Wells in the Blaine Gypsum

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

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Basin. However, prior to 1961 water levels had not declined materially except locally; the aquifer probably is not overdeveloped, and additional supplies of water can be obtained.

Problems

Problems associated with ground-water development in the Blaine Gypsum are those concerning the chemical quality of the water and the lack of hydrologic information. Data are not available concerning the transmissibility or storage capacity of the Blaine, nor are reliable estimates of the natural recharge or discharge available.

Under the present (1961) development, the chemical quality of water probably is the most serious problem. The sulfate content is excessive for municipal and domestic uses and probably most industrial uses. The chloride content is excessive for irrigation in some places. Water having a high chloride content underlies the Blaine Gypsum, and large withdrawals from the Blaine may cause the high chloride water to invade the pumped zone. High chloride water occurs in the Blaine near the outcrop. The source of the salt water is not known, but salt-water springs issue from the formation in southwestern Beckham County and southern Jackson County in Oklahoma (Ward, 1961, p. 60-62, 70).

Salt-water springs issue from Permian rocks in the Prairie Dog Town Fork of the Red River near Estelline in eastern Hall County, in the North and Middle forks of the Pease River in northern Cottle County, in Salt Creek in central Cottle County, and in the Wichita River in northeastern and eastern King County. Estelline Spring (Plate 1) flows an average of 1,800 gpm from a sinkhole in the Dog Creek Shale and the Blaine Gypsum. The chloride content of the spring water averages about 28,000 ppm, indicating that about 300 tons of chloride per day is discharged into the Red River (Ward, 1961, p. 72). The source of the salt has not been determined. The springs in the Pease River issue as seeps from the Dog Creek Shale and perhaps the Blaine Gypsum, contributing chloride estimated to be in excess of 40 tons per day (Ward, 1961, p. 75).

Quaternary Alluvium

Physical Description

Remnants of the Seymour Formation and other alluvial sediments of Quaternary age are present in much of the Osage Plains of the Red River Basin. Because of the similar hydrologic properties of the deposits, they are discussed together as the Quaternary alluvium in this report.

Alluvial deposits of Quaternary age locally cover small areas of the Triassic and Paleozoic rocks (Plates 1 and 2). Many of the deposits are small, but some are large enough to be of hydrologic significance, being as long as 40 miles and as wide as 10 miles. The larger deposits are in Wilbarger, Foard, Baylor, Knox, Wheeler, Collingsworth, Hall, Briscoe, Motley, and Dickens Counties.

The alluvium was deposited either on stream terraces or in channel fills. For discussion, some windblown material is considered as being a part of the Quaternary alluvium.

Certain characteristics of the alluvium, such as topography, thickness, uniformity, and grain size, depend on the mode of deposition and the topography of the underlying bedrock. The terraces are almost flat, having a gentle slope both toward the stream and downstream. The topography of windblown and channel-fill sediments is rolling. The surface soils of these sediments generally are coarser than those of the terraces.

Alluvium in depressions is thicker than the terrace deposits. The channel fill is as thick as 360 feet in Collingsworth County (Plate 1) and is about 150 feet thick near Memphis (Lang, 1943, p. 17). Some of the sinkholes common throughout much of the area contain alluvium and some wind-blown deposits. One sinkhole is filled with gravel and sand to a depth of 443 feet in eastern Hall County (George, 1945, p. 3) where the city of Childress has obtained a part of its water supply from a well tapping the sinkhole since 1942 (Plate 1). The alluvium in the Michie sand hills area, 8 miles northwest of Childress (Plate 1), is as thick as 200 feet in depressions either in old stream channels or sinks in the Permian surface (George, Barnes, and Broadhurst, 1946, p. 13). The maximum thickness of alluvium is at least 200 feet in northwestern Wilbarger County, northeastern Wheeler County, eastern Briscoe County, and near Paducah in Cottle County (Plates 1 and 2). In contrast, materials forming stream terraces range in thickness from about 10 to about 60 feet in southern Wilbarger, Foard, Baylor, and eastern Hall Counties. Terrace materials are thinner and less extensive along many of the stream valleys; however, they are more extensive along the Red River in Wichita County and part of Clay County (Plate 2), according to Sundstrom (1943, p. 4). Materials deposited by wind, such as in northeastern Wheeler County (Plate 1), are fine grained and uniform in size, whereas stream-deposited materials consist of interbedded gravel, sand, and clay.

Recharge, Movement, and Discharge of Ground Water

The source of recharge to the alluvium is chiefly by direct infiltration of precipitation on the surface. Only the present flood plains of streams are recharged by percolation from streamflow. The coarseness of the surface sediments of the rolling topography offer favorable conditions for recharge to wind-deposited materials and channel fill. The flat terrain of the finer surface material aids in holding rainfall until it infiltrates the stream terraces.

Water moves slowly downgradient toward points of discharge. Water is discharged naturally from alluvial deposits generally along streams as springs and seeps. The approximate altitude of the water table in some of the Quaternary alluvial sediments is shown in Figure 15. Springs near the Red River in Wilbarger County (Plate 2) form a part of the natural discharge from the Odell sand hills.

Discharge from pumped wells collectively accounts for a considerable amount of the discharge from some of the alluvial sediments where irrigation and municipal wells are concentrated (Plates 1 and 2).

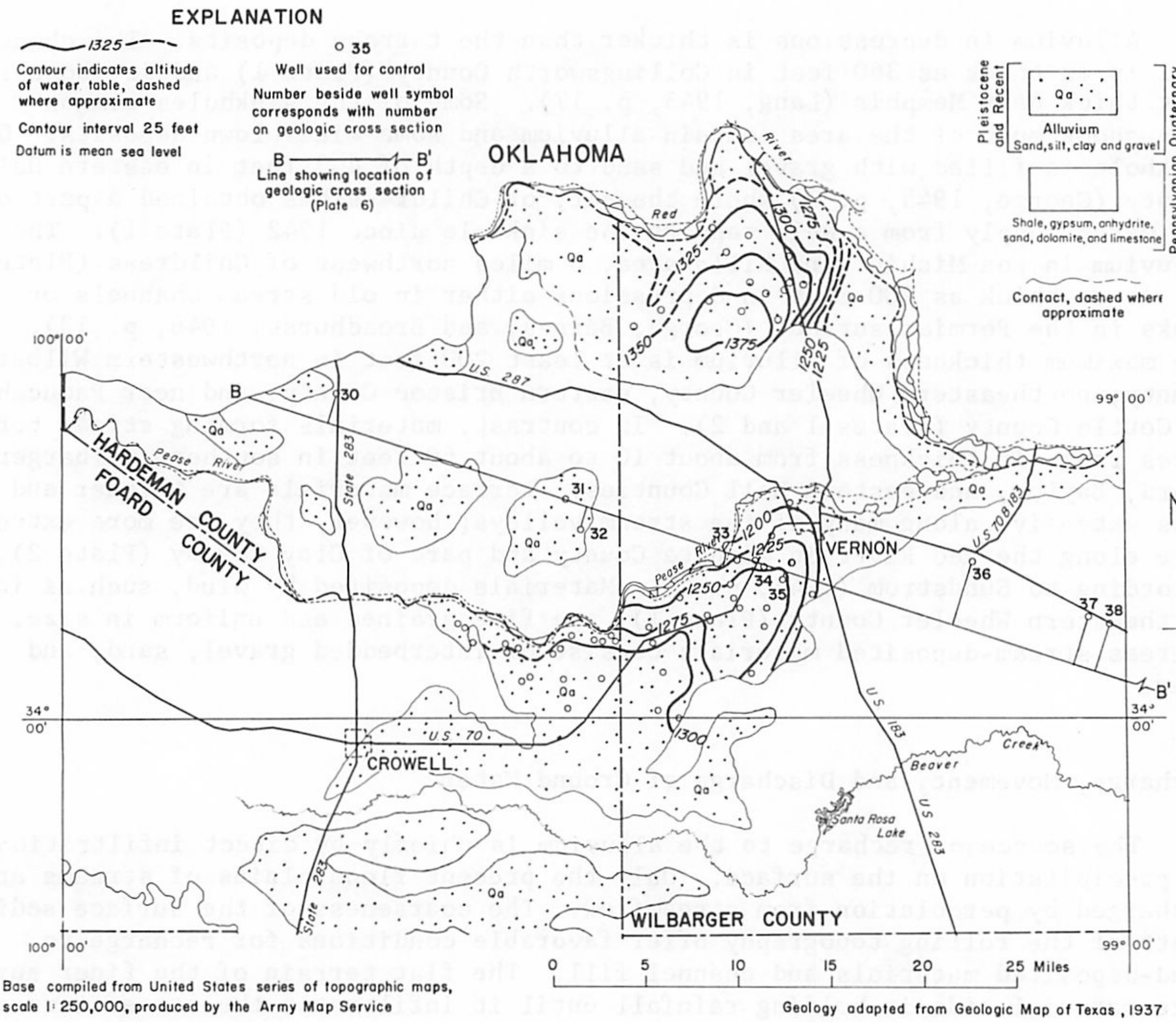

Figure 15

Map of Wilbarger and Parts of Hardeman and Foard Counties Showing the Approximate Altitude of the Water Table in the Quaternary Alluvium, 1960

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Chemical Quality

The analyses of nine selected samples of water from the Quaternary alluvium are shown in Table 12. 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 the ground water in the Seymour Formation and other Quaternary alluvial deposits at the general depth and vicinity of the wells. The analyses show that water from the alluvium is very hard, and the dissolved-solids content exceeded the standards recommended by the U. S. Public Health Service in six of the analyses. The fluoride content meets the standard in all but one analysis. The sulfate content is high in two analyses, being almost as high as that in some of the water from the Permian rocks. The highest, 1,220 ppm, is from a well in an alluvium-filled sink. Recharge in the form of leakage from the Permian beds into some parts of the alluvium is likely, especially in sediments deposited in depressions in the Permian bedrock. A comparison of the depths of the wells with the dissolved-solids contents tends to support this assumption. The chloride content exceeded the recommended limit in one of the analyses shown (from the well in the sink).

Water from the alluvium probably is suitable for use by industry if the formation of scale is not objectionable. The calcium and silica content shown by some analyses is rather high and would be active in forming scale in steam boilers.

The conductivity and SAR given in Table 12 indicate the suitability of the water from the alluvium for irrigation. The SAR of 4.7 or less is not excessive for use on most soils. However, the electrical conductivity of the water in all but three of the analyses is excessive for all except soils having adequate drainage. As the salinity hazard is high in some of the water, the effects of the use of the water for irrigation should be observed closely.

Utilization and Present Development

The amount of water pumped from the alluvium in 1959 (Table 13) was about 43,000 acre-feet (26,000 in region I and 17,000 in region II). About 5,100 acre-feet or about 4.6 mgd was used for public supply, about 840 acre-feet or about 0.75 mgd for industry, and about 37,000 acre-feet or 33 mgd for irrigation. About 86 percent of the water pumped from the alluvium in 1959 was for irrigation, the water being pumped from about 660 irrigation wells in 15 counties (Plates 1 and 2).

Changes in Water Levels

The depth to water in observation wells in the Quaternary alluvium ranged from less than 1 to about 130 feet in 1961. The greatest depths are in Collingsworth, Motley, and Childress Counties.

Hydrographs of wells in the alluvium (Figure 16) indicate that the water levels fluctuate in response to changes in rainfall, other conditions affecting recharge and natural discharge, and pumping from wells. Water levels rose in some areas during the early part of the 20th century in response to the removal

Table 12.--Chemical analyses of water from selected wells in the Quaternary alluvium, Osage Plains, Red 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.)	Silica (SiO_2)	Iron (Fe) (Total)	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
DU-12-15-204	120	29	b/ 0.00	110	23	44	1.4	295	152	33	0.6	24	0.15	604	369	20	1.0	876	7.1
ZB-05-31-602	80	34	--	74	5.1	c/ 23		256	10	9.5	.4	26	--	321	206	20	.7	487	7.2
ZH-13-46-503	107	16	--	66	17	c/ 40		265	31	30	.5	35	--	374	234	27	1.1	606	6.9
13-54-828	38	25	b/ .01	59	24	56	1.0	282	36	40	.9	58	--	439	246	33	1.6	711	7.6
HY-22-10-702	100	38	--	91	28	111	6.7	344	107	120	1.5	43	.28	715	342	41	2.6	1,160	7.5
KZ-12-37-201	443	22	1.1	412	89	402	4.4	122	1,220	660	.6	2.8	--	2,870	1,390	38	4.7	3,900	6.8
12-19-401	129	39	--	270	80	73	2.0	184	768	135	.9	46	.34	1,500	1,000	14	1.0	1,980	7.3
12-29-504	60	18	.02	47	33	170	3.8	353	162	88	.7	68	--	775	253	59	4.6	1,210	7.2
BL-12-41-201	100	32	.04	158	58	124	3.6	255	472	126	1.9	31	--	1,130	632	30	2.1	1,640	6.8

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

Table 13.--Pumpage from major wells tapping the Quaternary alluvium, 1959

Major subdivision	Public supply		Industrial		Irrigation		Total*	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
RE- 7	--	--	--	--	0.66	740	0.66	740
RE- 9	--	--	--	--	.83	930	.83	930
RE-10	--	--	--	--	6.6	7,400	6.6	7,400
RE-11	0.91	1,022	--	--	.69	770	1.6	1,800
RE-13	--	--	--	--	.20	220	.20	220
RE-14	--	--	--	--	.22	250	.22	250
RE-15	.36	403	--	--	3.7	4,200	4.1	4,600
RE-16	.01	11	0.12	134	--	--	.13	150
RE-18	.33	368	.60	670	.4	450	1.3	1,500
RE-20	--	--	--	--	1.0	1,100	.98	1,100
RE-21	.26	296	--	--	3.1	3,500	3.4	3,800
RE-23	.19	210	--	--	3.0	3,400	3.2	3,600
RE-24	.51	574	--	--	7.2	8,100	7.8	8,700
RE-25	1.26	1,410	--	--	3.5	3,900	4.7	5,300
RE-26	.75	845	.03	37	.12	130	.89	1,000
RE-27	--	--	--	--	.08	90	.08	90
RE-28	--	--	--	--	.08	90	.08	90
RE-29	--	--	--	--	1.7	1,900	1.7	1,900
RE-31	--	--	--	--	.04	45	.04	45
RE-36	--	--	--	--	.07	75	.07	75
Total*	4.6	5,100	0.75	840	33	37,000	38	43,000

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

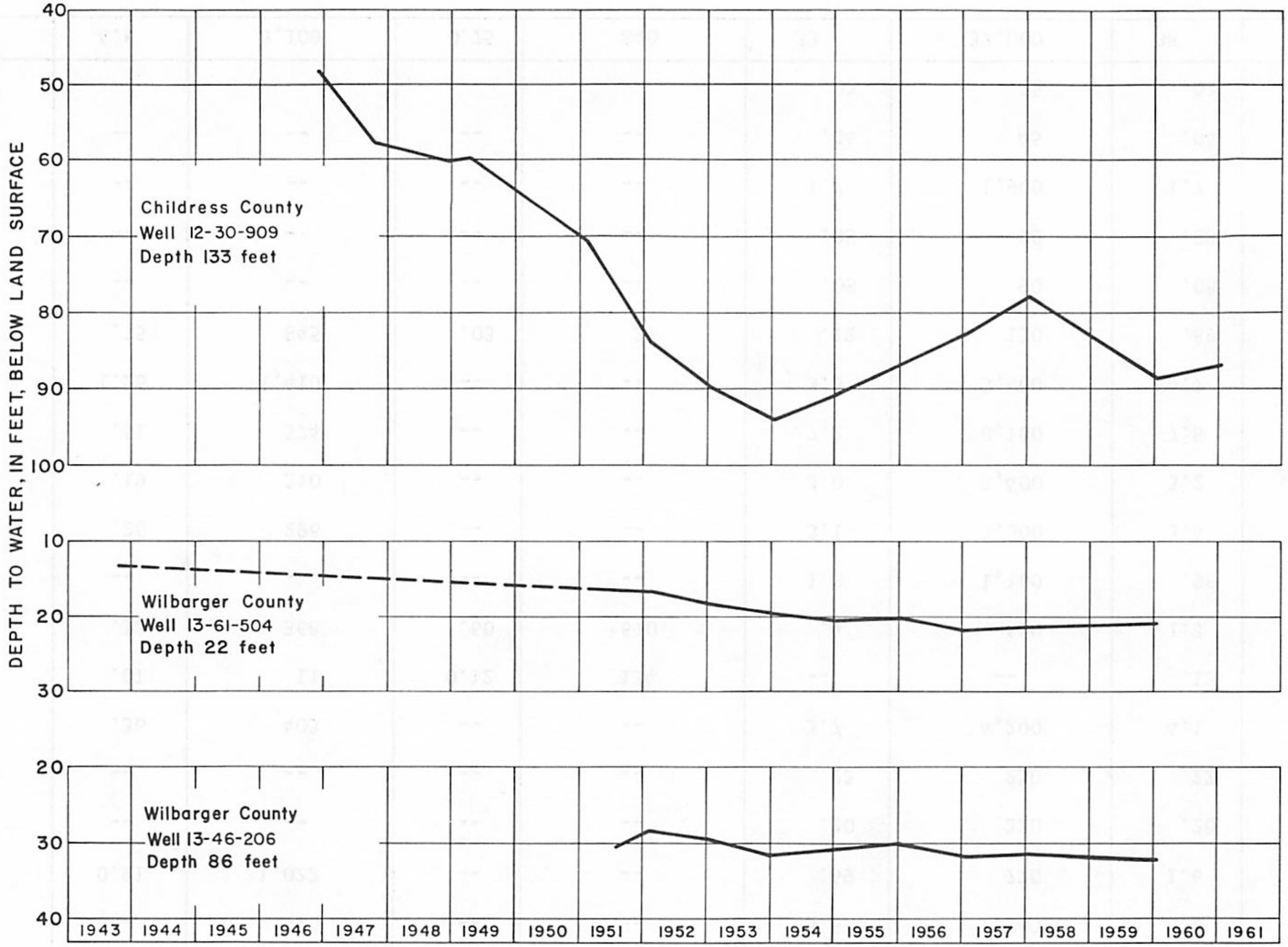

Figure 16

Changes in Water Levels in Wells in the Quaternary Alluvium

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of phreatophytes and other moisture-using perennial plants as the land was cleared for farming.

Soils developed on most alluvial material characteristically are fertile and support considerable vegetation. Much of the vegetation is composed of phreatophytes, such as mesquite, which transpire large amounts of ground water. According to early settlers in the areas, little or no water was contained in the alluvial sediments prior to the clearing of vegetation. After the removal of the phreatophytes, the water table rose in the alluvium. Data indicate that since late in the 19th century, when crop farming was begun, the water table has risen at least 20 feet in the alluvium southwest of Vernon and as much as 60 feet in parts of Knox County from about 1900 to 1933 (Ogilbee and Osborne, 1961, p. 34).

After heavy rains in 1941, water levels probably declined during most of the intervening period between 1942 and 1955, the rate of decline increasing in the early 1950's owing to the drought. The effects of the drought on the water table were due to a decrease in the rate of recharge and an increase in the removal of ground water. Levels in some wells were higher during the latter half of the 1950's, but in other wells water levels merely ceased to decline in heavily pumped areas or in areas where conditions were less favorable for recharge. Therefore, discharge from these areas seems to be about in balance with recharge during periods of adequate rainfall, whereas recharge is greater than discharge in other areas when rainfall is adequate.

Availability and Potential Development

The volume of ground water available to wells in some of the larger areas of Quaternary alluvium in the Osage Plains province of the Red River Basin was about 5,400,000 acre-feet in 1959. The data are tabulated by areas in Table 14. The thickness of water-saturated material in some of the alluvial deposits is shown by contour maps (Plate 19 and Figure 17) of the areas where ground-water supplies have been developed. Insufficient data are available to contour all areas.

Table 14.--Available water in storage in selected deposits of Quaternary alluvium, Osage Plains, Red River Basin, 1959

Area	Available water in storage (acre-feet)
Northeastern Floyd County Northwestern Motley County Southwestern Hall County Southeastern Briscoe County	1,100,000
Northern Hall County Northeastern Briscoe County	1,200,000
Collingsworth County Northern Childress County Donley County	2,300,000
Northern Wilbarger County Hardeman County	460,000
Southern Wilbarger County Foard County	300,000
Total	5,400,000

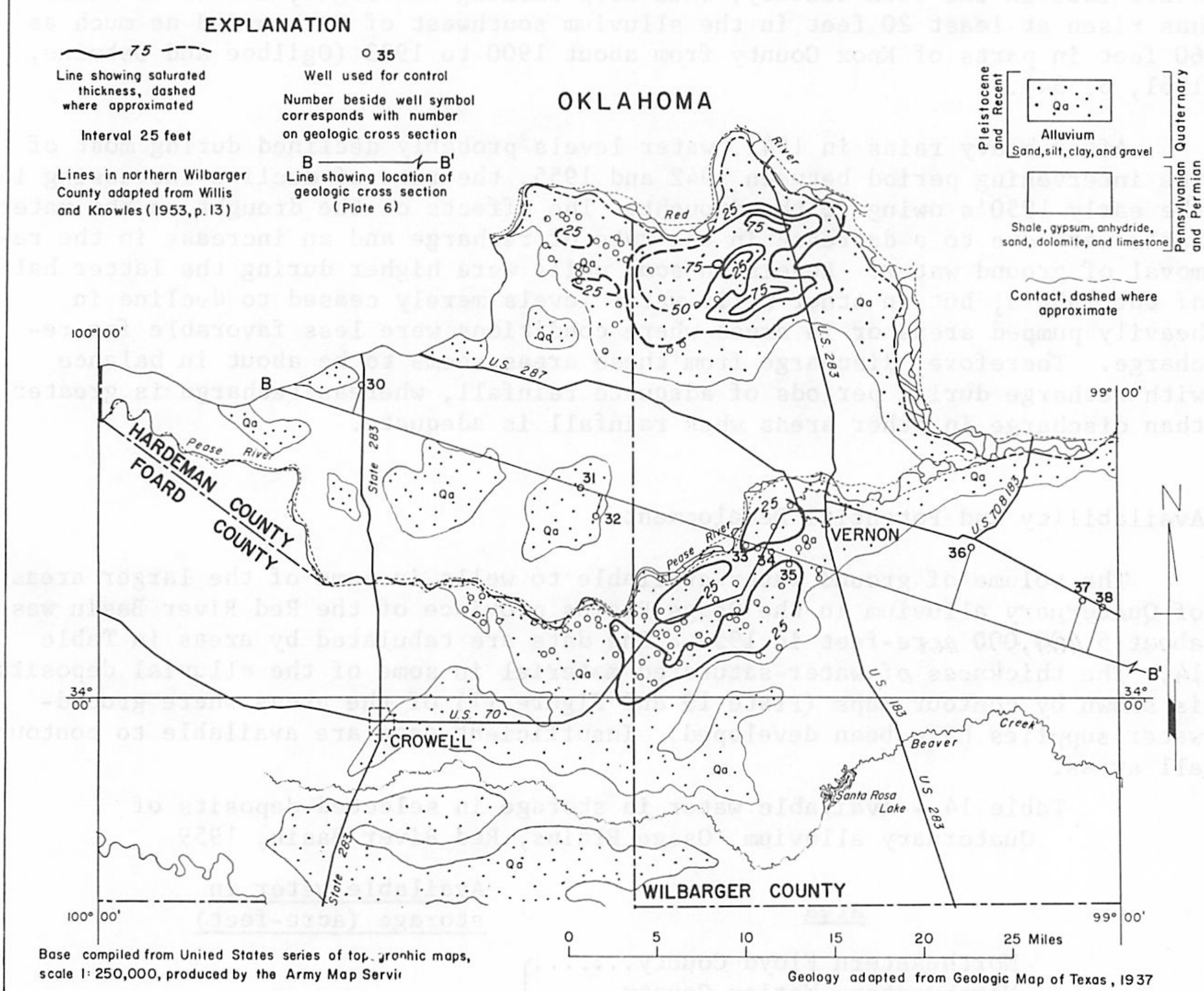

Figure 17

Map of Wilbarger and Parts of Hardeman and Foard Counties Showing the Saturated Thickness of the Quaternary Alluvium, 1960

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The yields of wells generally are largest where the saturated material is thickest, as in channel fills and sand dunes, and smallest where the saturated material is thinnest, as in stream terraces. Most wells used for irrigation yield more than 100 gpm, but a few are used where the yield is less than 50 gpm. Maximum reported yields are as follows: Collingsworth County, 1,175 gpm; northern Wilbarger County, 1,200 gpm; southwest of Vernon in Wilbarger County, 750 gpm; and Baylor County, about 800 gpm.

The relatively shallow depths to water of less than 1 foot to about 130 feet, as previously mentioned, are important economic factors in the development of ground-water supplies. Another important factor is the drawdown, which ranges from less than 1 foot in the area southwest of Vernon in Wilbarger County to 200 feet in the Childress well field. The amount of drawdown increases with the yield of the well. In general, drawdowns are greater in less permeable sediments than they are in more permeable sediments. The specific capacity of 22 irrigation wells tapping alluvial deposits ranged from 4 to 190 gpm per foot and averaged 43 gpm per foot.

Specific capacities measured in the city of Vernon wells ranged from 11.1 to 43.5 gpm per foot while the wells were pumping 93 to 405 gpm (Follett, Sundstrom, and White, 1944, p. 9).

Testing of two wells in the Michie sand hills area 8 miles northwest of Childress in 1945-46 indicated that the coefficient of transmissibility at the test sites ranged from 24,500 gpd per foot to 60,000 gpd per foot. The coefficient of storage ranged from about 0.015 to 0.043 (George, Barnes, and Broadhurst, 1946, p. 6-8).

Pumping tests were made on two wells in the Odell sand hills in northern Wilbarger County by Willis and Knowles (1953, p. 16-20). The coefficients of transmissibility from 1 test of 48 hours duration averaged 20,000 gpd per foot. The coefficient of transmissibility obtained from the other test was 46,900 gpd per foot, more than double the first. Willis and Knowles (1953, p. 20) state, "...This was to be expected because the Seymour formation is a heterogeneous unconsolidated mass of sand and gravel...The lower figure of 20,000 gpd per foot may be more nearly representative of the main part of the Seymour formation in this area where large capacity wells can be developed." One-day specific capacities of the pumped wells were 4.4 and 17.0 gpm per foot. The coefficient of storage was not determined; however, Willis and Knowles (1953, p. 15) estimated that the specific yield (approximately equal to the coefficient of storage) would have been about 0.15 had the pumping period been longer.

Recovery tests of 1 hour were made by Ogilbee and Osborne (1961, p. 45, Table 2) on eight irrigation wells in Knox County. The transmissibilities ranged from 23,000 to 177,000 gpd per foot and averaged 85,000 gpd per foot. The specific capacities during these tests ranged from 18 to 178 gpm per foot while the wells were pumping 145 to 915 gpm.

The specific yield, obtained by comparing the amount of water pumped to the volume of sand dewatered during 1956 in the Haskell-Knox County area was 0.14. This figure is about the same as that estimated for the Ogallala Formation in the High Plains.

Sundstrom (1943, p. 5) states "...conditions apparently are favorable for developing wells of small yield in the terrace deposits..." in northeastern Wichita County and northwestern Clay County. A test well drilled by the city of Wichita Falls in this area reached the base of the alluvium at a depth of 48 feet and yielded 75 to 80 gpm. Part of the present supply for the city of Burkburnett is obtained from the area.

Pumping tests on 10 of the municipal wells of the city of Electra, about 25 miles northwest of Wichita Falls, in Wichita County indicate specific capacities ranging from 15 to 37 gpm per foot while the wells were pumping 75 to 100 gpm.

The specific capacity of a public-supply well near Memphis in Hall County was found to be about 4 gpm per foot while pumping about 40 gpm (Lang, 1943, p. 7).

The limits of development of the ground-water resources of an alluvial aquifer and the effects of future pumping have been investigated in only one area in the Osage Plains province. Ogilbee and Osborne (1961, p. 26-29) described the occurrence of ground water in the Seymour Formation in Haskell and Knox Counties, and they estimated that more than 20,000 acre-feet of water may be withdrawn annually from the aquifer without permanently depleting the water in storage (Ogilbee and Osborne, 1961, p. 55).

Problems

An accurate evaluation of the ground-water resources of the Quaternary alluvial deposits in the Osage Plains province cannot be made because of insufficient data on the quantity of water in storage and the hydraulic properties of the aquifers.

The estimate of 5,400,000 acre-feet of available ground water in storage in 1959 was obtained in areas where reliable data are available. Some areas mapped as alluvium have not been developed as aquifers (Plates 1 and 2) and in other areas there has been very little development.

The large indicated thickness of water-saturated material in parts of Hall, Briscoe, Motley, and Dickens Counties has not been studied in detail to determine if it is composed entirely of Quaternary alluvium. If the basal part is composed of sands in the Whitehorse Group of Permian age and sands in the Dockum Group of Triassic age, these sediments may be better aquifers in these areas than previously indicated. This situation suggests the possibility that water from alluvial deposits may recharge permeable zones in the underlying older rocks and improve the quality of the water therein.

The work done during the present investigation indicates that considerable quantities of good quality water occur in sediments deposited by the wind, as in Wheeler County. These aquifers have not been developed because they contain large amounts of fine sand. The development of the aquifers may be possible by using proper screens and well-development methods to keep the fine sand from entering the wells.

Stream-deposited materials in some places, such as the Estelline terrace near Estelline in Hall County, have not been tested to determine the entire saturated thickness of the deposits. The possibility of finding additional buried channels and sinkholes filled with sand and gravel probably warrants more extensive drilling of test holes.

Locally, oil-field brines from surface disposal pits have contributed salt to the ground water.

More data are needed on the hydraulic characteristics of the alluvial aquifers to estimate the potential development of the ground-water resources and determine the proper spacing of large-yield wells.

Secondary Aquifers

Secondary aquifers in the Osage Plains include the Cisco and Wichita Groups, undifferentiated, the Whitehorse Group, and the Pease River Group exclusive of the Blaine Gypsum.

Cisco and Wichita Groups, Undifferentiated

The Cisco and Wichita Groups, undifferentiated, crop out in the eastern part of region II (Plate 2) and the western part of region III (Plate 3) in the Red River Basin. They form the surface in parts of Montague, Clay, Wichita, Baylor, and Wilbarger Counties. The rocks dip gently toward the west or northwest beneath younger Permian rocks or Quaternary alluvial deposits. The Cisco Group consists of alternating beds of shale, sandstone, limestone, and conglomerate. The overlying Wichita Group consists of shale, sandstone, and limestone. The rocks in both groups contain less sand downdip then they do in the outcrop, and the sandstones are more abundant in the lower part of the Wichita Group than in the upper part.

The Cisco and Wichita Groups are not differentiated on the geologic maps (Plates 2 and 3) because of difficulty in identifying the contacts between the two groups in the field. For discussion, the two groups are considered as a unit, although actually they consist of many small hydrologic units, the details of which are not well known. Some of the units contain water under artesian conditions and others under water-table conditions. The source of recharge to the Cisco and Wichita Groups is precipitation on the outcrop, streamflow, and percolation from overlying younger rocks. The amount of recharge has not been estimated.

Table 15 shows the chemical quality of the water from nine selected wells in the Cisco and Wichita Groups, undifferentiated. The locations of the wells are shown by means of bars over the well symbols on the well maps (Plates 2 and 3). The analyses indicate that the chemical quality of the water ranges between wide limits, and the variations apparently have little or no relation to depth of occurrence of the water; each analysis is representative of only the depth and location of the well. The dissolved-solids content of the water from the 9 samples was more than 1,000 ppm in 3 samples and more than 500 ppm in 7 samples. The range of dissolved-solids content was 285 to 2,350 ppm. The range in chemical quality of the water also is evident from the range in concentrations of

Table 15.--Chemical analyses of water from selected wells in the Wichita and Cisco Groups, undifferentiated, San Angelo Sandstone, and Whitehorse Group, Red 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.)	Silica (SiO_2)	Iron (Fe) (Total)	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
Wichita and Cisco Groups, undifferentiated																			
AJ-20-21-702	36	13	--	88	44	c/ 369		400	149	460	--	8.8	--	1,410	400	67	8.0	2,360	7.4
20-29-502	222	11	b/ 0.03	3.0	.8	455	1.9	729	106	198	2.8	1.8	--	1,140	11	99	60	1,880	8.2
DL-20-05-601	90	14	--	14	8.2	c/ 302		505	37	192	.5	.0	--	816	68	91	16	1,410	7.0
20-16-601	500	12	--	2.0	.3	c/ 331		564	72	132	--	1.2	--	831	6	99	59	1,400	8.5
20-24-901	346	12	b/ .00	2.0	.2	c/ 239		528	42	31	2.0	1.2	--	589	6	99	42	956	8.7
TR-19-09-501	200	10	--	4.5	1.8	c/ 887		780	544	520	3.1	.2	--	2,350	18	99	91	3,730	7.9
19-11-702	400	11	--	1.2	.4	c/ 219		513	31	16	1.7	.0	--	547	4	99	48	864	8.3
19-19-702	260	12	--	12	6.3	c/ 89		263	20	6.8	.3	2.5	--	285	56	78	5.2	458	7.7
19-04-401	205	10	--	.5	.1	c/ 193		477	8.8	14	.2	.5	--	473	2	100	59	753	8.4
San Angelo Sandstone																			
LD-13-44-904	65	26	0.12	80	29	57	4.2	328	62	52	0.2	51	--	523	318	28	1.4	836	7.4
13-52-603	57	28	--	85	34	152	2.8	355	214	100	1.0	13	0.46	819	352	48	3.5	1,330	7.9
Whitehorse Group																			
HP-22-06-702	70	14	--	555	157	145	5.7	168	1,920	172	0.7	15	0.91	3,070	2,030	13	1.4	3,430	7.3
d/ 12-62-802	240	--	0.20	100	18	52	--	270	133	25	.2	26	--	474	325	26	1.3	790	7.5

a/ Includes the equivalent of any carbonate (CO_3) present.
b/ In solution.
c/ Sodium and potassium calculated as sodium (Na).
d/ Chemical analysis by Texas State Department of Health, Austin, Texas.

practically all of the determined constituents. The electric logs of oil tests, chemical quality-of-water data, and depth of some of the public-supply wells in western Montague County and eastern Clay County indicate that the quality of the water in the Cisco is somewhat better than that in the Wichita Group. The base of the fresh to slightly saline water in western Montague and eastern Clay Counties in some places is more than 900 feet below land surface (Plate 7).

The Cisco and Wichita Groups, undifferentiated, yield small quantities of water to a few public-supply wells in the Red River Basin and to numerous domestic and livestock wells. The rocks yield water to 12 public-supply wells in western Montague and eastern Clay Counties, where in 1959 about 300 acre-feet of water was pumped for public supply. Small quantities of water are obtained for domestic and livestock use from wells in a sand member in the lower part of the Cisco Group in Archer, Clay, and Montague Counties. The water, however, becomes increasingly saline downdip from the outcrop. Small quantities of slightly saline water are obtained from the Wichita Group in some places, but large quantities generally are not available.

In regard to the Cisco and Wichita Groups, undifferentiated, in the vicinity of Wichita Falls, Sundstrom (1943, p. 3) said, "...Neither the Permian nor the Pennsylvanian rocks yield large quantities of water that are acceptable for public supply." Gordon (1913, p. 53) states, "...the water in these wells is derived from the red shales and sandstones of the Wichita formation and is usually too highly mineralized for use. Some of the shallow wells yield supplies for stock, but few of them are available for domestic use...The water from these shallow upland wells is rich in salt and gypsum." Sundstrom (1943, p. 3) states, "...Since Gordon wrote his report, a large number of oil wells have been drilled which have encountered highly mineralized brine in the Permian and Pennsylvanian rocks."

Problems of ground-water development in the Cisco and Wichita Groups, undifferentiated, are those concerned with the small areal extent of the aquifers and the low permeabilities. Other problems are concerned with the generally poor chemical quality of the water in the groups.

Pease River Group (exclusive of the Blaine Gypsum)

The Dog Creek Shale overlying the Blaine Gypsum and the Flowerpot Shale underlying the Blaine contain cavernous beds of gypsum capable of transmitting water. Some wells drilled probably into the Blaine may actually tap one of the gypsum beds in either the Dog Creek or the Flowerpot. The hydraulic characteristics of the Dog Creek and Flowerpot are similar to those of the Blaine and depend on the extent of solution and the thickness of the gypsum. Both the Dog Creek and Flowerpot Shales contain zones of salt in places, and, according to Ward (1961, p. 23), the salt zone in the Flowerpot probably is the source of salt for the spring at Estelline in Hall County.

The Dog Creek and Flowerpot generally are not regarded as aquifers in the Red River Basin; however, several industrial wells in southeastern Wheeler County probably tap the Dog Creek. The wells are used only as standby wells because the water is too poor in quality for regular use. An analysis of the water shows that it is similar to that from the Blaine Gypsum. The sulfate content was 1,510 ppm and the specific conductance was 2,500 micromhos at 25°C.

The San Angelo Sandstone, the only other aquifer in the Pease River Group, consists of sandstone, shale, and some gypsum in the lower part. The San Angelo generally yields only small quantities of water to wells, and most of the water is saline. However, in the area south of Chillicothe in Hardeman County, the municipal-supply wells for Chillicothe and a few irrigation wells tap the San Angelo. The wells yield as much as 500 gpm. According to Ogilbee and Osborne (1961, p. 24), "...The San Angelo probably has a very low permeability in Knox County, and only small quantities of mostly saline water should be expected from wells tapping the formation." In 1959 about 1,500 acre-feet of water was pumped from the San Angelo (Table 19). Of this amount, 61 acre-feet was used for public supply and the rest for irrigation.

Table 15 shows the chemical analyses of water from two wells in the San Angelo Sandstone. The locations of the wells are shown by means of bars over the well symbols on the well-location map (Plate 2). The samples are from an irrigation well (LD-13-52-603) and a public-supply well at Chillicothe (LD-13-44-904). The analyses show that the water is very hard, and the dissolved-solids content exceeds slightly the standards recommended by the U. S. Public Health Service. The analyses should not be considered as typical of the San Angelo, as most of the water from the formation is of poorer chemical quality.

Whitehorse Group

The Whitehorse Group in the Osage Plains part of the Red River Basin consists of fine sand, gypsum, anhydrite, shale, and dolomite. The predominance of fine unconsolidated sand in the Whitehorse distinguishes it from the rocks of the underlying Pease River Group. The source of ground water in the Whitehorse is precipitation on the outcrop and percolation from overlying alluvial deposits.

The chemical analyses of two samples of water from the Whitehorse Group are shown in Table 15. The locations of the wells are shown by means of bars over the well symbols on the well-location map (Plate 2). The first analysis (HP-22-06-702) shows concentrations of calcium, magnesium, and sulfate, which make the water unsuitable for domestic use. The water would be satisfactory for livestock use and for irrigation under special circumstances. The second analysis is from a public-supply well for the city of Paducah in Cottle County. The water is of good quality, closely resembling the quality of the water in the alluvium. The good quality of the water may be due to the proximity of the favorable recharge facility of the overlying alluvium. Each analysis is representative only of the water at that particular depth and location.

Table 19 shows that about 620 acre-feet of water was used from the Whitehorse Group in 1959. Part of this was pumped from a few scattered irrigation wells in Dickens, Cottle, Childress, and Donley Counties. The rest was used for public supply at Paducah. Some of the irrigation wells drilled into the Pease River Group also may derive some water from the Whitehorse. The Whitehorse yields small quantities of water to numerous livestock wells in the Red River Basin.

In general, only small supplies of water should be expected from the Whitehorse Group; however, in some areas moderate quantities of water have been obtained. Tests on three public-supply wells near the city of Paducah in Cottle County showed specific capacities ranging from 1.9 to 3.1 gpm per foot while the wells were pumping 190 to 270 gpm.

Problems connected with development of water from the Whitehorse Group are those concerned with the sporadic occurrence of permeable rocks and the generally inferior quality of the water. According to Ward (1961, p. 74), natural salt pollution in the Prairie Dog Town Fork of the Red River west of Estelline adds about 200 tons per day of chloride to the flow of the river. The source of the salt has not been determined, but in Briscoe and Armstrong Counties it may be from a salt zone in the Whitehorse.

HIGH PLAINS

General

The westernmost part of the Red River Basin in Texas is in the High Plains province (Figure 1 and Plate 1). The High Plains is a remnant of a plain that once extended from the Rocky Mountains to the Osage Plains (Fenneman, 1931, p. 11-30). The nearly flat surface slopes gently to the east. It is characterized by the absence of a well-developed drainage system and the presence of numerous depressions, which form wet-weather lakes.

The High Plains in Texas is bounded on the east in most places by a prominent escarpment and extends westward to the New Mexico line. Where the escarpment is absent, the eastern boundary of the High Plains, in this report, is placed at the eastern boundary of the Ogallala Formation. The area contains parts of 21 counties. The largest city, Amarillo, had a population of 137,969 in 1960, about two-thirds of the city being in the Red River Basin. The second largest city is Canyon, having a population of 5,864 in 1960.

The High Plains of Texas depends almost entirely on ground water for its water supply. Much of the economy of the area is agricultural, being based on the fertile soil and abundance of ground water. The principal irrigated district is part of the largest intensely cultivated area in Texas, the principal crops being cotton, grain sorghums, and wheat.

Industrial development in the High Plains is related largely to the production of oil and gas, the industry first becoming important after the expansion of the Panhandle oil field in 1926. Industries depending on the supply of oil and gas are synthetic rubber, carbon black, pipeline companies, refineries, and petrochemicals. The extensive development of irrigation and industries associated with agriculture, coupled with the production of oil and gas, has been the cause of the rapid growth in population and the even greater increase in economic wealth of the High Plains.

The climate of the High Plains in the Red River Basin is semiarid. It is characterized by low humidity, wide ranges in temperature, and precipitation (Figures 3 and 4), and occasional windstorms. The high summer temperatures, rather low humidity, and strong breezes cause a high rate of evaporation (Figure 5). The average annual precipitation ranges from 16 to 20 inches. The average annual temperature ranges from 56°F to 63°F.

Occurrence of Ground Water

Primary Aquifer

The only primary aquifer in the High Plains is the Ogallala Formation, which supplies almost all water for all uses.

Ogallala Formation

Physical Description

The Ogallala Formation underlies almost all of the High Plains of Texas. The greatest width of outcrop of the formation in the Red River Basin is at least 150 miles. The Ogallala consists of sand, clay, silt, gravel, and caliche. A study of drillers' logs indicates that at least 50 percent of the saturated material in the Ogallala is sand. The formation ranges in thickness from 0 to about 900 feet. The altitude of the base of the formation is shown in Plate 20.

Recharge, Movement, and Discharge of Ground Water

The source of the ground water in the Ogallala Formation in the Red River Basin in Texas is precipitation on the land surface and water that moves into the area through the Ogallala from the adjoining part of New Mexico. The areas where the opportunities for recharge are most favorable are those where the soil is most permeable and where runoff accumulates in topographic lows. Rises in water levels in wells near streams and in areas of sandy soil after periods of heavy precipitation are indications of increased recharge. The records of levels in wells near some lakes also indicate some infiltration from the lakes. In some places the caliche, which underlies much of the surface of the High Plains, is indurated and relatively impermeable, thus inhibiting seepage of surface water into the underlying rocks. However, in other places the caliche is absent or its character and composition are different. Various estimates by hydrologists in the High Plains indicate that the recharge probably is less than half an inch per year. The amount of water moving into the Texas part of the High Plains by underflow from New Mexico probably is small, but relatively constant from year to year.

Plate 21 shows the approximate altitude of the water table in the High Plains in the Red River Basin. The gradient of the water table is about 10 feet per mile toward the southeast, the movement of ground water being in the same direction toward areas of natural discharge. Locally the direction of movement is diverted toward streams or discharging wells.

Ground water is discharged by springs at the escarpment bounding the plains, by evaporation from water-table lakes in Donley County where the water table intersects the land surface, and by wells. A small amount possibly leaves the Red River Basin by underflow into adjacent basins. However, the amount of underflow probably is small because topographic divides, which determine the boundaries of the basins, are near ground-water divides, and the ground-water movement is nearly parallel to the boundaries of the basin. Cronin and Wells (1960, p. 26) state that ground water moves about 2 inches per day in the vicinity of Plainview in Hale County. The average movement in the High Plains in the Red River Basin probably is about the same.

The quantity of natural discharge from the Ogallala has not been estimated but probably is of about the same as the recharge. The artificial discharge is by far the largest part of the total discharge. In 1959 about 960,000 acre-feet of water was discharged by wells in the Ogallala Formation in the Red River Basin.

Chemical Quality

Table 16 shows the chemical analyses of water samples from seven wells in Armstrong, Carson, Gray, Donley, Briscoe, and Deaf Smith Counties. The locations of the wells are shown by means of bars over the well symbols on Plate 1. The analyses shown are only a few of the total number on record, but they may be considered representative of the quality of the ground water in the Ogallala Formation at the general depth and vicinity of the wells. The analyses show that the water is hard but otherwise generally of good quality. The analyses indicate that the water consistently meets the standards of the U. S. Public Health Service except for two constituents. The fluoride content exceeded the recommended limits in three samples and the iron content in one sample. The low SAR and conductivity values indicate that the water is suitable for irrigation. The water is suitable for most industrial uses except that the hardness and silica content may be excessive for the use of water in boilers.

Utilization and Present Development

About 7,800 major wells were in use in the High Plains in the Red River Basin in 1959. Of this number, more than 97 percent were irrigation wells and about 2 percent were public-supply wells. The areas of greatest concentration of wells are shown in Plate 1. The total quantity of water pumped in 1959 from the Ogallala Formation in the basin was about 960,000 acre-feet or about 870 mgd (Table 17). Of this amount, 940,000 acre-feet, or almost 97 percent, was used for irrigation. The rest was used for public supply and industry.

Irrigation from wells in the High Plains of Texas was started in Hale County in 1911; in the Red River Basin the first development was in Deaf Smith County prior to 1914. The development of ground water progressed slowly until 1937 and at an accelerated rate after 1937 when new wells were being drilled outside of the older and more or less isolated areas of development; by 1944 the areas were beginning to merge into one big irrigated area. By 1951 the area south of Amarillo was developed extensively for irrigation. Drilling continued at an accelerated pace through 1955 and slackened in 1957, when the drought of the late 1940's and early 1950's ended. Much of the development for irrigation in Armstrong, Donley, Carson, and Gray Counties has been since 1953.

Changes in Water Levels

The water table rises or declines in the Ogallala Formation as a result of both artificial and natural causes. A decline in the water table represents a

Table 16.--Chemical analyses of water from selected wells in the Ogallala Formation, Red 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.)	Silica (SiO_2)	Iron (Fe) (Total)	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
BL-11-38-205	200	60	1.1	--	35	34	34	7.6	302	38	12	4.1	0.5	--	--	380	228	24	1.0	569	7.0
HT-[b] 1	--	39	.00	0.00	34	42	42	8.7	331	41	27	1.6	8.0	0.00	--	404	258	25	1.1	656	7.8
AK-06-62-102	255	43	[c] .00	.01	44	30	22	5.6	286	33	12	1.8	4.9	.00	0.21	338	234	17	.6	542	7.2
DA-06-56-401	520	35	[c] .00	.01	38	19	27	5.6	260	15	5.2	1.0	4.8	.00	.20	279	173	25	.9	452	7.1
KS-05-52-103	209	29	[c] .00	.00	72	6.0	30	1.6	259	17	24	.3	7.7	.06	.04	315	204	24	.9	525	7.2
JA-12-01-606	102	32	.04	.01	80	7.4	24	2.4	272	24	15	.3	18	.06	.00	342	230	18	.7	540	7.3
JA-12-12-405	137	30	[c] .00	.01	68	6.3	8.6	1.1	232	8.4	7.5	.4	10	.00	.04	263	196	9	.3	412	6.9

[a] Includes the equivalent of any carbonate (CO_3) present.
[b] Analysis given in Bull. 6107, p. 95. Location given as 3 miles north of Hereford, Deaf Smith County, Texas.
[c] Iron in solution at time of analysis.

Table 17.--Pumpage from major wells tapping the Ogallala Formation, 1959

Major subdivision	Public supply		Industrial		Irrigation		Total*	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft /yr.	mgd	acre-ft./yr.
RE- 1	2.1	2,372	--	--	205	230,000	210	230,000
RE- 3	7.2	8,050	--	--	88	99,000	98	110,000
RE- 4	8.7	9,791	0.7	783	98	110,000	110	120,000
RE- 6	.75	844	--	--	205	230,000	210	230,000
RE- 7	.15	168	--	--	70	78,000	70	78,000
RE- 9	.08	94	--	--	3.9	4,400	4.0	4,500
RE-10	.06	65	--	--	.33	370	.38	430
RE-11	.23	260	--	--	.12	140	.36	400
RE-14	.42	476	--	--	3.5	3,900	3.9	4,400
RE-16	1.63	1,829	3.67	4,120	21	24,000	27	30,000
RE-18	.62	700	.22	242	.98	1,100	1.8	2,000
RE-20	.03	29	--	--	98	110,000	98	110,000
RE-21	--	--	.32	356	39	44,000	39	44,000
RE-36	--	--	--	--	.40	450	.40	450
Total*	21.97	25,000	4.9	5,500	830	940,000	870	960,000

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

decrease in the amount of water in storage resulting chiefly from pumping, and a rise represents an increase in storage resulting chiefly from recharge.

Hydrographs of representative wells (Figure 18) show the pattern of fluctuations of the water table from 1936 to 1961. Prior to 1941 the water table was lowered in what were then the heavily pumped areas at the average annual rate of 1 foot or less. The water-level decline was interrupted by the above-normal precipitation of 1941, which reduced the need for pumping and, in some places, contributed a substantial amount of recharge to the ground-water reservoir. The downward trend of the water table started again about 1943 or 1944 and has continued in most areas at varying rates. Significant declines of the water table in parts of Carson and Gray Counties began in about 1954 with the beginning of irrigation (Figure 18, well DA-06-47-202). The hydrographs show that the rate of decline has varied in individual wells from one area to another. Heavy pumping in parts of Carson, Gray, Armstrong, and Donley Counties has not spread throughout the counties; in fact, water levels in some wells remote from areas of heavy pumping have risen during the period of record. However, the levels in all wells in the heavily pumped areas have declined, reflecting the removal of water from storage.

Availability and Potential Development

The availability and potential development of ground water from the Ogallala Formation in the Red River Basin are dependent primarily on the amount of water in storage in the Ogallala. The volume of water stored in the formation is the product of the volume of saturated material and the porosity (ratio expressed in percentage of void space to total volume). Such an estimate of the total quantity of water in storage is of little use in itself because much of the water will not drain from the material, and, therefore, will not be available to wells. The quantity of water in storage that will be available to wells is determined by the specific yield of the material and is computed by multiplying the volume of saturated material by the specific yield. The specific yield of the Ogallala Formation has been estimated by various workers to be about 15 percent. This is based on laboratory testing of samples collected in the field and by pumping tests on wells. Using 15 percent and the volume of saturated material, as determined from the map showing the thickness of saturated material (Plate 19), the total volume of water theoretically available to wells from the Ogallala Formation in the Red River Basin was computed to be about 63 million acre-feet in 1958. The quantity of water theoretically available to wells, by counties, is shown in Table 18. The volume of water available in parts of Roberts, Hemphill, Wheeler, Collingsworth, and Motley Counties that are included in the Red River Basin in the High Plains was not estimated; however, the quantity is small and would not materially change the total.

The availability of water at any specific location in the High Plains is determined by the thickness of saturated material at the location and by the hydraulic properties of the aquifer. As previously stated, the specific yield of the formation has been estimated by various hydrologists to average about 15 percent for the Ogallala Formation in the High Plains. Coefficients of transmissibility based on long-term pumping tests near Amarillo in 1954-55 were determined to be 6,000 to 7,000 gpd per foot (Moulder and Frazor, 1957, p. 15). These values may be somewhat low for the Ogallala Formation as a unit. A long-term test at Plainview in Hale County indicated that the coefficient of transmissibility at that location was between 24,000 and 38,000 gpd per foot.

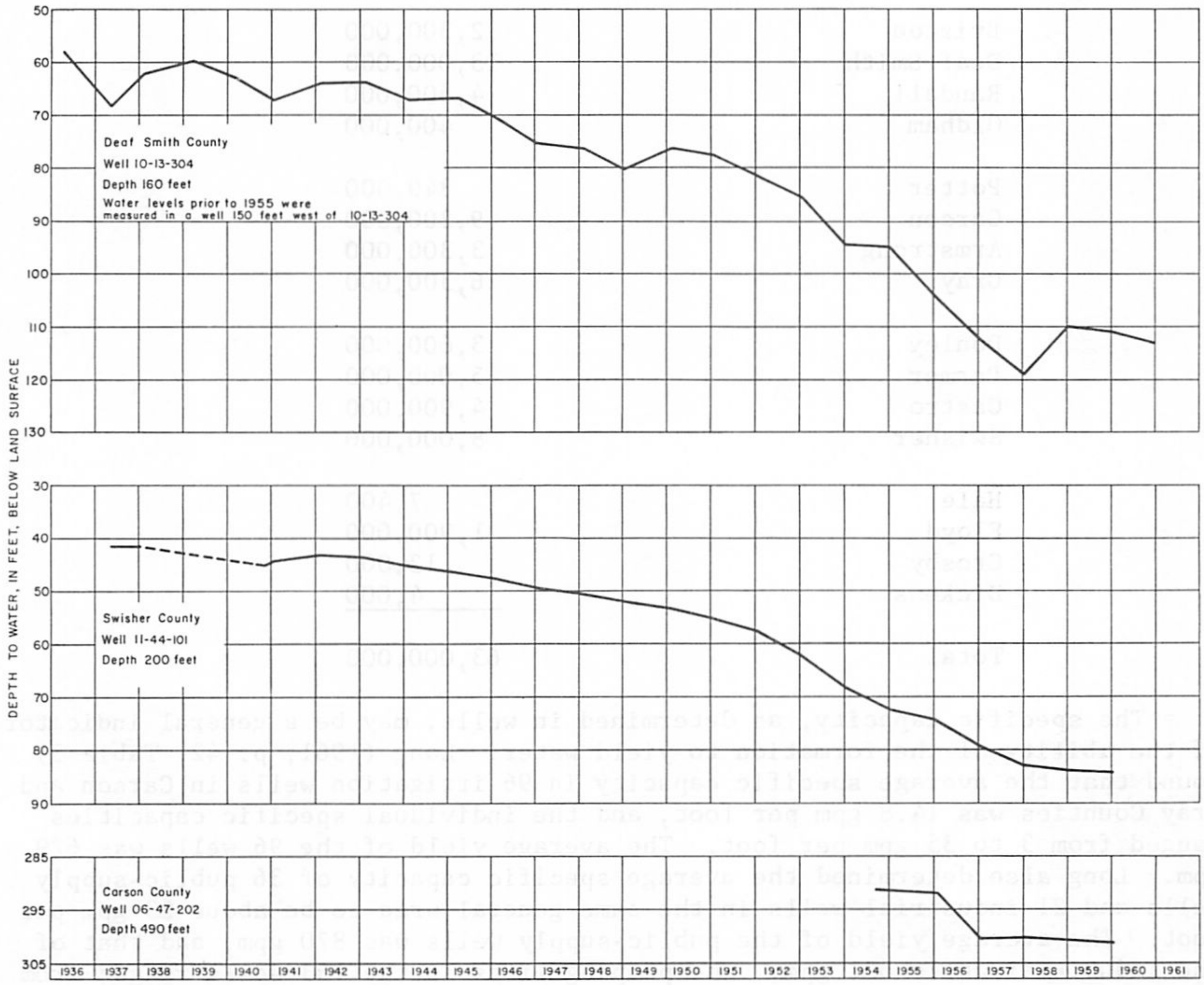

Figure 18

Changes in Water Levels in Wells in the Ogallala Formation

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

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Table 18.--Quantity of water available to wells in the Ogallala Formation in the Red River Basin, 1958

County	Volume of water in storage (acre-feet)
Briscoe	2,300,000
Deaf Smith	13,000,000
Randall	4,500,000
Oldham	400,000
Potter	340,000
Carson	9,200,000
Armstrong	3,300,000
Gray	6,300,000
Donley	3,600,000
Parmer	5,000,000
Castro	4,900,000
Swisher	8,000,000
Hale	7,400
Floyd	1,900,000
Crosby	12,000
Dickens	4,000
Total	63,000,000

The specific capacity, as determined in wells, may be a general indicator of the ability of the formation to yield water. Long (1961, p. 42, Table 5) found that the average specific capacity in 96 irrigation wells in Carson and Gray Counties was 14.8 gpm per foot, and the individual specific capacities ranged from 3 to 35 gpm per foot. The average yield of the 96 wells was 629 gpm. Long also determined the average specific capacity of 36 public-supply wells and 21 industrial wells in the same general area to be about 23 gpm per foot. The average yield of the public-supply wells was 870 gpm, and that of the industrial wells 621 gpm. The pumping lifts in the 153 wells ranged from 91 to 497 feet.

The potential development of ground water in the High Plains is dependent not only on the saturated thickness but also, at least for certain uses, on the depth to water in the formation. Plate 22 shows the approximate depth to water below the land surface in the Ogallala Formation in 1958. The map shows that the depth to water was about 100 feet in the Hereford area, where irrigation first developed in the Red River Basin, whereas the most recent development of irrigation has been in Carson and Gray Counties, where the depth to water was approximately 300 feet in many places. In the latter areas, the relatively great depth to water probably was a deterrent to the development of irrigation before the drought of the late 1940's and early 1950's.

Problems

The principal problems concerned with the development of ground water from the Ogallala Formation in the Red River Basin are those concerned with declining water levels. The recharge to the formation is small compared to the total yield of the wells, and the pumping of water for irrigation, therefore, is essentially a mining operation. As the water levels decline, the pumping costs will increase because of the increased lifts required. Also, as the levels decline, the saturated thickness of the deposits in the area of decline will decrease, and the yields of wells will decline. Declines of yields due to the development in the heavily irrigated areas have been reported as early as 1951 in some places (Leggat, 1954, p. 16, 17). The average yield of 10 wells in Swisher County declined from 828 gpm in 1938 to 680 gpm in 1951, and the average yield of 15 wells in Deaf Smith County decreased from 836 gpm in 1938 to 671 gpm in 1951. In Floyd County, the average decrease for 11 wells during the same period was from 753 to 668 gpm.

Irrigators in the High Plains have shown increasing interest in methods of conserving ground water. One of the methods proposed is to make as full use as possible of the water that accumulates in wet-weather lakes. A considerable amount of study has been made concerning the feasibility of artificially recharging the Ogallala Formation, by injecting the water in the lakes through wells. The principal difficulty in this process is the clogging of the well screen or formation by the suspended matter in the recharge water. Efforts have been made to eliminate this trouble by removing the material by settling prior to injection or by pumping the recharge well at intervals to remove the clogging material. Neither of these methods has been entirely successful.

Perhaps the best way to make use of the water in the lakes is to apply it directly for irrigation. This has been done in many places in the High Plains, and many irrigators are giving serious consideration to the method.

Another serious problem connected with the development of ground water from the Ogallala Formation is contamination by oil-field brines. In the past it has been the practice of many of the oil operators to dispose of the brine produced with the oil through surface disposal pits. In some areas this has resulted in a serious contamination of the underlying ground-water supplies. Steps have been taken by the Red River Authority and other groups to prohibit the use of surface pits for the disposal of oil-field brines.

Secondary Aquifer

Dockum Group

The Dockum Group is the only secondary aquifer in the Red River Basin in the High Plains. The beds of the Dockum Group are of continental origin and probably were laid down as river-channel and flood-plain deposits. They consist of shale and sandy shale, crossbedded sandstone, and conglomerate. The thickness of the Dockum Group ranges from 0 to probably more than 1,400 feet. The depth to the top of the beds ranges from 0 at the outcrop to more than 500 feet in parts of Parmer, Castro, and Floyd Counties.

The chemical quality of the water from the Dockum Group has been termed "uncertain" by Sellards and Baker (1943, p. 396), and saline water from the group has been reported in many areas. Electric logs of tests for oil and gas indicate the presence of water too highly mineralized for irrigation or public supply in Floyd County; however, wells have supplied water from the group in Randall and Deaf Smith Counties (Broadhurst, Sundstrom, and Weaver, 1951, p. 136-138).

The city of Canyon in Randall County pumped water for municipal use in 1947 from four wells in an aquifer in the Dockum Group. The depth of each well was approximately 500 feet and the static water level in 1 well was 250 feet below land surface. The yields of the wells ranged from 150 to 450 gpm. The chemical analysis of 1 composite water sample from the 4 wells shows the dissolved-solids content to be 390 ppm, considerably less than reported in analyses of water from the Dockum Group in most places.

An irrigation well 767 feet deep, about 6 miles northeast of Hereford in Deaf Smith County, is pumping water probably from an aquifer in the Dockum Group, the top of which was 215 feet below land surface at the well. The Dockum probably is about 1,000 feet thick in this vicinity. The static water level in the well was 378 feet below land surface in September 1956, and the yield was reported to be about 700 gpm. A chemical analysis of water from the well indicated 775 ppm dissolved-solids content, 37 ppm chloride, and 275 ppm sodium.

Although the Dockum Group has produced moderate quantities of fresh water in a few places, electric logs of oil tests and other information currently available indicate that yields from the group generally would range from low to moderate and that the water would be rather saline, probably unsuitable for irrigation or public supply and perhaps limited to certain industrial uses.

SUMMARY OF GROUND-WATER WITHDRAWALS IN THE RED RIVER, SULPHUR RIVER, AND CYPRESS CREEK BASINS

Table 19 shows a summary of ground-water withdrawals in the Red River, Sulphur River, and Cypress Creek Basins in 1959. The withdrawals have been tabulated by principal use, aquifer, and major subdivisions of the basins. The table shows that 1,100,000 acre-feet of water was pumped from wells in the Red River Basin in 1959. The major pumpage, by far, was for irrigation, 1,000,000 acre-feet, most of which was pumped from the Ogallala Formation in the High Plains. The table also shows that the greatest percentage of withdrawals was in regions I and II (major subdivisions RE-1 through RE-36, excluding major subdivision RE-35). This reflects both the more arid climate in regions I and II and the availability of water from the Ogallala Formation. Although the potential in regions III and IV is at least moderate, the climate is more humid, and the need for irrigation is considerably less than in regions I and II. Furthermore, surface-water supplies generally are more available in regions III and IV.

The total withdrawals for major uses in the Sulphur River and Cypress Creek Basins in 1959 were 2,300 and 5,000 acre-feet respectively. The largest use in both basins was for public supply, although in the Cypress Creek Basins moderate quantities were used by industry. Withdrawal for irrigation was

Table 19.--Summary of ground-water withdrawals in the Red River, Sulphur River, and Cypress Creek Basins, 1959, in acre-feet

Red River Basin

Major subdi-vision	Use: Public supply	Use: Industrial	Use: Irrigation	Ogallala Formation	Quaternary alluvium	Blaine Gypsum	Whitehorse Group	San Angelo Sandstone	Wichita and Cisco Groups undifferentiated	Trinity Group	Woodbine Formation	Nacatoch Sand	Total
RE- 1	2,400	--	230,000	230,000	--	--	--	--	--	--	--	--	230,000
3	8,000	--	98,000	110,000	--	--	--	--	--	--	--	--	110,000
4	9,800	780	110,000	120,000	--	--	--	--	--	--	--	--	120,000
6	900	--	230,000	230,000	--	--	--	--	--	--	--	--	230,000
7	170	--	79,000	78,000	740	--	--	--	--	--	--	--	79,000
9	94	--	5,300	4,500	930	--	--	--	--	--	--	--	5,400
10	65	--	7,800	430	7,400	--	--	--	--	--	--	--	7,800
11	1,300	--	11,000	400	1,800	10,000	--	--	--	--	--	--	12,000
13	--	--	12,000	--	220	12,000	--	--	--	--	--	--	12,000
14	480	--	4,200	4,400	250	--	30	--	--	--	--	--	4,700
15	400	--	6,300	--	4,600	2,100	--	--	--	--	--	--	6,700
16	1,800	4,300	24,000	30,000	150	--	--	--	--	--	--	--	30,000
18	1,100	900	3,100	2,000	1,500	1,600	--	--	--	--	--	--	5,100
20	29	--	110,000	110,000	1,100	--	--	--	--	--	--	--	110,000
21	300	400	47,000	44,000	3,800	300	--	--	--	--	--	--	48,000
23	210	--	3,400	--	3,600	--	--	--	--	--	--	--	3,600
24	570	--	8,200	--	8,700	65	--	--	--	--	--	--	8,800
25	1,500	--	6,200	--	5,300	1,000	--	1,500	--	--	--	--	7,700
26	850	37	130	--	1,000	--	--	--	--	--	--	--	1,000
27	230	--	13,000	--	90	13,000	490	--	--	--	--	--	13,000
28	--	--	180	--	90	--	90	--	--	--	--	--	180
29	--	--	1,900	--	1,900	--	--	--	--	--	--	--	1,900
30	--	--	--	--	--	--	--	--	--	--	--	--	--
31	--	--	45	--	45	--	--	--	--	--	--	--	45
32	--	--	--	--	--	--	--	--	--	--	--	--	--
33	--	--	--	--	--	--	--	--	--	--	---	--	--
34	--	--	--	--	--	--	--	--	--	--	--	--	--
35	980	56	--	--	--	--	--	--	300	740	--	--	1,000
36	--	--	530	450	75	--	--	--	--	--	--	--	530
37	490	1,100	78	--	--	--	--	--	--	650	1,000	--	1,700
38	2,800	870	150	--	130	--	--	--	--	1,600	2,000	--	3,800
39	1,400	--	40	--	30	--	--	--	--	--	1,400	--	1,400
40	--	--	--	--	--	--	--	--	--	--	--	--	--
41	--	--	--	--	--	--	--	--	--	--	--	--	--
42	300	--	56	--	130	--	--	--	--	--	--	220	350
Total	36,000	8,400	1,000,000	960,000	44,000	40,000	620	1,500	300	3,000	4,400	220	1,100,000

Sulphur River Basin

Major subdi-vision	Use: Public supply	Use: Industrial	Use: Irrigation	Woodbine Formation	Blossom Sand	Nacatoch Sand	Carrizo Sand and Wilcox Formation, undifferentiated	Mount Selman Formation and Sparta Sand, undifferentiated	Rocks of Austin age	Total
SU- 1	1,000	--	--	6	--	1,000	--	--	--	1,000
2	79	--	--	--	--	--	--	--	79	79
3	--	160	--	--	--	160	--	--	--	160
4	340	--	--	--	340	--	--	--	--	340
5	120	13	--	--	--	130	--	--	--	130
6	7	33	5	--	--	--	45	--	--	45
7	140	--	--	--	--	--	140	--	--	140
8	270	--	12	--	--	--	280	--	--	280
9	37	80	--	--	--	--	120	--	--	120
Total	2,000	290	17	6	340	1,300	580	--	79	2,300

Cypress Creek Basin

Major subdi-vision	Use: Public supply	Use: Industrial	Use: Irrigation	Woodbine Formation	Blossom Sand	Nacatoch Sand	Carrizo Sand and Wilcox Formation, undifferentiated	Mount Selman Formation and Sparta Sand, undifferentiated	Rocks of Austin age	Total
CY- 1	230	640	--	--	--	--	870	--	--	870
2	630	--	20	--	--	--	650	--	--	650
3	570	140	--	--	--	--	710	--	--	710
4	550	--	--	--	--	--	550	--	--	550
5	2	3	--	--	--	--	5	--	--	5
6	1,000	1,000	160	--	--	--	2,000	160	--	2,200
Total	3,000	1,800	180	--	--	--	4,800	160	--	5,000

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

negligible in both basins. The table shows that most of the withdrawal in both the Sulphur River and Cypress Creek Basins was from the Carrizo Sand and Wilcox Formation, undifferentiated. The withdrawal in the Sulphur River and Cypress Creek Basins was small and far below the potential of the aquifers in the basins. Additional uses in the future probably will be largely for public-supply and industrial use. The subhumid climate of the region precludes the need of much water for irrigation except on a supplementary basis.

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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