TEXAS
WATER
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BOARD

Report 166

GROUND-WATER RESOURCES OF COKE COUNTY, TEXAS

MARCH 1973

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REPORT 166

GROUND-WATER RESOURCES OF COKE COUNTY, TEXAS

By

Clyde A. Wilson
United States Geological Survey

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GROUND-WATER RESOURCES OF COKE COUNTY, TEXAS

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ABSTRACT

Coke County, located in semiarid west-central Texas, where large ranches, small farms, and oil production are the main bases of the economy, has a small supply of ground and surface water. Of the approximately 1,900 acre-feet of fresh to moderately saline ground water used in 1968, industry used 880 acre-feet, irrigation used 210 acre-feet, and domestic supply and livestock used 820 acre-feet. All of the water for municipal supply and some of the water for industry is obtained from surface-water reservoirs.

The oldest geologic units cropping out in the county are the westward-dipping Permian "red beds". These rocks are composed mainly of shale and fine-grained sandstone, and scattered beds, lenses, and stringers of gypsum, anhydrite, and dolomite. In the western and southern plateau areas, the Permian rocks are overlain by eastward-dipping sand, clay, and limestone of Cretaceous age. Alluvial deposits of Quaternary age occur in the valleys of the Colorado River and its tributaries.

Water in the alluvium and in the Cretaceous rocks (Fredericksburg and Trinity Groups) occurs under water-table conditions. Water in the Permian rocks (Clear Fork, Pease River, and Artesia Groups, and Ochoa Series) occurs under both water-table and artesian conditions. The water-producing zones in the geologic units are: (1) Sand and gravel in the alluvium; (2) fine sands or fractures and solution openings in limestone beds of the Fredericksburg and Trinity Groups; and (3) sand, gypsum, and dolomite stringers or lenses in the Permian rocks.

Recharge to the aquifers is mostly from precipitation on the outcrops or from infiltration of intermittent streamflow. Heavy pumping from the alluvium may, in places, induce recharge from the Colorado River. Generally, however, the slope of the water-table or potentiometric surface is toward the Colorado River.

Ground water in the Permian rocks is usually of the calcium-magnesium and sulfate or bicarbonate type. Most of the water samples collected from wells in the Permian rocks contained more than 1,000 mg/l (milligrams per liter) dissolved solids. Water from the Fredericksburg and Trinity Groups is of the calcium-magnesium or bicarbonate type, and seldom contains more than 500 mg/l dissolved solids. The chemical quality of the ground water from the alluvium is variable.

The most favorable areas in the county where well yields exceeding 50 gpm (gallons per minute) can be expected are: (1) In the floodplain alluvium along the Colorado River; (2) the "older alluvium" in the southwestern corner of the county; and (3) in the southeastern part of the county near Tennyson, where wells may penetrate solution openings and fractures in the dolomitic beds of the Clear Fork Group.

INTRODUCTION

Purpose and Scope of the Investigation

The purpose of this study is to evaluate the ground-water resources of Coke County, with particular emphasis on the source, occurrence, quality, and availability of ground water that is suitable for municipal supply, industrial use, and irrigation. The general scope of the study included the collection, compilation, and analysis of basic hydrologic data in relation to these objectives.

Location, Economics, and Water Supply of the Area

Coke County is located about 30 miles north of the city of San Angelo and 60 miles southwest of Abilene (Figure 1). The county encompasses an area of 911 square miles and had a population of about 2,900 in 1970. Robert Lee, a centrally located town with a population of about 1,100, is the county seat. About 88 percent (800 sq. mi.) of the county is range and pastureland.

The economy of Coke County is based on ranching, farming, and oil production. The annual income from agriculture is slightly more than one-half of the total annual income of approximately 7.9 million dollars (Texas Almanac, 1967, p. 257). Sheep and cattle sales represent more than 90 percent of the farm and ranch income. The county produced 5,852,904 barrels of oil in 1969; cumulative production since 1942 is approximately 148,000,000 barrels.

The water used in Coke County comes from both ground- and surface-water sources. Three major reservoirs in the county impound surface runoff. The largest is E. V. Spence Reservoir, which is formed on the Colorado River by Robert Lee Dam. The town of Robert Lee receives its water supply from nearby Mountain Creek Reservoir. Oak Creek Reservoir, in the northeast corner of the county, furnishes water to the towns of Bronte and Blackwell. Water for most of the rural-domestic and livestock needs is furnished by either small surface-water catchment tanks or by wells. Ground water of varying quality is used in the water flood or secondary recovery operations in many oilfields.

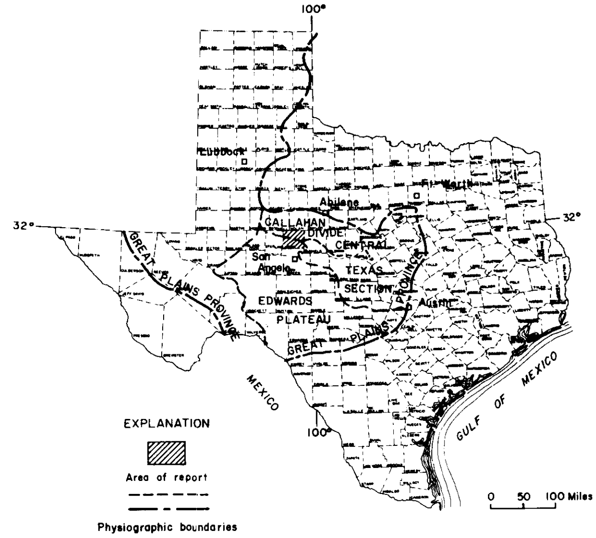


Figure 1.—Location of Coke County and Regional Physiography

Previous Ground-Water and Geological Studies

Beede and Bentley (1918) published the first detailed report on the geology of Coke County. The Permian and Cretaceous rocks of Coke County are described briefly by Sellards and others (1932).

Although this investigation is the first detailed study of the ground-water resources of Coke County, some information on wells and ground water in the county have been compiled previously. In 1946, data from an inventory of approximately 50 wells was included in an informal and unpublished report by J. H. Dante and W. L. Broadhurst. A reconnaissance study of ground water in the Colorado River Basin, which included Coke County, was made by Mount and others (1967). The water supplies of the towns of Robert Lee and Bronte were described by Broadhurst and others (1951, p. 28-29) in their inventory of the public water supplies in west Texas.

Recent geological studies in Coke County have been published by the West Texas-San Angelo Geological Societies (1961) and Mear (1963).

Adjacent counties in which ground-water studies have been completed include Mitchell and Nolan Counties (Shamburger, 1967); Runnels County (Shamburger, 1959); and Tom Green County (Willis, 1954). In addition, inventories of wells and springs have been published for Sterling County (George and Dalgarn, 1950) and Tom Green County (Frazier and others, 1941). Rayner (1959) compiled records of water-level measurements in observation wells in some of the adjoining counties.

The chemical quality of surface waters in the Colorado River Basin has been studied by Leifeste and Lansford (1968).

Methods of Investigation

The fieldwork for this investigation was conducted from September 1968 to April 1969. Basic data, such as the locations, depths, measured water levels, construction, and water use were obtained for 633 wells, springs, and test holes (Figure 15 and Table 5). This inventory included all municipal, industrial, and irrigation wells and selected domestic-supply or livestock wells. The altitude of each well was determined from 7½- or 15-minute U.S. Geological Survey topographic quadrangle maps or by altimeter surveys. Water samples from 153 wells and springs were collected for chemical analyses. These and previous analyses are given in Table 6.

A geologic map of Coke County was prepared from previously published data, supplemented by reconnaissance geologic mapping. Subsurface control for geologic correlations and structural mapping were obtained from geophysical and lithological logs of oil and gas tests.

Acknowledgments

Many ranchers, farmers, governmental officials, and oil producing and service company personnel provided access to their properties and supplied information on wells and springs. Completion data for many of the industrial water wells were generously furnished by Humble Oil and Refining Company, Mobil Oil Corporation, Pan-American Petroleum Corporation, Miami Petroleum Incorporated, and Perkins-Protho Company. A. H. Williford, Research Geologist for Texas Electric Service Company, contributed information on the geology of western Coke County. Many water-well drillers in Coke County, including T. W. Casey, Jack Dixon, J. Reeves, C. W. Smith, and S. H. Smith, provided information and logs on wells.

Well-Numbering System

The well-numbering system used in this report (Figure 2) is the same system that is used by the Texas Water Development Board throughout the State. Under this system, which is based on latitude and longitude, each 1-degree quadrangle in the State is given a two-digit number from 01 through 89. These are the first two digits of the well number. Coke County is in parts of quadrangles 29 and 43.

Each 1-degree quadrangle is subdivided into 7½-minute quadrangles which are given a 2-digit number from 01 to 64. These are the third and fourth digits of the well numbers. These two digits are shown in the upper left corner of each 7½-minute quadrangle. Each 7½-minute quadrangle is further subdivided into 2½-minute quadrangles and given a single digit number ranging from 1 through 9. This is the fifth digit of the well number. Finally, each well within a 2½-minute quadrangle is given a 2-digit number in the order in which the well was inventoried, starting with 01. These are the last two digits of the well number.

In addition to the 7-digit well number, a two-letter prefix is used to identify the county; the prefix for Coke County is DR.

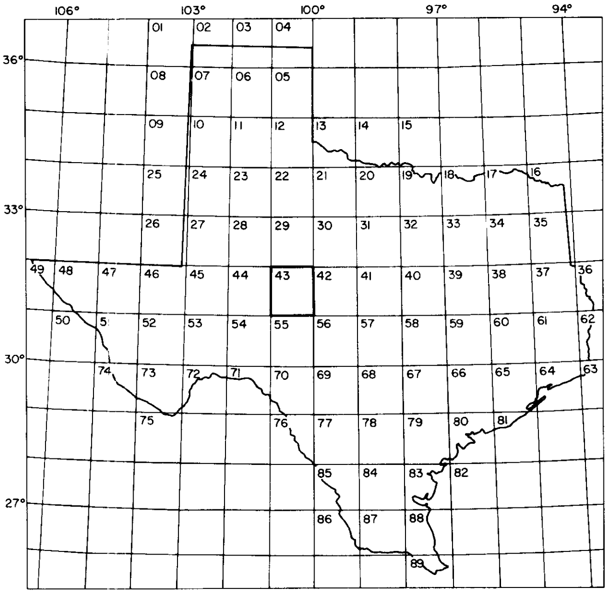
As an example, well DR-43-11-601, which is owned by C. A. Counts, is in Coke County (DR), in the 1-degree quadrangle (43), in the 7½-minute quadrangle (11), in the 2½-minute quadrangle (6), and was the first well inventoried (01).

Topography and Drainage

The southwestern part of Coke County is in the Edwards Plateau section of the Great Plains physiographic province; the northwestern part of the county is in the Central Texas section (Figure 1), which includes the Callahan Divide (Carr, 1967). The county is bisected diagonally by the southeastward flowing Colorado River. Altitudes range from about 1,700 feet above mean sea level in the river valley to more than 2,600 feet on the Edwards Plateau.

Except for the rugged and dissected escarpment, the Edwards Plateau is relatively flat. The soils are mostly thin, dark-colored, calcareous loams. The Central Texas section is characterized by a rolling topography and deep, red-brown loan soils. Much of the area, however, is capped with caliche.

Surface drainage on the plateau is mostly internal, but during periods of heavy rainfall, some intermittent low-gradient streams flow southward to the North Concho River. Intermittent streams in canyons along the escarpment flow to the Colorado River. The Central Texas section is drained by the Colorado River and its intermittent tributaries, many of which enter Robert Lee Reservoir.



1 - degree Quadrangles

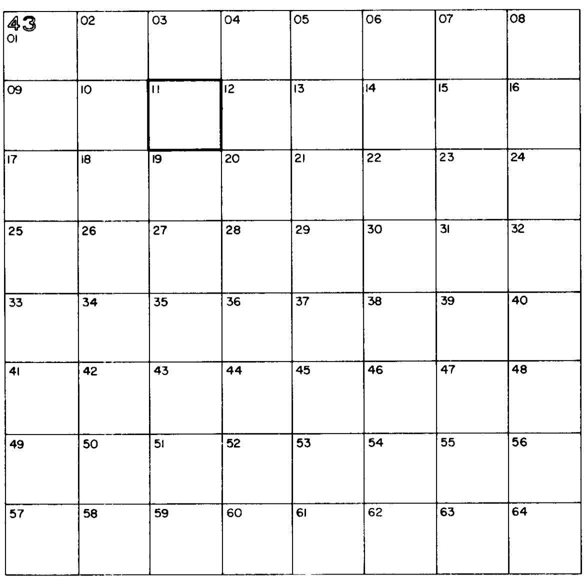
Location of Well 43-11-601

43 1 - degree quadrangle

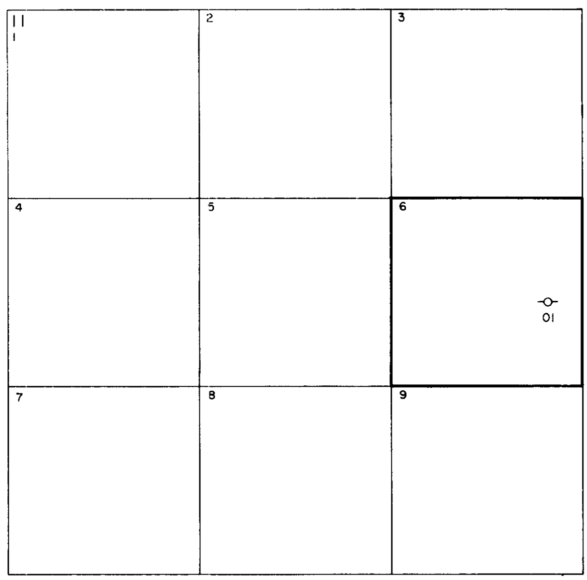
11 7 1/2 - minute quadrangle

6 2 1/2 - minute quadrangle

01 Well number within 2 1/2 - minute quadrangle



7 1/2 - minute Quadrangles



2 1/2 minute Quadrangles

Figure 2

Well-Numbering System

Climate

The climate of Coke County is semiarid, but has certain characteristics of both subtropical and desert climates. In general, warm dry weather predominates, but changes may be rapid and frequent with the passage of cold fronts. The summers are hot with moderate or occasionally high humidity.

Most of the rainfall occurs in the form of convective showers and thunderstorms which vary greatly in both the amount of precipitation and the area covered. Usually, precipiation is greater than normal during years when a tropical hurricane moves inland from the Gulf of Mexico. Snow averages about 2 to 3 inches per year and is not a significant source of moisture. The annual precipitation at San Angelo, Tom Green County, is shown on Figure 3. The average at San Angelo for the period 1904-68 is 19.40 inches; yearly amounts range from 7.41 inches in 1956 to 42.12 inches in 1882. The 30-year normal precipitation for the period 1931-60 at San Angelo is 18.63 inches. The average annual precipitation at Robert Lee is 17.78 inches for the period 1948-68.

The average monthly temperature and precipitation for localities near Coke County are shown on Figure 4. The average annual temperature at San Angelo was 65.4°F. The greatest monthly rainfall total recorded at San Angelo was 27.65 inches in September 1936.

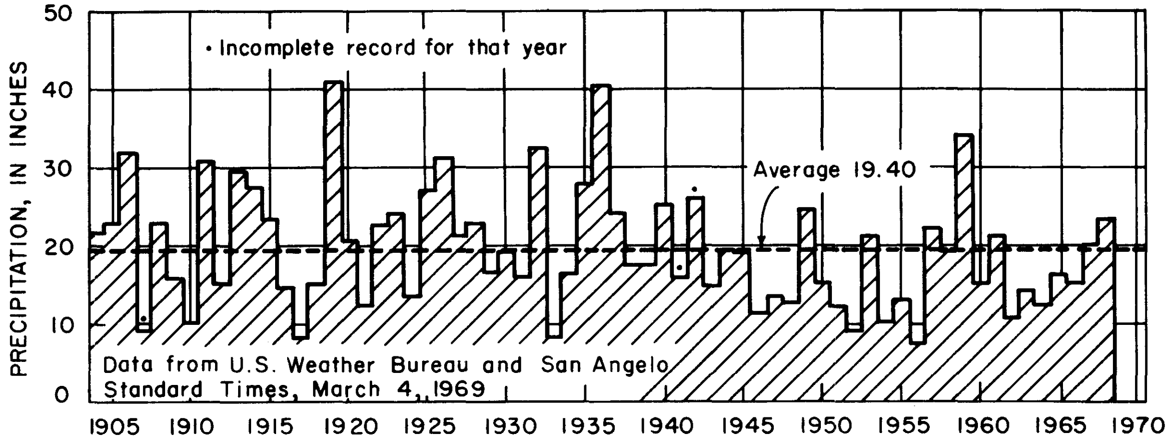


Figure 3.—Precipitation at San Angelo

Figure 4 also shows the estimated gross lake-surface evaporation (82 in.) for the Coke County area for the period 1940-65. The graph is based on data from Kane (1967, p. 58-71). Figure 4 also shows the consumptive use of water by alfalfa as estimated by methods given in Blaney and Criddle (1950) and discussed by Cruff and Thompson (1967). The assumption is made that ample water is available, although alfalfa can be grown on much less moisture. This method has been used in estimating potential evapotranspiration from the soil.

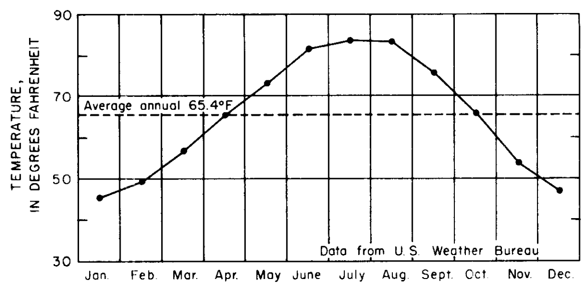
The graphs showing gross lake-surface evaporation and consumptive use indicate that the monthly demand for moisture is greater than is normally available from precipitation. The loss of moisture by evapotranspiration creates a soil-moisture deficiency. When precipitation occurs, this soil-moisture deficiency must be overcome before recharge to the ground-water reservoir can occur.

Surface-Water Runoff

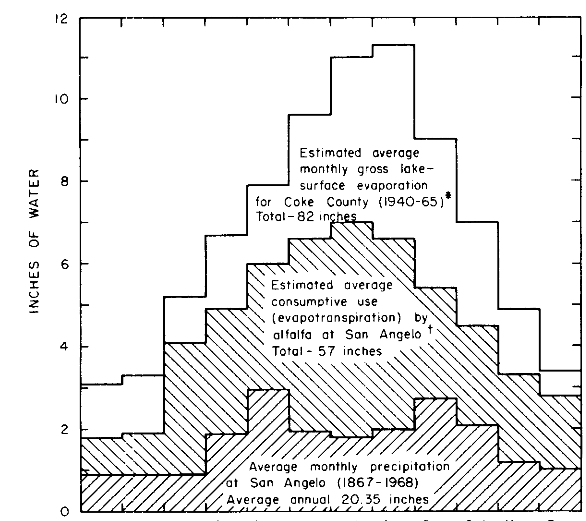
In Coke County, streamflow records are available for two gaging stations on the Colorado River (station 08123900, Colorado River near Silver and station 08124000, Colorado River at Robert Lee). Daily discharges and station descriptions are given in the annual publications of the U.S. Geological Survey entitled *Water-resources data for Texas, Part I: Surface-water records.*

Streamflow in the Colorado River in Coke County varies greatly. For example, at station 08123900, the daily flow at times during the year is zero. The peak discharge for the period of record (water years 1957-68) was 23,200 cfs (cubic feet per second) on May 12, 1957, (gage height of 24.19 ft). The average discharge for the 12 years of record was 117 cfs (84,700 ac-ft per year). Flow-duration studies for station 08123900 show that the daily discharge exceeded 0.1 cfs about 82 percent of the time, 1.0 cfs about 71 percent, 10 cfs about 32 percent, 100 cfs about 11 percent, and 1,000 cfs about 2 percent.

The amount of runoff depends on the intensity, duration, and distribution of precipitation; soil permeability; area and topography of the drainage basin; and stream-channel geometry. An annual average runoff of 0.75 inch for the period 1957-68 (water years) is estimated to have reached the Colorado River between station 08123900, near Silver, and the gaging station 08126500, at Ballinger, in central Runnels County. The contributing area between the gage near Silver and the gage at Ballinger is 1,360 square miles. During these 12 years, the highest estimated annual runoff was 3.16 inches in 1957.



Average monthly mean temperature at San Angelo, Tom Green County (1907-1968)



Average monthly precipitation versus estimated gross lake-surface evaporation and consumptive crop use

* Data from Kane, 1967

† Based on average monthly temperatures at San Angelo. Computation from Blaney and Criddle (1950) and Cruff and Thompson (1967)

(Temperature and precipitation data from U.S. Weather Bureau, Department of Agriculture, and Soil Conservation Service)

Figure 4.—Average Monthly Temperature, Precipitation, Gross Lake-Surface Evaporation, and Consumptive Water Use by Alfalfa

During the 1963 water year, the annual discharge was greater at the Silver gage than at the Ballinger gage. Assuming the average annual precipitation at Robert Lee applies to the entire contributing area, about 4 percent of all rainfall reaches the main stem of the Colorado as surface runoff.

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

Regional Stratigraphy and Structure

Coke County is located on the eastern shelf area of the Permian Basin. The general structural features of the basin and the location of the Permian outcrops are shown on Figure 5. Rocks ranging in age from Permian to Holocene crop out in the county, and the areal extent of these geologic units is shown on Figure 6. Subsurface relationships are shown on Figures 7 and 8.

Subsurface geologic units in Coke County include a Precambrian igneous basement and sedimentary rocks ranging in age from Cambrian to Permian. In the western part of the county, Clark (1961, p. 56) reported 250 to 300 feet of Cambrian sandstone, 500 to 600 feet of Ordovician dolomite, 0 to 50 feet of limestone possibly of Mississippian age, 900 to 2,500 feet of Pennsylvanian rocks and several thousand feet of Permian rocks. The geologic units (Table 1) older than the Permian Clear Fork Group of the Leonard Series are referred to as "older Paleozoic rocks." These units yield only saline water to wells in Coke County.

The Permian Basin is a large structural depression that extends over much of west Texas and southeastern New Mexico (Figure 5). Permian beds along the eastern shelf of the basin dip generally westward at tens of feet per mile until entering the margin of the basin, where they continue under the Midland Basin and Central Basin Platform subdivisions of the Permian Basin, then crop out again generally at higher elevations on the west side of the basin in southeastern New Mexico and west Texas. Mear (1963, p. 1958-1961) correlated the Permian formations that crop out in Coke County with equivalent beds on the west side of the basin.

In the Midland Basin, the lithologic sequence of the Permian rocks is a basal shale and limestone, becoming more dolomitic in the middle, and then grading upward into an evaporitic facies of anhydrite and salt. In the subsurface of the eastern shelf area, the Permian rocks are typically limestone and dolomite in the lower half, and shale, silty shale, and sand in the upper half (the "red beds").

Coke County is situated on the eastern shelf but is close enough to the depositional environment of the Midland Basin that both evaporitic and red bed facies summarized in Table 1; the locations of wells, springs, and test holes are shown on Figure 15. In the description of the water-bearing properties of the geologic units, the water is classified according to the range of dissolved solids as shown in the following table (Winslow and Kister, 1956, p. 5).

DESCRIPTION	DISSOLVED-SOLIDS CONTENT MG/L
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	Over 35,000

The yields of wells are described according to the following rating: Small, less than 100 gpm (gallons per minute); moderate, 100 to 500 gpm; and large, more than 500 gpm.

Because the units shown in Table 1 as "older Paleozoic rocks" yield only brine to wells in Coke County, any water produced from these rocks would be unsuitable for most purposes except oilfield repressuring. For this reason, these rocks will not be discussed further in this section.

Clear Fork Group

The Clear Fork Group of the Permian age is composed of (from oldest to youngest) the Arroyo, Vale, and Choza Formations. Only the Choza crops out in the county. The group consists of varicolored shales (predominantly red) with some persistent beds of dolomite and less extensive lenses and stringers of anhydrite, gypsum, limestone, and dolomite. In weathered beds containing water-bearing cavities, all of the anhydrite has normally been altered to gypsum.

The Choza Formation yields small to large amounts of water to wells in Coke County. Five moderate- to large-capacity irrigation wells (DR-43-14-601, DR-43-14-607, DR-43-14-808, DR-43-22-201, and DR-43-22-301) provide much of the available information on the water-yielding capacity of the formation in the southeast part of the county.

Well DR-43-14-607 is reported to have yielded more than 800 gpm for a period of a few days, and then the yield dropped to about 400 gpm. The other wells yielded considerably less than this amount (Table 5). Information on the water-bearing horizons in these five wells is difficult to obtain. The limestone unit reportedly penetrated in wells DR-43-14-607 and DR-43-22-201 and the gypsum unit penetrated in well DR-43-14-808 are probably within the Merkel Dolomite Member of the Choza Formation (Figure 7). Drill cuttings from well DR-43-22-301 contained some gypsum; the "water sand" from 115 to 125 feet, as reported by the driller, may represent the Merkel Member.

The Merkel Dolomite Member is a whitish-gray, hard, ledge-forming, fractured dolomite with some interbedded shale. In Coke County, the unit is about 25 feet thick. The depth of the Merkel below the top of the Choza Formation varies with geographic location because the top of the Choza is an erosional surface. The capacity of the Merkel to yield large amounts of water to wells in Coke County depends on the degree of fracturing and solution of the dolomite or gypsum.

The Bullwagon Dolomite Member of the Vale Formation (Figure 7) yields potable water in amounts of 100 to 1,000 gpm to wells in eastern Tom Green County (Willis 1954, p. 13). The yield depends on the degree of fracturing and solution of the dolomite.

Throughout the outcrop area of the Choza Formation, yields of a few gallons per minute are obtained from small-capacity wells tapping less permeable units in the formation.

Pease River Group

The Pease River Group includes a lower unit, the San Angelo Sandstone, and an upper unit which Mear (1963, p. 1952-62) designated as the San Andres. The San Angelo Sandstone consists of 100 to 200 feet of alternating beds of hard conglomerate, coarse-grained sandstone, and red to green shale. It generally forms a distinctive marker bed on drillers' and geophysical logs. The approximate altitude of the top of the San Angelo is shown by the contours on Figure 9. The depth to the top of the formation ranges from zero at the outcrop to nearly 1,900 feet at the western edge of the county.

The San Andres equivalent consists of alternating and interfingering beds of red, green, and gray shale; gray to green sandstone, and stringers of anhydrite and gypsum.

The yields of wells penetrating the San Angelo Sandstone are usually less than 5 gpm, but yields of 10 to more than 40 gpm have been reported in the vicinity of Oak Creek Reservoir. In general, the larger capacity wells are located on or slightly down-dip from the outcrop and north of the Colorado River. The water is fresh to moderately saline in these areas.

The water-yielding ability of the upper unit is very poor, usually less than a few gallons per minute of fresh to moderately saline water. In or near the outcrop area, south of Robert Lee and the Colorado River (quad. DR-43-13, Figure 15), saline water is reported to lie within 100 to 200 feet of the surface. In this area, it is

Table 1.—Geologic and Hydrologic Units and Their Water-Bearing Properties

ERA	SYSTEM	SERIES	GROUP	STRATIGRAPHIC UNIT	ESTIMATED MAXIMUM THICKNESS IN AREA (FT)	GENERAL COMPOSITION IN COKE COUNTY	SURFACE EXPRESSION	WATER-BEARING PROPERTIES
Cenozoic	Quaternary	Holocene	—	Alluvium	200	Basal stringers, lenses, or discontinuous beds of sand and gravel grading upward into fine-grained sand, silt, and clay. Sand and gravel units usually unsorted, some cross-bedding. Limestone pebbles predominantly.	Includes flood plain along the Colorado River and older deposits adjacent to North Concho River in southwestern part of county.	Produces small to moderate quantities of fresh to moderately saline water to wells. Yields large quantities of fresh water to wells in the southwestern part of the county.
		Holocene to Pleistocene	—	Fluviatile terrace deposits	50	Discontinuous thin lenses and stringers of sand and gravel, overlain by sand, silt, and clay. Sand and gravel usually unsorted.	Small, flat, featureless terraces adjoining the flood plain of the Colorado River and the flat, plain areas along Mule, Jack Miles and Buffalo Creeks.	Yields small to occasional moderate quantities of fresh to slightly saline water.
Mesozoic	Cretaceous	Comanche	Fredericksburg	Edwards Limestone	130	White to gray massive limestone. Fossiliferous. Some horizons of chert nodules.	Ledge-former. Soils are thin and dark.	May be located above the water table. Contains perched water in places which yields small quantities of water to wells.
				Comanche Peak Limestone	35	White to gray fossiliferous, nodular or marly limestone.	Forms distinct ledges on hillsides. "Nodular" appearance.	May yield very small quantities of water, especially to springs.
				Walnut Clay	25	Brown, fossiliferous sand or sandy marl.	Subdued weathered outcrop beneath limestone ledges.	Not known to yield water to wells.
			Trinity	—	120	Gray, yellow, pink, and purple marl and clay with lenses and beds of gray to buff sand or conglomeratic sand which usually occur near the base and top of the unit. Color has pastel appearance.	Forms gentle to steep slopes along the edge of the Edwards Plateau Region. Erodes easily. Soils light colored.	Produces small quantities of fresh water to wells.
	Triassic	—	Dockum	—	15±	Conglomerate and sandstone. Pebbles rounded, multicolored, and composed of limestone and quartz. Hematite and clay cement.	Forms ledges.	Not known to yield water to wells.
Paleozoic	Permian	Ochoa	—	Rocks of Ochoa age	340+	Reddish or mottled red-gray, silty shale with interbedded sandstone and thin stringers or beds of limestone, dolomite, and gypsum. Typical red beds.	Gentle to moderately rough terrain. Thin reddish soils.	Yields small quantities of fresh to moderately saline water.
		Guadalupe	Artesia	Yates Formation (may include rocks of Tansill age in places)	130	Mottled red and gray, fine-grained sandstone and shale. Red beds.	Gentle to moderately rough terrain. Thin reddish soils.	Yields small quantities of fresh to moderately saline water.
				Seven Rivers Formation	270	Soft red to yellowish, fine to very fine-grained sandstone and mottled red and gray silty shale. Some gypsum stringers. Red beds.	Gentle to moderately rough terrain. Thin reddish soils.	Yields small quantities of fresh to moderately saline water.
				Queen Formation	140	Soft, red to gray, fine-grained sandstone and silty shale. Red beds.	Flat to moderately rough terrain. Reddish deep soils.	Yields small quantities of fresh to moderately saline water.
				Grayburg Formation	150	Red, dense shale and silty shale with lenses and stringers of gypsum, and dolomite. Typical red beds.	Gentle to moderately rough terrain. Soils thin, reddish.	Yields small quantities of fresh to moderately saline water.
			Pease River	San Andres of Mear (1963)	470	Alternating and interfingering beds of red, gray, and green shale and fine-to-coarse grained gray to green sandstone. Some gypsum stringers.	Flat to moderately rough terrain. Light colored, thin soils.	Yields small quantities of fresh to moderately saline water.
				San Angelo Sandstone	200	Alternating beds of hard, well-cemented conglomerate, coarse-grained, buff sandstone, and red shale. Conglomerate is composed of rounded, multicolored quartz pebbles. Sandstone often cross-bedded.	Prominent ledges of conglomerate; flat to rough topography. Often caps low-lying hills.	Yields small to moderate quantities of potable water to wells. Also yields brine to deep wells in the western part of the county.
		Leonard	Clear Fork	Choza Formation	520	Mottled red, green, gray, and blue shale with occasional persistent thin beds of whitish-gray irridescent fractured dolomite. Some lenses and stringers of gypsum. Typical red bed unit.	Flat to gentle-rolling terrain. Light-colored, deep soils.	Yields small to large amounts of fresh to slightly saline water to wells near the outcrop. May yield large amounts of water to wells tapping fractures and solution openings in the dolomite beds.
				Vale Formation	400	Red shale in lower 100 feet of section ("Big Red" unit). Upper section consists of red shale with interbedded dolomite and limestones.	Does not crop out in Coke County.	Not known to yield water to wells in Coke County. Potential yield unknown.
				Arroyo Formation	360	Red and greenish shale with limestone, dolomite, and gypsum lenses, stringers, and thin beds.	Does not crop out in Coke County.	Not known to yield water to wells in Coke County.
Older Paleozoic rocks					5,000	Limestone, dolomite, sandstone, and shale.	Does not crop out in Coke County.	Yields only brine to wells in Coke County.

Note--Stratigraphic nomenclature for the Permian is modified from that used by McKee, Oriel, and others (1967a & b) for the Midland Basin and for Crockett and northern Val Verde Counties and from Mear (1961 and 1963). Nomenclature for the Cretaceous is taken from the geologic map of Texas (Darton, Stephenson, and Gardner, 1937).

very difficult to construct a water well that will produce fresh or slightly saline water.

In western Coke County, five wells (DR-29-58-904, DR-29-59-404, DR-29-59-407, DR-29-59-730, and DR-43-04-106) produce saline water from the Pease River Group, principally the San Angelo Sandstone. The depths of these wells range from 800 to 1,375 feet; reported or measured discharges ranged from 11 to 90 gpm. The permeability was reported poor, and formation fracturing techniques were often used during well completion.

Artesia Group

The Artesia Group includes, in ascending order: The Grayburg; Queen; Seven Rivers; Yates; and Tansill Formations. The group consists of a thick sequence of mottled red, gray, green, and yellow shale interbedded with similarly colored fine sand and occasional stringers or lenses of gypsum, anhydrite, and dolomite. The maximum thickness of the group is about 690 feet.

Wells drilled in or close to the outcrops of the formations composing the Artesia Group yield small quantities of fresh to moderately saline water. The water is used principally for domestic supply and livestock needs, although at least one well (DR-43-03-905) had sufficient yield (16 gpm) to supply the water for the drilling of an oil well. Similar yields have been reported for a few other wells that tap the Artesia Group.

Ochoa Series

The Ochoa Series is composed of reddish silty shale with interbedded fine-grained sandstone and scattered lenses and stringers of gypsum, anhydrite, dolomite, and limestone. The Ochoa generally yields only small quantities (probably not more than 5 gpm) of fresh to moderately saline water to wells; although in the sandy part of the outcrop, yields of as much as 15 gpm have been reported.

Dockum Group

Rocks of the Dockum Group of Triassic age occupy small areas in the northern part of Coke County. These rocks are not known to yield water to wells in the county.

Fredericksburg and Trinity Groups

The oldest rocks of the Cretaceous System in Coke County belong to the Trinity Group. These rocks, which consist of multicolored clay and interbedded sand, were deposited on the eroded surface of Permian and Triassic rocks. The Fredericksburg Group, which overlies the Trinity Group, consists mostly of limestone or marly limestone. The Cretaceous rocks in Coke County are part of the Plateau aquifer (Edwards and Trinity aquifers) described by Mount and others (1967, p. 59).

Wells tapping the rocks of the Trinity Group usually yield small quantities of water to domestic and stock wells. Well DR-43-02-501 is reported to have yielded 65 gpm and well DR-43-10-601 was reported capable of yielding 70 gpm. Well DR-43-11-801 had a measured discharge of 39 gpm. Rocks of the Fredericksburg Group, usually above the water table, yield small amounts of fresh water to wells, most of which comes from a perched zone of saturation in the Edwards Limestone.

Alluvium

Alluvial deposits of various ages occur at different altitudes along the major river and stream systems in Coke County. A thick alluvial unit, which the West Texas-San Angelo Geological Societies Guidebook (1961, p. 9) refers to as a continuation of the Ogallala Formation (Pliocene age) of the High Plains, occurs adjacent to the North Concho River in the southwestern corner of Coke County. Frye and Leonard (1964, p. 15) however, indicate that the exposed part of the valley fill of the North Concho River in Tom Green County is early Pleistocene in age. In this report, these deposits are referred to as "older alluvium".

In Coke County, two moderate- to large-capacity irrigation wells (DR-43-18-601 and DR-43-18-602) obtain water from the older alluvium. These wells are 200 and 180 feet deep, respectively. Sand and gravel were reported in well DR-43-18-601 from 110 to 175 feet, underlain by yellow clay of the Trinity Group. Well DR-43-18-601 is reported to yield 700 gpm and well DR-43-18-602 is reported to yield 200 gpm. The yield of the alluvium is greatest where wells have encountered a substantial thickness of well-sorted sand and gravel.

Deposits of flood-plain alluvium and a system of disconnected alluvial terraces occur along the Colorado River and many of its tributaries. The terraces, which occur at higher altitudes, are poorly defined and form only a veneer of sediments over the Permian bedrock. These terraces are not shown on the geologic map (Figure 6).

A series of lower-level fluviatile terraces, which locally contain some ground water, occur adjacent to the flood plain along the Colorado River and some of its tributaries. The extensive areas of shallow, water-bearing alluvium along the lower stretches of Mule, Jack Miles, and Buffalo Creeks (Figure 6), are also classified as fluviatile terraces. The fluviatile terrace deposits usually yield only small quantities of fresh to slightly saline water to wells. Although locally the deposits may yield moderate quantities of water.

The alluvium of the flood plain of the Colorado River contains fresh to moderately saline water. The maximum thickness encountered in a well (DR-43-14-301) was about 68 feet, but the thickness is generally less than 50 feet. The lithology of the alluvium varies; commonly, the basal part is sand and gravel, grading upward into finer grained sediments such as sand and clay. The degree of sorting varies from a heterogeneous mixture of sand and gravel to distinctly sorted beds of similar-sized particles.

The alluvium of the Colorado River floodplain yields small to moderate quantities of water to many industrial wells that supply water for use in the secondary recovery of oil. In places, the water approaches very saline concentrations. In previous years, the total pumpage from the alluvium was greater than in 1970. Discharges exceeding 200 gpm are reported for several of these industrial wells; the average was about 120 gpm. Well DR-43-04-103 was reported to have produced 330 gpm during an initial test.

GROUND-WATER HYDROLOGY

Recharge

The principal sources of recharge to the aquifers in Coke County are: (1) Direct precipitation on the outcrops; (2) infiltration of water from surface reservoirs, rivers, and numerous intermittent streams; and (3) subsurface inflow from adjoining counties.

Recharge at the outcrop begins when a sufficient amount of precipitation has increased the soil moisture to field capacity. Figure 4 shows that during months of normal precipitation, the consumptive use of moisture (and hence potential evapotranspiration) greatly exceeds the rainfall and causes a deficiency of soil moisture. For recharge to occur, several inches of generally continous precipitation is required to overcome this deficiency.

Stream-bed alluvium stores water during periods of flow, protects this moisture from evaporation, and allows later infiltration. Outcrops of gypsum or dolomite beds are common in the streambeds and banks. When water is present in the streams, the solution openings and joints in these rocks can contain and transmit large volumes of recharge to the aquifers. The owner of well DR-43-14-607 reported that discharge from the well at a rate of 800 gpm was possible for a period of two weeks or longer during wet years, but only for a few days during dry periods. The well is completed in limestone or dolomite which crops out in Juniper Creek, about 2 miles southeast of the well.

Three areas of large-scale pumping of ground water from the alluvium of the Colorado River are located in quadrangles DR-29-58, DR-29-59, and DR-43-04 (Figure 15). The water table in 1968-69 sloped from the alluvium toward the river; however, after these wells were pumped for some time, the pumping levels declined below the water level of the river. With time, the normal hydraulic gradient toward the river was reversed, and water moved from the river toward the pumping wells. Much of the water that was pumped by these industrial wells was from the Colorado River. Most of these wells are no longer in use.

As E. V. Spence Reservoir is filled, recharge to the aquifers underlying the reservoir will occur. The amount of recharge will depend upon the head difference between the lake level and the potentiometric surface in the aquifer, and the permeability of the rocks.

Estimates of annual recharge of less than half an inch for the Ogallala Formation in the High Plains (Theis, 1935, p. 564-568), may be applicable to the outcrops of "older alluvium" in the southwestern part of Coke County. Recharge to the Permian rocks, which generally are low in permeability, is considerably less, perhaps on the order of 0.1 inch per year or less.

Occurrence and Movement

Ground water that is usable for domestic supply, livestock, and irrigation occurs at shallow depths in the Permian rocks, either in the outcrop areas or for short distances downdip. At greater depths, usually several hundred feet or more, the ground water in the Permian becomes too highly mineralized for these uses, but can be used in the secondary recovery of oil.

The fresh to moderately saline water that overlies the very saline water or brine occurs under both water-table and artesian conditions. The water in the shallow wells and in some of the deeper wells in the Permian rocks is unconfined. Artesian conditions occur in most of the deeper wells tapping the Permian, although the rise in head in the well may not be large. Water in the alluvium and in the Fredericksburg and Trinity Groups normally occurs under water-table conditions.

Ground water is moving continually from areas of recharge to areas of discharge. The approximate configuration of the water table and potentiometric surface, as indicated by the altitude of water levels in wells, is shown on Figure 10.

The map represents a composite of the water levels in the various aquifers; therefore, the water level at a selected point may be somewhat different than that shown on the map. The uniform appearance of the contours and the similar directions of movement of the water indicate hydraulic continuity between the aquifers. The movement of ground water is down gradient and at right angles to the contours.

The regional movement of ground water throughout the entire eastern shelf of the Permian Basin is generally eastward and toward local areas of less altitude, such as a major river channel. In Coke County, the slope of the water table or potentiometric surface is mostly toward the Colorado River. A ground-water divide is located in the southwestern part of the county where the movement of some ground water is toward the North Concho River, a tributary of the Colorado River.

The slope of the water table varies with the geographic location. Along the escarpment of the Edwards Plateau, slopes greater than 200 feet per mile are common. Nearer the Colorado River, the slope of the water table is usually less than 50 feet per mile. The slope of the water table is also indicative of the transmissibility of the aquifer, and steeper gradients may indicate lower transmissibility. The water table in general is a subdued replica of the land-surface topography.

Figure 10 shows that two water tables or piezometric surfaces are present in the Fredericksburg and Trinity Groups about 15 miles southwest of Robert Lee and south of Robert Lee near the Tom Green County line. The upper or perched water table may occur at altitudes many tens of feet above the top of the water surface in the lower part of the aquifer. As an example, the water level in well DR-43-11-801 was below 205 feet on March 7, 1969. Well DR-43-11-802, located about 100 feet west of well DR-43-11-801, had a water level of 132.2 feet on the same date.

The movement of ground water will be affected by E. V. Spence Reservoir, which was completed and began impounding water in the spring of 1969. When the normal pool level of 1,898 feet is reached, the water level in the reservoir will be considerably higher than the local water table. The result will be a rise of the water table or potentiometric surface in the vicinity of the reservoir.

The aquifers in the vicinity of the dam contain dolomite and gypsum beds, lenses, and stringers. Ground water in the deeper parts of the aquifers is saline. Some seepage beneath and around the dam into these aquifers and subsequent discharge into the Colorado River downstream may impair the quality of water in the river.

Discharge

Ground water in Coke County is discharged by natural and artificial processes. Natural discharge is by springs, evapotranspiration, subsurface movement out of the county, and seepage into the Colorado River. Artificial discharge is by wells.

Few perennial springs were located in the county during the well inventory. However, landowners and ranchers report that springs and seeps are common during years of above average rainfall. Most of these springs and seeps are located in the middle or near the base of the outcrop of the Fredericksburg and Trinity Groups along the Edwards Plateau escarpment; some are along the contact of alluvium and bedrock near the Colorado River.

Hydraulic Characteristics of the Aquifers

The ability of an aquifer to store, transmit, and yield water is defined by its hydraulic characteristics. These characteristics (coefficients of permeability, transmissibility, and storage) may be measured by conducting aquifer tests on large-capacity wells, but no reliable aquifer tests were conducted in Coke County because the assumptions upon which the analyzing formulas are based could not be fulfilled or approximated (Ferris and others, 1962, p. 93).

Few large-capacity wells in the county were suitable or available for testing. Most of the wells in all aquifers except the alluvium were equipped with windmills, which do not provide a sufficient and constant discharge for testing. The complex bed structure created by seams, fractures, and solution openings in the dolomite and gypsum rocks of the anisotropic aquifers does not permit accurate calculations with the test measurements.

The specific capacity of a well (expressed as gpm per foot of drawdown) is a measure of the well's effectiveness because it is a function of time, transmissibility of the aquifer, and well losses. The specific capacity of some wells may be computed from data given in the "remarks" column of Table 5. The specific capacities measured during this study ranged from 0.03 gpm per ft. in well DR-43-06-202 to 146 gpm per ft. in well DR-43-05-709. Windmill-equipped wells usually have low specific capacities (usually less than 1 gpm per ft.) because of large well-entrance losses during pumping.

The relationship between well yield and drawdown is a good indication of the ability of an aquifer to transmit water. Usually, high specific capacities indicate high transmissibilities, and low specific capacities indicate low transmissibilities.

The small yields (generally less than 5 gpm) and the large drawdowns of the wells tapping the various formations in the Permian System show that the transmissibility of these units is very low. Estimates based on the many measurements of yield and drawdown made in small-capacity wells during this study indicate that the transmissibility of the Permian rocks generally ranges from 20 to 300 gpd per ft. (gallons per day per foot). The rocks of the Trinity Group are probably a little more permeable, and the alluvium deposits are probably much more permeable.

Use of Ground Water

Ground-water resources in Coke County are used for irrigation, industry, domestic supply, and livestock. In 1968, about 1,900 acre-feet or 1.7 mgd (million gallons per day) of ground water was pumped, of which 880 acre-feet (0.79 mgd) or 46 percent was used by industry, 820 acre-feet (0.73 mgd) or 43 percent was used for domestic supply and livestock needs, and 210 acre-feet (0.19 mgd) or 11 percent was used for irrigation (Table 2).

Ground water was not being used for municipal supply in 1970. The town of Robert Lee recently drilled a well (DR-43-05-701) in the alluvium of the Colorado River for emergency use, and during the summer of 1965, the town supplemented its supply with water from a nearby irrigation well (DR-43-05-709).

Table 2.—Estimated Pumpage of Fresh to Moderately Saline Ground Water, 1968

USE OF GROUND WATER	SOURCE			*TOTAL, ACRE-FEET PER YEAR	*TOTAL, MILLION GALLONS PER DAY
	ALLUVIUM	FREDERICKSBURG AND TRINITY GROUPS	OCHOA SERIES, ARTESIA, PEASE RIVER, AND CLEAR FORK GROUPS		
Municipal	–	–	–	0	0
Industrial	880	–	4	880	.79
Irrigation	175	–	38	210	.19
Domestic and livestock	27	190	600	820	.73
*Totals	1,100	190	640	1,900	1.7

* Quantities are rounded to two significant figures.

The principal industrial use of ground water in Coke County is for oilfield water-flood operations. Waterflooding, which began in Coke County in 1962, involves the injection of a mixture of ground water and "production" water that has been separated from the oil-water mixtures pumped from the oil wells. Normally, production water is too saline for purposes other than waterflooding; if not injected for water-flooding, it is disposed of as waste water. Ground water is used also in the drilling of oil wells; however, the amount is small. Nearly all of the 880 acre-feet of ground water used in 1968 for industrial purposes was from the alluvium of the flood plain of the Colorado River.

About 600 of the 820 acre-feet of ground water used for domestic supply and livestock needs in 1968 was from the Permian rocks (Table 2). Most of the domestic supply and livestock wells are equipped with windmills or small submergible pumps; the yields of the wells measured during the investigation averaged slightly over 1 gpm.

According to Gillett and Janca (1965, p. 87) 43 acre-feet of ground water was pumped for irrigation in 1958 and none in 1964. By 1968, irrigation with ground water had increased to about 210 acre-feet, of which 96 acre-feet was pumped from two wells in the alluvial deposits in the southwestern part of the county. Most of the 79 acre-feet of water pumped from the alluvium of the flood plain of the Colorado River was for the irrigation of the golf course and other small acreage in the vicinity of Robert Lee.

Well Construction

Most of the recently constructed small-capacity wells, such as those used for domestic or livestock purposes, are drilled with cable tools or rotary equipment. The diameter of the drill hole is usually 6 to 8 inches; the hole is drilled several feet or more into or beyond the producing interval to form a "pump-pit". A test hole of 4 inches in diameter is sometimes drilled first when using rotary equipment to test the water-bearing properties of the formations. Plastic or metal casing, 5 to 6 inches in diameter is set in the well. The lower 5 to 20 feet (and occasionally more) of the casing is either perforated or torch-slotted. Unsorted gravel is often used to fill the space between the casing and the wall of the drill hole.

Greater efficiency and production may be gained from these small-capacity wells by increasing the slot length and (or) number of perforations in the casing, using sized gravels for packing, developing the well for longer periods, and completely penetrating the aquifer.

Commercially manufactured well screens, the selection of which is based on the grain size of the sand in the well, are usually preferable, but are more expensive than perforated blank casing. If well screens are not used, the casing should be perforated by many narrow vertical slots. The length of the screened or perforated section should be less than the combined thickness of the water-bearing unit and the pump pit, and should extend upward from the bottom of the hole to a point that is beneath the proposed pumping level.

A gravel pack several inches thick will increase the effective radius of the well. The size of the gravel should range from coarse sand to about ¼-inch diameter, depending on the size of perforations in the well and the aquifer material. The gravel should be large enough so that it will not pass through the casing perforations.

Large-capacity wells in the alluvium are drilled with hydraulic-rotary or reverse-rotary equipment. A small-diameter test hole may be drilled first to determine if sufficient sand and gravel are present to warrant further consideration of the well location. The test hole is reamed out to a diameter of 16 to 36 inches. Metal casing, perforated from the bottom up for a length equal to or less than the saturated thickness, is set in the hole and is followed by gravel packing. The wells are equipped with turbine or submergible pumps. Development includes pumping at different rates, surging, and bailing.

Large-capacity wells drilled in the Clear Fork Group in the eastern part of the county are constructed in various ways. Ideally, a test hole is drilled and carefully logged to determine the lithology, character, and water-yielding characteristics of the units, especially of the limestone and dolomite rocks. If sufficient water-bearing rock is found, the hole is drilled and cased. The type and size of perforations depend on the water-bearing materials. If sand and clay are intermixed with rock, or if fractures are small, well screens or narrow perforations and possibly a gravel pack around the well are necessary. Large cavities or fractures require fewer perforations and no gravel pack.

Fluctuations of Water Levels

Water levels were measured in some wells in the Clear Fork Group in the vicinity of Bronte in 1946 and in a few other wells throughout the county in 1961. The water levels measured in wells during the 1968-69 inventory were higher in general than the water levels measured in the 1946 or 1961 inventories. Of the 21 wells in which water-level measurements were made in 1946 and again in 1968-69, 19 had a higher water level in the later period. Additionally, of eight wells in which water levels were measured in 1961 and again in 1968-69, five of these eight had higher water levels in 1968-69.

A decline in water levels in the Cretaceous rocks has been reported by many land owners in the Edwards Plateau region. During the 1968-69 inventory, few springs were found along the escarpment of the plateau. The decline in spring flow and the reported decline in water levels may be related to less recharge from precipitation in recent years.

CHEMICAL QUALITY OF THE GROUND WATER

The chemical character of ground water reflects the composition of the rock formations through which the water has moved. Factors that influence the types and concentrations of dissolved minerals in ground water include the source of the water, the lithology of the formations through which the water has moved, the temperature of the formations, and the rate of ground-water movement. The main mineral constituents or related properties of water, their source or cause, and their significance are given in Table 3.

Table 6 gives the results of 187 chemical analyses of water samples from 172 wells in the county. The wells sampled are shown on Figure 15 by a line over the well number. Selected chemical analyses of typical oilfield brines are given in Table 7, and the locations of producing fields are shown on Figure 13.

Concentrations of dissolved solids are given in mg/l (milligrams per liter), which may be considered equivalent to ppm (parts per million) when the concentration is less than 7,000 ppm.

Chemical Quality Standards and Suitability for Use

The U.S. Public Health Service (1962, p. 7) has established standards for the chemical quality of water to be used by common carriers engaged in interstate commerce. These standards are useful in evaluating domestic and municipal water supplies. According to the standards, chemical substances should not be present in a water supply in excess of the listed concentrations if more suitable supplies are available or can be made available at reasonable cost. The recommended limits of concentration for some of the constituents are as follows:

SUBSTANCE	CONCENTRATION (MG/L)
Chloride (Cl)	250
Fluoride (F)	.8*
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

* According to the U.S. Public Health Service (1962, p. 41), the optimum fluoride level depends on the climatic conditions because the amount of water ingested is influenced primarily by the air temperature. The optimum value of 0.8 mg/l in Coke County is based on the annual average of daily maximum air temperatures of 79.0°F. at San Angelo.

The significance of these standards is discussed briefly in Table 3. The water should be free of odor and turbidity, and should not contain color to the extent that is objectionable to the user. The water should not be excessively corrosive to the water-supply system.

Livestock usually require water similar to that which would be suitable for human consumption. However, many animals will tolerate water of poorer quality. Animals that have become accustomed to highly mineralized water have been observed to drink water containing up to approximately 10,000 mg/l dissolved solids (Hem, 1959, p. 241).

The chemical quality necessary for the industrial use of water depends on the process or product. Hem (1959, p. 253) and Todd (1959, p. 186-187) summarized water-quality tolerances for a number of industries; a very brief discussion on some aspects of industrial water quality is given in Table 3. In Coke County, the only industrial uses of ground water are for waterflood operations and in the drilling of oil tests. These uses require only that the water should be compatible with the "formation water".

The suitability of water for irrigation depends upon the chemicals in the water and upon the structure, permeability, and aeration of the soil. Some of the more important chemical characteristics that are considered in the evaluation of water for irrigation are: (1) The relative proportion of sodium to other cations, an index of the sodium or alkali hazard; (2) the concentration of soluble salts, an index of the salinity hazard; (3) the amount of residual sodium carbonate; and (4) the concentration of boron.

Wilcox (1955, p. 15-16) suggested that irrigation water is generally safe for supplemental irrigation if its conductivity is less than 2,250 micromhos per centimeter at 25°C and its SAR (sodium adsorption ratio) is less than 14. The RSC (residual sodium carbonate) value is another factor used in judging the suitability of water for irrigation. Wilcox (1955, p. 11) recommends the following limits for the RSC content: More than 2.6 me/l (milliequivalents per liter), not suitable; 1.25 to 2.5 me/l, marginal; and less than 1.25 me/l, safe.

To provide information on the presence and extent of pesticides in ground water, pesticide analyses were made on four samples of ground water. The water was analyzed for nine insecticides (aldrin; DDD; DDE; DDT; dieldrin; endrin; heptachlor; heptachlor epoxide; and lindane) and three herbicides (2,4-D; silvex; and 2,4-5-T). Samples of water were taken from wells DR-29-59-904 and DR-43-04-301, which tap the Artesia Group, DR-43-11-501, which taps the Fredericksburg-Trinity Groups, and DR-43-15-103 which is in the alluvium. The analyses indicated that for all practical purposes no pesticides were present in the water sampled. The sample from well DR-29-59-904 contained 0.01 micrograms per liter of DDT (the permissible limit is 42 micrograms per liter; Federal Water Pollution Control Administration, 1968) and that from well DR-43-15-103 contained 0.07 micrograms per liter of the herbicide 2,4-D, well below the permissible limit.

Quality of the Water

Partial chemical analyses of 118 selected samples are shown diagrammatically on Figure 11. Construction of the patterns is based on methods suggested by Stiff (1951, p. 15). The concentration in me/l of the six major ions present in the water is plotted horizontally on either side of the vertical axis of a graph; cations are plotted on the left side and anions on the right side. These six points are connected by lines to form a closed figure or pattern whose shape is characteristic of a particular type of water.

The specific conductance, expressed in micromhos at 25°C, is a measure of the capacity of water to conduct an electric current, and usually indicates the degree of mineralization. Figure 12 shows the relation of specific conductance to dissolved-solids concentration for selected samples of ground water from Coke County. Variations in the concentration of the individual ions cause differences in conductance for a given dissolved-solids content.

Fifteen wells in the county have been sampled at least twice (Table 6). In general, the change in the water quality has been negligible except in well DR-43-04-107, which yielded water that had a significantly higher chloride content in 1968 than in 1962.

Clear Fork Group

Characteristically, water from the Choza Formation of the Clear Fork Group in Coke County is high in sulfate and dissolved-solids content and is very hard (Table 6, Figure 11). In general, the water is of the calcium magnesium sulfate type.

Of the 18 wells sampled, 12 yielded water containing more than 250 mg/l of sulfate. The dissolved-solids content, as determined by laboratory analyses or estimated from the specific conductance, ranged from less than 500 mg/l to more than 3,000 mg/l. Eight of the sampled wells yielded fresh water (less than 1,000 mg/l dissolved solids), although the sulfate content in the water from two of these wells exceeded 250 mg/l.

Seventy percent of the water samples collected from wells in the Permian units contained more than 1,000 mg/l dissolved solids. The wells that yield fresh water from the Choza Formation are scattered throughout the outcrop area, except for two wells

Table 3.—Source and Significance of Dissolved-Mineral Constituents and Properties of Water

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/l of iron in surface waters generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stains laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. U.S. Public Health Service (1962) drinking-water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. U.S. Public Health Service (1962) drinking-water standards recommend that the sulfate content should not exceed 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. U.S. Public Health Service (1962) drinking-water standards recommend that the chloride content should not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptbility of the individual. (Maier, 1950)
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. U.S. Public Health Service (1962) drinking-water standards suggest a limit of 45 mg/l. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	U.S. Public Health Service (1962) drinking-water standards recommend that waters containing more than 500 mg/l dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1000 mg/l dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness as much as 60 ppm are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

(DR-43-14-801 and DR-43-22-504) which are on the outcrop of the Pease River Group.

Few samples were analyzed for nitrate or flouride. The water from well DR-43-06-807, which is 82 feet deep, contained 134 mg/l of nitrate. The high nitrate content indicates possible pollution from organic waste. Fluoride does not seem to be a problem.

Water from the Choza Formation is used to a limited extent for irrigation. According to standards of the U.S. Salinity Laboratory Staff (1954, p. 80) the water has a slightly high salinity hazard, but otherwise is suitable for irrigation.

Pease River Group

The mineralization of the water in the Pease River Group ranges over wide limits, but in general the water in the area north of the Colorado River is less mineralized than water in the area south of the river. The wide range in the chemical quality of the water collected from wells is shown on Figure 11.

North of the Colorado River, about half of the wells yielded water of the bicarbonate type; most of the others yielded water of the sulfate type. South of the river, sulfate usually was the dominant anion, although some of the water was high in chloride. Farther downdip from the outcrop, the water is brine. Wells DR-29-59-725 and DR-43-04-106, which are 1,763 and 800 feet deep respectively, yielded sodium chloride brine.

In general, at least one constituent in the water from wells in the outcrop area of the Pease River Group exceeds the limits recommended by the U.S. Public Health Service. The dissolved-solids content of samples ranged from about 400 to 92,100 mg/l; about half the samples contained more than 1,000 mg/l dissolved solids. The fluoride content exceeded 0.8 mg/l (the optimum limit recommended by the U.S. Public Health Service) in 12 of the 13 samples in which analyses were made. The content of the 13 samples averaged 1.5 mg/l.

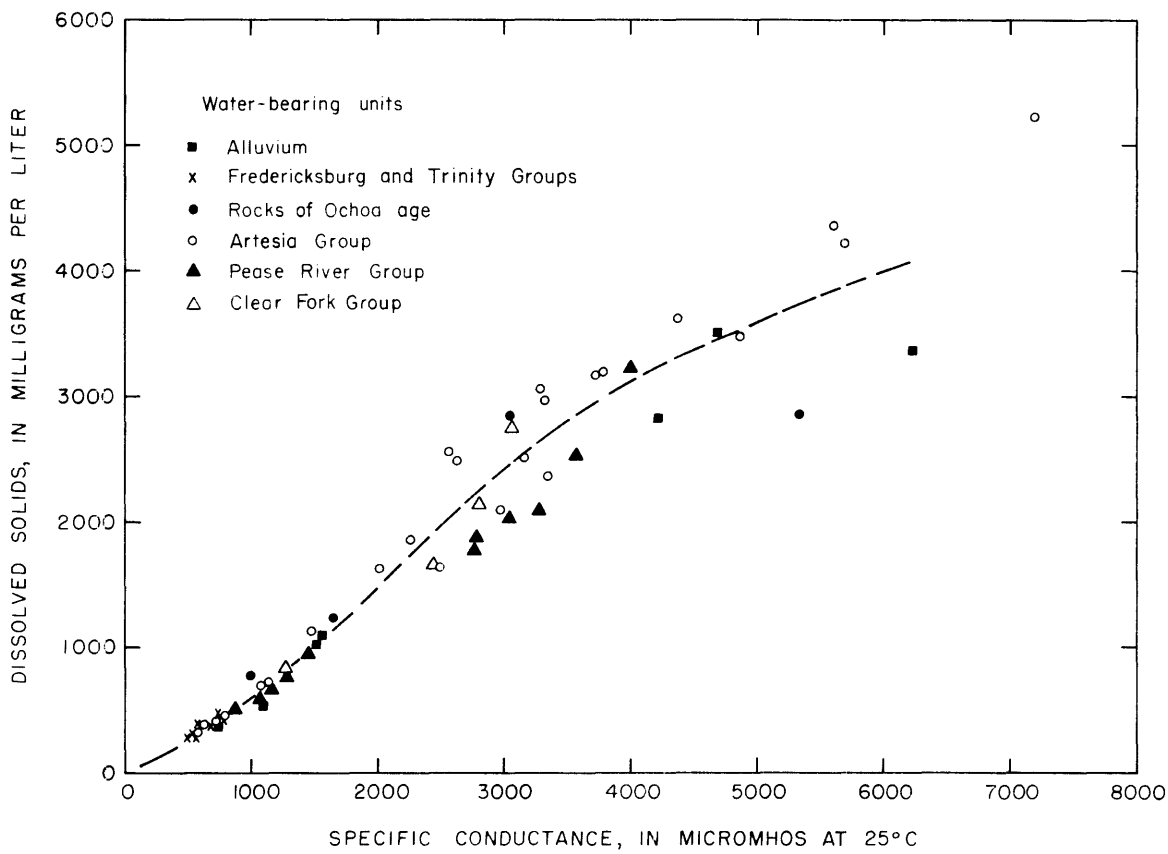


Figure 12.—Relation of Specific Conductance to Dissolved-Solids Content for Selected Samples of Ground Water

Artesia Group

Ground water from the Artesia Group is usually of the calcium sulfate, but occasionally is of the calcium bicarbonate type. When either anion (sulfate or bicarbonate) predominates, the other is usually present only in minor quantities. Where the dissolved-solids content is low, the water is usually of the calcium bicarbonate type; where it is high, the water is usually of the calcium sulfate type. The latter is characteristic of water from the beds of gypsum. Usually, only small quantities of chloride are present.

The dissolved-solids content of water samples from the Artesia Group ranged from 329 to 5,220 mg/l. On the basis of laboratory analyses or specific-conductance measurements, eight of 57 samples contained less than 500 mg/l dissolved solids. The samples contained from 18 to 2,450 mg/l of sulfate and 12 to 2,950 mg/l of chloride. The iron content ranged from 0.07 to 11 mg/l. Nine of the 22 samples tested for fluoride had concentrations greater than 0.8 mg/l. The water is usually very hard; the hardness of all but one sample was greater than 180 mg/l.

Water from the Artesia Group usually is of a slightly better quality than water from the Pease River or Clear Fork Groups; nevertheless, the water generally does not meet the recommended standards of the U.S. Public Health Service. The water is suitable, however, for livestock.

Ochoa Series

Ground water in rocks of the Ochoa Series is generally of the calcium sulfate type. The water usually ranges from slightly to moderately saline. In general, the sulfate content of the water is high; all but one of the nine samples analyzed for sulfate contained more than 250 mg/l. Water from well DR-29-59-511, which is in the vicinity of the Jameson oilfield, is of the calcium chloride type. The water from the Ochoa Series does not meet the chemical standards established by the U.S. Public Health Service for drinking water. Nevertheless, in some places, the aquifer furnishes water for domestic use.

Fredericksburg and Trinity Groups

Ground water from the Fredericksburg and Trinity Groups is characterized by a low dissolved-solids content and is of the calcium magnesium bicarbonate type. The dissolved solids range from 285 to 430 mg/l. The specific conductance of samples range from 488 to 1,030 micromhos. The dissolved-solids content, based on laboratory analyses and specific-conductance measurements, ranged from about 280 to 600 mg/l (Figure 12). Water from the aquifer is very hard; the minimum hardness was 232 mg/l. Fluoride content averages 1.6 mg/l. The Fredericksburg and Trinity Groups will usually yield water that meets the recommended standards of the U.S. Public Health Service. The water also meets the criteria for irrigation use.

Alluvium

The chemical quality of ground water from the alluvium varies greatly. The water from the terraces above the flood plain is usually of better quality than water from the flood plain because most of the water in the terraces is derived from the direct infiltration of precipitation. The water in the flood-plain alluvium is derived not only from precipitation, but also from inflow through the Permian rocks and locally, during the pumping of wells, from the Colorado River.

Determined values of the dissolved-solids content of water samples from the terraces and flood-plain alluvium ranged from 396 to 4,000 mg/l. The specific conductance, however, indicates a much wider range in dissolved solids. The specific conductance of the water from well DR-29-59-710 and spring DR-43-14-102 (Table 6) indicates that the water from the alluvium can be very saline to brine. The chloride content of samples ranged from 8.1 to 29,500 mg/l and exceeded 250 mg/l in 13 of 21 samples. The high chloride content of 29,000 mg/l in spring DR-43-14-102 is further discussed in the section on "Disposal of oilfield brines". The water is very hard.

In general, water from the alluvium does not meet the U.S. Public Health Service standards for the concentrations of dissolved solids, sulfate, and chloride. The water generally is suitable for livestock, except in isolated instances of very high content of dissolved solids. Almost all ground water that is used for industrial purposes in Coke County is pumped from the alluvium. The main use of this water is for waterflood operations, which requires only that the water be compatible with the native water. Water from the alluvium has a high salinity hazard for irrigation.

DISPOSAL OF OILFIELD BRINES

Most of the oilfield brine in Coke County is disposed of by injection wells, and much of the brine is used in waterflood operations by injecting it into the oil-producing strata of the field. Injection is accomplished both by gravity flow and by pumping.

The amount of brine produced, the methods of disposal for the years 1961 and 1967, and the pressures used in the injection wells are given in Table 4. Production and injection data are listed by the designated field name. The data for 1961 were taken from a report by the Texas Water Commission and Texas Water Pollution Control Board (1963). Information for

1967 was tabulated from the questionnaires sent to oil-producing firms by the Texas Railroad Commission. These data should be considered approximate because the study has not been completed.

In 1961, a total of 3,717,583 barrels of brine was produced in Coke County, not including the brine from the Fort Chadbourne Field (Figure 13). Of this total, 263,493 barrels or 7 percent was disposed of in surface pits. The remaining 93 percent was disposed of in injection wells (3,434,250 barrels) or by unknown methods (19,840 barrels).

By 1967, the total brine production had increased to 7,612,810 barrels, of which only 90 barrels was disposed of in surface pits. Disposal of 103,566 barrels or about 1 percent of the total was by unknown methods. The 1967 total production does not include an estimated 3,000,000 barrels produced in the Coke County part of the Fort Chadbourne Field.

The Texas Railroad Commission requires that strata containing usable water be protected by surface casing of new or reconditioned pipe, cemented as directed, or by alternate approved protection methods. The depth to which surface casing must be set as specified by field rules for certain fields is given in Table 4. Some of the older fields do not have rules pertaining to surface-casing requirements.

In Coke County, the depth to the base of usable water differs from place to place. In certain fields, however, fresh to moderately saline water occurs at depths near or beneath the depth which is protected under the field rules of the Railroad Commission.

In the Panther Gap Field, surface casing is required to a depth of only 120 feet, despite the fact that nearby wells obtain water from depths as much as 200 feet. In the Rawling (4100) Field, nearby water wells are deeper than the required 50 feet of surface casing. Similarly, water wells around the Wendkirk (Cisco) Field pump water for domestic and livestock use from depths greater than the 100 feet of protection required by the field rules.

The ratio of chloride to total anion concentration in samples from selected wells and oilfields is shown in Figure 13. The ground waters in the outcrop areas of the aquifers in Coke County are characterized by a low chloride-anion ratio, generally less than 0.25. Ratios in excess of 0.5 may be indicative of contamination of the water by oilfield brines, particularly if the well is shallow.

The ratio of chloride to total anions for water wells DR-29-59-511 and DR-29-59-704, both located in the Jameson Field, indicate possible contamination by oilfield brine. No surface disposal pits are near these wells at present, but such pits were commonly used in the field during past years. Spring DR-43-14-102, in the Wendkirk East Field, discharges water that has a 0.99 chloride-anion ratio, indicating possible contamination from either improperly cased oil wells or from the improper disposal of brine. In general, the available data suggest that contamination from oilfield brine is fairly localized and does not seem to be a major problem in the county.

AVAILABILITY OF GROUND WATER

On the basis of the volume of material saturated with usable water and a specific yield of 15 percent for the alluvial deposits and 10 percent for the Trinity Group, it is estimated that 850,000 acre-feet of water is available to wells in Coke County. Of this amount, 700,000 acre-feet is estimated to be in the Trinity Group.

The development of a substantial part of the water available in the Trinity Group probably is not economically feasible because the low transmissivity of the aquifer would require a large number of low-yield wells. Development of the water in the alluvium also would be limited because part of the water in storage is not suitable for use except for waterflooding.

The quantity of usable water stored in the Permian rocks could not be determined with the available data. Nevertheless, little additional development seems likely because of the very low permeability of the aquifers and the occurrence of water unsuitable for most purposes at fairly shallow depths. A recharge rate of 0.1 inch per year to the Permian rocks would exceed the 1968 pumpage from these units by several times.

The yields that might be expected from wells tapping the various aquifers are shown on Figure 14. The map is based on measured or reported discharges of wells and the extrapolation of these values to areas having similar hydrologic properties. It is assumed that wells would be properly drilled and that the pumping units would be of adequate capacity to pump the estimated quantity of water.

The most favorable areas for obtaining yields greater than 50 gpm are in the alluvium in the southwestern part of the county, in the flood-plain alluvium along the Colorado River, and in parts of the Clear Fork Group near Tennyson in the southeast corner of the county.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

The periodic collection of basic data, such as changes in water levels, quantities of water pumped from the various aquifers for various uses, and the collection of water samples for chemical analyses, are necessary to a detailed evaluation of the ground-water availability of

Table 4.--Oilfield Brine Production and Disposal in 1961 and 1967 and Minimum Surface-Casing Requirements

Symbols: A, average; E, estimated; M, maximum; U, unknown method or amount of disposal.

FIELD	PRODUCING HORIZON 1/	1961* TOTAL BRINE PRODUCTION (BARRELS)	1961* DISPOSED OF BY SURFACE PITS (BARRELS)	1961* DISPOSED OF THROUGH INJECTION WELLS: AMOUNT (BARRELS)	1961* DISPOSED OF THROUGH INJECTION WELLS: INTERVAL OF INJECTION (FEET)	1961* DISPOSED OF THROUGH INJECTION WELLS: PRESSURE OF INJECTION (PSI)	1967+ TOTAL BRINE PRODUCTION (BARRELS)	1967+ DISPOSED OF BY SURFACE PITS (BARRELS)	1967+ DISPOSED OF THROUGH INJECTION WELLS: AMOUNT (BARRELS)	1967+ DISPOSED OF THROUGH INJECTION WELLS: APPROXIMATE INTERVAL OF INJECTION (FEET)	1967+ DISPOSED OF THROUGH INJECTION WELLS: APPROXIMATE PRESSURE OF INJECTION (PSI)	SURFACE CASING REQUIRED BY FIELD RULES (FEET) 2/
Arledge	Strawn Group Pennsylvanian	0	--	--	--	--	0	--	--	--	--	--
Bloodworth, North	Canyon Group Pennsylvanian	--	--	--	--	--	2,150	U	U	--	--	--
Bloodworth, Northeast	do.	--	--	--	--	--	258	--	258	--	--	--
Bloodworth, South (5600)	Strawn Group? Pennsylvanian	730	730	--	--	--	164 E	U	U	--	--	--
Bloodworth, South (5700)	do.	365	365	--	--	--	164 E	U	U	--	--	--
Bloodworth (5700)	do.	0	--	--	--	--	15,844	U	15,330	5,702-5,710	300M	400
Bronte	Palo Pinto Limestone, Pennsylvanian	553,004	--	553,004	4,353-4,416	1,100A, 1,400M	272,501	--	272,501	4,353-4,416	1,175-1,415A 2,000M	250
Bronte (Cambrian)	Cambrian	13,685	--	13,685	do.	1,100A, 1,400M	181,467	--	181,467	4,826-4,875	325A, 480M	250
Bronte (Ellenburger)	Ellenburger Group Ordovician	133,125	--	133,125	2,250-2,340	500	--	--	--	--	--	--
Bronte (Capps)	Capps Lime-stone member Pennsylvanian	645,796	--	645,796	4,353-4,416	1,100A-1,400M	157,150	--	157,150	4,826-4,875	325A, 480M	250
Bronte (Gardner)	Pennsylvanian (Gardner)	--	--	--	--	--	0	--	--	--	--	--
Bronte (4,800)	Pennsylvanian (Goen)	54,500	--	54,500	4,353-4,416	1,100A, 1,400M	24,180	--	24.180	4,826-4,875	325, 480M	250
C. Copeland	Ellenburger Group Ordovician	3,600	3,600	--	--	--	--	--	--	--	--	--
Ft. Chadbourne (Gardner)	Pennsylvanian (Gardner)	4,507	--	4,507	2,208-2,508	200A, 450M	5,056	--	5,056	4,085-4,520	900A, 1,000M	--
Ft. Chadbourne, North	Pennsylvanian (Gray)	--	--	--	--	--	2,651	--	2,651	do.	do.	--
Ft. Chadbourne, Northwest	do.	603	--	603	below 449	50A, 100M	2,434	--	2,434	--	--	--
Ft. Chadbourne, West	do.	26,223	4,015	22,208	692-3,900	Gravity flow to 300	30,714	--	30,714	692-3,902	Gravity flow to 350	--

See footnotes at end of table.

Table 4.--Oilfield Brine Production and Disposal in 1961 and 1967 and Minimum Surface-Casing Requirements--Continued

FIELD	PRODUCING HORIZON 1/	1961* TOTAL BRINE PRODUCTION (BARRELS)	1961* DISPOSED OF BY SURFACE PITS (BARRELS)	1961* DISPOSED OF THROUGH INJECTION WELLS: AMOUNT (BARRELS)	1961* DISPOSED OF THROUGH INJECTION WELLS: INTERVAL OF INJECTION (FEET)	1961* DISPOSED OF THROUGH INJECTION WELLS: PRESSURE OF INJECTION (PSI)	1967+ TOTAL BRINE PRODUCTION (BARRELS)	1967+ DISPOSED OF BY SURFACE PITS (BARRELS)	1967+ DISPOSED OF THROUGH INJECTION WELLS: AMOUNT (BARRELS)	1967+ DISPOSED OF THROUGH INJECTION WELLS: APPROXIMATE INTERVAL OF INJECTION (FEET)	1967+ DISPOSED OF THROUGH INJECTION WELLS: APPROXIMATE PRESSURE OF INJECTION (PSI)	SURFACE CASING REQUIRED BY FIELD RULES (FEET) 2/
Ft. Chadbourne, West (Gardner)	Pennsylvanian (Gardner)	5,335	100	5,235	3,640-3,900	Gravity flow	13,464	--	13,464	3,652-3,902	Gravity flow	--
Ft. Chadbourne 3/ (unit)	Canyon Group Pennsylvanian (Odom)	--	--	--	--	--	--	--	--	--	--	--
Edita (Strawn)	Strawn Group Pennsylvanian	0	--	--	--	--	--	--	--	--	--	--
Edita (Canyon)	Canyon Group Pennsylvanian	0	--	--	--	--	--	--	--	--	--	--
Goen	Pennsylvanian (Goen)	73	--	73	3,610-3,900	Gravity flow	--	--	--	--	--	--
IAB (Menielle Penn)	Strawn, Canyon, Cisco Groups, Pennsylvanian	20,012	20,012	--	--	--	359,395	--	359,395	5,436-6,026	1,680A, 1,850M	250
IAB, Northeast (Strawn)	Strawn Group Pennsylvanian	0	--	--	--	--	124	U	U	--	--	--
IAB, Northeast (5,150)	Strawn Group? Pennsylvanian	0	--	--	--	--	3,665	U	U	--	--	150
IAB, Southwest	Canyon Group Pennsylvanian	34	34	--	--	--	1,729	--	1,729	5,436-6,026	1,680A, 1,850M	--
IAB (5,070)	do.	19,215	19,215	--	--	--	15,137	U	9,706	5,436-6,026	1,680A, 1,850M	--
Jameson (Reef)	Strawn Group Pennsylvanian	1,304,251	36,500	1,267,751	6,500-6,570	1,150 to 1,400	4,282, 374	--	4,282,374	6,342-6,600	2,001A, 2,575M	400
Jameson (Strawn)	do.	136,816	136,816	--	--	--	1,319,667	U	1,244,899	5,800-6,898	450 to 3,000	400
Leppart	Palo Pinto Limestone Pennsylvanian	18,000	18,000	--	--	--	23,360	--	23,360	1,900-3,695	350A, 500M	200
Lygay	Strawn Group? Pennsylvanian	1,100	1,100	--	--	--	--	--	--	--	--	400
McCutchen	Cisco Group Pennsylvanian	64,383	3,298	61,085	2,400-3,999	Gravity flow to 500	48,600	--	48,600	4,000	450A, 600M	400
Millican	Strawn Group Pennsylvanian	3,255	3,255	--	--	--	12,119	U	U	--	--	--
Munn	Canyon Group Pennsylvanian	750	750	--	--	--	90	90	--	--	--	To base of San Angelo
Panther Gap	Canyon Group Pennsylvanian	0	--	--	--	--	--	--	--	--	--	120
Rawlings (Jennings)	(Jennings)	711	--	711	5,031-5,175	400A, 500M	1,038	--	1,038	4,838-4,852	250A, 480M	--

See footnotes at end of table.

Table 4.--Oilfield Brine Production and Disposal in 1961 and 1967 and Minimum Surface-Casing Requirements--Continued

FIELD	PRODUCING HORIZON 1/	1961* TOTAL BRINE PRODUCTION (BARRELS)	1961* DISPOSED OF BY SURFACE PITS (BARRELS)	1961* DISPOSED OF THROUGH INJECTION WELLS: AMOUNT (BARRELS)	1961* INTERVAL OF INJECTION (FEET)	1961* PRESSURE OF INJECTION (PSI)	1967+ TOTAL BRINE PRODUCTION (BARRELS)	1967+ DISPOSED OF BY SURFACE PITS (BARRELS)	1967+ DISPOSED OF THROUGH INJECTION WELLS: AMOUNT (BARRELS)	1967+ APPROXIMATE INTERVAL OF INJECTION (FEET)	1967+ APPROXIMATE PRESSURE OF INJECTION (PSI)	SURFACE CASING REQUIRED BY FIELD RULES (FEET) 2/
Rawlings (4,100)	--	4,380	--	4,380	5,031-5,175	400A, 500M	--	--	--	--	--	50
Rawlings (4,200)	--	1,995	--	1,995	do.	do.	--	--	--	--	--	250
Rawlings (4,500)	--	153,035	--	153,035	2,250-5,175	400-500	--	--	--	--	--	250
Rawlings (5,100)	Pennsylvanian (Goen)	213,159	--	218,159	do.	do.	91,733	--	91,733	4,838-4,852	250A, 480M	--
Rawlings (5,300)	Pennsylvanian (Gardner)	14,992	--	14,992	5,031-5,175	400A, 500M	14,056	--	14,056	do.	do.	250
Rawlings (5,500)	Cambrian	44,696	--	44,696	do.	do.	138,781	--	138,781	do.	do.	250
Weaver Ranch	Strawn Group Pennsylvanian	399	399	--	--	--	--	--	--	--	--	--
Wendkirk (Cisco)	Cisco Group, Pennsylvanian (Swastika)	229,350	U	209,510	2,326-2,346	350,600	329,368	--	329,368	2,280-3,735	260-500	100
Wendkirk, East	Pennsylvanian (Swastika)	25,200	--	25,200	3,690-3,700	400A, 475M	258,910	--	258,910	2,280-3,735	260-500	--
Wendkirk, North	Cisco Group Pennsylvanian	14,400	14,400	--	--	--	--	--	--	--	--	--
Wendkirk, West	Pennsylvanian (Cross-cut)	904	904	--	--	--	4,467	U	U	--	--	--
Totals		3,717,583	263,493	3,434,250	(19,840 bbls. unknown method)		7,612,810	90	7,509,154	(103,566 bbls. unknown method)		

* Data for 1961 from Texas Water Commission and Texas Water Pollution Control Board (1963).

+ Data for 1967 was extracted from individual salt-water production and disposal questionnaires of the Texas Railroad Commission. Values given are subject to modification pending release of the official tabulations and summaries by the Railroad Commission.

1/ Term in parentheses is the locally used name of the producing horizon.

2/ See field rules of the Railroad Commission of Texas. Depth given here is minimum required for that field. Where depth of casing is not given, or in new areas or for first wells in a field, the Surface Casing Section of the Texas Water Development Board should be contacted for a recommended depth.

3/ Production amounts are assigned to Runnels County. It is estimated that 3 million barrels of salt water was produced in the Coke County part of the field in 1967. This amount is not included in the county totals. Disposal of this salt water was by injection wells.

the area. Probably the most serious potential problem is contamination of ground water by oilfield brines. A water-quality monitoring program would evaluate the seriousness and extent of this problem.

DEFINITIONS OF TERMS

Many of the following definitions have been taken or modified from publications by: American Geological Institute (1960), Davis (1966), Ferris (1962), Hem (1959), Langbein and Iseri (1960), Meinzer (1923), and Todd (1959).

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

Anion.—An atom or group of atoms with a negative electric charge.

Aquifer.—A formation, group of formations, or part of a formation that is water bearing and yields significant amounts of water.

Aquifer test.—A test whereby measurements are made at selected intervals of: (1) the discharge of a pumped well; and (2) the water level in the pumping well, in the well when pumping has stopped, or in nearby observation wells. These measurements are mathematically related to give an integrated permeability value for a section of the aquifer.

Artesian aquifer, confined aquifer.—Artesian (confined) water occurs where an aquifer is overlain by rock of lower permeability that confines the water under pressure greater than atmospheric pressure. The water level in a well perforated in the aquifer will rise above the top of the aquifer.

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

Cation.—An atom or group of atoms with a positive electric charge.

Coefficient of transmissibility (transmissivity).—The rate of flow of water in gpd (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, expressed as gpd (gallons per day) per foot. The coefficient of transmissibility in gpd per foot divided by 7.48 gallons per cubic foot equals the transmissivity in square feet per day. The coefficient divided by the aquifer thickness equals the field coefficient of permeability.

Drawdown.—The lowering of the water table or potentiometric surface caused by pumping or artesian flow. In most instances, it is the difference, in feet, between the static level and pumping level in a well.

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

Field capacity.—The quantity of water that can be permanently retained in the soil in opposition to the downward pull of gravity.

Field coefficient of permeability.—The rate of flow of water in gpd through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot and at the prevailing temperature. Expressed as gpd per square foot. The coefficient gpd per square foot divided by 7.48 gallons per cubic foot equals the hydraulic conductivity in feet per day.

Gross lake-surface evaporation.—Total evaporation loss from a unit area of lake surface. Value is usually based on correction of a measured pan evaporation.

Hydraulic gradient.—The slope of the water table or potentiometric surface, usually expressed in feet per mile.

Milligram equivalents per liter (milliequivalents per liter or me/l).—An expression of the concentration of chemical substances in terms of the reacting values of electrically charged particles or ions in solution.

Milligrams per liter (mg/l).—A unit representing 1 milligram of solute in 1 liter of solution. Usually considered equivalent to the unit ppm (parts per million) when the dissolved solids are less than 7,000 ppm. Parts per million multiplied by the solute density equals mg/l.

Perched ground water.—Ground water separated from an underlying body of ground water by a relatively impervious layer underlain by unsaturated material.

Potential evapotranspiration.—Water loss that will occur if at no time there is a deficiency of water in the soil for use of vegetation.

Potentiometric surface (piezometric surface).—An imaginary surface that everywhere coincides with the static level of the water in the aquifer. The surface to which the water from a given aquifer will rise under its full head.

Pumping level.—The water level in a well during pumping, measured in feet below land surface.

Specific capacity.—The rate of yield of a well per unit of drawdown, usually expressed as gpm per ft. (gallons per minute per foot) of drawdown.

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

Static water level.—The water level in an unpumped or nonflowing well measured in feet above or below the land surface or referred to as sea-level datum.

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

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

Water-table.—The upper surface of a zone of saturation. No water table exists where that surface is formed by an impermeable body.

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

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Table 7.--Chemical Analyses of Oilfield Production Brine

(Analyses are given in milligrams per liter except for density and pH)

ANALYSIS	FIELD	PRODUCING HORIZON++	DEPTH OF SAMPLE, FEET	SOURCE OF SAMPLE	ANALYST	DATE OF COLLECTION	SODIUM*	CALCIUM	MAGNESIUM	BICARBONATE	SULFATE	CHLORIDE	TOTAL DISSOLVED SOLIDS+	DENSITY	pH	REMARKS
1	Arledge	Ordovician Ellenburger	6878	--	--	--	31,500	10,500	0	359	1,490	66,200	110,000	1.082	6.3	Analysis from B.J. Service Laboratory Booklet
2	Bloodworth (5700)	Pennsylvanian Strawn Group	5657-5665	Wellhead	Sun Oil Co.	1967	68,600	14,400	2,480	0	115	139,000	224,000	1.151	5.1	Fe-1,330
3	I.A.B. (Menielle Penn)	Pennsylvanian Strawn, Canyon, Cisco Groups	5783-5850	Wellhead	Sun Oil Co.	1959	42,600	17,000	3,190	311	682	104,000	168,000	1.115	6.4	Fe-79
4	I.A.B.	Pennsylvanian Canyon Group	6375-6400	Drill stem test	Humble Oil and Refining Co.	1958	58,800	9,620	1,940	110	847	113,000	184,000	1.11	6.9	Fe-56
5	Jameson (Reef)	Pennsylvanian Strawn Group	6254-6273	Wellhead	Sun Oil Co.	1963	46,700	8,280	1,463	245	928	90,000	148,000	1.101	6.6	
6	Jameson (Strawn)	Pennsylvanian Strawn Group	6062-6084	Separator	Sun Oil Co.	1952	54,500	13,200	1,870	73	202	113,000	183,000	1.123	5.7	Fe-177
7	Do.	do.	do.	Wellhead	do.	1967	63,700	12,700	1,890	154	80	126,000	205,000	1.141	6.1	Same well as No. 6
8	Jameson (Strawn)	Pennsylvanian Strawn Group	6090-6557	Flow line	Humble Oil and Refining Co.	1954	66,100	11,000	1,730	170	28	126,000	205,000	1.126	6.0	
9	Jameson (Strawn)	Pennsylvanian Strawn Group	--	--	B.J. Service Inc.	1961	4,900	1,158	249	309	1,040	9,390	17,000	1.014	7.6	Sample from injection well. May represent quality of water used for secondary recovery.
10	Millican	Pennsylvanian Strawn Group	6255-6270	Drill stem test	Sun Oil Co.	1949	52,100	11,600	1,850	43	604	106,000	172,000	1.121	5.5	
11	Millican	Pennsylvanian Strawn Group	6016-6048	Wellhead	Sun Oil Co.	1968	53,300	12,000	2,500	113	107	110,000	178,000	1.128	5.9	
12	Rawlings (5500)	Cambrian	5541-5543	Wellhead	Humble Oil and Refining Co.	1959	21,600	2,100	572	591	1,830	37,000	63,700	1.043	7.3	
13	Rawlings (5300)	Pennsylvanian (Gardner)	5312-5324	--	Humble Oil and Refining Co.	1959	23,100	2,830	707	593	2,550	40,500	70,300	1.046	7.2	
14	Rawlings (5100)	Pennsylvanian (Goen)	5100	--	B.J. Service Inc.	1961	31,400	1,980	1,170	654	600	54,600	90,500	1.065	7.2	

* Sodium and potassium given as sodium.
\+ Total dissolved solids may be based on summation of the six major constituents and rounded to three significant figures.
++ Term in parentheses is locally used name of formation.