TEXAS
WATER
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BOARD

REPORT 78

GROUND-WATER RESOURCES OF UPTON COUNTY, TEXAS

MAY 1968

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GROUND-WATER RESOURCES OF UPTON COUNTY, TEXAS

By

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GROUND-WATER RESOURCES OF UPTON COUNTY, TEXAS

ABSTRACT

Upton County, 1,312 square miles in area, is in west Texas. The water needs of the county are supplied entirely from ground water, the Trinity Sand being the principal source.

Water used in the county during 1965 was 6,781 acre-feet, of which 2,887 acre-feet, or 42 percent, was supplied by wells in adjacent counties. Of the 3,928 acre-feet of water pumped from wells in Upton County, 3,590 acre-feet, or 91 percent, was from the Trinity Sand. By far the greatest use of ground water pumped from wells in the county is for irrigation.

Recharge to the Trinity Sand of Cretaceous age is small. The amount being transmitted through the aquifer at the present hydraulic gradient, which is roughly equivalent to the annual recharge, is about 1 mgd (million gallons per day), or about 1,100 acre-feet per year, considerably less than was pumped from the aquifer in 1965.

The water from the Trinity Sand is of the calcium magnesium sulfate type; few wells yield water containing less than 1,000 ppm (parts per million) dissolved solids. Rocks older than the Trinity Sand—principally the Santa Rosa Sandstone of Triassic age and San Andres Limestone of Permian age—contain water too highly mineralized for uses other than livestock watering and oil-field waterflooding.

Because of the low rate of recharge, present pumping from the Trinity Sand is, in effect, a mining operation. Additional development of the aquifer is expected, with the water being obtained from the 8 million acre-feet of water estimated to be available to wells in the Trinity Sand. The percentage of this water that can be developed is not known; it will depend on the construction, spacing, and discharge rates of the wells. Because of the low transmissibility of the aquifer, many low-yield and adequately spaced wells will be required for maximum development of the water in storage. Contamination of the water in the Trinity Sand by the disposal of oil-field brines in unlined surface pits also may reduce the amount of water that can be developed for purposes other than waterflooding.

INTRODUCTION

Purpose and Scope of Investigation

The investigation of the ground-water resources of Upton County began in September 1965 as a cooperative project of the U.S. Geological Survey, the Texas Water Development Board, and the Commissioners Court of Upton County. The purpose of the investigation was to determine and evaluate the ground-water resources of the county. The results of the investigation are presented in this report, which includes an analytical discussion of the occurrence and availability of ground water and a tabulation of basic data obtained during the investigation.

The scope of the investigation encompassed the collection, compilation, and analysis of data related to ground water, including: determination of the location and extent of the water-bearing formations, the chemical quality of the water they contain, the quantity of water being withdrawn, and the effects of these withdrawals on the water levels; the hydraulic characteristics of the principal water-bearing formation; and estimates of the quantities of ground water available for development.

Methods of Investigation

The following procedures were used in the investigation.

1. Public supply, irrigation, and industrial wells, and a representative number of domestic and livestock wells (a total of 622 wells) were inventoried. Records of wells are included in Table 5; locations of wells are shown on Figure 19.

2. Electric, radioactivity, and drillers' logs of wells were collected for correlation and evaluation of subsurface characteristics of the water-bearing units.

3. The quantities of water used for public supply and industry were inventoried, and the quantities used for irrigation, domestic supply, and livestock were estimated (Figure 11).

4. The results of 21 pumping tests (Table 2) were used to determine the hydraulic characteristics of the water-bearing sands.

5. Water levels were measured and available records of past fluctuations of water levels were compiled (Figures 13 and 14; Table 5).

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

7. Water samples were collected from wells to determine the chemical quality of water (Table 6 and Figure 15).

8. Chemical analyses of oil-field brines and industrial waste water (Table 7) and reported 1961 oil-field brine production and disposal data were compiled (Table 4).

9. A map was drawn showing the 1965-66 chloride and sulfate concentrations in water from the shallow aquifers and areas and amounts of 1961 reported brine disposal (Figure 16).

10. Maps showing the altitude of the top and base of the Trinity Sand (Figures 6 and 7) and two geologic sections (Figures 20 and 21) were constructed from electric, radioactivity, and drillers' logs.

11. A map showing the altitude of water levels in selected wells tapping the alluvium, Fredericksburg Group, Trinity Sand, Chinle Formation equivalent, and Santa Rosa Sandstone (Figure 8) was constructed from water-level measurements and altitudes of wells. (The altitudes had been obtained from topographic maps and altimeter surveys.)

12. The hydrologic data were analyzed to determine the quantity and quality of ground water available for development. A map showing areas most favorable for future development was drawn (Figure 18).

Location and Extent of Area

Upton County is an area of 1,312 square miles in west Texas (Figure 1). The county is bordered by: Ector and Midland Counties on the north, Reagan County on the east, Crockett County on the south, and Crane County on the west. Rankin, the county seat, is in the southeastern part of the county, about 55 miles south of Midland. Most of the county is sparsely populated ranch land. In 1960, the county had a population of 6,239, of which McCamey had 3,375 and Rankin, 1,214. Midkiff, a small oil and farming center in the northeast corner of the county, had an estimated population of 75.

Previous Investigations

No detailed investigation of the ground-water resources of Upton County had been made prior to this study. A reconnaissance report by Brown and others (1965) provides a generalized evaluation of the ground-water conditions in the Rio Grande basin, which includes the southwestern three-fifths of Upton County. A similar report on a study of the ground-water resources of the Colorado River basin, by Mount and others (1967), includes the northeastern two-fifths of the county.

Rayner (1959) compiled records of water-level measurements in observation wells in Upton County from 1954 through 1957. Currently, water levels in six wells in the county are being measured at annual or bimonthly intervals as part of the Texas Water Development Board's observation well program.

The water supplies of Rankin and McCamey were described by Broadhurst, Sundstrom, and Weaver (1951, p. 157-158) in their inventory of the public water supplies of 81 counties in west Texas.

Reports on ground-water resources of areas adjacent to Upton County are, by county: Crane (Shafer, 1956); Crockett (Iglehart, 1967); and Ector (Knowles, 1952).

The geologic formations in Upton County were described by Sellards and others (1932) and Jones (1953). The latter report contains an extensive bibliography of the numerous papers pertaining to the regional geology.

Economic Development

The economy of Upton County is dependent largely upon the production of oil and gas, but is also supported by income from sheep, cattle, and irrigated farm production. Ground water is basic to the economy of the county. All water for public supply, industry, irrigation, domestic supply, and nearly all water for livestock is pumped from wells.

In 1925, oil was discovered south of King Mountain in the southwestern part of the county. The resulting boom increased the population from 253 in 1920 to 5,968 in 1930. The city of McCamey quickly developed as a base for the oil-field operations. In a few months, a city of ten thousand was housed in tents and hastily constructed frame buildings. A law force of one ranger had difficulty in preserving order. Water hauled to town brought one dollar a barrel (Webb, 1952, p. 101).

A second oil boom that began in the late 1940's substantially revitalized the economy of the county. According to the records of the Railroad Commission of Texas (1966), 128 oil and gas fields (including multiple county fields) have been delineated during the period from 1950 through 1965.

Development of irrigated farming, begun in the Midkiff area during the early 1950's, has also contributed to the economy of the county. Acreage under irrigation increased from 550 in 1958 to 2,810 in 1964 (Gillett and Janca, 1965, p. 281). The principal crops are grain and forage sorghum, oats, barley, wheat, cotton, and pasture grasses.

Topography and Drainage

The principal topographic features in Upton County are (1) a relatively undissected plateau in the northeastern half of the county, (2) a southwest-facing escarpment called Concho Bluff in the northwest part of the county, and (3) seven flat-topped "mountains" in the southern and southwestern parts.

The plateau is underlain by limestone strata, and the surface is covered by a veneer of caliche and silty clay loam. The surface slopes southeasterly at about 8 feet per mile, which is also the approximate direction and rate of dip of the underlying limestones. The altitude ranges from 2,650 feet in the east-central part of the county to about 2,900 feet in the northwest corner.

The surface is characterized by numerous small depressions and a few small eastward-flowing ephemeral streams tributary to the Middle Concho River. Drainage of the surface is primarily interior; very little water reaches the streams. Drainage from the escarpment along the southwestern edge of the plateau is toward the Pecos River to the south and west.

The topography in the southern and southwestern parts of the county is characterized by broad, flat-topped ridges, mesas, and buttes that are underlain by resistant limestone strata. Altitudes range from about 2,300 feet along Fivemile Creek at the southern boundary of the county to 3,125 feet at King Mountain, the highest point in the county. The areas of higher altitudes are separated by wide valleys that are drained by tributaries of the Pecos River. These streams flow only

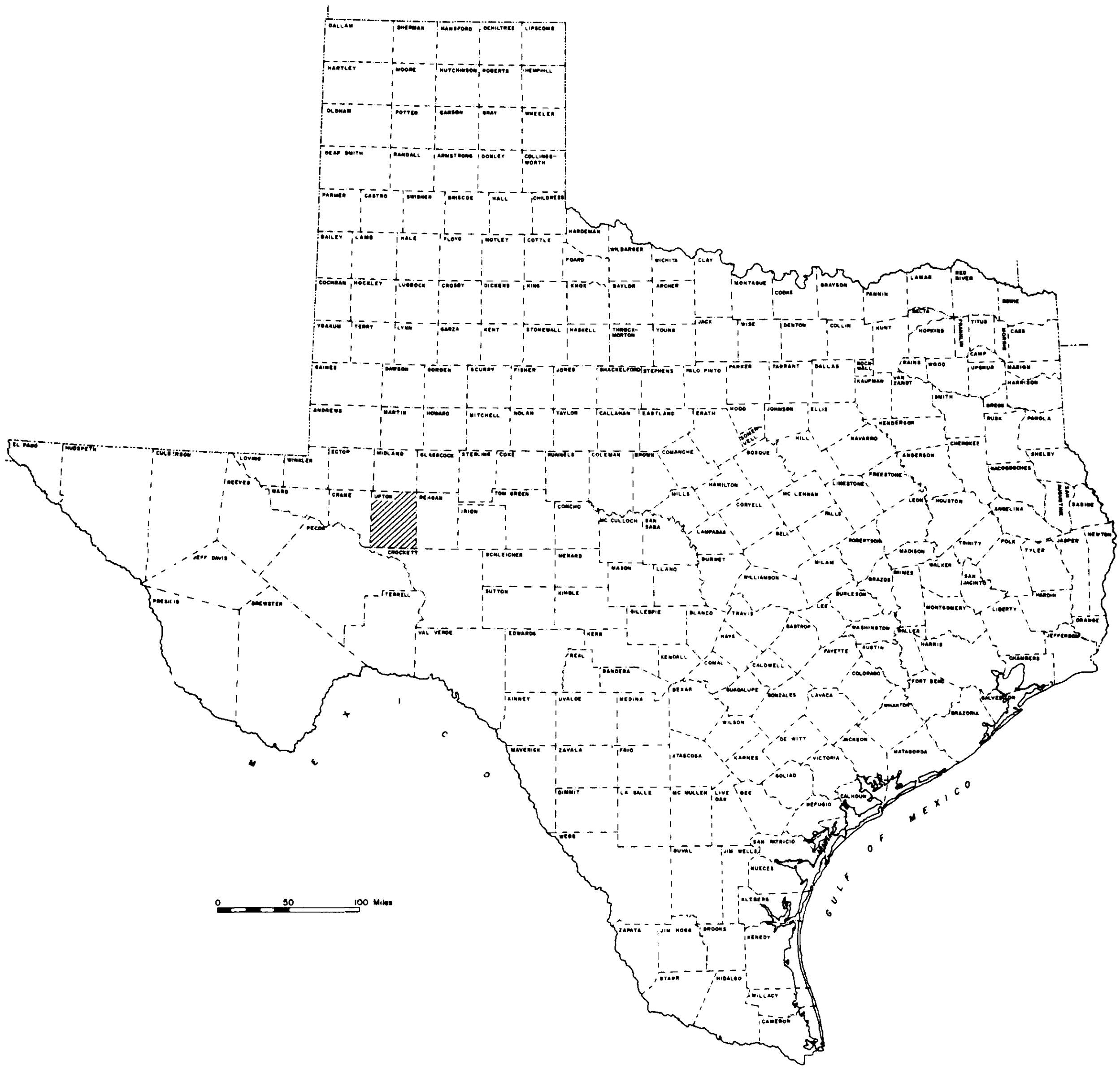

Figure 1

Location of Upton County

U.S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

during periods of heavy rainfall and most of the runoff is absorbed by the alluvial deposits.

Climate

The climate of Upton County is semiarid and is characterized by a wide range in temperature and a high rate of evaporation.

The records of the U.S. Weather Bureau at McCamey, which date from 1933, provide the most complete climatological data for the county. Annual precipitation from 1933 to 1965 (Figure 2) averaged 12.55 inches. The period maximum, 28.98 inches, occurred in 1941; the period minimum, 5.57 inches, occurred in 1953. Normally, about 72 percent of the annual precipitation falls in the 6-month period from May through October (Figure 3). The highest recorded precipitation for 1 month was 8.49 inches in September 1964.

Precipitation has been measured at Rankin since 1948, but available records are incomplete prior to 1963. During the period 1963 through 1965, the annual precipitation averaged 14.78 inches at Rankin and 12.65 inches at McCamey.

The average monthly temperature at McCamey ranges from 46.5°F in January to 84.9°F in July (Figure 3). The yearly average temperature is 66.9°F, and the recorded extremes are 113°F and -2°F. The growing season is about 230 days. The approximate dates for the last and first killing frosts are March 26 and November 12.

The average annual gross lake evaporation for Upton County is about 83 inches (Kane, 1967), or more than six times the average annual precipitation. Evaporation rates are highest during the summer when the soil moisture demand of plants is also large.

Well-Numbering System

The well-numbering system used in this report, based on the divisions of latitude and longitude, is the one adopted by the Texas Water Development Board for use throughout the State (Figure 4). Under this system, each 1-degree quadrangle in the State is given a number consisting of two digits; Upton County includes parts of quadrangles 44 and 45. These are the first two digits appearing in the well number. Each 1-degree quadrangle is divided into 7½-minute quadrangles which are given 2-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7½-minute quadrangle is subdivided into 2½-minute quadrangles given a single digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2½-minute quadrangle is given a 2-digit number in the order in which it was inventoried, starting with 01. These are the last two digits of the well number. In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefixes for Upton and adjacent counties are as follows:

COUNTY	PREFIX	COUNTY	PREFIX
Crane	HH	Midland	TJ
Crockett	HJ	Reagan	UZ
Ector	JH	Upton	YL

Thus, well YL-45-46-601, which is owned by the Jacob Livestock Co., is in Upton County (YL), in the 1-degree quadrangle 45, in the 7½-minute quadrangle 46, in the 2½-minute quadrangle 6, and was the first well (01) inventoried in that 2½-minute quadrangle (Figure 4).

Acknowledgments

The author is indebted to the many ranchers, farmers, and oil-company personnel for supplying information about their wells and permitting access to their properties; to the well drillers for logs and other information on water wells; and to the officials of the cities of Rankin and McCamey for municipal pumpage data. Appreciation is expressed for support given by members of the Upton County Commissioners Court, headed by Judge Allen Moore, and for aid contributed by Dub Day, county agent, and Jim Haralson of the Soil Conservation Service of the U.S. Department of Agriculture, all of whom maintained a strong interest in the progress of the project.

Water-level, pumpage, and completion data for industrial water-supply wells were generously furnished by the Trinity Water Co. and by staffs of the Gulf Oil Corp. at Crane, Texas, Humble Oil and Refining, Mobil, Phillips Petroleum, Shell, and Sohio oil companies at Midland, and El Paso Natural Gas Co. at Jal, New Mexico.

Ed L. Reed, consulting hydrologist, Midland, provided a large amount of the pumping-test data included in Table 2.

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

General Stratigraphy and Structure

The geologic units that yield water suitable for most purposes range in age from Triassic to Recent. The thickness, lithology, and water-bearing properties of these units are discussed in detail in the following section, and are summarized in Table I. The areal extent

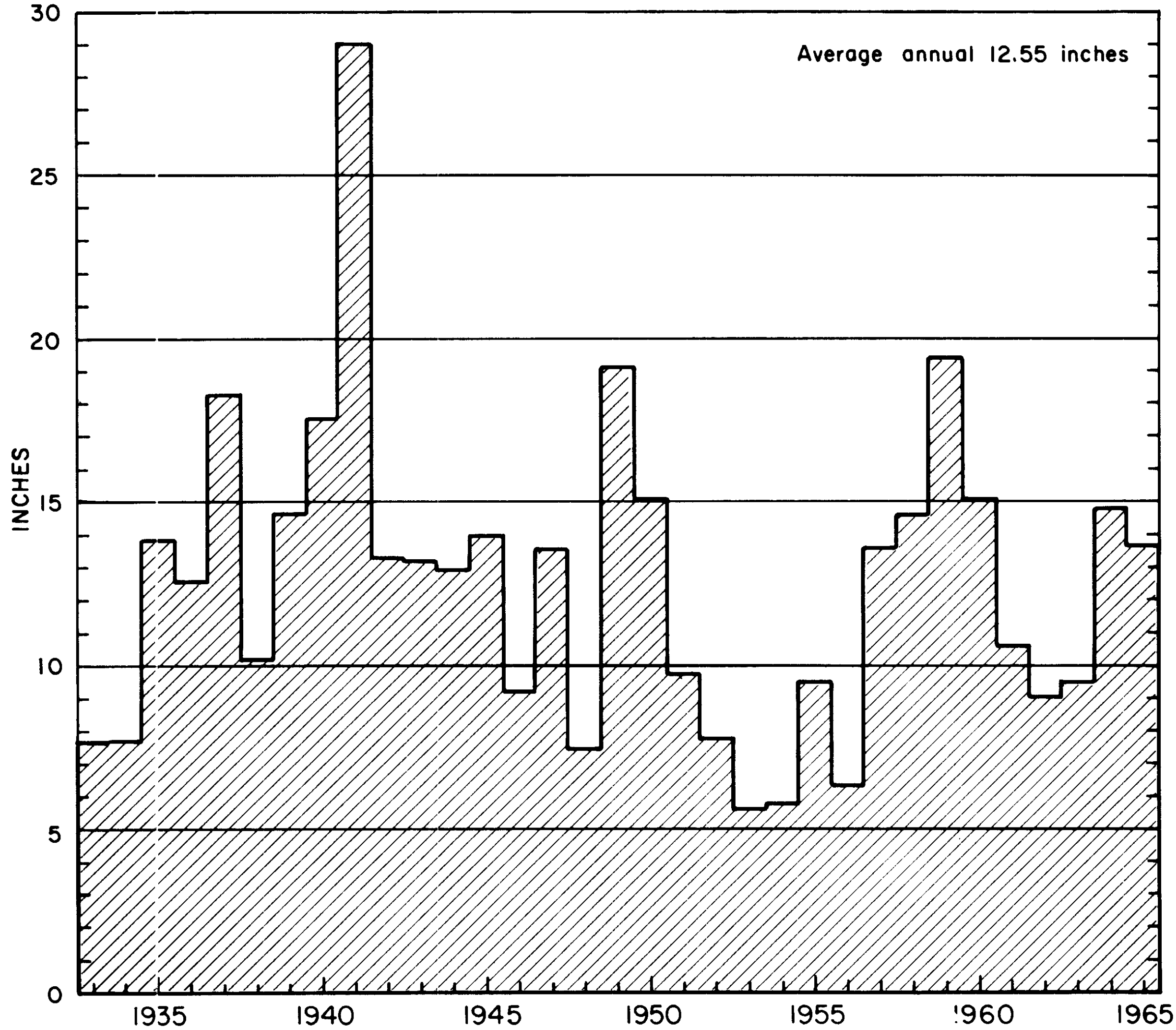

Figure 2

Annual Precipitation at McCamey, 1933-65

U.S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

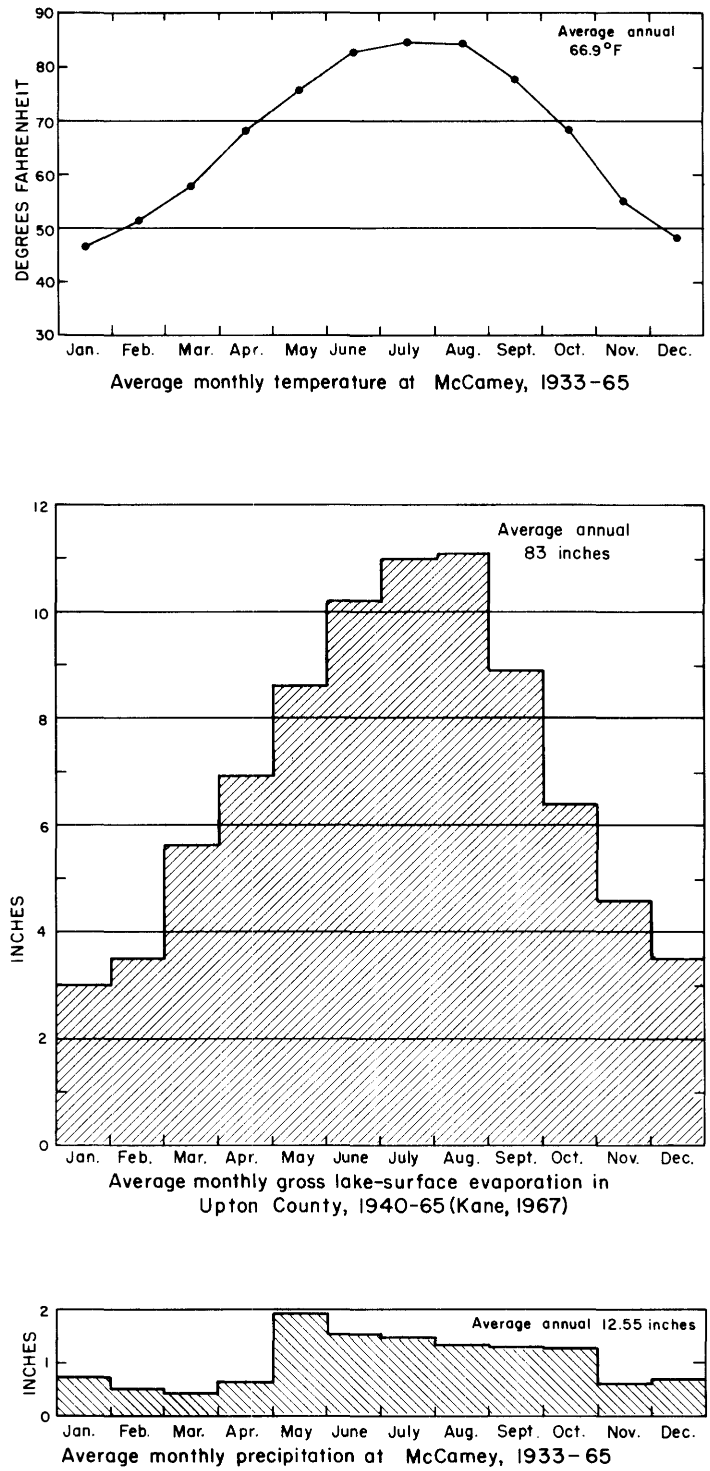

Figure 3

Average Monthly Temperature and Precipitation at Mc Camey and Gross Lake Evaporation in Upton County

U. S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

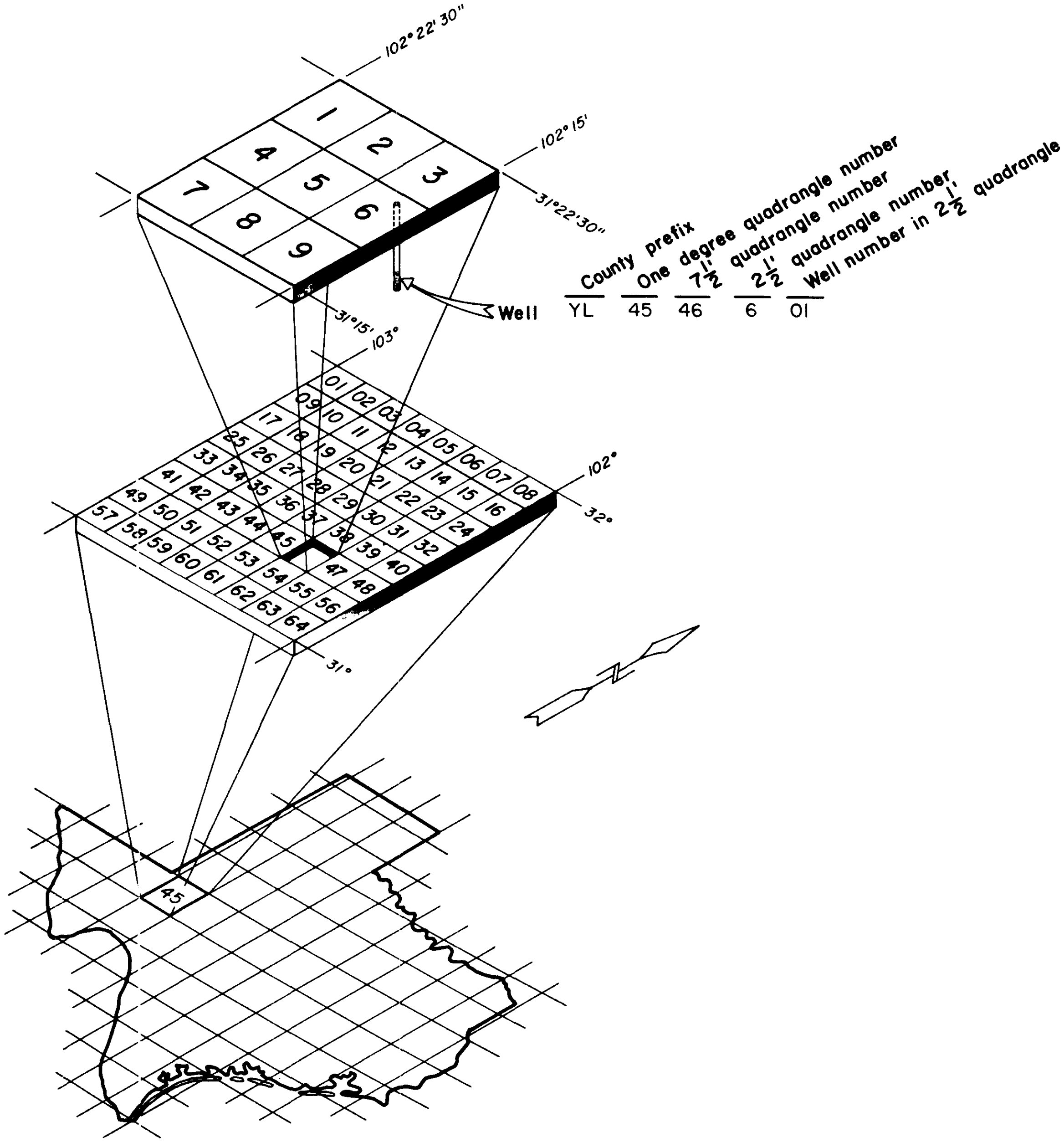

Figure 4

Well-Numbering System

U. S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

Table 1.--Geologic Units and Their Water-Bearing Characteristics, Upton County and Adjacent Areas

ERA	SYSTEM	SERIES	GROUP	STRATIGRAPHIC UNIT	APPROXIMATE MAXIMUM THICKNESS (FT)	CHARACTER OF ROCKS	WATER-BEARING CHARACTERISTICS
Cenozoic	Quaternary	Recent to Pleistocene		Alluvial and eolian deposits	200	Caliche, clay, sand and gravel. Locally mantled with windblown silt and sand.	Yields small quantities of fresh to slightly saline water to livestock and domestic wells along stream courses in the southern and western parts of the county.
Mesozoic	Cretaceous	Comanche	Washita		250	Massive to thin-bedded limestone and calcareous clay and marl.	Not an aquifer in Upton County.
			Fredericksburg	Kiamichi Formation Edwards Limestone Comanche Peak Limestone	270	Calcareous clay, marl, and pale gray to yellowish-brown massive, nodular, fossiliferous limestone. Yellowish-brown argillaceous limestone at base.	All strata are above the water-table except near the southeastern edge of Upton County where the lower beds yield small quantities of fresh water from joints and fractures to a few wells.
			Trinity	Trinity Sand	275	Buff to gray, fine- to medium-grained sand and sandstone interbedded with subordinate amounts of red, gray, and purple shale. Fine gravel at base in some areas.	The principal aquifer in Upton County. Yields small to moderate quantities of fresh to slightly saline water to several hundred wells.
	Triassic		Dockum	Chinle Formation equivalent	570	Brick-red to maroon and purple shale; thin discontinuous beds of red or gray sandstone and siltstone.	Yields small quantities of fresh to moderately saline water to wells in the western and southwestern parts of the county.
				Santa Rosa Sandstone	560	Reddish-brown to gray, medium- to coarse-grained, micaceous, conglomeratic sandstone interbedded with shale.	Yields small quantities of slightly to moderately saline water to shallow wells in the southwestern part of the county. Small to moderate quantities of moderately to very saline water have been pumped from deep wells in the northern part of the county.
				Tecovas Formation	270	Red shale, siltstone, and fine-grained sandstone.	Not known to yield water to wells in Upton County.

(Continued on next page)

Table 1.--Geologic Units and Their Water-Bearing Characteristics, Upton County and Adjacent Areas--Continued

ERA	SYSTEM	SERIES	GROUP	STRATIGRAPHIC UNIT	APPROXIMATE MAXIMUM THICKNESS (FT)	CHARACTER OF ROCKS	WATER-BEARING CHARACTERISTICS
Paleozoic	Permian	Ochoa		Dewey Lake Redbeds	230	Thin-bedded siltstone and gypsum.	Not known to yield water to wells in Upton County. Probably capable of yielding small amounts of moderately saline water in the southwestern part of the county.
				Rustler Formation	150	Anhydrite, dolomite, and limestone interbedded with sand and shale.	Not known to yield water to wells in Upton County. Probably capable of yielding small amounts of moderately saline to very saline water.
				Salado Formation	850	Salt (halite), anhydrite, sylvite and polyhalite.	Not known to yield water to wells in Upton County.
		Guadalupe	Artesia	Tansill Formation Yates Sandstone Seven Rivers Formation Queen Formation	2,050	Dolomite, anhydrite, sandstone, shale, and some salt.	Not known to yield water to wells in Upton County. Probably capable of yielding small amounts of very saline or brine water.
				Grayburg Formation	270	Tan to brown dolomite. Fine- to medium-grained sandstone with subordinate amounts of bentonite and anhydrite.	Yields small quantities of moderate to very saline sulfur water in conjunction with oil.
		Guadalupe and Leonard		San Andres Limestone	1,100	Limestone and gray dolomite with sandstone and interbedded black shale.	Yields moderate quantities of a sulfurous brine to wells for waterflood operation in the northern part of the county.

of these units and the locations of selected wells are shown on Figure 19; the subsurface relationship of these rocks are shown by geologic sections A-A′ and B-B′ (Figures 20 and 21). Rocks of Permian age are significant principally because they are the source rocks for oil and gas, but they furnish most of the saline water presently (1967) being used in the secondary recovery of oil. Although these rocks are not discussed in this report, their physical characteristics and water-bearing properties are summarized in Table 1.

The most prominent geologic structures in Upton County are the Central Basin Platform, a structural high in the southwestern corner of the county, and the Midland Basin, a structural depression underlying the rest of the county. Both of these features are subdivisions of the more extensive Permian Basin (Figure 5). As shown in section A-A′ (Figure 20), the pre-Cretaceous strata are relatively thin and flat-lying on the Central Basin Platform; the strata thicken and dip sharply basinward along the flanks of the platform, and are thickest in the Midland Basin. In contrast, the Cretaceous strata dip gently toward the southeast (section B-B′, Figure 21) and do not appreciably reflect the underlying platform-basin structure.

Physical Characteristics and Water-Bearing Properties of the Geologic Units

In the description of the water-bearing properties of geologic units, the yields of wells are described according to the following rating:

DESCRIPTION	YIELD (GALLONS PER MINUTE)
Small	Less than 50
Moderate	50 to 500
Large	More than 500

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

DESCRIPTION	DISSOLVED-SOLIDS CONTENT (PARTS PER MILLION)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Triassic System

Dockum Group

The Dockum Group is divided into the Tecovas Formation, the Santa Rosa Sandstone, and the Chinle Formation equivalent in ascending order. The upper section of the Dockum Group is exposed in small scattered outcrops in the Pecos River valley west of Upton County. Hoots (1926, p. 96) described 95 feet of the uppermost part of the Dockum at Red Point, 15 miles northwest of McCamey and 2½-miles west of the Crane-Upton County line. At Red Point, Hoots also measured 182 feet of overlying Cretaceous strata and provisionally placed the Triassic-Cretaceous contact at the top of the highest bed of red clay.

The Dockum Group is almost the exact equivalent of the Chinle Formation of the Colorado Plateau region (Reeside and others, 1957, p. 1476). Because of local usage, however, Garza and Wesselman (1959, p. 18) in Winkler County and Armstrong and McMillion (1961, p. 37) in Pecos County included only the upper part of the Dockum Group as the equivalent of the Chinle Formation of the type area. The restricted "Chinle Formation equivalent" terminology used in the above reports is used in this report.

Tecovas Formation

The Tecovas Formation consists of red shale, siltstone, and fine-grained sandstone. The Tecovas unconformably overlies the Dewey Lake Redbeds, the uppermost formation of the Permian System. Lithologically, the two formations are similar and are often lumped together under the general term "Permian-Triassic redbeds." The thickness of the Tecovas ranges from 150 feet to 270 feet in the Midland Basin. On the Central Basin Platform in the southwestern corner of the county, the Tecovas is overlapped by the Santa Rosa Sandstone (Figure 20).

The Tecovas Formation is not known to yield water to wells in Upton County.

Santa Rosa Sandstone

The Santa Rosa Sandstone consists of reddish-brown to gray, medium- to coarse-grained, micaceous, well-cemented conglomeratic sandstone interbedded with shale. On the Central Basin Platform in the southwestern corner of Upton County, the Santa Rosa, about 100 to 160 feet thick, is underlain by the Dewey Lake Redbeds and overlain by the Chinle Formation equivalent in some places, and by Quaternary alluvium in other places. From the flanks of the Central Basin Platform, the formation dips and thickens northeastward. In the Midland Basin, the formation is 360 to 560 feet thick and is underlain by the Tecovas Formation and overlain by the Chinle Formation equivalent. Depths to the top of the formation range from 10 feet in the southwestern corner of the county to 750 feet along the north-central edge of the county.

The Santa Rosa Sandstone yields small quantities of slightly to moderately saline water to shallow wells in the southwestern part of Upton County. Most of the water is pumped for livestock supply, and very little is suitable for human consumption. In northern Upton County, small to moderate quantities of moderately to very saline water have been pumped from 14 deep wells for the secondary recovery of oil. These wells screen a 200-foot section of well cemented sandstone and conglomerate in the lower part of the formation.

Chinle Formation Equivalent

The Chinle Formation equivalent consists of brick-red to maroon and purple shale and lenticular beds of fine-grained red or gray sandstone and siltstone. The formation underlies all of Upton County except the southwest corner where it has been removed by erosion (Figure 20). The formation has a thickness ranging from a few feet in places on the Central Basin Platform to as much as 570 feet in the Midland Basin. The base of the formation is conformable with the underlying Santa Rosa Sandstone; the top, however, has been subjected to erosion and is overlain with angular unconformity by either basal Cretaceous sand or Quaternary alluvium.

In western and southwestern Upton County where the Trinity Sand is absent, the thinly bedded discontinuous beds of sandstone of the Chinle Formation equivalent yield small quantities of fresh to moderately saline water to a few domestic and livestock wells. Elsewhere, the formation has not been tapped because water can be obtained from shallower depths. Furthermore, the relatively impermeable clay and shale beds retard downward percolation of water into the underlying beds of sand, which according to drillers' reports, are frequently dry. Drillers also report that the shales tend to "ball up" on the drilling bits and then cave into uncased wells.

Cretaceous System

Rocks of Cretaceous age crop out in, or underlie at shallow depths, most of Upton County. The youngest Cretaceous rocks belong to the Washita Group and cap the more prominent mesas, buttes, and ridges in the southern part of the county; elsewhere in the county, they have been removed by erosion. Limestones of the underlying Fredericksburg Group cap the lower buttes and benches in the southeastern half of the county and support the plateau surface in the northeastern half. Sandstone at the base of the Cretaceous System, either Fredericksburg or Trinity in age, crops out on the lower slopes of the upland features. The Cretaceous rocks are thickest (about 700 feet) near the summit of Noltke (Noelke) Hill, 6 miles south of Rankin. About 600 feet of Cretaceous rocks were penetrated in well YL-45-55-102 (Figure 19) on King Mountain north of McCamey. At McCamey and in much of the southwestern half of the county, headward erosion by the tributaries of the Pecos River have removed all the Cretaceous rocks and a part of the underlying rocks of the Dockum Group.

Trinity Sand

The term "Trinity Sand," as used in this report, refers to the Maxon Sand and the Basement sands of P. B. King (1930, p. 92-93) and to the basal Cretaceous sandstone of Adkins (1927, p. 31-33). The term has widespread usage in west Texas even though fossil evidence (Adkins, 1927, p. 33) indicates that at least the upper part of the "basal Cretaceous sandstone" is of Fredericksburg age. The lower part of the unit, according to King (1930, p. 93), is probably of Trinity age.

In Upton County, the Trinity Sand crops out in a narrow band at the base of the irregular but generally continuous escarpment that marks the dissected perimeter of the Edwards Plateau. The formation is also exposed near the base of several isolated mesas and buttes in the southwestern part of the county (Figure 19).

The Trinity Sand consists of buff to gray, fine- to medium-grained, crossbedded quartz sand and sandstone interbedded with lesser amounts of red, gray, and purple shale. A fine gravel occurs locally at the base of the formation. In some places the sand is tightly cemented; in other places it is loose or poorly cemented and commonly is referred to as "pack sand" by local drillers.

The Trinity Sand has a maximum thickness of 215 feet in north-central Upton County, but elsewhere in the county the thickness normally ranges between 120 and 180 feet. The variations in thickness are due principally to the irregularly eroded Triassic surface upon which the formation was deposited.

The approximate altitude of the top and base of the Trinity Sand in Upton County is shown on Figures 6 and 7. As shown by Figure 6, the top of the formation dips southeasterly at an average rate of about 10 feet per mile. In most of the northeastern half of the county, the top of the formation ranges from 60 to 150 feet below the land surface; however, in the southern and southwestern parts of the county, where the topography is very irregular, the top is as much as 450 to 500 feet below the summits of the highest mesas and ridges.

The Trinity Sand, the principal aquifer in the county, yields small to moderate quantities of fresh to slightly saline water to several hundred wells for public supply, irrigation, industry, domestic supply, and livestock.

Fredericksburg Group

The Fredericksburg Group is divided into the Comanche Peak Limestone, Edwards Limestone, and Kiamichi Formation in ascending order (Adkins, 1927, p. 37). In Upton County the group has a maximum thickness of about 270 feet and consists of yellowish-brown, massive nodular fossiliferous limestone, calcareous clay, and marl. Eargle (1956, p. 9) measured a full section of the Fredericksburg Group on the south side of King Mountain. On the basis of fossils, he assigned the lower 168 feet of predominately limestone to the Comanche Peak and Edwards Limestone, undifferentiated, and the upper 93 feet of calcareous clay and marl to the Kiamichi Formation.

The Fredericksburg Group lies above the water table except near the east-southeastern edge of the county. Wells that tap the underlying Trinity Sand in that area, particularly those wells that have surface casing only, may draw water from the lower 5 to 25 feet of the Fredericksburg Group. One well, YL-44-42-901, is known to tap a water-bearing zone that is perched above the regional ground-water reservoir in the Trinity Sand.

Washita Group

Rocks of the Washita Group crop out on the upper slopes and cap the summits of seven flat-topped "mountains" in southern and southwestern Upton County; elsewhere in the county, these rocks have been removed by erosion. On the south side of King Mountain, the most prominent of the erosional remnants, the Washita Group consists of, in ascending order, 54 feet of calcareous clay and marl, 22 feet of marl and thin-bedded limestone, and about 120 feet of thick-bedded to massive limestone. The upper part of the resistant limestone is commonly called the "caprock." A well developed system of nearly vertical joints and fractures causes the limestone beds of the caprock to weather to a characteristically blocky outline. The clay and marl beds in the lower part are poorly exposed on the slopes below the caprock.

In Upton County, the Washita Group lies above the water table. During storms, precipitation and surface runoff infiltrate the joints and bedding-plane crevices in the limestone. However, most of this water is discharged through seeps and small springs near the base of the caprock, and only a small part of the water percolates downward through the clay and marl beds in the lower part of the Washita and upper part of the Fredericksburg Groups to the ground-water reservoir in the Trinity Sand.

Quaternary System

Pleistocene and Recent Series

Alluvium and Eolian Deposits

Alluvium of Pleistocene and Recent ages rests unconformably on rocks of Triassic and Cretaceous age in stream valleys in Upton County. The alluvium consists of clay, sand, gravel, and caliche—material that has been eroded largely from Cretaceous rocks. The deposits are poorly sorted and are generally unconsolidated. Locally, however, indurated caliche and caliche-cemented gravels resembling hard Cretaceous limestone occur. The alluvial deposits are thinnest where they wedge out against the outcrops of older rocks on the valley walls. In the upper reaches, the alluvium of creeks and draws is relatively thin and gravelly, but gradually becomes thicker and finer-grained downstream. The alluvium is thickest (about 200 feet) in the valley of Fivemile Creek near the Upton-Crockett County line.

Alluvial deposits yield small quantities of fresh to slightly saline water to livestock and rural domestic wells along stream courses in the southern and western parts of Upton County.

Windblown sand of Recent age mantles alluvial deposits in valleys crossing the Upton-Crane County line. The thicker deposits, called sandhills, cover about 1½-square miles in Upton County, and extend westward into Crane County and northwestward through parts of Ward, Winkler, Ector, and Andrews Counties into New Mexico. In Upton County, the sand has a maximum thickness of about 20 feet in the sandhill area shown on Figure 19. Thin—less than 3 feet—eolian deposits also form sparsely vegetated low hummocks in areas adjoining the sandhills, and soil of eolian origin mantles most of the surface in the northeastern half of the county.

The eolian deposits are above the water table; consequently, they are not sources of water.

Aquifers

A formation, group of formations, or a part of a formation that is capable of yielding usable quantities of water is termed an aquifer. Most of the ground water used in the county for municipal, domestic, livestock, and irrigation supplies, and a part of that for industrial needs is obtained from three aquifers: The Trinity Sand, Santa Rosa Sandstone, and the alluvium. The Chinle

Formation equivalent is of minor importance, yielding small quantities of water to a few wells in the western and southwestern parts of the county. The main function of the Chinle is to retard the movement of water from the overlying Trinity Sand to the underlying Santa Rosa. The deeper aquifers, such as the San Andres Limestone, are important primarily as a source of saline water for the secondary recovery of oil, or as they pertain to the possible contamination of the overlying aquifers.

The principal aquifer in the county is the Trinity Sand. It underlies all the northeastern half of the county but is absent in much of the southwestern half. The Santa Rosa Sandstone has no lateral boundaries in the county although it thins substantially over the Central Basin Platform in the southwestern corner of the county.

GROUND-WATER HYDROLOGY

The general principles of ground-water hydrology as they apply to the study area are discussed in the following report sections. For additional technical information and other hydrologic principles, the reader is referred to: Meinzer (1923a, 1923b), Meinzer and others (1942), Todd (1959), Tolman (1937), and Wisler and Brater (1959); and for nontechnical discussions to: Leopold and Langbein (1960) and Baldwin and McGuinness (1963).

Source and Occurrence of Ground Water

The source of ground water in Upton County is precipitation in the county and in areas mainly to the north and west. Most of the precipitation is evaporated at the surface or is transpired by vegetation. In normal years only a small amount runs off into streams. Water that escapes runoff, evaporation, and transpiration migrates slowly downward by gravity through the zone of aeration until it reaches the zone of saturation. In the zone of saturation, all the voids and pore spaces in the rocks are filled with water. The surface of this zone is called the water table, and the water within it is called ground water.

Ground water in Upton County occurs under two conditions—water table, or unconfined; and artesian, or confined. Under water-table conditions, the water will not rise in wells above the level at which it is found in the formation; under artesian conditions, the water rises to a level above the top of the formation.

The water in the Trinity Sand is generally unconfined. However, in the southeastern corner of the county where the formation is fully saturated and a zone of low permeability occurs near the base of the overlying Fredericksburg Group, wells tapping this aquifer have as much as 25 feet of artesian head. Some of the wells release H_2S gas which has been entrapped in the aquifer by the overlying confining layer.

The Santa Rosa Sandstone is an artesian aquifer in which the water is confined by the less permeable material of the overlying Chinle Formation equivalent. The pressure in the Santa Rosa is sufficient to cause the water in a tightly cased well, for example, well YL-44-18-710, to rise nearly 690 feet above the top of the formation, or 175 feet below the water table in the Trinity Sand. Where the Chinle is absent, as over the Central Basin Platform in the southwest corner of the county, the Santa Rosa and the alluvium are in contact, forming in effect a single unconfined aquifer.

The aquifers older than the Santa Rosa are under artesian pressure. Reportedly, the hydrostatic pressure in the San Andres Limestone was sufficient to cause the water to rise in well TJ-45-23-907 in Midland County (Figure 19) to within 120 feet of the land surface in 1955.

Recharge, Movement, and Discharge

The aquifers underlying Upton County are recharged naturally by infiltration from precipitation in the county or in counties to the north and west and by seepage from streams and lakes. The direct infiltration of rainfall probably is negligible because most of the precipitation is evaporated or transpired by plants. Hence, recharge occurs only when storms provide more than enough water to restore the soil moisture to field capacity.

Recharge to the Trinity Sand is small, considerably less than the quantity of water pumped from the aquifer in 1966. The quantity of water moving through the aquifer is roughly equivalent to the recharge. On the basis of the ability of the aquifer to transmit water (the coefficient of transmissibility) and the present (1966) hydraulic gradient (10 feet per mile), approximately 1 mgd (million gallons per day) or about 1,100 acre-feet per year is moving through the aquifer. The amount of recharge necessary to replace the water moving through the aquifer is equivalent to less than one-fourth inch of precipitation on that part of the county underlain by the Trinity Sand. This value agrees with that reported by Theis (1964, p. 332) for the heavily irrigated southern High Plains north of Upton County. Because of the small outcrop area of the Trinity Sand and the low permeability of the surficial material, a large part of the recharge to the Trinity Sand probably occurs outside the county; only a small amount can be attributed to the infiltration of streamflow.

Recharge to the Trinity Sand and to the alluvium from streamflow occurs principally in the southern and southwestern parts of the county. The rapid rise in water levels in well YL-44-49-301 (Figure 14), following the heavy precipitation in the spring of 1965, is due to recharge from Rankin Creek and its tributaries.

The principal areas of recharge of the Chinle Formation equivalent and Santa Rosa Sandstone are in counties to the north and west. An unknown but probably small amount of water is added to these aquifers in the southwestern part of Upton County where they are locally in hydrologic continuity with the alluvium.

Ground water in Upton County moves slowly, probably 10 to 100 feet per year, through the aquifers from areas of recharge to areas of discharge, gravity being the motivating force. Initially, the movement is downward in the areas of recharge; thereafter, the water moves in the general direction of the dip of the consolidated aquifers, and parallel to the slope of the land surface in the alluvial deposits. Exceptions to the downdip and downslope movement of water are in the areas where large quantities of water are withdrawn from the aquifers. In those areas, water moves from all directions to the centers of heavy pumping.

The general direction of movement of ground water in the county is shown by the altitude of the water levels in wells tapping the Trinity Sand and Quaternary alluvium, and Chinle Formation equivalent and Santa Rosa Sandstone where the latter two formations occur at shallow depths in the southwestern part of the county (Figure 8). The map represents a composite of the water levels of the aquifers tapped; thus, the water level at any particular location may be somewhat different than that shown on the map. The movement of water is in the direction of decreasing altitude and is at right angles to the contours. Accordingly, the ground water moves southeasterly except in the southwestern part of the county where it moves southwesterly to the Pecos River.

Ground water in Upton County is discharged both naturally and artificially. The only apparent natural discharge is from evapotranspiration in those areas in which the water table is near the land surface; no perennial springs or effluent seepage were reported or observed in the county.

Ground water is discharged artificially by wells. (See section on "Use of Ground Water.") In 1965, the discharge from all wells in the county amounted to 3,928 acre-feet (3.5 mgd).

The transfer of water from one aquifer to another is neither discharge nor recharge, but only an incident of ground-water movement. Some water moves from the Trinity Sand into the Quaternary alluvium in the southwestern half of the county as indicated by the contours in Figure 8; an equally small amount of water moves downward from these aquifers into the Chinle Formation equivalent and Santa Rosa Sandstone.

Hydraulic Properties of the Aquifers

Aquifer tests were made on a few wells in Upton County to determine the coefficients of permeability, transmissibility, and storage, which govern the ability of the aquifer to transmit, yield, or store water.

The field coefficient of permeability is the flow of water in gallons per day at the prevailing temperature through a cross section of 1 square foot of the aquifer under unit hydraulic gradient.

The coefficient of transmissibility, a similar measure for the entire thickness of the aquifer, is defined as the rate of flow of water in gallons per day at the prevailing water temperature through a vertical strip of the aquifer 1 foot wide extending the full height of the aquifer under a hydraulic gradient of 1 foot per foot. The volume of water that will flow each day through each foot of the aquifer is the product of the coefficient of transmissibility and the hydraulic gradient. The smaller the coefficient of transmissibility, the greater the hydraulic gradient must be for the water to move through the aquifer at a given rate.

The coefficient of storage is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change of the component head normal to that surface. Under water-table conditions, the coefficient of storage is practically equal to the specific yield. The specific yield is the quantity of water that a formation will yield under the force of gravity, if it is first saturated and then allowed to drain, the ratio being expressed in percentage of the volume of this water to the volume of the material drained.

The results of 21 aquifer tests in Upton County are given in Table 2. Of these tests, 20 were in wells tapping the Trinity Sand and one was in a well tapping the Chinle Formation equivalent. Data for 16 of the aquifer tests in the Midkiff area were provided by Ed L. Reed, consulting hydrologist, Midland, Texas. These data and those from the five aquifer tests that were conducted during the current investigation were analyzed by one or more of the following methods: The Theis non-equilibrium method (Theis, 1935, p. 519-524), the Cooper and Jacob straight-line method of approximation (Cooper and Jacob, 1946, p. 526-534), and the Theis recovery method (Wenzel, 1942, p. 94-97). The field coefficients of permeability shown in Table 2 were determined by dividing the transmissibility coefficients by the estimated thickness of sand supplying the water to the well. The sand thicknesses were obtained from a study of drillers' logs or electrical logs.

The coefficients of transmissibility determined from the wells tapping the Trinity Sand ranged from less than 1,000 to 10,000 gpd (gallons per day) per foot; all but two were less than 3,500 gpd per foot. The tests indicate that generally a transmissibility of less than 1,000 gpd per foot can be expected from the Trinity in

Table 2.--Coefficients of Permeability and Transmissibility Determined from Pumping Tests of Selected Wells in Upton County

WELL	AQUIFER (WATER-BEARING FORMATION)	DATE TEST BEGAN	PRODUCING INTERVALS (FT)	FIELD COEFFICIENT OF PERMEABILITY (GPD PER FT^2)	COEFFICIENT OF TRANSMISSIBILITY (GPD PER FT)	YIELD (GPM)	REMARKS
YL-44-26-104	Trinity Sand	Feb. 15, 1962	120-285	106	10,000	300	Recovery test.[1]
44-26-110	do	July 3, 1963	180-310	57	5,500	240	Do.
44-26-505	do	May 22, 1961	193-293	--	2,000	150	Do.
44-26-506	do	Mar. 30, 1963	193-293	--	2,400	151	Do.
44-26-508	do	May 10, 1963	185-285	--	3,200	108	Do.
44-26-509	do	Mar. 21, 1963	205-305	--	2,900	151	Do.
44-26-510	do	Mar. 13, 1963	180-280	--	3,200	127	Do.
44-26-511	do	Mar. 18, 1963	180-280	--	2,300	104	Do.
44-26-512	do	May 8, 1963	200-300	--	3,000	100	Do.
44-26-513	do	June 29, 1963	212-312	--	3,200	151	Do.
44-26-514	do	Apr. 20, 1963	228-328	--	2,500	100	Do.
44-26-515	do	Mar. 28, 1963	223-323	--	2,200	110	Do.
44-26-516	do	June 21, 1963	228-328	--	3,200	111	Do.
44-26-517	do	--	225-325	--	2,500	100	Do.
44-34-203	do	June 13, 1963	132-315	16	2,700	151	Do.
44-34-204	do	June 10, 1963	--	--	1,100	131	Do.
44-41-907	do	Sept. 13, 1966	80-210	14	1,400	--	Interference test: Well YL-44-41-905 pumping 23 gpm.
44-49-209	do	Nov. 24, 1965	20-170	13	900	36	Recovery test.
45-23-701	do	Dec. 8, 1965	140-148 195-218	32	1,100	53	Do.
45-23-702	do	Dec. do 965	40-210	38	1,500	--	Interference test: Well YL-45-23-701 pumping 52.6 gpm.
45-46-603	Chinle Formation equivalent	Mar. 8, 1966	428-490	8	360	36	Drawdown test.

[1] Pumping test conducted by Ed L. Reed, Consulting Hydrologist, Midland, Texas.

and near its outcrop; 1,000 to 3,000 gpd per foot in most of the northeastern half of the county; and from 3,000 to 6,000 gpd per foot in parts of the northeast corner of the county. The field permeabilities determined from the tests ranged between 13 and 106 gpd per square foot.

A coefficient of transmissibility of 360 gpd per foot and a field permeability of 8 gpd per square foot were obtained from a test made in well YL-45-46-603 which taps the Chinle Formation equivalent. A storage coefficient of 0.0004 was computed from this test.

The specific yield of the Trinity Sand could not be determined from the aquifer tests because of their short duration. On the basis of specific yield or water-table aquifers elsewhere a value of at least 10 percent seems reasonable.

The yields of wells in Upton County also provide a general index of the ability of the aquifers to transmit water. The yields are in the small and moderate range. For purposes of this report, small yields are considered to be less than 50 gpm (gallons per minute), and moderate yields are 50 to 500 gpm. Many of the yields (Table 2) were reported and some were obtained during the development tests when wells commonly are pumped in excess of the sustained yield of the aquifer.

The measured yields of wells in the Trinity Sand ranged from less than 50 to 300 gallons per minute. The yields of nine wells in the Santa Rosa that formerly supplied a waterflood project in the Midkiff area reportedly ranged from 60 to 190 gpm and averaged 115 gpm. Yields ranging from 120 to 165 gpm have been reported from five wells tapping the San Andres Limestone 8 to 10 miles south of Midkiff.

The specific capacity of a well is the ratio of the yield in gallons per minute to the observed drawdown of water level in the well in feet. Specific capacities are useful in estimating the coefficient of transmissibility in areas where aquifer tests are not available. In general, high specific capacities indicate high transmissibilities and low specific capacities indicate low transmissibilities. However, other factors such as the amount of screened, slotted, or perforated intervals and the manner in which the well is developed and maintained also affect the specific capacity. The length of time that a well has been pumped is also a factor. Because of the increase in drawdown with time (Figure 10), the specific capacity of a well decreases with time.

The specific capacities of 33 wells in the Trinity Sand in Upton County ranged from 0.6 gpm/ft in well YL-44-49-209 to 6.6 gpm/ft in well YL-44-26-104 and averaged 1.8 gpm/ft. The specific capacities of 5 wells tapping the other aquifers were less than 0.5 gpm/ft. Well YL-45-46-603 in the Chinle Formation equivalent had a specific capacity of 0.3; 2 wells in the Santa Rosa had specific capacities of 0.3 and 0.1; and 2 wells in the San Andres had 0.2 and 0.1.

The coefficients of transmissibility and storage may be used to predict future drawdowns of water levels caused by pumping. Figure 9 shows the theoretical relation of decline of water levels to distance from the center of pumping for different rates of discharge and transmissibility. The calculations were based on an assumed storage coefficient of 0.1 and a pumping period of 100 days. The 500 to 10,000 gpd per foot range in transmissibility is representative of the Trinity Sand in Upton County. Transmissibilities being as indicated, the rates of discharge that were used to compute the drawdown curves are representative of rates that can be sustained in wells for 100 days or longer.

Figure 10 illustrates the theoretical relation of declines to distance from the center of pumping and time. It indicates that water levels are lowered by continued pumping, but that the rate of decline decreases with time. For example, with a well pumping 60 gpm, the decline in an observation well 10 feet from the pumped well would be 30 feet after 100 days and about 38 feet after 3 years. The total decline at any one place within the cone of depression or influence of several wells would be the sum of the influences of the several wells.

Use of Ground Water

Since the early 1950's, the demand for water in Upton County has increased markedly, the quantity used generally far exceeding that supplied by wells in the county (Figure 11). Because of the low annual rainfall and the lack of surface-water supplies, all the water needs of the county are supplied from aquifers not only in Upton County, but also from Reagan, Crane, Midland, Ward, Winkler, and Pecos Counties.

In 1965, water use amounted to 2,210 million gallons (6,781 acre-feet), of which 941 million gallons (2,887 acre-feet) or about 42 percent was supplied by wells outside the county. Of the 1,280 million gallons (3,928 acre-feet) of water pumped from wells in Upton County, 91 percent or 1,170 million gallons (3,590 acre-feet) was from the Trinity Sand. About two-thirds of the ground water pumped in the county in 1965 was used for irrigation. All irrigation was from wells in the Trinity Sand.

Public Supply

In 1965, Rankin and McCamey pumped 286 million gallons (878 acre-feet), about 13 percent of all the ground water used in the county. However, only the water needs of Rankin are supplied from the ground-water sources in the county.

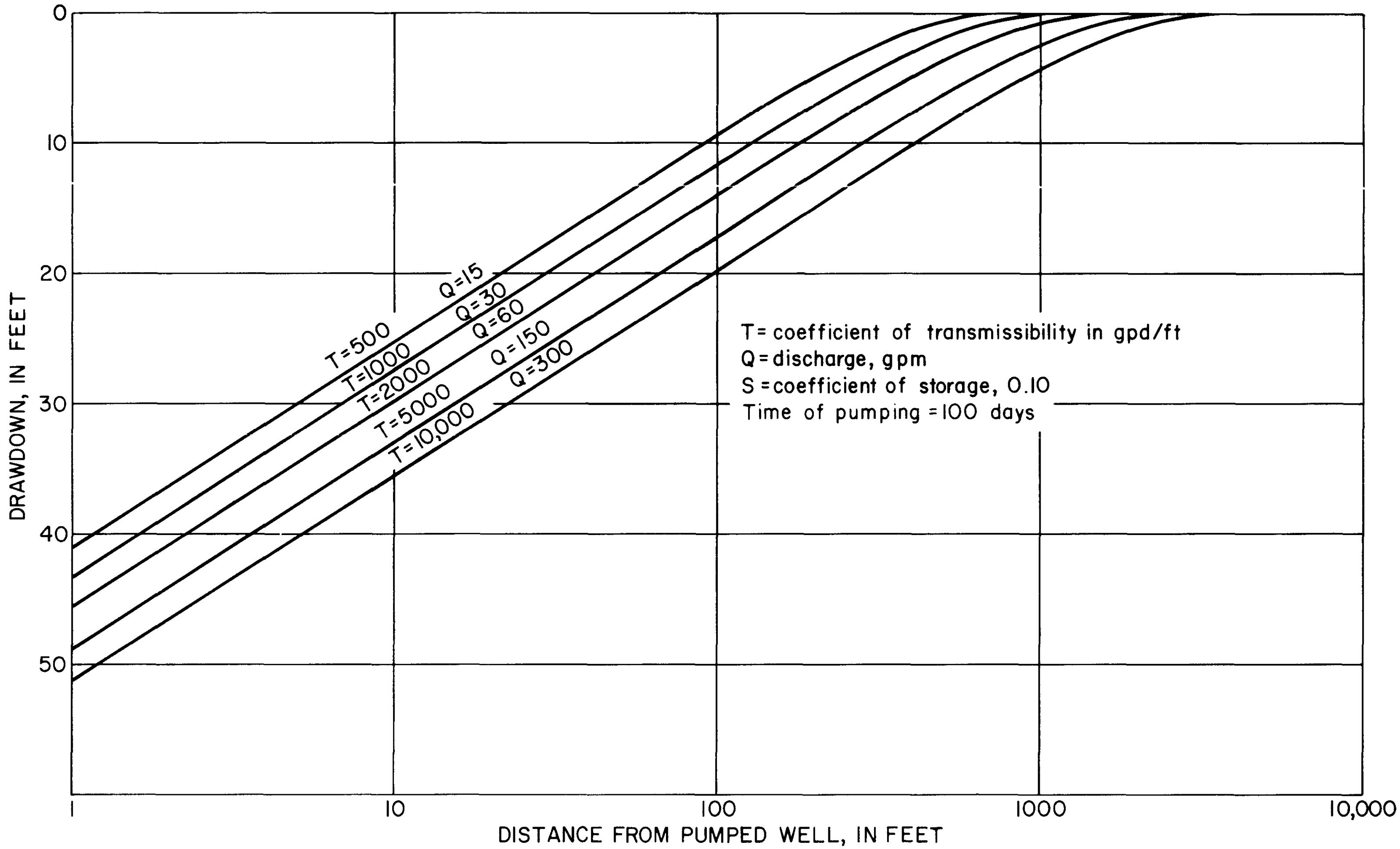

Figure 9

Relation of Drawdown to Distance From Center of Pumping With Different Discharges and Coefficients of Transmissibility

U. S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

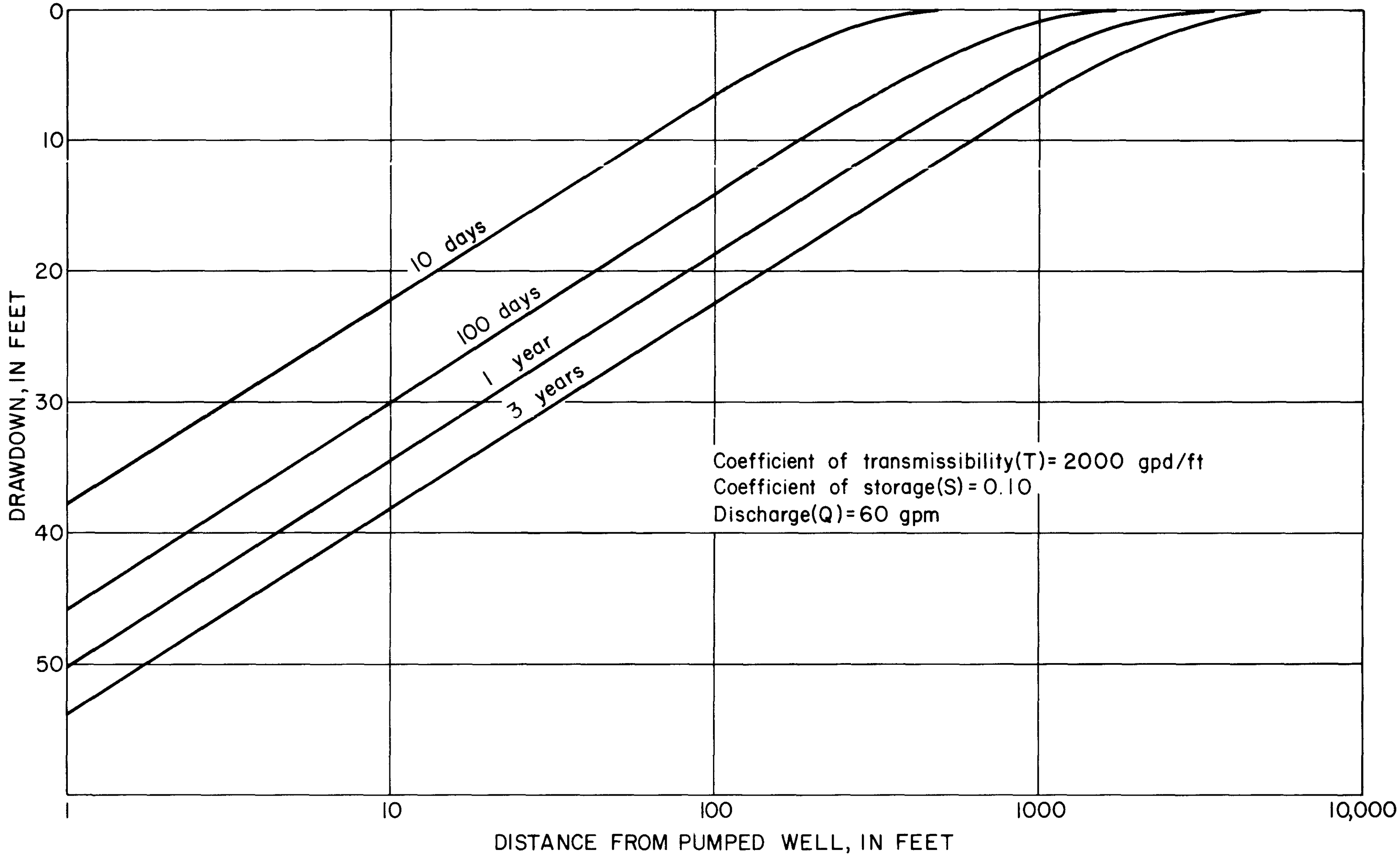

Figure 10

Relation of Drawdown to Distance From Center of Pumping and Time in an Aquifer Having the Characteristics of the Trinity Sand

U. S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

City of Rankin

Windmill wells supplied the water needs of the residents of Rankin until 1939 when the city installed a municipal water system. At that time, the system consisted of one well having a capacity of about 70 gpm. The city added one well in 1948, when pumping averaged nearly 100,000 gpd, and a third well was added in 1951, when pumpage increased to about 135,000 gpd. In 1965, Rankin was supplied by 10 wells owned by the county in a well field 2½-miles northeast of the city and by three wells in the municipal system. Pumping in 1965 amounted to 94 million gallons, or slightly more than 225,000 gpd. The wells, ranging in depth from 160 to 242 feet and having a maximum total capacity of 560 gpm (43 gpm per well average), are screened in the Trinity Sand.

City of McCamey

The municipal water system at McCamey consists of five wells 15 miles southwest of the city in Pecos County. The city's water supply has been previously described by Armstrong and McMillion (1961, v. I, p. 69, 197) who wrote:

> "The Texas Public Service Company operated the first municipal water system of the city of McCamey, Upton County, using wells in Pecos County. In 1928 the system was supplied by three wells (V-12, V-13, and V-14) tapping the 'Trinity Sand.' After the city assumed control of the system, one well (V-12) was abandoned and three new wells (V-9, V-10, and V-11) were drilled, making a total of five 'Trinity Sand' wells in use. The yield per well is reported to range from 280 to 350 gpm and to average about 300 gpm."

In 1965, municipal pumpage was slightly less than 192 million gallons, or about 526,000 gpd; an additional but small amount of water was pumped from the 10 or 15 domestic wells in and near the city, but this water was used primarily for lawn irrigation.

Industrial Supply

Industry in Upton County pumped about 242 million gallons (743 acre-feet) of ground water from wells in the county in 1965. Of this amount 141 million gallons, or nearly 60 percent, was for waterflood operations and 86 million gallons (35 percent) was for gasoline plants and compressor stations.

Waterflooding

Waterflooding, a method used in the secondary recovery of oil, involves the injection of water to the oil-bearing strata. In some wells, the water is injected by gravity flow; in others, it is injected under pressure exerted at the well head. (A maximum surface pressure of one-half pound per square inch per foot of well depth has been recommended by the Railroad Commission of Texas.) Once injected, the water raises the pressure in the oil reservoir and displaces the oil, forcing it to flow toward the producing wells.

Water used for waterflooding consists generally of "production" and "extraneous" water mixed in varying proportions. Production water is that which has been separated from the oil-water mixture pumped from the oil wells. Normally, production water is too saline for purposes other than waterflooding; if not injected for secondary recovery, it is disposed of as waste water. Extraneous water is derived from other sources such as water wells and surface-water diversions. Extraneous water may be fresh (although use of fresh water is discouraged), or it may be brine, and may require treatment to be compatible with the fluids and gases in the oil reservoir.

The first waterflood units in Upton County, the Pegasus (Ellenburger) and Pegasus (Pennsylvanian) began operations in 1955. Three units were injecting water by the end of 1961; another was started in 1962; seven were operating from 1963 through 1965; and three more have been proposed. None of the units has been abandoned, but injection in several has been sharply curtailed.

Since 1955, about 3,000 million gallons (71 million barrels or 9,152 acre-feet) of extraneous water has been used for waterflood operations in Upton County. Of this amount, 1,100 million gallons or nearly one-third was from wells in Upton County; the rest was from wells in Glasscock, Midland, Reagan, Ward, and Winkler Counties. The quantity, quality, and source of ground water pumped and used for waterflood operations during the period 1955-65 are shown in Figure 12.

The graph shows that during the period 1955-62, nearly all the water pumped in Upton County for waterflood operations was from the Santa Rosa Sandstone with only a small percentage from the San Andres Limestone. In the period 1963-65, about 514 million gallons or slightly more than one-fourth of all extraneous water used in the county was pumped from wells tapping the Trinity Sand.

The volume of water used for waterflooding reached a maximum in 1963 when 742 million gallons was used, of which 342 million gallons or about 46 percent was from 17 wells in Upton County. Use of water for this purpose showed a downward trend, and by 1965, when 596 million gallons was used for waterflooding, only 141 million gallons or about 24 percent was from wells in Upton County. Of the 141 million gallons, 43 million gallons or about 33 percent was from 12 wells in the Trinity Sand; the rest was from 5 wells in the San Andres Limestone.

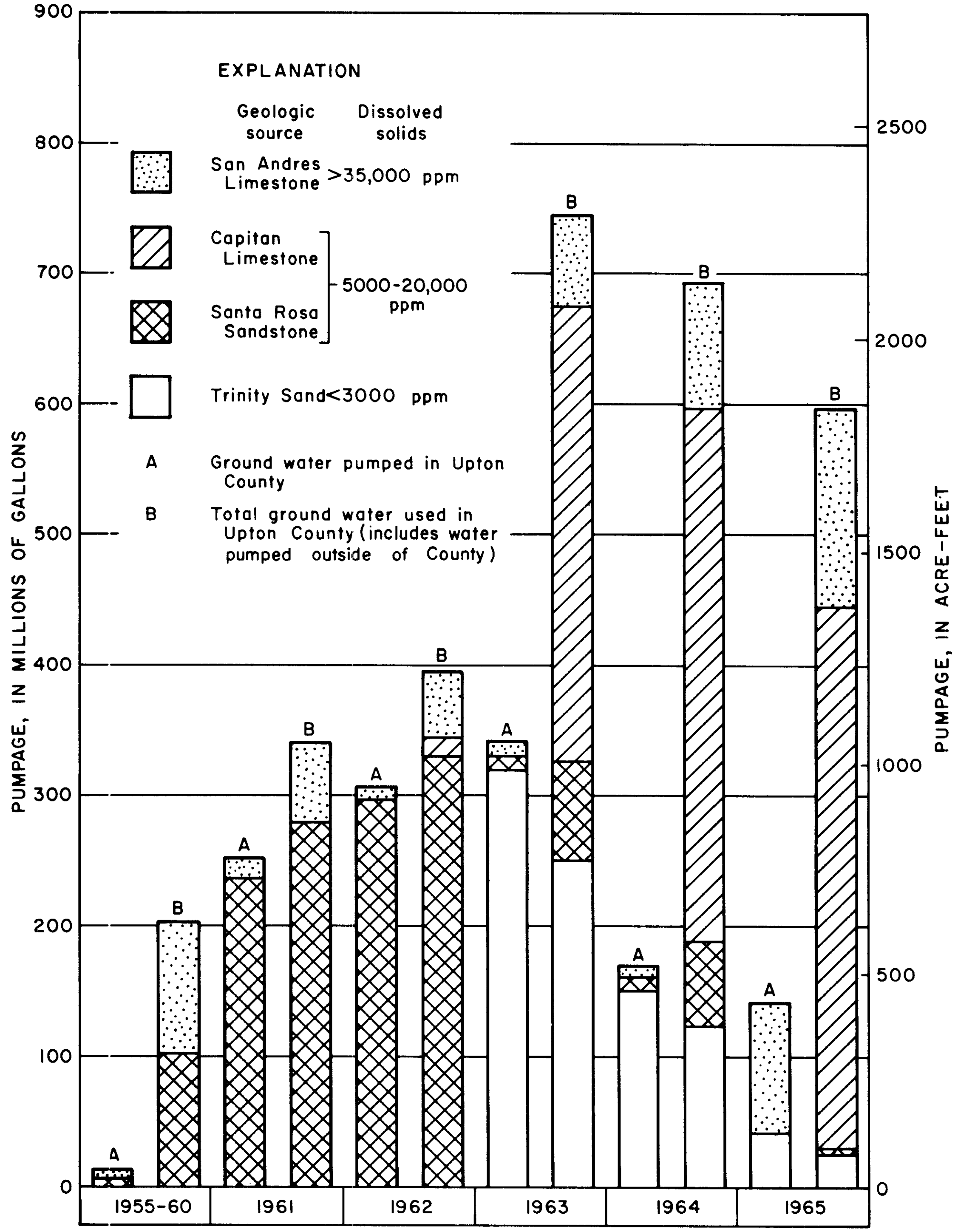

Figure 12

Quantity, Quality, and Source of Ground Water Pumped for Waterflooding, 1955-65

U.S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

Gasoline Plants and Compressor Stations

In 1965, about 248 million gallons (761 acre-feet) of ground water was used in the operation of gasoline plants and compressor stations in Upton County. Of this amount, 115 million gallons (about 46 percent) was from 17 wells in the county. Yields of the wells, all completed in the Trinity Sand, ranged from 20 to 96 gpm and averaged 46 gpm.

Of the five gasoline plants in the county, four used a total of 218 million gallons, 85.5 million gallons of which was from 11 wells in the county. The water needs of the Crossett plant, 4 miles west of McCamey, was supplied from McCamey's water system.

The four compressor stations in Upton County reportedly used 29.7 million gallons (91.1 acre-feet) of ground water from six wells in the county in 1965.

Other Industrial Uses

Other industrial uses of ground water include supplies for: (1) drilling oil and gas wells, (2) washing down equipment at gas recycling plants, (3) sealing wooden tanks used to store crude oil, and (4) lease water in oil fields. In 1965, approximately 16 million gallons (55 acre-feet) of ground water was used for these purposes, of which 85 percent or 13.6 million gallons was from the Trinity Sand.

Irrigation

Irrigation of crop land in Upton County began in 1956. During the next 8 years, the practice slowly developed and by 1960, 13 wells were in operation. Irrigation accelerated during the 1960's and by 1965, 39 wells were used to irrigate 2,440 acres in the county. All the wells were in the northeast quarter of the county, principally in the Midkiff area. An additional four wells in Reagan County and one well in Midland were used to irrigate land in Upton County.

The irrigation wells, all tapping the Trinity Sand, range in depth from 230 to 395 feet; the yields range from less than 100 gpm to a maximum of 350 gpm, most of the yields ranging between 100 and 150 gpm.

Water for irrigation is applied by sprinkler systems or in furrows. Pre-planting irrigation, in which as much as 9 inches of water per acre is applied during the winter and early spring months, is a common practice. In 1965 an estimated 3,000 acre-feet of ground water was pumped for irrigation. This is about two-thirds of the total quantity of ground water pumped in Upton County for all purposes.

Domestic and Livestock

Pumping of ground water for domestic and livestock use is relatively small, amounting to only 84 million gallons or 230,000 gpd in 1965. About 80 to 90 percent of this amount was from the Trinity Sand; the rest was obtained from the Triassic rocks and alluvium in the southwestern part of the county where the Trinity Sand is absent. Most of the domestic and livestock wells are equipped with windmills, the yields of which generally are less than 5 gpm; a few livestock and domestic wells are equipped with small submergible pumps.

Fluctuations of Water Levels

The fluctuations of water levels in wells depend upon various factors, the most important of which are the discharges from wells and the natural recharge.

Long-term records of annual changes in water levels in Upton County are available in only two wells, YL-44-33-503 and YL-44-33-504. The hydrographs of these unused wells (Figure 13) show that during the period 1954-65, the water levels declined 2.4 and 2.1 feet. The declines reflect pumping of ground water in an area where development of irrigation has been on a small scale—only six wells were used in 1965. The low (211 feet) water level in well YL-44-33-503 in December 1960 probably reflects pumping in this well and in a nearby well. The decline in well YL-44-33-501, currently in use, was somewhat greater; since 1959, the level declined slightly less than 10 feet. The larger decline in well YL-44-33-501 probably can be attributed to the fact that the well not only is being used for irrigation but is closer to the center of pumping than are the other two wells.

In the east-central part of the county, along the Upton-Reagan County line, water levels have declined as much as 25 feet since 1949, when pumping for gasoline plants began in this area.

In the Midkiff area, the principal area of irrigation, the water levels have declined as much as 30 feet since 1937, of which nearly 23 feet occurred since 1952, when irrigation began.

The hydrograph (Figure 14) of well YL-44-49-301, in the Upton County well field near Rankin, shows changes in water levels related to nearly continuous pumping for municipal supply and to recharge from infiltration of storm runoff in Rankin Creek. From late 1953 to mid-1964, water levels in well YL-44-49-301 declined a maximum of about 34 feet. Water levels rose several feet folowing the heavy precipitation in September 1964 and as much as 39 feet after the 6.8 inches of rain in May 1965. However, the water levels again resumed their downward trend and by September 1966, the water level had declined a net 18 feet since 1953.

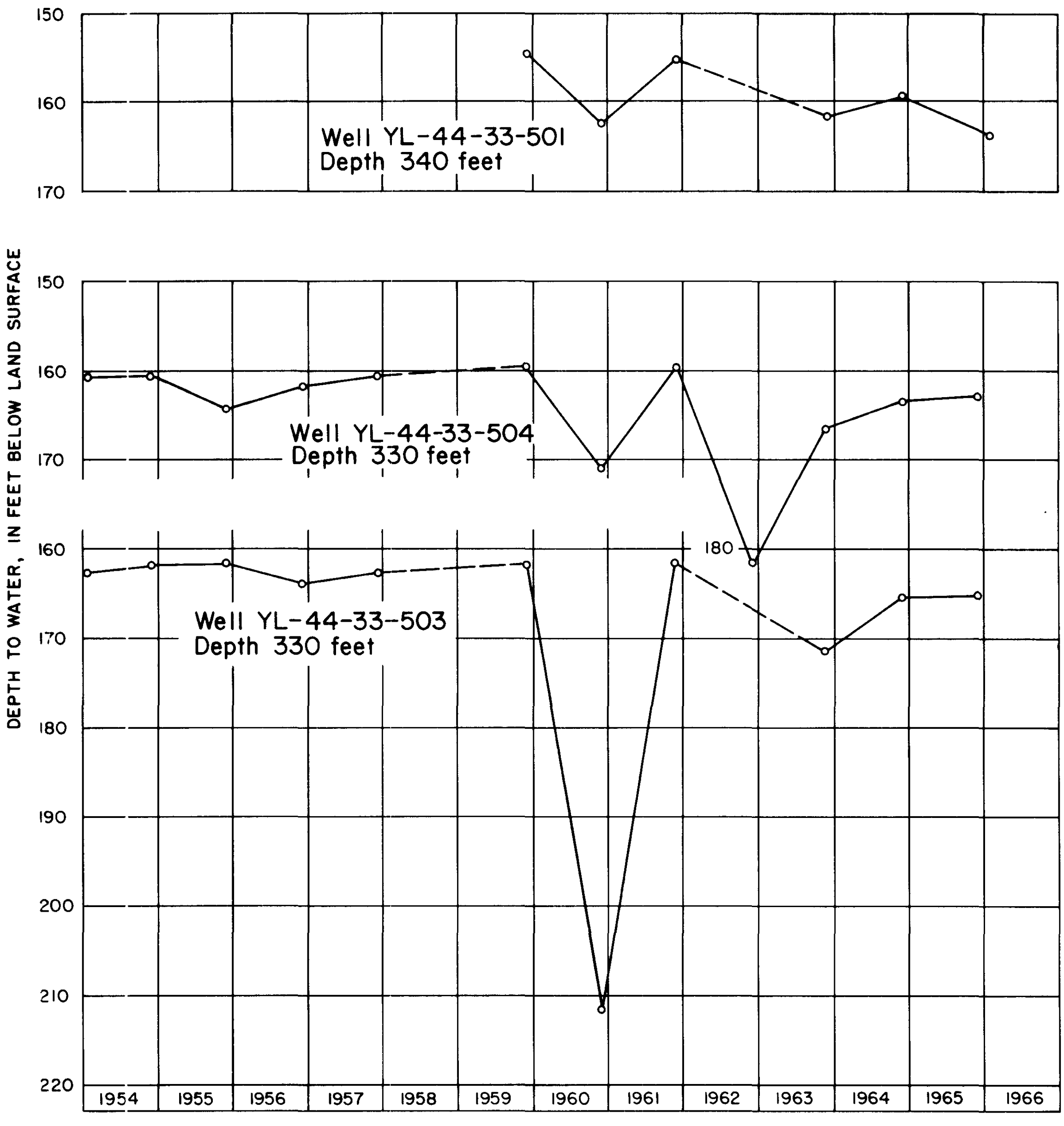

Figure 13

Hydrographs of Three Wells in the Trinity Sand

U.S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

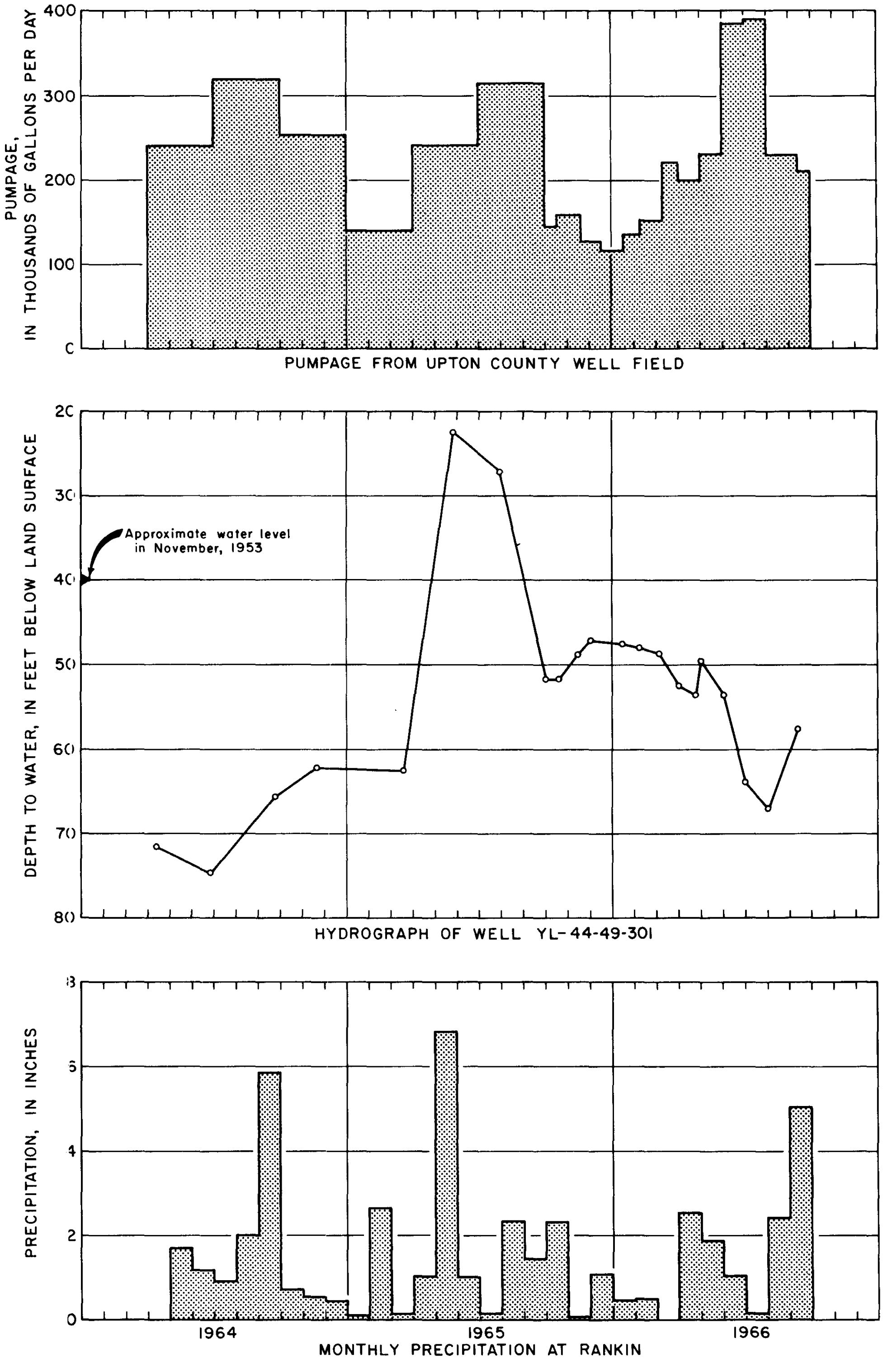

Figure 14

Hydrograph of Well YL-44-49-301, Pumpage From Wells in the Upton County Well Field, and Precipitation at Rankin, May 1964—September 1966

U. S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

The rather large declines experienced in several parts of the county are in accord with the generally low permeability of the Trinity Sand and the low specific capacities of the wells tapping the Trinity. Records of water-level fluctuations in wells tapping the deeper formations, principally the Santa Rosa Sandstone, are two meager for comparative purposes.

Well Construction

Of the 622 wells inventoried in Upton County, only one was dug; the rest were drilled.

Most of the domestic and livestock wells that have been recently drilled in the county have small diameter casing, 5 to 6 inches, and are cased to the bottom of the well. The casings are either torch-slotted or perforated opposite the water-bearing sand. In the older wells, it was common practice to set only a joint of surface casing—10 or 20 feet long—through the surficial deposits, and the rest of the well was completed without casing; this practice resulted in the loss of some wells due to caving.

Municipal, industrial, and irrigation wells are larger in diameter—8 to 20 inches—and are usually completed with large-diameter surface casing which is cemented to the wall of the well. Smaller-sized casing is set from the surface to the bottom of the producing sand. Slotted or perforated casing is set opposite the sand and the space between the perforated casing and the wall of the well is filled with small-size gravel, pea-sized gravel being the most commonly used. The gravel increases the effective diameter of the well and protects the casing from caving of the sand.

Most wells of the type described above are developed by pumping. However, those tapping the San Andres Limestone commonly are acidized to increase the permeability of the limestone. Some wells tapping the Santa Rosa have been sand fractured to create fissures, thereby increasing the yield. The use of explosives to increase the yield of the Trinity Sand has been reported.

CHEMICAL QUALITY OF GROUND WATER

Precipitation, in the form of rain or snow, contains only small amounts of mineral matter. Once the water reaches the land surface, however, it dissolves mineral substances from the soil and rocks over and through which it moves. Thus, all ground water naturally contains dissolved minerals, the degree of mineralization determining its suitability for municipal, irrigation, and industrial uses. Contamination or pollution by various means may change the character of a water. Organic materials are common polluting agents. However, pollution may result from mixing with highly mineralized water; such may be the case in some areas where highly mineralized water produced with oil is placed in earthern pits.

During the investigation in Upton County, 178 samples of water from wells and earthen pits were collected and, except where noted, the samples were analyzed by the Texas State Department of Health. The locations of all the wells sampled are shown in Figure 19. The results of the analyses are shown in Table 6 included with analyses of water obtained during previous investigations. The concentrations of the chemical constituents in the water (Table 6) are expressed in ppm (parts per million) which is the unit weight of a substance in a million unit weights of water. However, it is frequently more convenient for interpretive purposes to compare water in terms of equivalents per million, which is a measure of the reactive weights of the different constituents. The concentration of an ion in equivalents per million is determined by multiplying its concentration in parts per million by the reciprocal of the combining weight of the appropriate ions. The chemical character of samples of water from the aquifers underlying Upton County is illustrated in Figure 15 in terms of the percentage equivalents per million (reacting values) of the anions and cations in solution. The three principal cations—calcium, magnesium, and sodium (includes potassium) are shown in the left half of the circle, being separated from the three principal anions—bicarbonate, sulfate, and chloride (includes nitrate and fluoride) by a vertical line. To make the illustration more easily understood, that part of the diagram showing the magnesium and sulfate was made solid. The source and significance of the dissolved-mineral constituents and properties of water in Upton County summarized in Table 3 was adapted from Doll and others (1963, Table 7).

Most state and municipal authorities have adopted the standards set by the U.S. Public Health Service (1962, p. 7-8) for drinking water used on common carriers in interstate commerce. The standards are designed to protect the traveling public and are useful in evaluating public-water supplies, although they may not be directly applicable in an area such as Upton County where much of the water may exceed the standards for some constituents. According to the standards, in a public water supply the chemical constituents should not be present in excess of the concentrations shown below except where more suitable supplies are not available.

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

(From Doll and Others, 1963, Table 7)

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 ppm. High concentrations, as much as 100 ppm, 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 ppm of iron in surface waters generally indicate 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 ppm stain 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 ppm. 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 ppm.
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 ppm.
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 ppm. 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 ppm dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1000 ppm 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; 61-120 ppm, moderately hard; 121-180 ppm, hard; more than 180 ppm, 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.

SUBSTANCE	CONCENTRATION (PPM)
Chloride (Cl)	250
Fluoride (F)	1.0*
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

*Based on the average of maximum daily air temperature of 77°F at Midland, Texas, for the period 1931-60.

Chemical requirements for industrial uses of water vary according to the industry, but they are fairly rigid where water is used in food, paper, or some chemical-process industries. The most common industrial uses of water in Upton County are for cooling, boiler feed, and waterflooding of oil reservoirs. Excessive concentrations of dissolved solids are a problem in water used for cooling because they tend to accelerate corrosion (California State Water Pollution Control Board, 1963, p. 182). The use of water for boiler feed is dependent on very strict limits relative to the dissolved-solids content and silica because of the formation of scale in the boilers. High-pressure systems, operating at a pressure of more than 400 psi (pounds per square inch), require a dissolved-solids content of 50 ppm or less and a silica content of not more than 1 ppm; low-pressure systems, less than 150 psi, can use water having as much as 3,000 ppm dissolved solids and 40 ppm silica (Moore, 1940, p. 263).

According to the U.S. Salinity Laboratory Staff (1954, p. 69-82), some of the principal factors that determine the quality of water for irrigation are the concentrations of dissolved solids, sodium, and boron. The relative importance of the dissolved constituents in irrigation water is dependent upon the degree to which they accumulate in the soil. Sodium is a significant factor in evaluating irrigation water because a high SAR (sodium-adsorption ratio) may cause the soil structure to break down. The RSC (residual sodium carbonate) is another factor used in assessing the quality of water for irrigation. According to Wilcox (1955, p. 11) water containing more than 2.5 epm (equivalents per million) RSC is not suitable for irrigation, 1.25 to 2.5 epm is marginal, and less than 1.25 epm probably is safe. Residual sodium carbonate values are not shown in Table 6 because all samples contained 0 epm.

Of the water samples analyzed, 143 were from the Trinity Sand, 29 from the Santa Rosa Sandstone and Chinle Formation equivalent of Triassic age, 12 from the alluvium, and 1 from the Fredericksburg Group of rocks. Some of the samples collected represent a mixture of water from more than one aquifer. No analyses were made of water from the Permian rocks, except for samples of water produced with oil (Table 7). All available data indicate that the water in the Permian rocks is highly mineralized and would be unsuitable for use except in waterflood operations.

Although parts of Upton County now yield ground water that has been contaminated, presumably by the disposal of oil-field brines, it is desirable first to summarize the chemical character of the ground water in the various formations where it has not been contaminated. This affords a basis for comparison of the native waters, those whose chemical character is natural to a particular water-bearing zone and locality.

Trinity Sand

Characteristically, water from the Trinity Sand, the principal aquifer in the county, is high in sulfate, dissolved-solids, and fluoride content and is very hard. In general, the water is of the calcium magnesium sulfate type, in which calcium and magnesium, expressed in chemical equivalents, are first and second in order of abundance among the cations but neither amounts to 50 percent of all the cations. Sulfate is the predominant anion, generally exceeding 50 percent of the total anions. Of the 143 water samples from wells known to be screened in the Trinity Sand, only 8 contained less than 250 ppm of sulfate, and two-thirds of the samples contained more than 500 ppm.

The dissolved-solids content, which influences or limits the general use of ground water, ranged over wide limits (283 to 8,420 ppm), although the higher concentration is probably the result of contamination. Nearly three-fourths of the samples exceeded 1,000 ppm. The wells that yield fresh (less than 1,000 ppm dissolved solids) water are not confined to any one part of the county but are widely scattered throughout the aquifers (Figure 15). In general, however, much of the fresh water is from wells along Concho Bluff and the north edge of the county where the Trinity Sand underlies the surface at fairly shallow depths and conditions are more favorable for recharge (Figures 15 to 18).

Fluoride is a problem in the water from the Trinity Sand in Upton County. Most of the samples contained more than 1.0 ppm fluoride; the average was about 2.7 ppm.

The hardness of water is most commonly recognized by its effect upon soap consumption. Calcium and magnesium—primarily as salts of sulfate—cause nearly all the hardness in the water from the Trinity Sand. Of the samples tested, none contained less than 180 ppm hardness, which is the lower limit of water classified as very hard.

The water from the Trinity Sand does not meet the chemical standards established by the U.S. Public Health Service for drinking water used on common carriers engaged in interstate commerce. Nevertheless, this aquifer furnishes the municipal water for Rankin and most of the water for domestic use, the water from the other aquifers being either more mineralized or in quantities too small for use.

The water from the Trinity Sand is used extensively for industrial purposes. However, the water is usually treated to reduce the hardness. Nearly all the compressor and gasoline plants use zeolite exchange columns for this purpose. The columns are recharged periodically by flushing with sodium chloride brine. The silica content of the water from the Trinity generally is not a problem except when used in boilers. The present trend is toward closed cooling systems in which the water is chemically treated to prevent corrosion and formation of scale. In the closed systems, the water is recycled which results in a considerable reduction in water consumption and pumping costs.

Water from the Trinity Sand has been used for irrigation successfully for several years. The chemical quality data show that the sodium-adsorption ratio (SAR) is fairly low, generally less than 5. According to the U.S. Salinity Laboratory Staff (1954, p. 80), the uncontaminated water in the Trinity Sand is classed as high to very high in salinity hazard (based on the specific conductance in micromhos per centimeter at 25°C) and is low to medium in sodium hazard. Generally, water having high to very high salinity hazard should be used on well drained soils, and the crops should be very salt tolerant. The calcareous character of the soils in Upton County tends to reduce the effect of the sodium hazard.

Santa Rosa Sandstone

Samples of water were collected for chemical analysis from 14 wells, of which 12 are known to be screened in the Santa Rosa Sandstone and 2 presumably tap the aquifer (Table 6 and Figure 15). Most of the wells are in the southwest corner of the county where the depth to the top of Santa Rosa is less than 25 feet in many places.

In general, the water in the Santa Rosa is more highly mineralized than that in the Trinity Sand, the dissolved-solids content of the water ranging from 1,260 ppm in well YL-45-54-902 (160 feet deep) to 15,000 ppm in well YL-44-26-103 (1,100 feet deep). The least mineralized water is from wells in the southwestern part of the county. In this area, the Santa Rosa yields water containing as much as 4,800 ppm dissolved solids, 2,100 ppm sulfate, and 1,230 ppm chloride. In most of the wells, the sulfate content greatly exceeds the chloride content. Wells screened in the Santa Rosa in the northern and northeastern parts of the county are more than 600 feet deep and yield moderately to very saline water, in which the chloride content is considerably in excess of the sulfate.

The high sulfate, hardness, and dissolved-solids content preclude the use of water from the Santa Rosa for public or domestic supplies. At present (1966) the principal use of the water is for livestock watering, although until recently some of the water was used for waterflooding. Because of the low specific capacities and concomitant high pumping lifts, however, use of the Santa Rosa as a source of water for waterflooding was discontinued.

Other Aquifers

Few water samples were obtained from wells tapping the other aquifers, the San Andres Limestone, Chinle Formation equivalent, Fredericksburg Group, and alluvial deposits.

One water sample was collected from a well tapping the San Andres Limestone. The well, YL-45-23-902, drilled as an oil test and later converted to a water well, yielded brine that had a low pH (5.3) and a high hydrogen sulfide (335 ppm) content. Use of the well was discontinued in 1964.

Samples of water were obtained from four wells in the Chinle Formation equivalent (Table 6). The water from three of the wells was high in sulfate and fluoride, and was slightly saline; water from the fourth well was also high in sulfate and fluoride but contained only 790 ppm dissolved solids.

Only one well (YL-44-42-901) in the county is known to be supplied from the Fredericksburg Group. The water from this well was fresh—less than 1,000 ppm dissolved solids—, low in sulfate (166 ppm) and chloride (112 ppm), but very hard (378 ppm). Except for the excessive fluoride content (2.6 ppm), the water is suitable for drinking. Water in this well is perched above the main aquifer—the Trinity Sand—and during extended periods of drought, the well reportedly goes dry.

The chemical quality of the water from the alluvium is similar to that from the Trinity Sand, with which it is in hydraulic continuity. Water from six wells in the alluvium was slightly saline, high in sulfate and fluoride, and very hard. Although the wells tapping the alluvium are shallow, 36 to 118 feet deep, the nitrate content—commonly high in shallow wells—was less than 44 ppm (the recommended limit) except in one well (YL-45-39-401) which contained 157 ppm of nitrate. The nitrate in this well was probably derived from organic wastes from a nearby stock yard. Because of the high sulfate content, the water in the alluvium is not suitable for drinking purposes, but it is used for livestock watering.

In summary, the Trinity Sand yields water that commonly exceeds the limits for drinking water suggested by the U.S. Public Health Service in at least several constituents—the dissolved-solids, sulfate, and fluoride content. However, because water of better quality is not readily available, the Trinity Sand is the principal source of water for public and domestic supplies.

GROUND-WATER PROBLEMS

Contamination from Disposal of Oil-Field Brines

The public and domestic water supplies of Upton County are dependent entirely on the ground-water resources of the county and adjacent areas. The present practice of disposing of oil-field brine through unlined earthen pits is a potential hazard to the chemical quality of the ground-water supplies in the county.

Brine placed in unlined surface pits either evaporates or seeps into the ground, eventually percolating downward to the water table in a manner similar to that of precipitation on the land surface. Although the average yearly potential evaporation rate from a free-water surface in Upton County is slightly less than 7 feet, it cannot be depended upon to dispose of the large quantities of brine continuously being produced. Actually, the evaporation rate of the brine is considerably less than that of fresh water because of the presence of an oil film on the brine in most of the pits. Furthermore, the evaporation disposes of the water but leaves the salt in the pits as a potential contaminant.

The records of the Texas Water Commission and Texas Water Pollution Control Board (1963, p. 233) show that 18¼-million barrels (766.5 million gallons or about 2,352 acre-feet) of brine reportedly was produced in Upton County in 1961. Of this amount nearly 11½-million barrels (483 million gallons or about 1,482 acre-feet), or about 63 percent of the total, was disposed of through unlined surface pits. The rest of the brine was disposed of through injection wells (nearly 6¾-million barrels or 37 percent of the total) or by unknown methods. The reported amounts of brine production and amounts and methods of brine disposal are listed in Table 4 by oil fields and by the 20 brine-producing areas shown on Figure 16.

Figure 16 shows the areas of brine production and disposal in 1961. The figure also shows the chloride and sulfate concentrations in water samples from wells tapping the Quaternary alluvium, Fredericksburg Group, Trinity Sand, and the Chinle Formation equivalent and Santa Rosa Sandstone where the latter two formations occur at shallow depths. The natural water in these aquifers is characterized by a low chloride-sulfate ratio less than 0.5 in all but 14 samples. However, six samples had chloride-sulfate ratios of 1 or greater and were presumably contaminated by brine that was disposed of in nearby surface pits. Four of the six samples had chloride concentrations that exceeded 3,000 ppm which indicates that a considerable degree of contamination has occurred. The four samples were from wells located in the McCamey oil field (area 11) which produced 11 million barrels of brine in 1961 or 60 percent of the total amount produced in the county in that year. Of the 11 million barrels produced in the field, 6½-million barrels was disposed of through unlined surface pits.

Water from well YL-44-26-513 in area 2 also showed strong evidence of contamination (Figure 16). The well, 312 feet deep, is 100 feet southeast of abandoned salt-water disposal pits. Figure 17 shows the relationship between pumping and the chemical qualtiy of the water from the well. The first sample, collected in June 1963 after the well had pumped an estimated 54,000 gallons of water, contained 11,200 ppm chloride and 940 ppm sulfate. By March I, 1964, after pumping more or less continuously for 8 months, the chloride content had decreased to 1,070 ppm; during this same period the sulfate content remained almost unchanged. Two water samples collected during the next two years, when the well was operated only intermittently, showed a slight increase in chloride content—1,280 and 1,760 ppm, respectively; whereas, the sulfate content decreased to 790 ppm. These data indicate that after a long period of continuous pumping, a substantial part of the contaminant within the radius of influence of the well had been pumped from the aquifer and that after pumping had stopped, the chloride content began to increase slowly.

At least one other well in area 2 probably has been contaminated (the water contained 900 ppm chloride and 900 ppm sulfate) and three wells that yield water containing normal concentrations of sulfate but unusually high concentrations of chloride may be contaminated.

In general, Figure 16 shows that a marked degradation in the chemical quality of the ground water apparently has not occurred except locally. It is possible that contamination may be more extensive than is indicated by Figure 16 because of the low velocity of movement of the ground water. Brine that is placed in a pit may not affect the chemical qualtiy of the water in wells nearby for many years. Moreover, in some areas of surface-disposal pits, wells either are not available, or if available, were not sampled.

Recently, a statewide "no-pit" order was issued by the Railroad Commission of Texas to become effective January 1, 1969. As a result of this order and the expansion of secondary recovery operations in the county, most of the brine is now being injected into wells.

Table 4.--Reported Brine Production and Disposal in 1961, Upton County

AREA SHOWN ON FIGURE 16	FIELD		DISPOSAL IN SURFACE PITS (BBL)	DISPOSAL IN INJECTION WELLS (BBL)	TOTAL BRINE PRODUCTION (BBL)
1	Pegasus/Devonian/		0	0	0
	Pegasus/Ellenburger/		0	238,463	238,463
	Pegasus/Pennsylvanian/		0	396,816	396,816
	Pegasus/Spraberry/		37,958	0	37,958
	Pegasus/Wolfcamp/		0	0	0
		Total	37,958	635,279	673,237
2	Benedum		506,455	186,400	692,855
	Benedum/Spraberry/		685,544	9,855	695,399
	Neal Ranch		0	0	0
	Spraberry/Trend area/		1,603,497	231,975	1,874,107*
	Spraberry/Trend area, Clearfork/		35,486	0	35,486
		Total	2,830,982	428,230	3,297,847*
3	Adamc/Bend/		0	0	0
	Adamc/Devonian/		43,095	0	43,095
	Adamc/Ellenburger/		1,345	0	1,345
	Adamc/Silurian/		0	0	0
	Adamc/Wolfcamp/		0	0	0
	Jigger-Y/Pennsylvanian/		359	0	359
	McElroy		309,998	0	309,998
	Miether/Grayburg/		4,230	0	4,230
	Texel/Devonian/		720	0	720
	Texel/Ellenburger/		78,041	0	78,041
	Texel/Pennsylvanian/		2,358	0	2,358
		Total	440,146	0	440,146
4	Davis		7,576	0	7,576
	Davis/Ellenburger/		17,009	0	17,009
	Davis/Pennsylvanian/		200	0	200
	Davis/Wolfcamp-oil/		0	0	0
		Total	24,785	0	24,785
5	Wilshire		0	0	0
	Wilshire/Ellenburger/		801,461	0	801,461
	Wilshire/Pennsylvanian/		0	0	0
		Total	801,461	0	801,461
6	Hazel/Spraberry/		4,252	0	4,252
		Total	4,252	0	4,252

See footnote at end of table.

Table 4.--Reported Brine Production and Disposal in 1961, Upton County--Continued

AREA SHOWN ON FIGURE 16	FIELD		DISPOSAL IN SURFACE PITS (BBL)	DISPOSAL IN INJECTION WELLS (BBL)	TOTAL BRINE PRODUCTION (BBL)
7	Amacker-Tippett		2,435	0	2,435
	Amacker-Tippett/Detrital/		0	0	0
	Amacker-Tippett/Ellenburger/		83,235	0	83,235
	Amacker-Tippett/Fusselman/		1,931	0	1,931
	Amacker-Tippett/Strawn/		2,360	1,460	3,820
	Amacker-Tippett/Strawn-A-/		150	0	150
	Amacker-Tippett/Wolfcamp/		658	0	658
	Amacker-Tippett, E.		540	0	540
	Amacker-Tippett, S.		0	0	0
	Amacker-Tippett, S./Detrital/		0	0	0
	Amacker-Tippett, S./8750 Strawn/		0	0	0
	Amacker-Tippett, S./Wolfcamp/		17,225	0	17,225
	Jack Herbert		6,037	0	6,037
	Jack Herbert/Devonian/		9,630	0	9,630
		Total	124,201	1,460	125,661
8	Willrode/Cisco/		0	0	0
	Willrode/Leonard Lime/		0	0	0
	Willrode/Strawn/		365	0	365
		Total	365	0	365
9	Heluma/Devonian/		0	0	0
	Heluma/Ellenburger/		11,550	27,061	38,611
	Heluma/Pennsylvanian/		0	0	0
		Total	11,550	27,061	38,611
10	Fradean/Ellenburger/		2,368	0	2,368
	Fradean/Strawn/		6,219	0	6,219
	King Mountain		0	0	0
	King Mountain/Devonian/		30,222	0	30,222
	King Mountain/Ellenburger/		208,939	0	208,939
	King Mountain/Fusselman/		18,252	0	18,252
		Total	266,000	0	266,000
11	McCamey		6,522,598	4,538,990	11,061,588
	McCamey/Ellenburger/		13,730	0	13,730
	Shirk/Grayburg/		22,147	0	22,147
		Total	6,558,475	4,538,990	11,097,465

See footnote at end cf table.

Table 4.--Reported Brine Production and Disposal in 1961, Upton County--Continued

AREA SHOWN ON FIGURE 16	FIELD		DISPOSAL IN SURFACE PITS (BBL)	DISPOSAL IN INJECTION WELLS (BBL)	TOTAL BRINE PRODUCTION (BBL)
12	Crossett, N/Clearfork UP./		38,723	0	38,723
	Crossett, S./Devonian/		12,951	0	12,951
		Total	51,674	0	51,674
13	Webb Ray		9,000	0	9,000
		Total	9,000	0	9,000
14	Hurdle		3,766	0	3,766
	Hurdle/Queen/		0	0	0
		Total	3,766	0	3,766
15	Rodman-Noel/Grayburg/		0	1,000,000	1,000,000
	Rodman-Noel/San Andres/		0	100,000	100,000
		Total	0	1,100,000	1,100,000
16	Crockett		139,977	0	139,977
		Total	139,977	0	139,977
17	Corbett/Ellenburger/		73,000	0	73,000
		Total	73,000	0	73,000
18	Blue Danube/Ellenburger/		1,400	0	1,400
	Blue Danube/Strawn/		0	0	0
		Total	1,400	0	1,400
19	Flat Rock/Ellenburger/		45,720	0	45,720
	Flat Rock/Spraberry/		25,039	0	25,039
		Total	70,759	0	70,759
20	Block 4/Devonian/		2,370	0	2,370
	Block 4/Wolfcamp/		31,000	0	31,000
	Block 4/Pennsylvanian/		0	0	0
		Total	33,370	0	33,377
1 to 20	County total		11,483,121	6,731,020	18,252,776*

* Includes 38,635 barrels disposed of by methods other than surface pits and injection wells.

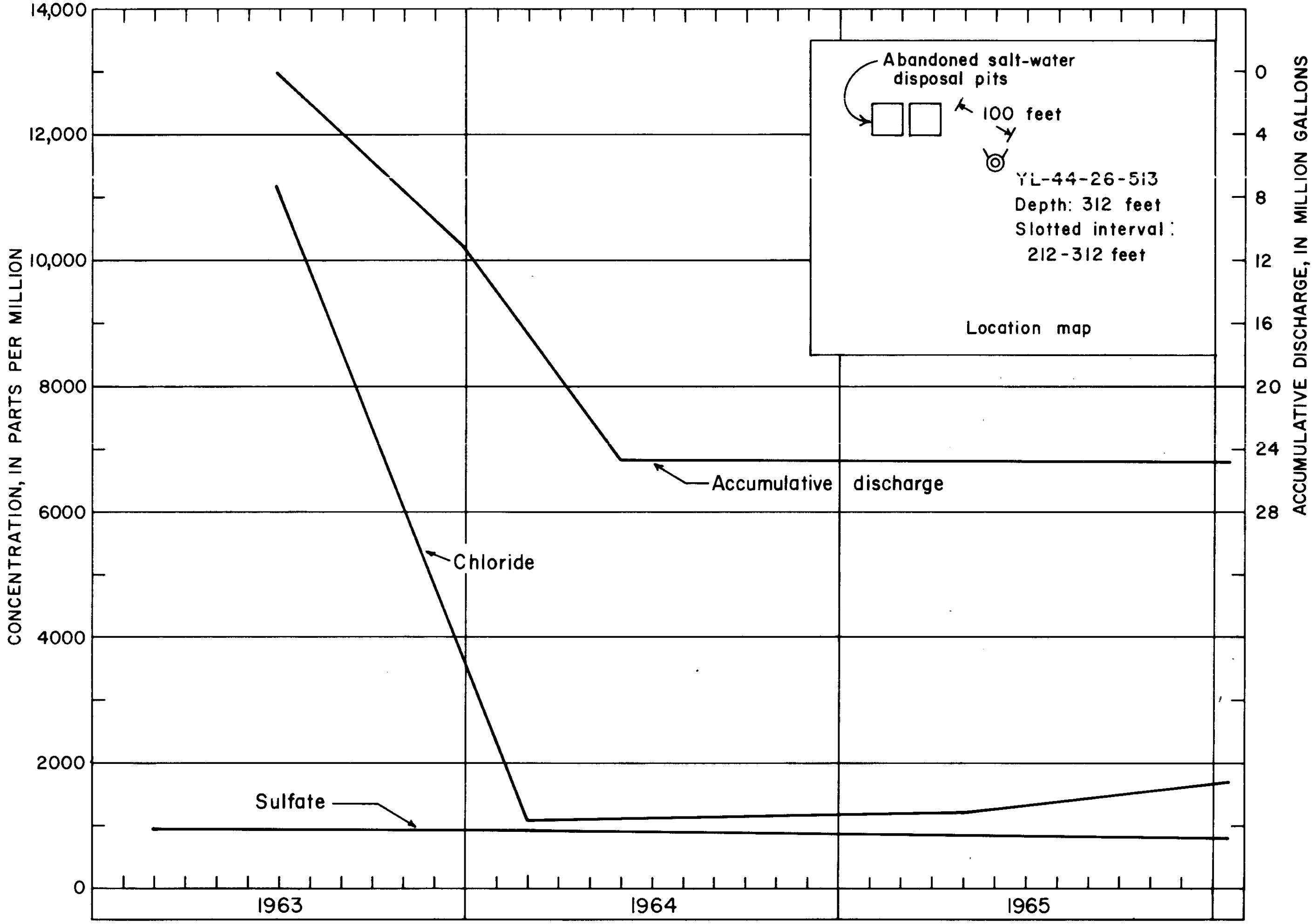

Figure 17

Relation of Chloride and Sulfate Concentrations to Discharge of Well YL-44-26-513

U. S. Geological Survey in cooperation with the Texas Water Development Board and the Commissioners Court of Upton County

Contamination from Improperly Cased Wells

Improperly or inadequately cased oil or gas wells are also potential sources of contamination of the ground-water supplies. The Oil and Gas Division of the Railroad Commission of Texas is responsible for seeing that oil and gas wells are properly constructed, and the Texas Water Development Board furnishes ground-water data to oil operators and to the Railroad Commission in order that all fresh water may be protected. The term "fresh water" is considered by the Surface Casing Program of the Texas Water Development Board to include water of usable qualtiy. The term "usable" in itself is rather indefinite in that the qualitative limits differ from place to place in the State. In Upton County, the term "water of usable quality" denotes water that may be of satisfactory quality for domestic, livestock, irrigation, or public supply purposes or for some restricted industrial purposes. Thus, "water of usable quality" in Upton County may contain as much as 5,000 ppm dissolved solids.

The Railroad Commission requires that strata containing usable water be protected by surface casing of new or reconditioned pipe and cement, or by alternate protection devices. The amount of protection required in the county differs from place to place, but generally casing and cement is required to a depth of a few tens of feet below the base of the Trinity Sand. However, most of the older oil fields such as the McCamey field do not have rules pertaining to surface-casing requirements. As a consequence, many of the wells have been inadequately cased, improperly cemented, or, in some of the abandoned wells, the casing was removed.

One of the larger oil fields in the county, the multiple county Spraberry-Trend Area field (in area 2, Figure 16) has field rules requiring a minimum of 120 feet of surface casing. Inasmuch as the base of the Trinity Sand ranges from about 270 to 320 feet below the surface in that area, the minimum surface-casing requirement is deficient by as much as 200 feet. Of principal concern is the fact that some of the oil wells in this area have been converted to injection wells for secondary recovery of oil. Injection of oil-field brines into wells for purposes of either secondary recovery or for brine disposal is a potential source of contamination of ground water in this field and in the older fields in the county in which some of the wells may be inadequately cased.

Declines of Water Levels and Well Yields

The problem of declining water levels and decreasing yields is becoming annually more serious in several areas in Upton County. At present, the area most affected is the Upton County well field (see hydrograph of well YL-44-49-301, Figure 14), which supplies a large part of the water needs of Rankin.

In this area, and to a lesser extent in the Midkiff area and in an area near the east-central edge of the county, wells are closely spaced. As a result, the water table has been lowered excessively, particularly during the summer months when water needs are the greatest, and the well yields have declined substantially. Generally, the wells in these areas fully penetrate the aquifer and the pumps are at or near the bottoms of the wells; hence, the yields cannot be increased. In fact, the yields and the water table can be expected to continue to decline, assuming, of course, that there is no decrease in pumping. These effects can be modified somewhat by adequate well spacing or well-field spacing.

AVAILABILITY OF GROUND WATER

Although ground water is considered as a renewable resource, the rate at which it is renewed in Upton County is so slow as to preclude its consideration in determining the quantity that would be perennially available for use.

In Upton County, pumpage in 1965 (about 3,600 acre-feet) from the Trinity Sand, the principal aquifer, was at least three times the quantity that the aquifer conceivably could transmit into the report area at the present hydraulic gradient—about 10 feet per mile. Consequently, most of the water is being removed from storage—in other words, the aquifer is being "mined." However, the aquifer contains a substantial quantity of water in transient storage. On the basis of an average saturated thickness of 115 feet and a specific yield of 10 percent, about 8 million acre-feet of water is available to wells. The average coefficient of transmissibility of the Trinity Sand is low, probably not more than 2,500 gpd per foot. As a result, development of a substantial part of the water in storage probably is not economically feasible because it would require a large number of widely spaced low-yield wells. In addition, part of the water in storage is not suitable for all purposes. In some localized areas of the county, particularly the eastern part, the water in the Trinity Sand is too highly mineralized for drinking.

Data are not sufficient to evaluate quantitatively the potential development of the Santa Rosa Sandstone. Because of the generally poor chemical quality of the water in the Santa Rosa and the low yields and specific capacities of the few wells that tap the aquifer, very little additional development is anticipated.

The alluvial deposits presently furnish only small quantities of water for livestock and rural domestic use. Additional development is possible in those parts of the county where the alluvium is thick and the potential for recharge is good. Such an area is in Fivemile Creek Valley near the Upton-Crockett County line where the alluvium has a saturated thickness of as much as 150 feet. The quality and quantity of the water in the area probably is satisfactory for irrigation. However, during extended droughts, the yields of wells in the alluvium may be substantially reduced.

Data are not available to determine the water-supply potential of other water-bearing formations such as the Grayburg Formation and the San Andres Limestone. At present, moderate quantities of very saline to brine water is being pumped from wells tapping the San Andres in the Midland Basin, and small quantities of moderately to very saline water associated with oil are being produced from wells in the Grayburg Formation on the Central Basin Platform. Additional quantities of water suitable for secondary recovery of oil probably can be obtained from non-oil-bearing zones in these units throughout the county.

Figure 18 shows areas in Upton County favorable for future development of ground-water supplies, principally from the Trinity Sand but also from the alluvium. The relative degrees of favorability—most favorable, favorable, less favorable, and least favorable—are based on the yields of wells presently being used, the thickness of the aquifer, the estimated transmissibility of the water-bearing section, and the observed specific capacities of wells in use. The chemical quality of the water was not a criterion in determining areas of favorability.

The term "favorable" as used in this report does not imply that additional water supplies can be obtained from the Trinity Sand without depleting the aquifer. On the contrary, any additional pumping from the Trinity in any part of the county will only lead to acceleration of the rate of depletion because, as already mentioned, pumping in 1965 exceeded the probable rate of recharge to the Trinity Sand. Nevertheless, the map is useful in designating areas wherein additional supplies can be obtained.

The map shows that the most favorable area for development is in the northeast quarter of the county where relatively large-scale development already has occurred. Properly drilled and completed wells in this area can be expected to yield more than 100 gpm. The least favorable is in the southwest quarter of the county where the aquifer (Trinity Sand) is thin or absent. Yields of wells in this area would be small, probably less than 25 gpm. The finger-shaped area in the southern part of the county probably is favorable for the development of additional ground-water supplies. In this area, the alluvium along Fivemile Creek is the principal source of water suitable for domestic supply and livestock.

CONCLUSIONS

The ground-water resources of Upton County are insufficient to furnish all the water needs of cities, industries, irrigation, and livestock. Consequently, a substantial part of these needs have been met by the importation of ground water from adjoining counties. The Trinity Sand, the principal source of water for public supply, irrigation, and domestic and livestock needs, in 1965 supplied water somewhat in excess of the estimated annual recharge to the aquifer. Further development, which is anticipated, can only result in an acceleration of the rate of water-level decline and a concomitant decrease in yields. Insofar as possible, any new large-scale development should not be located near present areas of concentrated withdrawals. Furthermore, because of the low rate at which the Trinity transmits water, wider spacing of wells and smaller yields should be considered.

Chemical analyses of water samples collected during this and previous investigations show that few of the wells in the Trinity Sand yield water that meets the standards recommended for public supplies by the U.S. Public Health Service, the sulfate, fluoride, and dissolved-solids concentrations being the principal constituents that affect the quality of the water. Because no other sources of water are presently available, the quality of the present supply should be protected.

The present study yielded evidence that some of the wells have been contaminated, presumably from the disposal of oil-field brines into unlined surface pits. Even if these sources of contamination were eliminated, it is expected that contamination would continue for a long time. A program of periodic resampling of water from key wells is recommended to trace changes in the extent and intensity of contamination; for most of the wells so sampled, a determination of chloride should be sufficient.

A network of six observation wells has been established in Upton County, and water levels in these wells are measured and recorded at least annually by the Texas Water Development Board. As development, particularly of the Trinity Sand, continues, additional observation wells should be measured in areas where present coverage is sparse or lacking.

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