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RECONNAISSANCE INVESTIGATION OF THE GROUND WATER RESOURCES OF THE CANADIAN RIVER BASIN, TEXAS

This report was prepared by the staff of the Ground Water Division of the Texas Board of Water Engineers from data collected in cooperative programs with the North Plains Ground Water Conservation District No. 2, the Panhandle Ground Water Conservation District No. 3, and the U. S. Geological Survey

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RECONNAISSANCE INVESTIGATION OF THE GROUND WATER RESOURCES OF THE CANADIAN RIVER BASIN, TEXAS

ABSTRACT

The reconnaissance study of the Canadian River Basin was undertaken as part of a statewide program designed to provide the general order of magnitude of ground water supplies potentially available from the principal water-bearing formations of Texas. The basin area defined for the study covers about 13,000 square miles from the divide between the Red and Canadian River basins north to the state line.

The plains of the Canadian River Basin are part of the North Plains and Southern High Plains topographic features which have been dissected by the Canadian and North Canadian Rivers and their tributaries. The slope of the land surface is generally eastward. There is little well-defined drainage except in valleys cut by streams through the relatively flat plains. The altitude of the land surface above mean sea level ranges from 4,735 feet in northwest Dallam County to 2,167 feet in the valley of the Canadian River in eastern Hemphill County.

The availability and use of ground water in the Canadian River Basin is influenced strongly by arid to semi-arid climatic conditions featured by low rainfall, high evaporation losses, and frequent strong winds. The development of irrigation in the area can be traced largely to the impetus given its growth during periods of deficient rainfall, although dry-land farming is practiced with moderate success during periods of normal rainfall.

The principal aquifer in the basin is the Ogallala formation of Tertiary age, although significant quantities of water are also found in Cretaceous and Triassic rocks. The Ogallala is a stream-deposited formation composed of interconnected sands and gravels which form a large unconfined ground water reservoir. It ranges in thickness in the basin area from 0 to about 900 feet, and is found over most of the basin. The thickness of saturated material is closely related to the thickness of the formation.

Water occurring under artesian conditions in the Dakota sandstone of Cretaceous age supplies irrigation wells and municipal demands in northwestern Dallam County. Fresh water in Triassic and Permian rocks is similar in quality to the water in the Ogallala and probably moved into the older beds from the Ogallala where they are in contact. No appreciable supplies of water are found in the Quaternary sediments although some of these deposits at the surface offer favorable conditions for recharge to underlying beds.

Recharge to the Ogallala formation is from rainfall and snow in Texas and New Mexico. Less than 1 inch annually of such precipitation reaches the water table as recharge to storage. Preliminary studies indicate that no appreciable

quantities of water reach the ground water reservoir through infiltration from depression ponds that dot the High Plains. Ground water moves generally eastward through the Ogallala. The normal gradient of the water table is generally about 10 feet per mile with steeper gradients in areas of heavy pumpage and near valleys cut through the water table.

In 1958 there were 1,356 irrigation wells, 116 municipal wells and 118 industrial wells in the basin. Yields from about 10 percent of the irrigation wells in the basin ranged from 204 to 1,225 gpm, drawdowns from 17.5 feet to 170.3 feet, and specific capacities from 2.9 to 62.6 gpm per foot of drawdown. The depth to water in the basin ranges from 0 in stream valleys to about 400 feet. The average annual decline of water levels in wells was less than 1 foot for the period of record.

The quality of water in the Ogallala rocks, based on analyses of samples from 33 municipal wells, is generally suitable for most purposes, although some of the samples analyzed revealed undesirable concentrations of hardness, iron, silica, and fluoride. Water from the older formations is variable in quality and may be unsuitable for use.

The present annual irrigation, municipal and industrial pumpage of ground water exceeds the rate of replenishment of the reservoir, so that reductions of water in storage are occurring. There was estimated to be more than 200 million acre-feet of water in storage in the Canadian basin portion of the Ogallala in 1958, and the rate of withdrawal for all purposes in the same year was about 520,000 acre-feet.

Future additional water uses in any area in the basin will be conditioned in part on the thickness of saturated sands and gravels available. At an assumed rate of annual replenishment of 0.1 acre-foot per acre per year, which is probably an optimistic estimate, and an assumed average use for irrigation from 1958 to 1975 of one and one half times the 1958 rate of withdrawal, the amount of water available in storage underlying the plains area in 1958 would be depleted by 6.5 million acre-feet by 1975, which is about 3 percent of the estimated total amount in storage in 1958.

INTRODUCTION

The Canadian River Basin in Texas is in the northern part of the Texas Panhandle and includes a total area of approximately 13,000 square miles. The area extends northward to the Texas-Oklahoma line from the divide between the basins of the Red and Canadian Rivers and is bounded on the east and west by the state lines (Figure 1). The Canadian River flows in an easterly direction across the basin and marks the division between the North Plains and the Southern High Plains or Llano Estacado.

Preliminary figures from the 1960 census showed the population of the principal cities in the basin to be as follows: Amarillo, 137,083; Pampa; 24,303, Borger, 20,815; Dumas, 8,437; Dalhart, 5,172; Perryton, 7,823; Phillips, 3,609; and Spearman, 3,545.

PURPOSE AND SCOPE

Investigation of the Canadian River Basin was begun in 1958 as a part of a reconnaissance program of study of ground water resources in all the river basins of Texas. These reconnaissance studies were outlined in the Texas Board of Water Engineers Progress Report to the 56th Legislature and are scheduled for completion by August 31, 1962. The reconnaissance investigations are being made chiefly to determine the order of magnitude of ground water supplies potentially available from the principal water bearing formations in the state. The results are suitable for generalized evaluations of ground water conditions over large areas, but are not adequate for detailed water planning or for the planning of individual water supplies. The work necessary for the reconnaissance studies is a part of the work eventually required for later completion of detailed studies.

Principal emphasis in the reconnaissance studies includes the following items:

1. Inventory of large wells and springs.

2. Compilation of readily available logs of wells and preparation of generalized cross sections and maps showing subsurface geology.

3. Inventory of major pumpage.

4. Pumping tests of principal water bearing formations.

5. Measurements of water levels in selected wells.

6. Determination of areas of recharge and discharge.

7. Compilation of existing chemical analyses of water and sampling of selected wells and springs for additional analyses.

8. Correlation and generalized analysis of all data to determine the order of magnitude of water supplies available from each major formation in the area and the general effects of future pumping.

9. Preparation of generalized reports on principal ground water resources of each river basin.

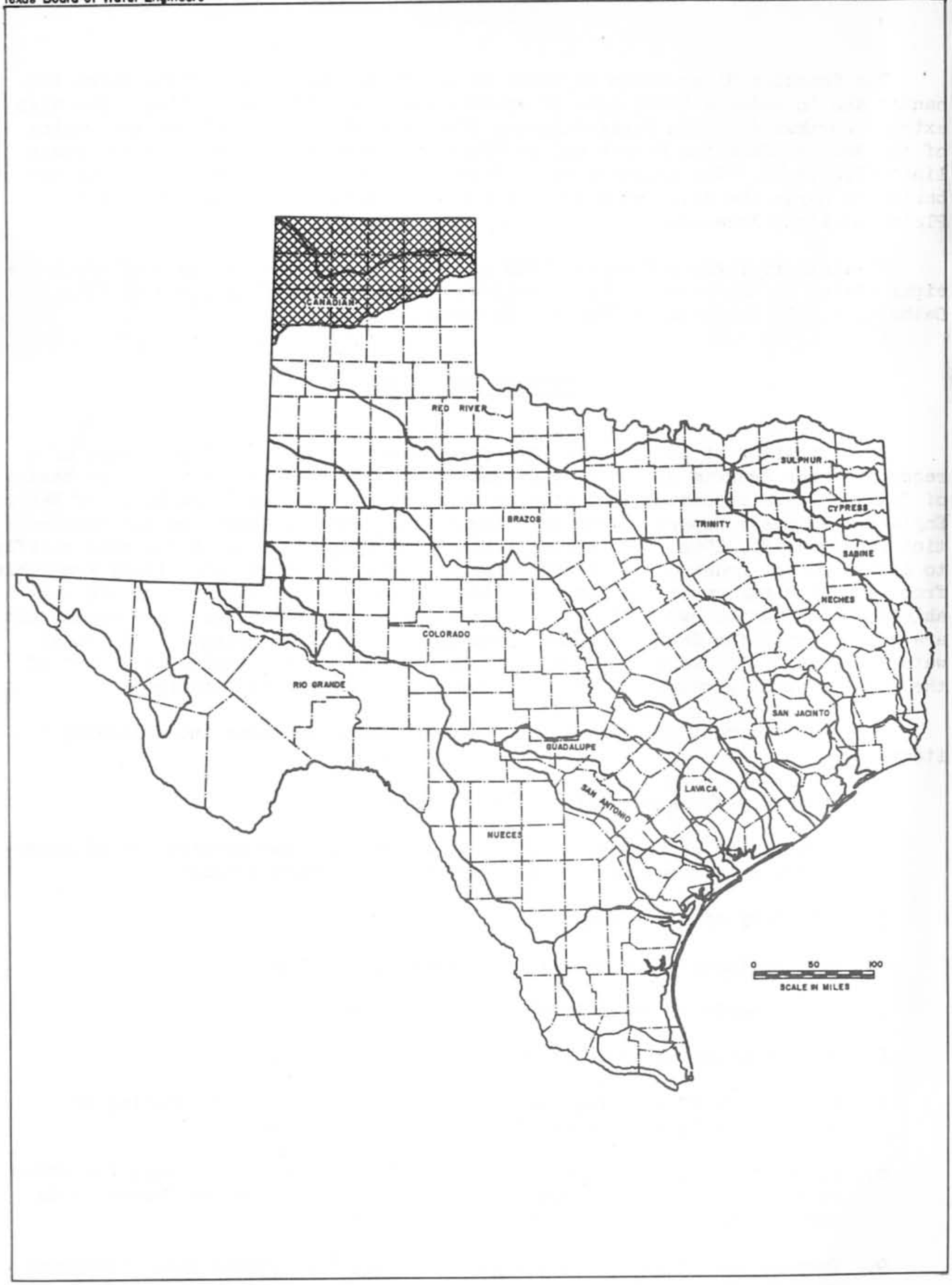

FIGURE 1.- Canadian River Basin, Texas

The Canadian River Basin studies were integrated with concurrent continuing investigations being conducted north and south of the Canadian River, which were related to the development of ground water for irrigation in the High Plains area. The investigation north of the Canadian River was sponsored jointly by the North Plains Ground Water Conservation District No. 2, the Texas Board of Water Engineers, and the U. S. Geological Survey. The study south of the Canadian was sponsored by the Panhandle Ground Water Conservation District No. 3, the Board, and the Survey. The areas included in these districts, as well as the area of the Dallam County Water Conservation District No. 1, are shown on Plate 1. Information from the two continuing studies was supplemented with data accumulated in a short field study; information from previous investigations; and from a canvass of water well drillers, industries operating in the area, municipalities, and other governmental agencies.

Basic records on which this report is based are on file and available for inspection in the offices of the North Plains Ground Water Conservation District in Dumas, Texas, and the Panhandle Ground Water Conservation District in White Deer, Texas.

GEOGRAPHY

The Canadian River Basin includes part of the North Plains and Southern High Plains sections of the Great Plains physiographic province. Sharply contrasting flat plains and rolling to rugged erosional "breaks" mark the topography of the basin.

The plains, estimated at an area of about 6,900 square miles, slopes eastward at a rate of approximately 10 feet per mile. There is no well developed drainage on the plains, and surface runoff is limited to catchment in hundreds of depression ponds dotting the plains. Nearly all of the precipitation on the plains is evaporated, absorbed by the soil, or collected in these small depressions. Water impounded in the land-bound lakes ultimately evaporates or percolates into the ground. Recharge experiments in the Southern High Plains, under climatic and lithologic conditions similar to those throughout the Canadian River Basin, indicate a computed average evaporation loss of from 60 to 65% of the observed total water caught in these lakes.

The "breaks" area, estimated at about 6,100 square miles, is drained by the Canadian River and its tributaries, and most surface runoff contributes to the flow of these waterways. Although much of the land in the breaks in unsuitable for cultivation, there are several irrigation wells on the flood plains of Palo Duro Creek in Hansford County and in other areas.

The basin area ranges in altitude from a high in northwestern Dallam County of 4,735 feet above mean sea level to a low of 2,167 feet above mean sea level in the valley of the Canadian River where it enters into Oklahoma at the eastern edge of Hemphill County.

The flow in the two principal streams, the Canadian and the North Canadian Rivers, is from runoff in New Mexico and Texas, and from springs and seeps issuing chiefly from the Ogallala formation. The principal tributaries in Texas contributing appreciable amounts of runoff to the Canadian River are Red Deer and Punta de Agua Creeks. The principal tributaries to the North Canadian are Palo Duro, Wolf Creek, and Coldwater Creeks. The springs and seeps sustain the base flow in the Canadian River during the winter months, but large evaporation and transpiration losses consume most and sometimes all of the base flow during the summer months.

CLIMATE

The climate of the Canadian River Basin is characterized by low humidity, low annual precipitation, hot summers, and frigid winters. The summer heat and frequent strong steady breezes contribute to a high evaporation rate. The problem of scanty rainfall is alleviated somewhat because of the frequently recurring seasonal pattern of greatest rainfall during the crop growing season from early spring through the summer. Climatic conditions at Amarillo, where records have been accumulated continuously since 1905, are typical of the basin area. The mean annual precipitation at Amarillo is 20.12 inches, but the records show a wide range from year to year from a maximum of nearly 40 inches in 1923 to a little less than 10 inches in 1956.

The average effective rainfall in the basin area (that portion of the total rainfall which remains after surface runoff) for the period 1940-1957 was 19.2 inches while the average gross evaporation rate for the same period was 73.9 inches.

AGRICULTURAL AND INDUSTRIAL DEVELOPMENT

Prior to 1900, most of the land of the Canadian River Basin was utilized for ranching and grazing, and little land was under cultivation. The advent of the railroads in the 1880's opened the region to farming, and dry-land cultivation of crops such as wheat and grain sorghum was practiced extensively by the 1920's. Irrigated farming began in shallow water areas in northwest Dallam County and along Palo Duro Creek in Hansford County, and spread into the rest of the basin as improvements in irrigation methods and equipment proved the economic feasibility of irrigation in areas with deeper water levels. Irrigation development mushroomed during the drought years beginning in 1951, and has continued to increase to the present. In 1959, there were more than 1,300 irrigation wells in the basin area and more than 324,000 acres of land under irrigation.

Industrial development in the basin is largely associated with the petroleum industry. Among the 200 or so manufacturing and industrial plants are oil refineries, helium plants, commercial fertilizer plants, zinc smelters, pipeline compressor stations, carbon black plants, an acetate factory, and manufacturers of farm implements.

OCCURRENCE OF GROUND WATER

Most of the fresh ground water in the Canadian River Basin occurs in the sands and gravels of the Ogallala formation of Tertiary age, although substantial amounts are found in the Cretaceous, Jurassic, and Triassic rocks underlying the Ogallala in the central and western part of the basin. The Permian deposits which underlie the Ogallala in the eastern part of the basin yield small amounts of fresh water to wells in local areas, but in most places contain only saline water.

Ground water in the Ogallala formation in unconfined occurring in interconnected lenses and layers of sands and gravels. Water levels in the Ogallala range from less than 50 feet below the land surface down to about 400 feet, with springs and seeps occurring where valleys have been cut through the water table.

Water level declines in the heavily pumped areas average less than 1 foot per year. The saturated thickness of the Ogallala varies within a wide range but is generally associated with the variations in total thickness of the formation. (See Plate 2).

Water occurs under artesian conditions in the permeable Cretaceous beds in northwest Dallam County and in some places rises in wells above the level of saturation in the overlying Ogallala formation.

GENERAL GEOLOGY

Plate 1 shows the distribution of the outcrops of the principal geologic formations in the Canadian River Basin. The Ogallala formation of Tertiary age is at the surface in the plains, and older rocks of Triassic and Permian age crop out along and near the canyon of the Canadian River in Oldham, Potter, southeastern Moore, and Hutchinson Counties.

The thickness of the Ogallàla formation, the principal aquifer in the Canadian River Basin, its relation to adjacent beds, and the water table are shown in the geologic section (Plate 3).

REGIONAL STRUCTURE AND GEOLOGIC HISTORY

Water-transported sands and gravels of the Ogallala formation of Tertiary age are at the surface in the Canadian River Basin plains area. These deposits overlie an old erosional surface of Cretaceous, Triassic, and Permian rocks. (See Table 1). An impure caliche caprock occurring at the margins of the High Plains escarpment may have some effect on ground water occurrence and movement in some parts of the area.

Major subsurface structural features of the Texas area of the Canadian River Basin are (Totten, 1956, p. 1963): 1) the Amarillo uplift in northeastern Potter County and northern Carson County extending into Gray and Wheeler Counties in the Red River Basin; 2) the Cimarron uplift in western Moore County and western Sherman County; 3) the western Anadarko basin in Lipscomb, Hemphill, Roberts, and Ochiltree Counties, central and eastern Hansford County, and northeastern Hutchinson County; and 4) the Dalhart basin in Dallam County and in central and eastern Hartley County.

These structural features do not have an appreciable effect on the Tertiary, Ogallala, and Cretaceous beds, and Triassic rocks are only mildly deformed. Permian beds, however, exposed by the deeply entrenched Canadian River, were deformed by structural movements to the extent of producing local features important in the accumulation of oil and gas.

Permian System

The Permian rocks, the oldest rocks exposed in the Canadian River Basin, crop out in the canyon of the Canadian River in western Oldham County, Potter County, southeastern Moore County, and Hutchinson County. Small outcrops of Permian strata have been mapped along the Canadian River in Hemphill County. The thickness of the Permian strata ranges from 3,000 feet over the Cimarron

Table 1.--Geologic formations and their water-bearing properties, Canadian River Basin, Texas

System	Series	Group	Stratigraphic unit	Approximate thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Pleistocene and Recent			0 - 100+	Sand, silt, clay, and gravel of alluvial origin, sand dunes and lake clays.	Yields small amounts of water. Forms important areas of natural recharge locally.
Tertiary	Pliocene		Ogallala formation	0 - 900	Sand, silt, clay, gravel, and caliche.	Principal source of water in Northern High Plains in Texas.
Cretaceous			Graneros shale	0 - 44	Dark-gray shale.	Yields no water to wells.
		Dakota	Dakota sandstone	0 - 181	Yellow to brown sandstone and gray shale.	Supplies irrigation and municipal wells in northwestern part of Dallam County.
			Purgatoire formation	0 - 59	Dark-gray shale and light-colored to white sandstone.	do
Jurassic				0 - 217	Green and red shale, white to brown lenticular beds of sandstone.	Yields small amounts of water to stock wells in central Dallam County.
Triassic		Dockum		0 - 1,000	Dark-gray and variegated shale, red, brown, or gray sandstone. About half sand and half shale.	Yields small amounts of water to stock wells in parts of eastern Dallam County
Permian				3,000-5,400+	Salt, gypsum, anhydrite, red shale, and sandstone in upper two-thirds; limestone, dolomite, and shale in lower one-third.	Yields small amounts of water, generally saline.

uplift in western Sherman County to more than 5,400 feet in Lipscomb County in the western Anadarko Basin. The upper two-thirds of the Permian rocks in the Canadian River Basin consists of salt, gypsum, anhydrite, red shale, and sandstone; the lower one-third is composed of limestone, dolomite, and shale. Red shales and sandstones including minor amounts of gypsum underlie the Ogallala formation in the eastern part of the basin, and where gypsum is present, the ground water is too highly mineralized for most uses.

The Alibates lentil of the Quartermaster formation, the Blaine gypsum, and the "Glorietta" sandstone are marker horizons in the upper Permian strata. These marker beds are shown on the geologic section (Plate 3).

Triassic System

Sandstones and shales of the Dockum group, generally considered to be upper Triassic in age, were deposited on the eroded surface of the Permian rocks. In the Canadian River Basin, the Triassic ranges in thickness from about 100 feet in Sherman and western Hansford counties to 1,000 feet in Dallam and Hartley Counties. The sandstones are red, brown, or gray; and the shales are predominantly dark red. Red, fresh-water-bearing sands, red clays, and red shales overlying redbeds of Permian age have been reported in many irrigation wells in Moore, Sherman, and Hansford Counties, and in northwestern Hutchinson County. These fresh-water-bearing sediments, probably Triassic in age, may be developed into an important source of fresh water in the central part of the irrigated area north of the Canadian River. Data available indicates that where fresh water occurs in Triassic rocks, it is similar in quality to water produced from the Ogallala, suggesting that the source of fresh water in the Triassic is the Ogallala where the two formations are in contact.

Jurassic System

Green and red shales and white to brown lenticular sandstones of Jurassic age, reaching a total thickness of more than 200 feet, have been reported in oil test wells located in an area of about 625 square miles in western Dallam County, and similar strata have been reported in the logs of water wells drilled in an adjoining area of about 75 square miles in the northwestern corner of Hartley County. Water found in the sandstones supplies stock wells in central Dallam County. The Jurassic rocks overlie the Triassic beds, and are overlain by Cretaceous rocks in the northwestern corner of Dallam County and elsewhere by the Ogallala formation of Tertiary age.

Cretaceous System

Rocks of Cretaceous age, overlain by the Ogallala formation, extend over an area of about 150 square miles in the northwestern corner of Dallam County. These beds range to more than 250 feet in thickness, and are composed of white and yellow to brown sandstones, and gray to dark gray shale forming in ascending order the Purgatoire formation, Dakota sandstone, and the Graneros shale. The Purgatoire formation and the Dakota sandstone are the Principal aquifers in this area. In the western part of Dallam County where the Graneros shale is present, the water in the underlying Dakota sandstones is confined under artesian pressure. These sandstones supply the two municipal wells at Texline, a few irrigation wells near the Texline city limits, and several irrigation wells in Union County, New Mexico, adjacent to the Texline area.

Tertiary System

In the Canadian River Basin the Pliocene series is represented by the Ogallala formation which is the principal aquifer in the basin. The Ogallala lies on the eroded surfaces of Cretaceous, Jurassic, Triassic and Permian rocks. It is composed of light-colored gravel, sands, silts, clays, and white, limy material called "caliche". Caliche is found near the top of the Ogallala formation in the western and central parts of the basin and in distinct beds throughout the formation in the eastern part of the basin.

Sediments forming the Ogallala were deposited by streams that had their headwaters in the Rocky Mountains. At the time of their deposition the sediments completely covered the underlying irregular land surface throughout the Canadian basin. Consequently, the Ogallala formation is generally thicker in the places where the old land surface is at lower elevations. (See Plate 3). The maximum known thickness of the Ogallala formation is about 900 feet in southwestern Ochiltree County. The variations in the thickness of the water saturated material in the Ogallala shown on Plate 2 are closely related to variations in the thickness of formation as a whole.

Because these sediments were deposited by streams, their character varies both vertically and laterally, with sand, silt, and clay distributed irregularly throughout the formation. Generally, however, the gravels are more abundant in the basal part of the formation, especially in the old stream channels cut in the pre-Ogallala surface. Since its deposition, the Ogallala has been dissected by the Canadian River and its tributaries which have eroded canyons into the Ogallala and through the Ogallala into the older rocks. Where caliche beds are exposed along these erosional "breaks" of the High Plains, they form light-colored ledges known locally as the "caprock".

Quaternary System

Pleistocene and recent sediments of Quaternary age are not important sources of water in the Canadian River Basin but supply small amounts of water for domestic use and for livestock. Evans and Meade (1945, p. 486) classified the Pleistocene sediments of the Texas High Plains into three types: (1) lake or pond deposits, (2) stream-valley deposits, and (3) wind deposits. The lake or pond deposits are predominantly impermeable clays, which retard the infiltration of surface water. The sand and gravel of the stream terraces, and the sand dunes on the plains and along the streams are connected hydraulically with the Ogallala formation and are important locally as areas favorable to the natural recharge of ground water. Extensive areas of sand dunes in Hemphill County extend across the southern part of adjacent Lipscomb County north of the Canadian River, and others have been mapped in western Hartley County and in Dallam County.

Quaternary sediments in the basin generally are less than 100 feet thick. However, soundings made prior to the construction of bridges across the Canadian have revealed a gorge filled with Pleistocene and Recent sands to a depth of a hundred or more feet below the level of the present channel. At the crossing of the Fort Worth and Denver railroad at Tascosa, in Oldham County, soundings were made through 120 feet of sand filling; and through a thickness of about 108 feet of sand filling at the Santa Fe railroad bridge north of Amarillo in Potter County (Evans and Meade, 1945, p. 500). At the Santa Fe railroad bridge in the city of Canadian, the sand fill is more than 123 feet thick (Reed and Longnecker, 1932, p. 12).

HYDROLOGY

All supplies of ground water of good quality have their source in precipitation of rain and snow on the earth's surface. A part of the water that reaches the surface as rain or snow runs off in the streams, part is lost through the joint agencies of evaporation and transpiration of plants, and part is drawn by gravity to the zone of saturation where all spaces and other openings in the rocks are completely filled with water.

The source of water to the Ogallala formation is precipitation by rain and snow on its surface in Texas and New Mexico. The amount of precipitation which actually reaches the zone of saturation as recharge to the Ogallala is a very small part of the total moisture from rainfall and snow at the surface. No means have been devised to determine accurately the percentage of the total precipitation which is lost through runoff, evaporation, and transpiration. It is known however, that only a very small percentage of the total, probably a fraction of an inch, reaches the ground water reservoir annually as recharge. The areas where the surface soils are most permeable and the areas in which runoff accumulates in topographically low areas offer the most favorable opportunities for recharge to the aquifer. The sand hills areas in western Dallam and Hartley Counties and southern Lipscomb and northern Hemphill Counties appear favorable for recharge as do the small drainageways cutting into the Ogallala. In these drainageways overland runoff accumulates and part of it infiltrates through the coarse sandy materials at the bottoms of the drainageways to become recharge to the underlying formations. Preliminary studies suggest that little substantial recharge reaches the ground water reservoir through infiltration from the many lakes dotting the High Plains areas. The accumulation of silt in the lake bottoms may prevent most of the water from moving into the ground. Most of the water held in the lakes is ultimately consumed by evapotranspiration.

In most places in the Canadian River Basin, water in the Ogallala formation is unconfined and will not rise in wells above the level at which it is first encountered. In such areas the upper surface of the zone of saturation is called the water table. In artesian areas where the water is confined both at the bottom and the top by more or less impermeable beds water in wells will rise above the level at which the permeable beds are penetrated. Locally in the Ogallala, artesian conditions may occur where lentils of dense, relatively impermeable shales and clays overlie more permeable sands and gravels.

Water in the permeable Cretaceous beds in northwestern Dallam County occurs under artesian conditions, and in some places will rise in wells above the level of saturation in the Ogallala. The Cretaceous rocks dip generally eastward and water in the Dakota sandstones is confined by the overlying Granerous shale where it is present. The source of artesian water in the Dakota sandstone probably is precipitation in northeastern New Mexico where the formation is near to or outcrops at the surface.

Ground water moves in the Ogallala at a rate of a few inches per day from areas of recharge to areas of discharge. Under natural hydraulic gradients water moves in the direction of the greatest slope of the water table. In the Ogallala, the water table slopes generally toward the east at a rate of about 10 feet per mile, with steeper gradients occurring in areas of heavy pumpage and toward valleys cut below the water table.

Water is discharged from the Ogallala along the streams and drainageways that have cut into or through the zone of saturation. Some of the water is discharged from springs; a large part is discharged from seeps and consumed by plants and evaporation. Thus, only a part of the water discharged contributes flow to the streams. The amount of water discharged by wells has increased each year as more and more wells are drilled. Ultimately, the well discharge will reduce the natural discharge but no appreciable reduction has occurred so far.

Water may move from one geologic formation to another. For example, in Dallam County the artesian pressure in the permeable Cretaceous beds is released where the beds come in contact with the Ogallala deposits. Thus, water moves from the Cretaceous beds into the Ogallala deposits. Along the Canadian River in the breaks areas, some of the water being discharged as springs and seeps from the Permian rocks is water that has moved from the Ogallala into the Permian. Most of the fresh water found in the Permian rocks is believed to be water from the Ogallala that has recharged the Permian.

Well Performance

Most irrigation wells in the river basin are drilled to the redbeds to utilize the full water-bearing section. The wells are large in diameter, 30 to 32 inches, and are sometimes even underreamed to increase the hold size. Casing averaging 12 to 16 inches in diameter is placed in the center of the hole, and gravel is packed in the annular space usually all the way back to the surface. The bottom 100 feet of casing is usually slotted and some wells have slotted pipe through the entire saturated zone to insure maximum water entry into the well.

After completion and development of the wells, pumps ranging from 6 to 10 inches, depending on the well capacity, are installed. The top of the pump bowl assembly is set from 100 to 150 feet below the static water level to prevent breaking suction when the well is being pumped. According to Sherrill (1959) about 50 percent of the irrigation pumps in the area are powered by natural gas; 41 percent by butane; 8 percent by electricity; and 1 percent by gasoline and diesel.

Average yields and drawdowns of 125 wells, about 10 percent of the 1,300 irrigation wells in the Canadian River Basin, are shown in Table 2. The yields of these wells ranged from 204 to 1,225 gpm (gallons per minute) and averaged 702 gpm. The drawdowns (differences between static water levels and pumping levels) ranged from 17.5 feet to 170.3 feet, and averaged 41.1 feet. The specific capacities, or the yield of the well in gallons per minute per foot of drawdown, which is a useful index of the ability of a well to yield water, ranged from 2.9 to 62.6 and averaged 20.2 gpm per foot of drawdown. About 34 percent of the wells tested were in areas where the static water levels were between 150 and 250 feet, and the yields of these wells ranged from 700 to 1,000 gpm.

Water Levels

The depth to water in the Canadian River Basin ranges from 0 to 400 feet. (See Plate 4). Water levels in the basin have declined appreciably only in the areas of intensive development. The publications containing water level records are in the reference at the end of this report. The declines in the heavily developed areas rarely exceed 3 feet in a single year and average generally less than 1 foot per year. Contrary to the expected decline pattern, wells in three areas in Dallam County have shown a net rise in water level for the period 1937-1958 despite rather intensive irrigation development, although during the drought period 1951-1957 water levels near Texline declined 13.67 feet. Other areas may

Table 2.--Summary of records of performance of irrigation wells in the Canadian River Basin, Texas

County	No. * Wells Measured	Gallons per minute			Drawdown			Specific Capacity		
		Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
Dallam	20	1,225	252	706	63.2	19.6	39.0	62.6	4.5	21.6
Hansford	22	953	204	702	170.3	17.5	46.0	43.4	2.7	20.3
Hartley	7	997	272	706	92.3	25.8	45.0	31.4	5.9	18.2
Hutchinson	12	1,004	373	720	83.4	20.9	41.4	29.6	8.5	19.0
Moore	30	1,004	217	696	82.0	17.7	35.6	55.3	7.0	22.1
Ochiltree	7	1,025	634	769	46.0	26.0	35.6	25.0	15.8	21.8
Sherman	27	970	314	679	129.6	17.7	45.4	42.0	2.9	17.1
Canadian River Basin	125	1,225	204	702	170.3	17.5	41.1	62.6	2.9	20.2

* Total of 125 wells included in this tabulation represents almost 10% of the 1,356 irrigation wells in the Canadian River Basin.

have similar rises but long-term records throughout most of the basin are scarce. A cause for the observed rises is not readily apparent.

Records of water level changes in observation wells in the basin are summarized in Table 3. Reduced pumpage and above average rainfall which may have contributed appreciable amounts of recharge during 1957 and succeeding years are reflected in a noticeable rise or very little net decline of water levels for these years. A longer period of record is needed in most of the Canadian River Basin to show any definite trends in water level changes.

QUALITY OF GROUND WATER

The suitability of ground water for municipal, industrial, and irrigation uses is determined largely by the type and amount of dissolved minerals it contains. In the Canadian River Basin the ground water in the Ogallala formation, the Cretaceous rocks, and some of the ground water in the Jurrassic and Triassic rocks is suitable for most uses, and water from underlying Permian rocks is usually unsuitable for most uses.

The U. S. Public Health Service (1946) has placed the following limits on some of the most common minerals found in solution for drinking water on interstate carriers:

Iron (Fe) and Manganese (Mn) should not exceed 0.3 ppm*
Magnesium (Mg) should not exceed 125 ppm
Chloride (Cl) should not exceed 250 ppm
Sulfate (SO_4) should not exceed 250 ppm
Fluoride (F) should not exceed 1.5 ppm
Dissolved solids should not exceed 500 ppm. However, if such water is not available, a dissolved solids content of 1,000 ppm may be permitted.

* Parts per million

Water samples from 33 municipal wells in the Canadian River Basin, ranging in depth from 80 to 916 feet and representative of most of the fresh ground water in the basin, had a dissolved solids content ranging from 246 to 866 ppm. (See Table 4). Analyses of these water samples were made by the Quality of Water Branch of the U. S. Geological Survey, supplementing analyses published in a report titled "Public Water Supplies in Western Texas", by Broadhurst, Sundstrom, and Weaver (1949 and 1951). Other analyses have been published in the county well inventory reports.

Although the Ogallala and Cretaceous formations contain water which is suitable in quality for most uses, some of the water samples analyzed revealed undesirable concentrations of hardness, iron, silica, and fluoride.

Excessive hardness in water used for municipal and domestic purposes is an objectionable quality found in much of the water in the basin. A generalized classification for hardness which is useful as an index to the analyses of water in the basin is as follows:

Less than 60 ppm - soft
61 to 120 ppm - moderately hard
121 to 200 ppm - hard
More than 200 ppm - very hard

Table 3.--Average change in water levels, in feet, in observation wells, Canadian River Basin, Texas, 1956-60

County	1956 to 1957		1957 to 1958		1958 to 1959		1959 to 1960		1956 to 1960	
	Number of wells	Average change	Number of wells	Average change	Number of wells	Average change	Number of wells	Average change	Number of wells	Average change per year
Dallam	16	-1.75	23	-0.47	36	+0.12	35	-0.14	17	-0.46
Hansford	20	-1.68	46	0.00	37	-0.53	35	-0.59	23	-0.77
Hartley	10	-1.66	13	-0.07	17	-0.17	21	-0.14	14	-0.45
Hutchinson	9	-1.75	19	+0.12	18	-1.04	19	-0.85	11	-1.03
Lipscomb	-	-	-	-	4	+0.89	4	-0.62	-	-
Moore	20	-2.77	40	-0.29	50	-0.85	59	-1.05	26	-1.41
Ochiltree	9	-1.06	24	+0.49	23	-0.06	21	-0.60	5	-0.38
Sherman	21	-2.32	38	+0.26	47	-0.83	56	-0.50	25	-0.88

Water having a hardness of more than 200 ppm needs to be softened before use for most purposes. The analyses in Table 4 indicate that ground water in the basin ranges in hardness from 169 to 378 ppm, and is classified generally as hard to very hard.

The iron in samples collected in the basin ranged between 0.00 and 0.48 ppm. However, only two samples, both in Ochiltree County, exceeded 0.3 ppm which is the upper limit recommended by the U. S. Public Health Service.

The scale-forming properties of water, a significant factor in industrial considerations, is related in part to the concentration of silica which forms a hard, adherent scale in boilers. Moore (1940, p. 263) has suggested the following allowable concentration of silica in water for boilers operating at various pressures:

Less than 150 psi (pounds per square inch) - 40 ppm
150 - 250 psi - 20 ppm
250 - 400 psi - 5 ppm
More than 400 psi - 1 ppm

Seven of the 33 samples taken in the basin contained more than 40 ppm silica and two-thirds of the samples contained 30 ppm or more.

Eleven samples from wells throughout the basin which are included in this report indicated an excessive concentration of fluoride. Continuous use of water containing fluoride in excess of 1.5 ppm by young children may cause permenent mottling of the teeth. The presence of fluoride in quantities less than this amount tends to reduce tooth decay.

A system of classification commonly used for judging the quality of a water for irrigation was proposed in 1954 by the U. S. Salinity Laboratory Staff (1954, p. 69-82). The classification is based chiefly on the salinity hazard as measured by the electrical conductivity of the water and the sodium hazard as measured by the sodium-adsorption ratio (SAR). The relative importance of the dissolved constituents in irrigation water is dependent upon the degree to which they accumulate in the soil. Wilcox (1955, p. 16) indicates that generally water may be used safely for supplemental irrigation if its conductivity is less than 2,250 micromhos per centimeter at 25°C and its SAR is less than 14. In the water samples in table 4 the conductivity ranged from 411 to 1,440.

There are a number of factors other than chemical quality involved in determining the suitability of water for irrigation purposes. The type of soil, adequacy of drainage, crops grown, climatic conditions, and quantity of water used all have important bearing on the continued productivity of irrigated acreage. Almost all of the sampled water in Table 4 is suitable for irrigation of the crops grown in the river basin. In general, the native water produced from the Ogallala formation probably is suitable for irrigation, but water from the older formations is more variable in quality and should be analyzed before considering its use for irrigation.

PRESENT DEVELOPMENT OF GROUND WATER

Ground water is the sole source of municipal, industrial, and domestic supplies and is the source of nearly all of the irrigation and stock supplies in the Canadian River Basin. Before 1900 most of the ground water supply was from

Table 4.--Chemical analyses of water from wells, Canadian River Basin, Texas
(Constituents shown in parts per million)

City & Well No.	Depth of well (ft.)	Water-Bearing Formation	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Non-carbonate Hardness	pH	Specific conductance (micromhos at 25°C)	Sodium adsorption ratio (SAR)	Residual Sodium Carbonate (RSC) (EPM)	Temp. (°F)
Dallam County																						
Dalhart No. 18	563	Ogallala	32	.00	37	29	22	4.8	240	41	8.5	1.6	6.4	.10	300	212	15	7.7	483	.7	0	65.0
Texline No. 1	265	Dakota	12	.01	40	23	30	4.2	256	38	8.5	1.2	.0	.03	283	194	0	7.3	489	.9	.31	6[illegible].5
Hartley County																						
Channing No. 3	400	Ogallala	33	.00	43	19	12	4.4	204	19	9.8	.9	16.0	.07	257	185	18	7.5	411	.4	0	54.5
Hartley	400	do	32	.00	38	29	28	6.3	270	35	9.2	1.4	8.3	.22	320	214	0	7.6	516	.8	.15	65.0
Lipscomb County																						
Booker No. 2	316	do	45	.00	68	29	37	7.3	269	37	78.0	1.1	6.4	.21	441	288	68	7.4	736	.9	0	62.0
Darrouzette No. 1	300	do	53	.00	56	28	37	6.2	244	34	68.0	1.3	6.6	.26	410	254	54	7.5	671	1.0	0	61.0
Follett No. 1	369	do	52	.00	48	23	45	5.7	260	23	53.0	1.1	4.5	.07	383	214	2	7.6	614	1.3	0	63.0
Higgins No. 2	133	do	44	.00	74	10	20	1.4	283	9.0	10.0	.6	14.0	.12	322	226	0	7.2	504	.6	.13	62.0
Moore County																						
Dumas No. 9	400	do	30	.14	35	30	19	5.3	242	34	7.2	1.1	12.0	.17	293	211	12	7.4	484	.6	0	53.5
Sunray No. 2	300	do	29	.04	40	24	16	4.8	222	28	12.0	1.2	8.5	.03	273	198	17	7.5	459	.5	0	62.0
Ochiltree County																						
Farnsworth No. 2	305	do	42	.05	42	23	38	5.3	228	34	39.0	1.9	5.8	.17	343	200	12	7.5	558	1.2	0	63.0
Perryton No. 5	619	do	44	.33	49	30	130	7.1	248	64	179.0	2.3	8.7	.14	636	246	43	7.3	1,100	3.6	0	64.0
Oldham County																						
Adrian	496	do	17	.00	60	14	13	5.0	253	18	8.5	.4	6.6	.01	267	207	0	7.9	455	.4	0	63.0
Vega No. 3	350	do	50	.00	23	31	45	5.3	251	39	17.0	2.8	18.0	.13	354	185	0	7.8	547	1.4	.41	62.0
Sherman County																						
Stratford No. 4	380	do	30	.03	33	31	32	6.6	251	54	10.0	1.6	11.0	.08	332	210	4	7.6	537	1.0	0	62.5
Hansford County																						
Gruver No. 1	342	do	31	.06	43	28	36	6.1	275	52	9.2	2.1	10.0	.37	358	222	0	7.4	562	1.1	.06	63.5
Morse	354	do	38	.06	38	26	14	4.8	236	25	6.8	2.2	7.1	.15	280	202	8	7.2	449	0.4	0	64
Spearman No. 4	405	do	34	.04	48	22	18	4.5	234	35	10.0	1.7	7.4	.00	310	210	18	7.2	478	0.5	0	63
Hutchinson County																						
Herring No. 15	544	do	28	.06	44	30	28	6.2	252	76	6.0	1.8	7.3	.32	352	234	27	7.3	553	0.8	0	63.5
Kay No. 2A	527	do	30	.04	43	26	21	5.1	248	39	5.8	1.8	7.2	.22	301	214	12	7.2	485	0.6	0	64.5
Stinnett No. 2	522	do	29	.04	41	23	16	4.5	224	28	8.0	1.5	7.5	.18	275	197	13	7.0	442	0.5	0	65

Table 4.--Chemical analyses of water from wells, Canadian River Basin--Continued

City & Well No.	Depth of well (ft.)	Water-Bearing Formation	Silica (SiO_2)	Iron (Fe)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium (Na)	Potassium (K)	Bicar-bonate (HCO_3)	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Boron (B)	Dis-solved solids *	Hard-ness as $CaCO_3$	Non-car-bonate Hardness	pH	Specific conduct-ance (micro-mhos at 25°C)	Sodium adsorp-tion ratio (SAR)	Residual Sodium Carbon-ate (RSC) (EPM)	Temp.
Ochiltree County																						
Waka	300	Ogallala	36	.48	44	23	22	4.6	234	41	8.2	1.6	7.8	.23	306	204	12	7.2	481	0.7	0	63
Roberts County																						
Miami	104	do	24	.04	68	7.3	6.3	2.8	216	12	12	.6	13.0	.09	266	200	23	8.4	415	0.2	0	62
Hemphill County																						
Canadian	80	Alluvium	31	.04	94	35	161	4.5	342	111	230	1.5	14.0	.21	866	378	98	7.3	1,440	3.6	0	62
Glazier	220	Ogallala	28	.04	86	11	24	2.6	272	16	25	.4	50.0	.09	392	260	36	7.3	612	0.6	0	62
Oldham County																						
Boys Ranch	120	Alluvium	24	.02	48	12	21	2.3	223	17	6.0	.7	4.8	.15	246	169	0	7.3	416	0.7	.27	-
Carson County																						
Amarillo	916	Ogallala	31	.00	36	22	22	6.1	240	16	12	1.3	4.8	.03	269	180	0	7.7	447	0.7	.33	65
Huber (Borger)	301	do	29	.05	50	19	14	4.5	222	27	12	.6	9.7	.09	275	203	21	7.0	456	4.3	0	64
Plains	535	do	31	.02	49	20	14	4.8	232	22	13	.8	5.7	.00	274	204	14	7.5	454	0.4	0	65
Panhandle	685	do	37	.00	40	26	22	6.5	278	18	8.2	1.2	7.1	.06	303	207	0	7.7	497	0.7	.42	65
White Deer	394	do	30	.04	44	19	26	5.5	258	18	11	.6	6.6	.13	288	188	0	7.3	475	0.8	.47	-
Skellytown	418	do	26	.00	44	22	13	4.0	215	30	14	.5	9.6	.01	269	200	24	7.4	451	0.4	0	-
Pampa	528	do	27	.04	43	18	75	5.3	260	68	41	.9	6.2	.24	413	182	0	7.7	674	2.4	.63	65

* All samples collected April - July 1959.

springs, but in 1958 springs accounted for a very small part of the total, and most of the withdrawal was by wells. Most of the water withdrawn from wells is used for irrigation.

About sixty irrigation wells were in operation in parts of Dallam County in 1937, where the depth to water was less than 50 feet, but irrigation development elsewhere in the Canadian River Basin, where the water levels were much deeper, did not reach significant proportions until after 1950. From 1953 to 1958 the number of irrigation wells and the withdrawals increased rapidly. By 1958 irrigation accounted for eighty-seven percent of the total ground water use.

The greater depth to water has been a major factor causing ground water development in much of the area north of the Canadian River to lag behind development in the Southern High Plains. The cost of a well, its pumping equipment, and the cost of pumping water are related directly to the depth to water. Irrigation wells were considered an expensive risk until the recent drought, which became severe in 1953, substantially reduced profits from dry-land farming. As irrigation proved to be profitable, the number of irrigation wells increased from 236 in 1953 to 1,356 in 1958 (Table 5). A similar increase in irrigation development occurred during the same period in the eastern part of the basin south of the Canadian River. For example, the number of irrigation wells in the part of Carson County within the basin increased from 68 in March 1956 to 103 by the end of 1958. In 1958 there were 1,356 irrigation wells, 116 municipal wells, and 118 industrial wells in the basin. (See Table 5).

The withdrawals for 1958 from irrigation wells is estimated to be approximately 460,000 acre-feet (Table 5). The use of water averaged about 1.1 acre-feet per acre of irrigated land and about 340 acre-feet per well.

The amount of water pumped yearly is related to the annual precipitation although not as closely as might be expected. Many of the farmers pump nearly as much water during years of near-normal precipitation as they do during dry years. Thus, the use of water per well in 1958 probably is representative of near average use. However, during very wet years, and especially in those years when most of the precipitation falls during the growing season, the use may be substantially less.

The concentration of development is shown by the density of wells on Plate 1. The largest area of concentrated development is in northern Moore, southern Sherman, and northwestern Hutchinson Counties. The density of wells in this area is as much as 4 per square mile. The greatest density, however, is in northwestern Dallam County where some areas have as many as 6 irrigation wells per square mile. Withdrawals in Moore, Dallam, Hutchinson, Hansford, Carson, and Sherman Counties accounted for more than 80 per cent of the total withdrawals in the basin in 1958. Most of the irrigation development falls within the boundaries of the Ground Water Conservation Districts (Plate 1) and within the area shown as flat land. Irrigation development outside the District boundaries generally is scattered.

The entire water supply for some cities and a part of the water supply for other cities is located miles from the population centers. For example, part of the water supply for the city of Amarillo is obtained from wells in Carson County, and from wells south of the Canadian River Basin, chiefly in Randall County. The city has also acquired water rights on other lands chiefly in Hartley County. Some of the other cities that have wells outside of their

Table 5.--Number of wells and withdrawals of ground water in 1958 for irrigation, municipal, and industrial use, Canadian River Basin, Texas

County	Number of wells				Withdrawals in thousands of acre-ft.			
	Irrigation	Municipal Supply	Industrial	Both M. S. and Ind.	Irrigation	Municipal Supply	Industrial	Total
Carson	103	27	12	17	39	10	10	59
Dallam	237	10	0	0	80	1.02	0	81.02
Deaf Smith	0	0	0	0	0	0	0	0
Gray	9	12	7	0	1.5	1.8	.96	4.26
Hansford	226	8	10	0	65	0.66	.79	66.45
Hartley	66	5	0	0	13	0.07	0	13.07
Hemphill	4	2	0	0	0.5	0.01	0	0.51
Hutchinson	92	3	6	24	47	1.00	17.60	65.60
Lipscomb	13	9	1	0	2.5	0.29	*	2.79
Moore	250	11	61	0	101	1.5	12	114.50
Ochiltree	75	9	5	0	24	1.07	*	25.07
Oldham	27	7	1	0	10	0.14	0.03	10.17
Potter	30	1	12	0	16	0.01	1.6	17.61
Randall	22	7	0	0	7.8	2.2	0	10
Roberts	11	2	0	0	3.4	0.08	0	3.5
Sherman	191	3	3	0	50	0.26	0.01	50.27
Totals	1,356	116	118	41	460.7	20.11	42.99	523.82

* Less than 10 acre-feet.

city limits are Borger, Pampa, Dumas, and Perryton. Some municipalities are supplied by wells owned by industries where the supply system for the industry and municipality is combined (Table 5). The total withdrawal for municipal use in 1958 was 20,110 acre-feet.

The largest industrial supplies are found in Hutchinson, Moore, and Carson Counties (Table 5). The total withdrawal for industrial use from the basin in 1958 was 42,990 acre-feet. The principal industrial use of water is by oil companies for manufacturing and processing petroleum products.

GROUND WATER AVAILABLE FOR FUTURE DEVELOPMENT

The ground water available for extensive development in the Canadian River Basin is represented largely by the amount of water in storage because the replenishment rate is small compared to the potential withdrawal rate. Concentrated withdrawals within a small area can reduce the water in storage substantially because the water from surrounding undeveloped areas cannot move laterally fast enough to appreciably replenish the developed part of the reservoir. Other things being equal, the depletion rate is more rapid in a large area of concentrated withdrawal than in a smaller area because the opportunities for replenishment by lateral movement are reduced. If all of the irrigable land in the Canadian River Basin were in use, the withdrawals for irrigation would average approximately seven hundred acre-feet per square mile annually over a large area. However, the demand for municipal and industrial supplies generally is concentrated in a much smaller area and the rate of withdrawal per unit area may be several times as great as the demand for irrigation water. Thus, an area developed for industrial or municipal supply may be depleted much more rapidly than the one developed for irrigation despite the more favorable conditions for lateral replenishment. To insure an adequate long-term supply a municipality or an industry must either pump at a small rate from a large area or plan to acquire additional areas for development as the initially developed areas become depleted from high rate pumping.

The thickness of saturated material determines to a great extent the availability of water from storage. In general, the greater the saturated thickness the greater is the amount of water available. Plate 2 shows the approximate thickness of saturated material throughout most of the Canadian River Basin and thereby the relative availability of water. When exploring for new supplies of water, however, this map should be used only as an indication of the availability of water supply because the saturated thickness must be evaluated with the lithology of the formation to give an accurate appraisal of the possibilities for development in a local area, and because interpretations between control points may be somewhat in error. Where the control points are closely spaced, abrupt changes in saturated thickness are revealed. Where control is less adequate, these abrupt changes may also occur, but are not revealed by data available. Although in most places the saturated material consists of sand and gravel and is capable of yielding large quantities of water, a few small areas have been encountered where nearly the entire saturated section is composed of silt and clay. Wells drilled in the clayey material yield insufficient quantities of water for irrigation, municipal, and industrial use, but should be adequate for domestic and stock supplies.

The amount of water ultimately available from storage is dependent on the specific yield which is the ratio, expressed in percentage, of the volume of water the formation will yield by gravity to the volume of material drained.

Insufficient data are available to determine the specific yield of the Ogallala in the Canadian River Basin. The formation as it occurs in the basin is, however, very similar in lithologic and hydraulic characteristics to the Ogallala as it occurs in the Southern High Plains where a figure for specific yield of 15 per cent is commonly used in calculations of water in storage.

More than 200 million acre-feet of water was estimated to be available from storage in 1958 in the Canadian River Basin (Table 6). In using this figure it should be realized that not all of the water in storage is recoverable. As the water levels decline the yield of the wells decrease so that perhaps the lower 20 to 50 feet of the saturated section may be uneconomical to develop.

The rate of future ground water development will be determined by a combination of economic, regulatory, climatic, and technological factors such as the cost of pumping water, the value of crops, the value of land, and the cost of labor; regulations imposed by Federal, State, and local units of government, such as subsidies, price control programs, the soil bank, and regulation of well spacing; and progress in development of pumping equipment, agricultural products that require less water, water-conservation practices, artificial recharge, and farming equipment.

Although the use of ground water appears certain to increase, the rate of increase is uncertain. In the North Plains the County Conservation Needs Committee has predicted that by 1975 the acreage under irrigation will be approximately double the amount used in 1958. Assuming that this estimate is correct and that the average use between 1958 and 1975 is one and one half times the 1958 rate of withdrawal, the depletion from the reservoir can be estimated. If the annual replenishment rate is optimistically assumed to be 0.1 acre-foot per acre per year, the annual depletion rate would be 1 acre-foot per irrigated acre per year. Thus, the reservoir would be depleted by 6.5 million acre-feet by 1975 from storage underlying the plains area in 1958.

Foreseeable supplies of surface water appear adequate only to supplement municipal and perhaps some industrial supplies. The ground water supply appears adequate to meet demands for all uses in the near future, but the preceding estimates show that ultimately it may be exhausted. Careful planning based on detailed studies of water resources appear warranted so that the greatest benefit can be obtained through wise management of the remaining water resources.

RECOMMENDATIONS FOR FUTURE STUDIES

Managing the ground water resources of the basin on the local level will require more detailed information than is contained in this report. Current information is needed continually on the extent of development and its effect on the future availability of ground water.

Continuing studies will be needed to collect, compile, and periodically analyze records of pumpage and water levels and relate them to climatological records. These data are useful in developing trends of natural recharge and reservoir depletion. Long-term records on the availability of surface water that collects in lakes and evaporates is needed to determine the average amount which may be available for artificial recharge.

Additional studies are needed to show the extent of water-bearing deposits in the Cretaceous and other older formations, and detailed studies of limited duration are needed to determine the water-bearing properties of the saturated

Table 6.--Estimated volume of water available from storage in thousands of acre-feet, 1958, Canadian River Basin, Texas

County	Plains	Breaks	Total
Carson	5,800	4,900	10,700
Dallam	21,000	00	21,000
Deaf Smith	50	00	50
Gray	2,000	930	2,930
Hansford	12,000	5,500	17,500
Hartley	21,000	8,600	29,600
Hemphill	0	9,600	9,600
Hutchinson	3,600	6,000	9,600
Lipscomb	300	24,000	24,300
Moore	9,700	2,400	12,100
Ochiltree	10,400	6,000	16,400
Oldham	600	600	1,200
Potter	200	1,600	1,800
Randall	80	00	80
Roberts	3,600	23,000	26,600
Sherman	16,000	3,000	19,000
Total			
Canadian River Basin	106,330	96,130	202,460

material in order to prepare maps showing the configuration of the water table and bedrock surface. As more information becomes available, the thickness of saturated material should be mapped in greater detail and in areas not covered by this report. Likewise, the map showing depth to water should be further refined. Maps showing the thickness of the most permeable zones of the saturated material can be prepared from data available from the water district files and the records of oil companies. Pumping tests should be made to determine the hydraulic characteristics of the aquifers. Specific yield studies in the basin will permit development of more precise calculations of the amount of water available from storage. Extensive leveling will be needed to prepare maps showing the configuration of the water table and bedrock surfaces.

Another study that may be important to the future of the area is the determination of the quality and amount of saline waters underlying the fresh water-bearing deposits in the Canadian River Basin. Experiments being conducted by various agencies may develop economical methods for demineralizing water, making it usable for irrigation, municipal, and industrial supplies. Problems that may arise regarding the disposal of wastes also should be investigated to protect the supply of fresh water.

The ground water studies should be coordinated with surface-water, agricultural, and economic studies if they are to be of maximum benefit.

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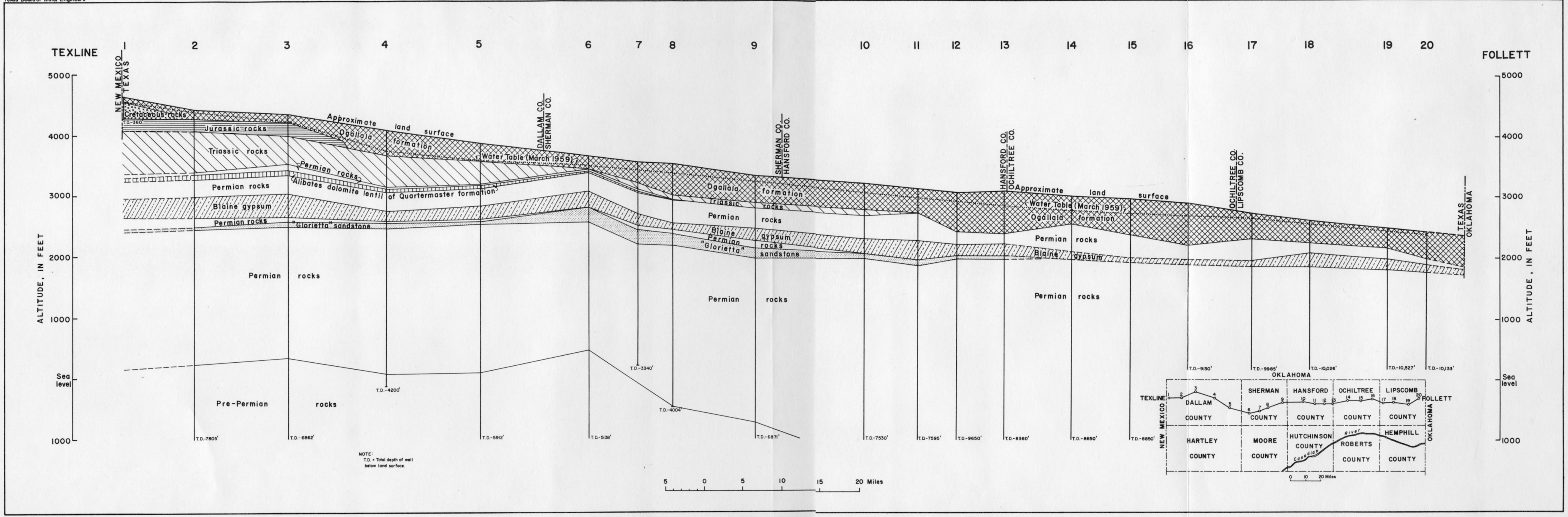
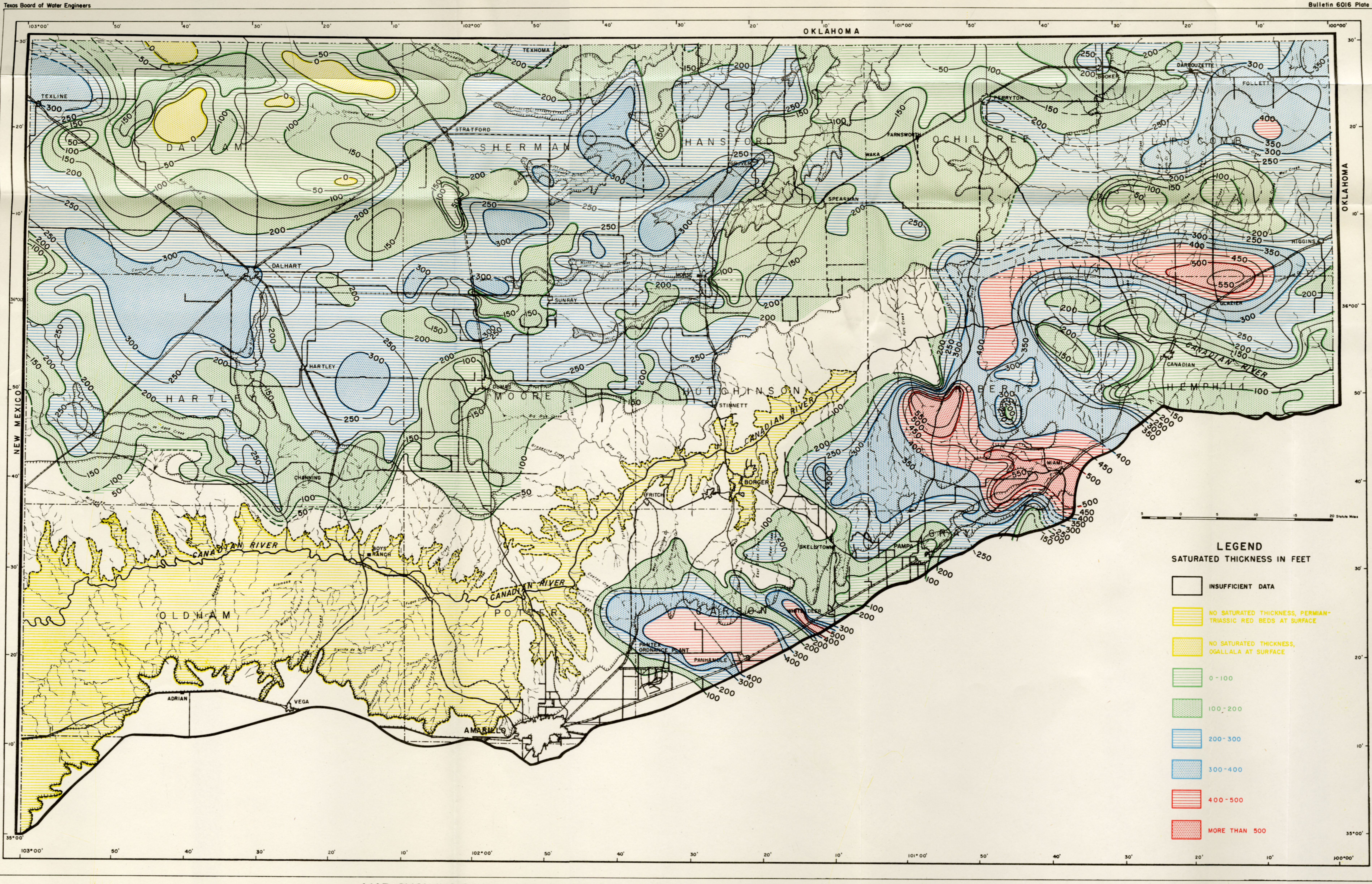
GEOLOGIC MAP SHOWING BOUNDARIES OF UNDERGROUND WATER CONSERVATION DISTRICTS, AND LOCATION OF MUNICIPAL, INDUSTRIAL AND IRRIGATION WELLS, CANADIAN RIVER BASIN, TEXAS

MAP SHOWING DEPTH TO WATER BELOW LAND SURFACE, CANADIAN RIVER BASIN, TEXAS 1959



GEOLOGIC SECTION FROM TEXLINE TO FOLLETT



MAP SHOWING SATURATED THICKNESS OF OGALLALA FORMATION, CANADIAN RIVER BASIN, TEXAS