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GEOLOGY AND GROUND-WATER RESOURCES OF CARSON COUNTY AND PART OF GRAY COUNTY, TEXAS, PROGRESS REPORT NO. 1

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United States Department of the Interior
and the
Ground Water Conservation District No. 3,
South of the Canadian River

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GEOLOGY AND GROUND-WATER RESOURCES OF CARSON COUNTY AND PART OF GRAY COUNTY, TEXAS, PROGRESS REPORT NO. 1

ABSTRACT

This is the first report on the progress of an investigation of the geology and ground-water resources of Carson County and part of Gray County, an area of about 1,400 square miles approximately in the center of the Panhandle of Texas. The economy of the area depends largely on ground water.

The climate is characterized by low humidity, a wide range in temperature and precipitation, and occasional windstorms. The flat plains area is typical of the topography of the High Plains region in general. The land surface, forming the topographic divide between the Canadian and Red Rivers, slopes gently eastward. The breaks areas are drained by the two streams.

Almost all the plains area is under cultivation. Irrigation farming began in 1953 as a result of the drought. Industrial development became important after the expansion of the Panhandle oil field in 1926. Natural gas in abundance is a cheap fuel for pumping irrigation wells.

The Ogallala formation of Pliocene age, underlying the plains and part of the breaks, is the principal aquifer. The Ogallala, deposited on older rocks of Triassic and Permian age, is more than 900 feet thick in western Carson County. It consists of sand, silt, clay, and gravel, the thicker sections generally containing more of the coarser material. The water occurs generally under water-table conditions, but in a few places it appears to be under artesian pressure. Sediments of Quaternary age on the surface of the plains and along streams are above the water table in most places and supply practically no water to wells.

Precipitation in Carson and Gray Counties is the source of nearly all of the ground water in the area. A barrier to the movement of ground water in southwestern Carson County and a ground-water divide in eastern Potter County limit the amount of underflow into the area.

The increase in the use of water by industries and cities followed the expansion in industry, the greatest increase being since 1940. The establishment of well fields some distance from cities followed their rapid growth, especially in the last decade.

The rapid development of wells for irrigation during the period 1953-57 was a direct result of the drought. Since 1957, when the drought ended, the use of water for irrigation increased at a slower rate. The total use of ground water for irrigation in 1958 was estimated to be about 35,000 acre-feet. The area irrigated in 1959 was about 64,000 acres, about 12 percent of the irrigable land in Carson and Gray Counties. The total withdrawal of ground water in 1958 for irrigation, municipal, and industrial uses was about 62,900 acre-feet.

Water levels in wells fluctuate in response to artificial and natural causes, discharge by pumping being the major factor. Water-level fluctuations reflect natural recharge and atmospheric pressure changes in some places.

The chemical quality of ground water in the wells sampled is satisfactory for continued irrigation, and most of it meets the recommended standards for public supplies. The water is hard and is softened for some uses. The analyses indicate that Carson County wells yield water of somewhat better quality than those of Gray County, which may be due to the infiltration of oil-field wastes in Gray County or it may be that water in Gray County has been altered by being in contact with more soluble rocks.

The water available for use is represented largely by the amount in storage in the aquifer because the replenishment rate is small compared to the potential rate of withdrawal. Approximately 26 million acre-feet of ground water is in storage in the aquifer, of which about 18 million acre-feet under the plains area is available for irrigation use.

The differences in the performance of wells are due to differences in well construction and development and in the ability of the aquifer to transmit water.

INTRODUCTION

Location

This report describes the geology and ground-water resources of Carson County and part of Gray County, Texas, approximately in the center of the Panhandle of Texas (Figure 1). The report area includes about 1,400 square miles, 1,220 of which lies within the boundary of the Ground Water Conservation District No. 3, South of the Canadian River. The district includes 730 square miles of Carson County and 490 square miles of Gray County.

Purpose and Scope

All the water used for irrigation, industrial, and municipal supplies in the area is obtained from wells. Small amounts of water from streams and springs supply part of the needs of livestock; the rest of the water is obtained from wells. Thus, the economy of the area depends, to a large extent, on ground-water supplies.

The current investigation, which began in June 1957, is being done by the U. S. Geological Survey in cooperation with the Ground Water Conservation District No. 3, South of the Canadian River, and the Texas Board of Water Engineers. The basic objectives of the investigation are to obtain information on the occurrence, availability, development, and quality of ground water. The current report has three main purposes: (1) To describe the progress and results of the cooperative ground-water studies, (2) to furnish up-to-date information on the development and availability of ground water, and (3) to describe the areas and problems that need future study.

The investigation is under the administrative supervision of A. N. Sayre and P. E. LaMoreaux, successive chiefs of the Ground Water Branch of the U. S. Geological Survey, and under the immediate supervision of R. W. Sundstrom, district engineer in charge of ground-water investigations in Texas.

Previous Investigations

Johnson (1901, 1902) made the first studies of ground water in the High Plains, and Gould (1906) made the first studies of the geology and ground-water resources of the Texas Panhandle. Baker's (1915) report on the geology and ground water of the northern Llano Estacado included the area studied in this report. Theis, Burleigh, and Waite (1935) made a ground-water reconnaissance of the High Plains in 1933-34.

Since 1936, the U. S. Geological Survey in cooperation with the Texas Board of Water Engineers has carried on studies of the occurrence of ground water in the High Plains of Texas, the work being concentrated in the heavily irrigated areas. This work has resulted in a series of progress reports, one of the most comprehensive of which is the report by Barnes and others (1949). The work since 1936 also has included inventories of water wells and measurements of water levels in observation wells. A report by Adair (1939) contains measurements of water levels, well logs, water analyses, records of springs, and a map showing

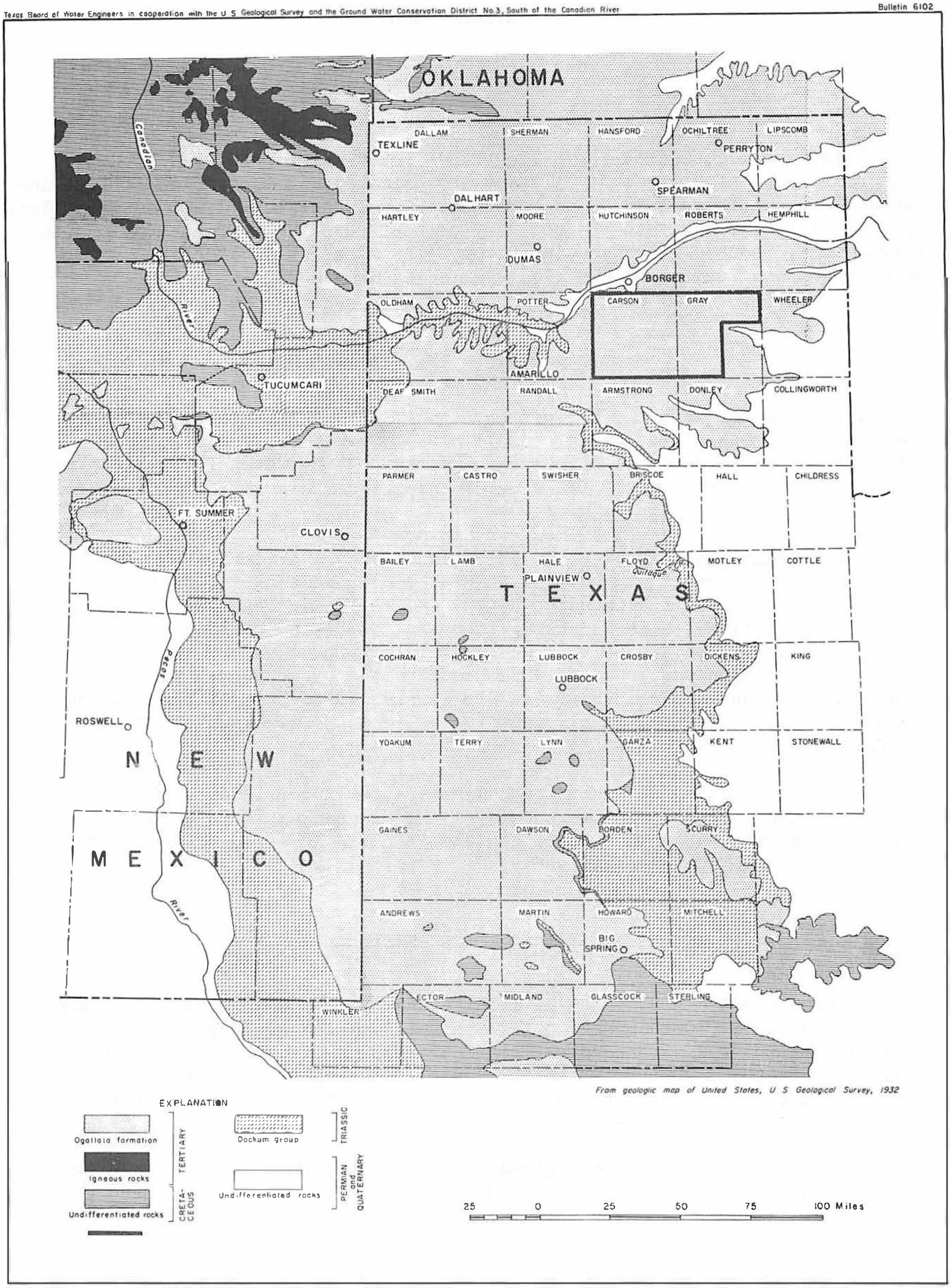

FIGURE I. - Geologic map of the High Plains in Texas and adjacent areas showing location of area discussed in this report well locations in Carson County. Water-level measurements made in Carson County in 1939-40 were published by the U. S. Geological Survey (1939, 1940), and water-level measurements made in 1958 and 1959 were included in a report by Rayner (1959). The water-level measurements made in Carson and Gray Counties during the period 1956-60 were published by the Ground Water Conservation District No. 3, South of the Canadian River (1958, 1959, 1960).

Carson and Gray Counties are included in the report on public-water supplies in western Texas by Broadhurst and others (1951, p. 21-23, 77-80). The report includes chemical analyses of the water and data on the amount of water used at Groom, Panhandle, Skellytown, and White Deer in Carson County, and Lefors, McLean, and Pampa in Gray County. Gard (1958) described the ground-water conditions in Carson County.

Reports on areas adjacent to Carson County were prepared by Moulder and Frazor (1957) on artificial-recharge experiments near Amarillo and by Alexander and Dante (1946) on the ground-water resources of the area southwest of Amarillo.

The Texas Board of Water Engineers (1960) published in cooperation with the Geological Survey a reconnaissance of the ground-water resources of the Canadian River basin in Texas, which includes about half of the Carson and Gray county area. The northwestern part of Gray County and all of Carson County, except the southeastern part, lie in the Canadian River basin. Maps were prepared showing the locations of the irrigation, industrial, and municipal wells, the thickness of material saturated with fresh water, and the depth to water in the irrigable areas. Estimates were made of the volume of water pumped during 1958 and the volume of water available from storage in 1958. Part of this information has been incorporated in this report.

Acknowledgments

Appreciation is expressed for the personal assistance given during the investigation by Mr. F. W. Ryals, manager, and other officials of the Ground Water Conservation District No. 3, South of the Canadian River. Most of the information on irrigation wells was obtained from the well logs and other data supplied to the water district by the drillers and pump companies. Mr. H. H. Heiskell of Pampa, Texas, supplied the logs of numerous water wells. Logs of oil and gas wells and information on the geologic formations were obtained from oil companies and well-logging companies.

Acknowledgment also is made for data furnished by officials of the cities, the industries, and the State and Federal agencies, especially the Soil Conservation Service of the U. S. Department of Agriculture and the county agricultural agents.

GEOGRAPHY

Climate

The climate of Carson and Gray Counties is typical of that of the Texas High Plains. It is characterized by low humidity, a wide range in temperature and precipitation, and occasional windstorms. Precipitation varies widely within short distances and times. Heavy rains within a short time are common; thus, rainfall records may show adequate total amounts of rainfall during a year in which crops were damaged by a drought of several months.

The climate, as indicated by records collected continuously since 1905 at Amarillo, Texas, is typical of the climate in Carson and Gray Counties (figure 2). The long-term mean annual precipitation at Amarillo is 21.12 inches. Most of the precipitation falls during the growing season, which normally averages about 200 days, starting in mid-April and extending to the first part of November. A part of the precipitation in winter is snow, the snowfall averaging 18.7 inches annually. Precipitation at Amarillo varies widely from year to year, having ranged from nearly 40 inches in 1923 to slightly less than 10 inches in 1956. Most rain falls during local thundershowers.

The mean annual temperature at Amarillo is 57°F. The monthly mean ranges from a low in January of 35°F to a high in July of 78°F. The temperature range during the day commonly is as much as 30°F. The maximum recorded temperature at Amarillo was 108°F in June 1953 and the lowest was minus 16°F in February 1899.

The high summer temperatures, low humidity, and strong winds cause a high rate of evaporation. The evaporation from a free water surface based on observations in a Young screen-type evaporation pan at Amarillo averaged 86 inches per year for the 9-year period, 1951-59.

Topography and Drainage

Carson and Gray Counties are in the Southern High Plains, or Llano Estacado, which is the most southern part of the High Plains section of the Great Plains physiographic province. The report area is a peninsulalike arm of the Southern High Plains, extending northeastward from the city of Amarillo and forming the topographic divide between the Canadian and Red Rivers (figure 1). The two types of topography in the area are the relatively flat upland or plains and the eroded, rolling breaks. The plains area, about 900 square miles, slopes eastward about 10 feet per mile and is poorly drained. The breaks area, about 500 square miles, is drained by the tributaries of the Canadian River in northern Carson County and part of northern Gray County and tributaries of the Red River in part of southern Carson County and southern Gray County. The runoff from the breaks contributes flow to these streams, whereas, the plains area contributes practically none. Nearly all the precipitation on the plains is evaporated, absorbed by the soil, or collects in the many playa lakes scattered throughout the area.

Many of the playa lakes are in large depressions several miles in diameter and as much as 60 feet in depth below the general level of the plains. Some of the depressions contain several small saucer-shaped lakes. Many lakes appear to be parts of established drainage systems; in fact, the position of the streams in the plains is probably largely determined by the position of the lakes. This is particularly well demonstrated in the upper reaches of McClellan Creek in southern Carson County.

Smaller playa lakes, known as "buffalo wallows," are common in the plains areas but are not present in the large depressions. These small depressions may be only a foot or less in depth below the general level of the plains.

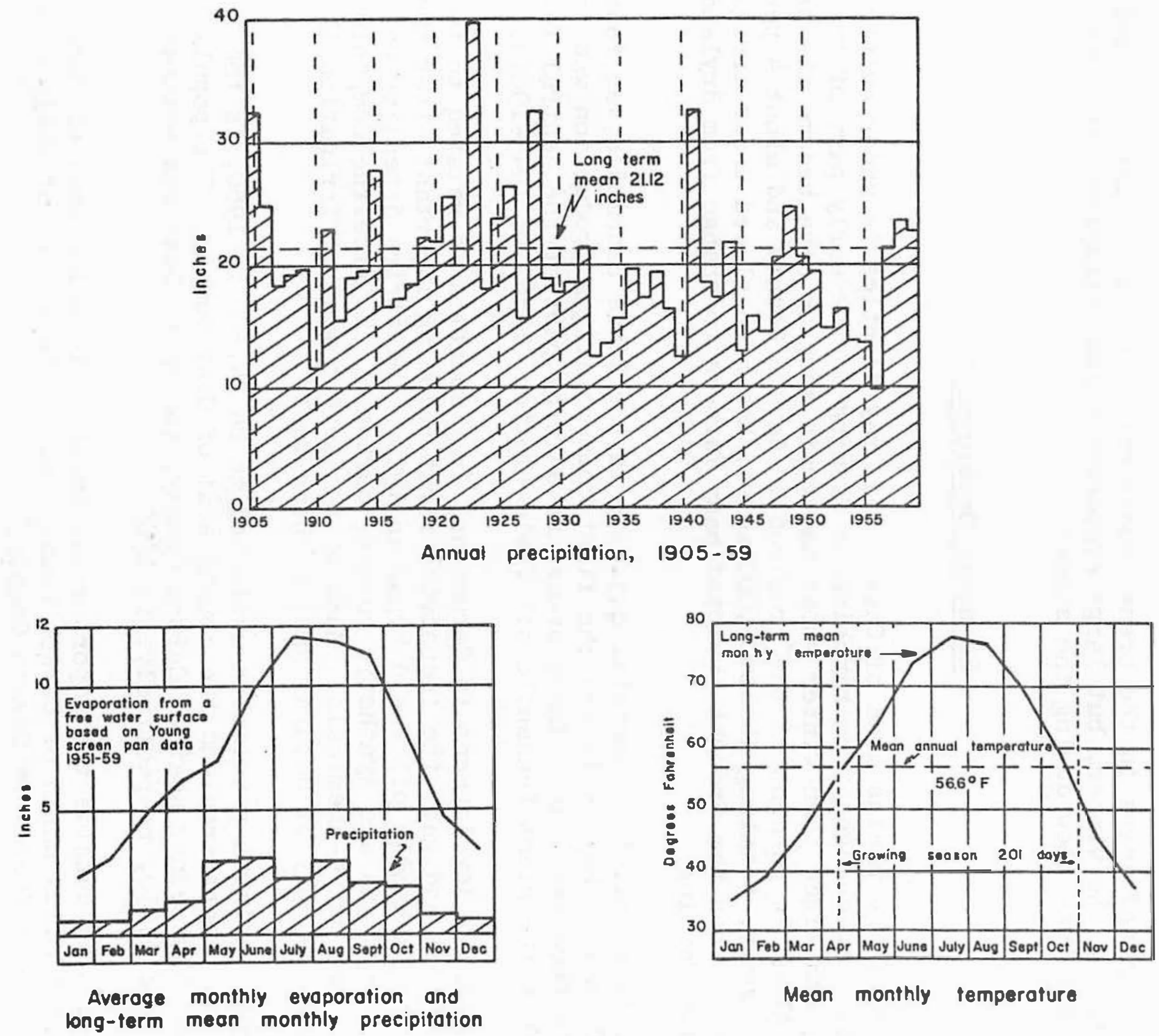

FIGURE 2. - Precipitation, temperature, and evaporation at Amarillo

(From records of the U.S. Weather Bureau and Texas Board of Water Engineers)

According to L. L. Jacquot of the Soil Conservation Service of the Department of Agriculture (personal communication, 1959), the total area in lake-bottom soil in Carson County is 16,860 acres, or about 2.9 percent of the county. Studies of aerial photographs and partly completed soil maps of the Soil Conservation Service in Gray County indicate that the area in lake-bottom soils in Gray County is about 5,000 acres.

The altitude of the land surface in Carson and Gray Counties ranges from a high in western Carson County of 3,596 feet above mean sea level to a low of about 2,800 feet in the valley of the North Fork of the Red River near Lefors.

Springs and seeps in the breaks contribute flow to the Canadian and Red Rivers during the winter, but large evaporation and transpiration losses consume most of the base flow during the summer.

Economic Development

Most of the plains area of Carson and Gray Counties is under cultivation. The landowners changed from ranching to farming in the early part of the 20th century, and since then winter wheat and grain sorghum have become the principal crops. About 14 percent of the cropland in Carson County and about 4 percent in Gray County, totaling about 65,000 acres, has been placed under irrigation since 1953, when the drought prompted many farmers to change from dryland to irrigation farming.

The first oil in commercial quantity in the Texas Panhandle was found in Carson County in May 1921, and the first commercial gas production was in Potter County in December 1918. These areas and a large part of the central Texas Panhandle form the giant Panhandle oil field (Totten, 1956, p. 1945-1967).

Industrial development in Carson and Gray Counties is related to the production of oil and gas, the industries first becoming important after the expansion of the Panhandle oil field began in 1926. Industries depending on the supply of oil and gas are synthetic rubber, carbon black, pipeline companies, refineries, and petro-chemicals. Much of the development of irrigation is due to the abundant supply of natural gas, a cheap fuel.

Pampa, having a population estimated to be 24,500 in 1960, is the largest city in the report area and the county seat of Gray County. The population of Panhandle, the county seat of Carson County, and White Deer was estimated to be 1,900 and 1,050, respectively, in 1960.

The cities outside the report area, Amarillo 10 miles west of Carson County, and Borger 5 miles north of Carson County, each obtain part of their water supplies from well fields in Carson County.

The Carson and Gray county area is served by three railroads: the Panhandle and Santa Fe, the Chicago, Rock Island, and Pacific, and the Fort Worth and Denver. Two transcontinental highways, U. S. Highways 60 and 66, and a commercial airport at Pampa serve the area.

Ground Water Conservation District

The Ground Water Conservation District No. 3, South of the Canadian River includes 730 square miles in Carson County and 490 square miles in Gray County. The district was organized in May 1955 and validated by the State Legislature in 1957. The general nature of the work of the district is the conservation of ground water within the boundaries of the district.

The landowners in the district are represented by five elected officials, all members of the board of directors, and regular meetings are held at the district's office in White Deer. The district employs a manager and is active in its work. It promotes the efficient development of its water resources by requiring that large-capacity wells be spaced according to the sizes of the pumps. The district's records of well-completion data, well logs, and well measurements are important sources of information on its ground-water resources.

Well-Numbering System

The wells for which records are available in the Carson and Gray county area are numbered according to their location within the county. Each county has been divided into quadrangles encompassing 10 minutes of latitude and longitude. The quadrangles are lettered alphabetically beginning in the northwest corner of each county. The wells are numbered consecutively within each quadrangle, beginning in the northwest part of the quadrangle. For example, Carson County well B-1 would be in the northwest part of quadrangle B in Carson County. Figure 3 shows the location of public supply, industrial, and irrigation wells, and other wells used for various types of control. All the wells for which records are available are numbered; however, only those used in the preparation of this report are shown on figure 3.

GENERAL GEOLOGY

The entire plains area in Carson and Gray Counties is underlain by the Ogallala formation of Pliocene age, and much of the surface of the plains is composed of sediments of Pleistocene and Recent age. Most of the breaks area is composed of outcrops of the Ogallala formation, although older rocks of Permian age crop out in northern Carson County and in the tributaries to the Red River in central and southeastern Gray County. Rocks of Triassic age underlie the Ogallala formation in southwestern Carson County and crop out in the Prairie Dog Town Fork of the Red River in Armstrong County and in the Canadian River Canyon in Potter County (figure 1). Where the Permian and Triassic rocks are not differentiated in this report, they are collectively called red beds. Figure 4 shows the relation of the Ogallala formation to the red beds of Permian and Triassic age. Table 1 summarizes the characteristics of the geologic units.

The major geologic structures underlying Carson and Gray Counties are the Amarillo uplift, which trends northwest through Gray and northern Carson Counties, and the western Anadarko basin in northeastern Gray County. The relatively thin section of Ogallala formation in northern Carson County is probably at least in part related to the underlying Amarillo uplift.

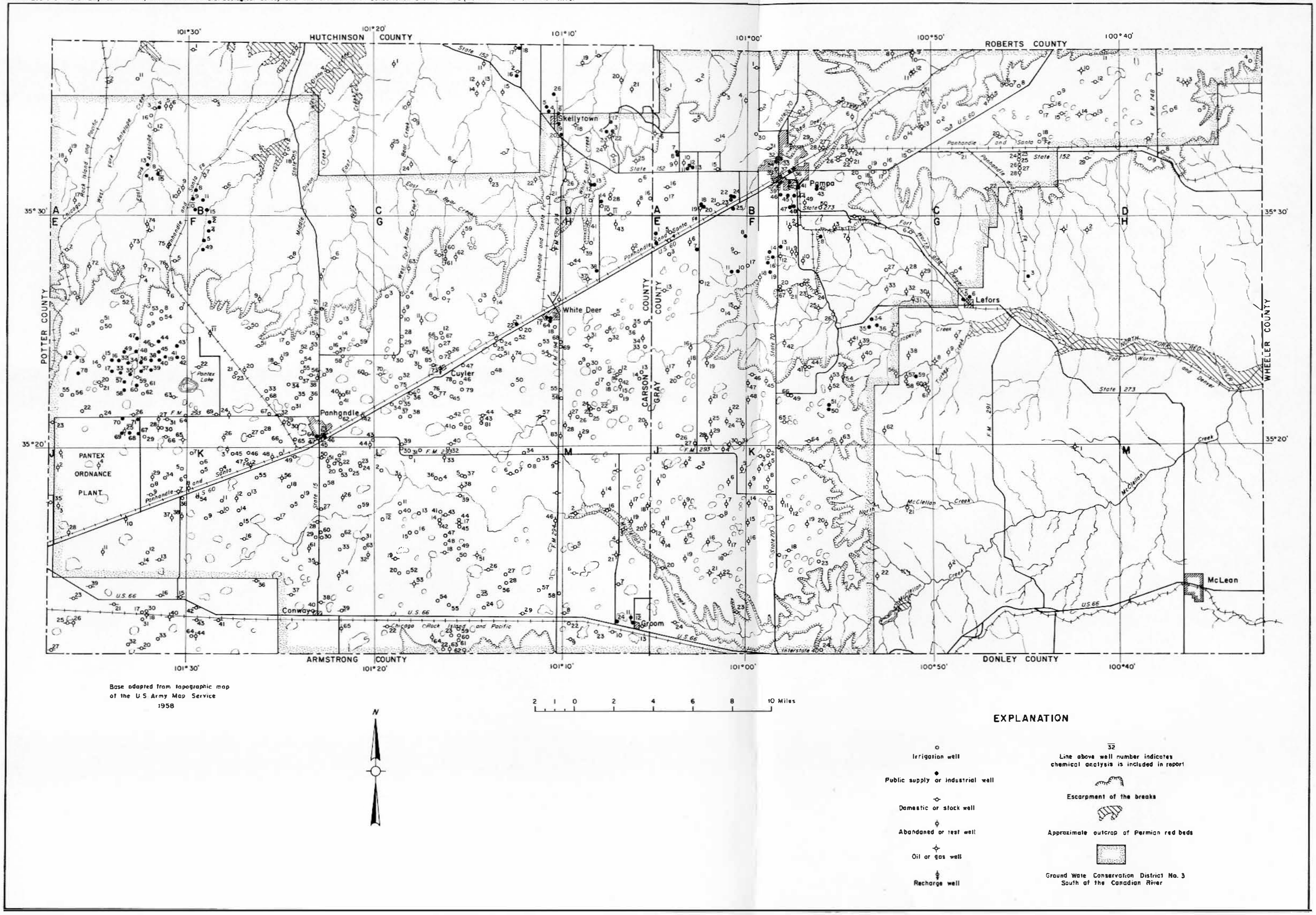

FIGURE 3. - Map showing location of selected wells, Carson and Gray Counties

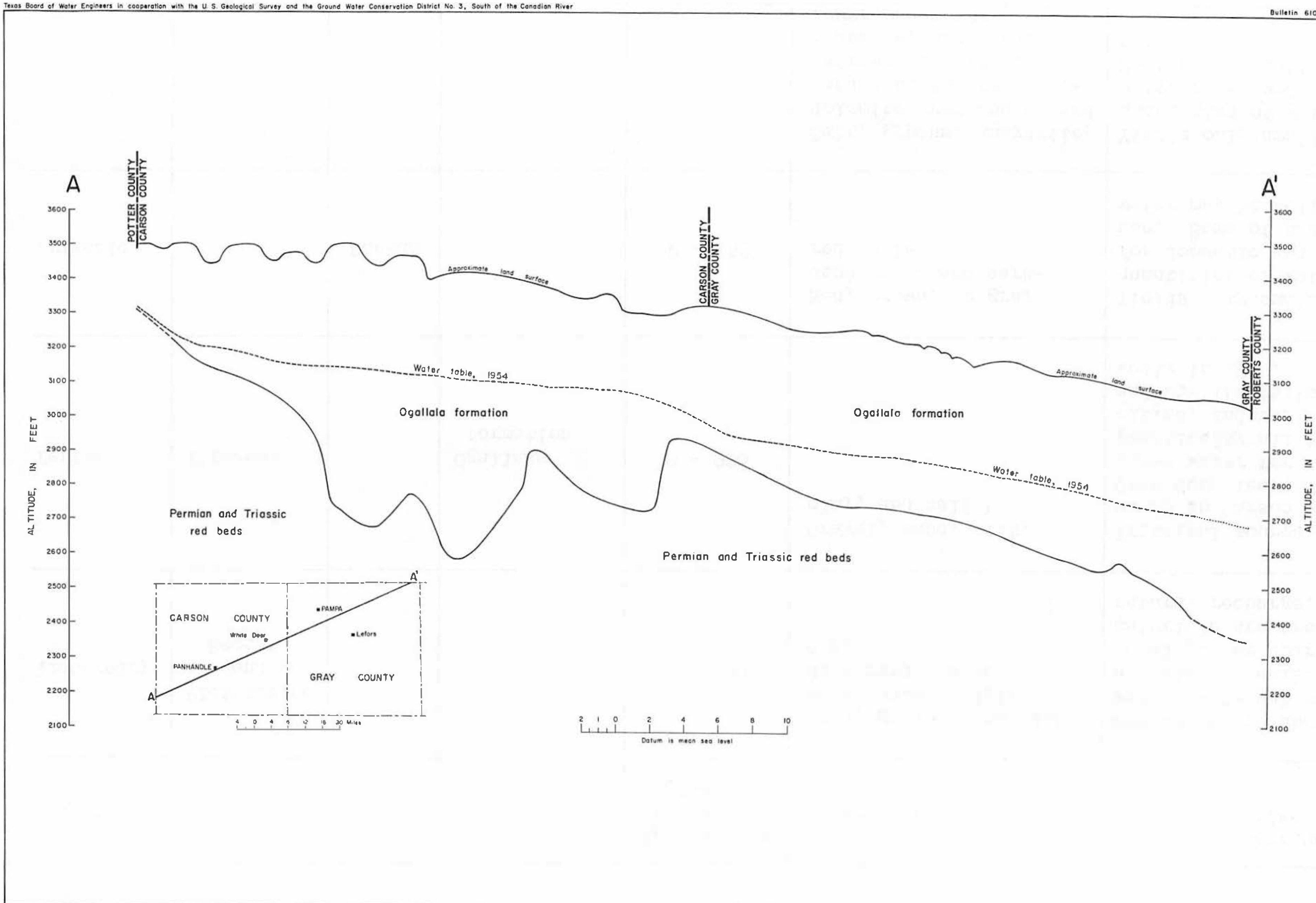

FIGURE 4. - Geologic section A-A', Carson and Gray Counties

Table 1.--Geologic formations and their water-bearing properties, Carson and Gray Counties

System	Series	Group	Stratigraphic unit	Approximate thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Pleistocene and Recent			0 - 40	Sand, gravel, and clay of alluvial origin; dune sand and lake clay	Sediments are above water table and supply no water to wells. Locally, the coarser materials are areas of natural recharge.
Tertiary	Pliocene		Ogallala formation	0 - 928	Gravel, sand, silt, clay, and caliche	Principal source of water in Carson and Gray Counties. Supplies water for practically all the cities, industries, and 252 irrigation wells in 1959.
Triassic		Dockum		0 - 252	Red, brown, or gray sandstone, and dark-red shale	Yields only small quantities of water for domestic and stock use. Some of the water may be saline.
Permian				2,000+	Salt, gypsum, anhydrite, dolomite, red shale, and sandstone in upper two-thirds; limestone, dolomite, and shale in lower one-third	Yields only small quantities of water to a few stock wells. Most of the water is saline.

Minor geologic structural features in the area include a basin in the red-bed surface in Carson County and a red-bed ridge in southwestern Carson County. The minor features are shown on the geologic section (figure 4) by an increase in thickness of the Ogallala formation in the basin and a decrease over the red-bed ridge. The presence of Triassic rocks on a protuberance in the basin indicates that the basin was formed at least in part by structural deformation, although it was no doubt modified by pre-Ogallala erosion.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Permian System

The Permian rocks, the oldest exposed in Carson and Gray Counties, crop out in northern Carson County and in central and southeastern Gray County. The thickness of the Permian strata was not definitely determined; however, it probably is not less than 2,000 feet anywhere in Carson and Gray Counties. The upper two-thirds of the Permian rocks consist of salt, gypsum, anhydrite, dolomite, red shale, and sandstone; the lower one-third is composed of limestone, dolomite, and shale. The Alibates lentil of the Quartermaster formation, a resistant bed of dolomite, forms a prominent marker, which is easily recognized in the subsurface throughout the area.

The Permian rocks yield only small quantities of water to a few stock wells in the Carson and Gray county area, and most of the water is saline.

Triassic System

The Dockum group, generally considered to be Late Triassic in age, lies unconformably on Permian rocks in southwestern Carson County; elsewhere in the report area, Triassic rocks are probably absent. The Triassic rocks consist of sandstone and shale; the sandstone is red, brown, or gray, and the dominant color of the shale is dark red.

Several oil-test wells have been drilled through the Triassic rocks in southwestern Carson County, and a few water wells in the area probably tap Triassic strata. In well J-40, an oil-test well in Carson County, 90 feet of Triassic rock was reported below a depth of 240 feet; and in well K-56, also an oil-test well in Carson County, 252 feet of Triassic rocks was reported below a depth of 711 feet. Several wells in western and southern Carson County are perforated not only opposite the Ogallala formation but also opposite red fresh-water-bearing sands, which may be Triassic in age. One of these, well E-57 owned by the city of Amarillo, yields water from 50 feet of red sand, the top of which is 805 feet below the land surface. The chemical analysis of water from well E-57 (table 4) indicates that the water is typical of that from the Ogallala formation.

In general, Triassic rocks should be expected to yield only small quantities of water to wells, perhaps enough for domestic and stock use. The chemical quality of the water is not definitely known, and some of the water may be saline.

Tertiary System

Ogallala Formation

The Ogallala formation was named for the town of Ogallala, Nebraska, where the formation was first described in 1898 (Darton, 1898, p. 732-742). The Ogallala is of Pliocene age and extends from South Dakota to Texas.

The source of the Ogallala sediments was predominantly in the mountainous region to the west of the plains. Uplift of the mountains and erosion supplied the sediments, which were deposited on the eroded surface east of the mountains. Thus, the plains were built by deposition from the several streams originating in the mountains and flowing eastward and southeastward across the plains. The first Ogallala sediments, mainly coarse sand and gravel, filled the valleys in the bedrock. Later the sediments covered the entire area, the coarser material being deposited in the new stream channels and the finer material in the interstream areas. Since Tertiary time, the Pecos and Canadian Rivers in New Mexico and Texas have cut through the Ogallala formation into the underlying older rock, removing the Ogallala from the area between the High Plains and the mountainous areas to the west. Headward erosion by tributaries of the Red and Brazos Rivers has formed an irregular escarpment at the eastern edge of the Southern High Plains. Thus, the Southern High Plains remnant of the Ogallala formation now stands above the areas to the east and west, isolated geologically and hydrologically from the Rocky Mountains.

The Ogallala formation consists of light-colored sand, silt, clay, and gravel. A white calcareous material called caliche generally is found near the top of the formation, although it has been reported in well logs throughout the formation. The formation is thicker in the old valleys cut into the red-bed surface, the thickness ranging from 0 at the Permian outcrop areas to 928 feet in well E-45 in western Carson County.

The sediments in the Ogallala rapidly change in character both laterally and vertically because they were deposited in the main by braiding streams. The coarser materials generally are in the lower part of the formation.

The Ogallala formation is the principal source of ground water in Carson and Gray Counties. The formation supplies water for practically all the cities and industries and for the 252 irrigation wells in operation in 1959. The average yield of 23 irrigation wells measured in 1959 was 615 gpm (gallons per minute), this figure probably being representative of the yields of the large-capacity wells pumping from the Ogallala formation in Carson and Gray Counties. The volume of water pumped during 1958 for irrigation, industrial, and municipal uses in the area investigated was estimated to be about 63,000 acre-feet.

Quaternary System

Pleistocene and Recent Series

The Pleistocene and Recent sediments of the Texas High Plains have been classified by Evans and Meade (1944, p. 486) into three types: (1) lake or pond deposits, (2) stream-valley deposits, and (3) wind deposits. The lake or pond deposits are predominantly nearly impermeable clay, which retards the infiltration of surface water. The sand and gravel of the stream-valley deposits and the sandy areas of the dunes are locally important as areas favorable to the natural recharge of ground-water reservoirs. Sand dunes are located only in the breaks areas in north-central Carson County and southeastern Gray County. Although the dunes overlie the Ogallala formation in these areas, they are topographically lower than the irrigated areas and, consequently, water recharged in these areas is not available to irrigation wells.

The Pleistocene and Recent sediments in Carson and Gray Counties are thin; nowhere do they exceed about 40 feet in thickness. The sediments are above the water table in practically the entire area and yield no water to wells.

OCCURRENCE OF GROUND WATER

The Ogallala formation is the principal water-bearing formation in Carson and Gray Counties. Regionally, ground water occurs in the Ogallala under unconfined or water-table conditions. Locally, the water may be confined beneath relatively impermeable material and occur under artesian conditions. Under such conditions, the water will rise in wells above the level at which it is confined.

The configuration of the water table, the top of the saturated material, in Carson and Gray Counties is shown by a contour map (figure 5). This map is based on measurements of the static water level, the depth to the top of the water table, which ranges from a few feet in wells along the streams in the breaks areas to more than 400 feet in wells on the plains area in western Carson County (figure 6). The depth to the base of the Ogallala formation may be estimated by comparing the saturated-thickness map (figure 11) with the depth to water map (figure 6).

In some parts of Carson and Gray Counties, water is trapped above layers of impervious rocks well above the general water table in the Ogallala formation, thus forming perched water bodies. These perched water bodies are of local extent and should not be considered as dependable sources of large supplies of water. Well E-26, used for watering stock in Carson County, and abandoned well A-9 in Gray County were developed in perched water bodies.

The saturated part of the Ogallala formation extends well beyond the limits of Carson and Gray Counties, except in northwestern Carson County and in parts of south-central Gray County where outcrops of Permian red beds limit the extent of the reservoir. A partial barrier of red beds in the subsurface projects above the water table in at least two points in the southwestern part of Carson County and extends northwestward into Potter County and southeastward into Armstrong County. The narrow spacing of the contours on the water-table map (figure 5) reflects the thinness of the Ogallala over the barrier.

Source of Ground Water

Precipitation on the plains is the source of all the water in the saturated part of the Ogallala formation. Recharge to the ground-water reservoir is contributed from the report area and small parts of Potter and Armstrong Counties. A ground-water divide a few miles west of and parallel to the Potter-Carson County line prevents underground movement of substantial amounts of water into the report area from the west.

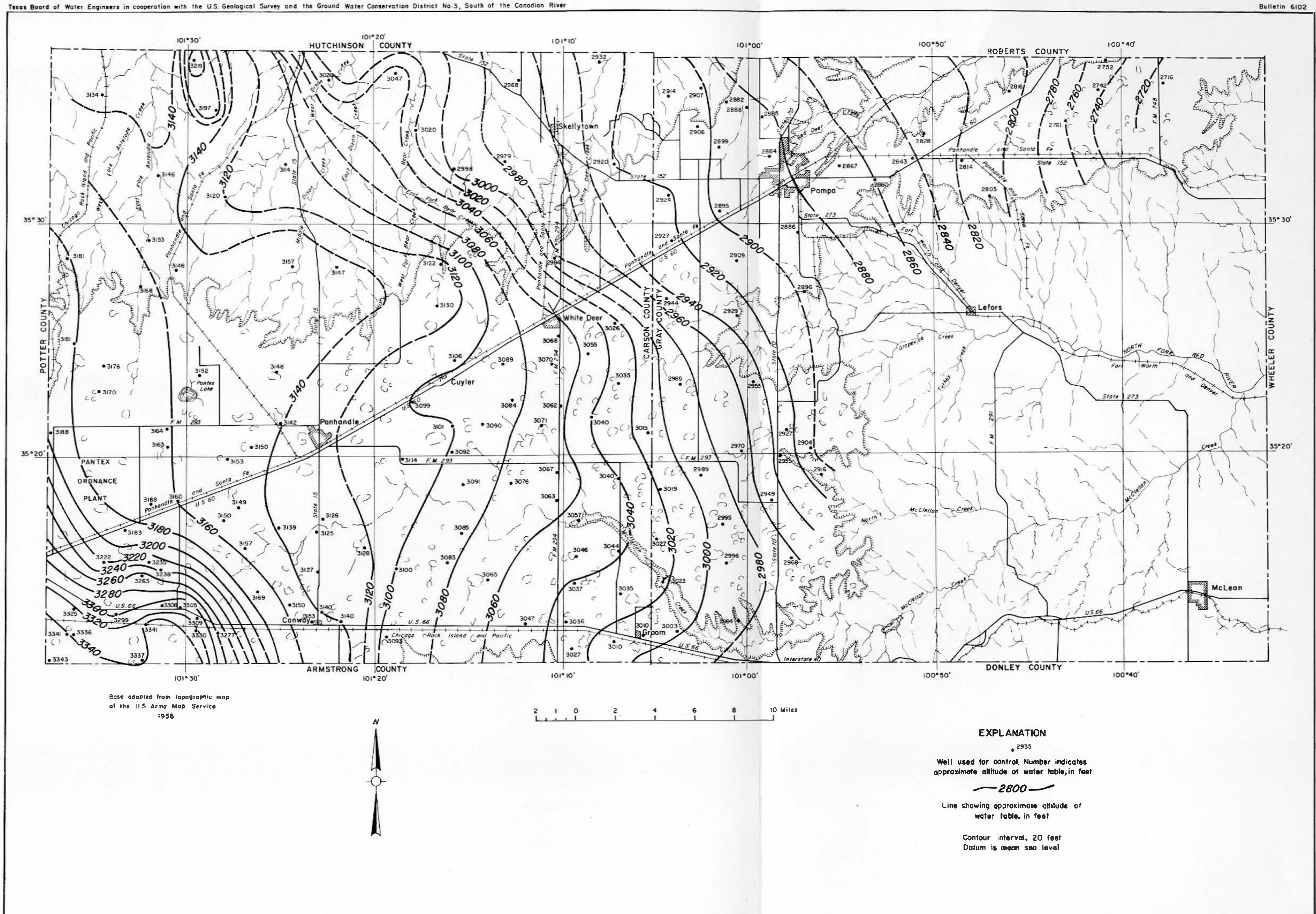

FIGURE 5. - Approximate altitude of water table, Carson County and part of Gray County, 1954

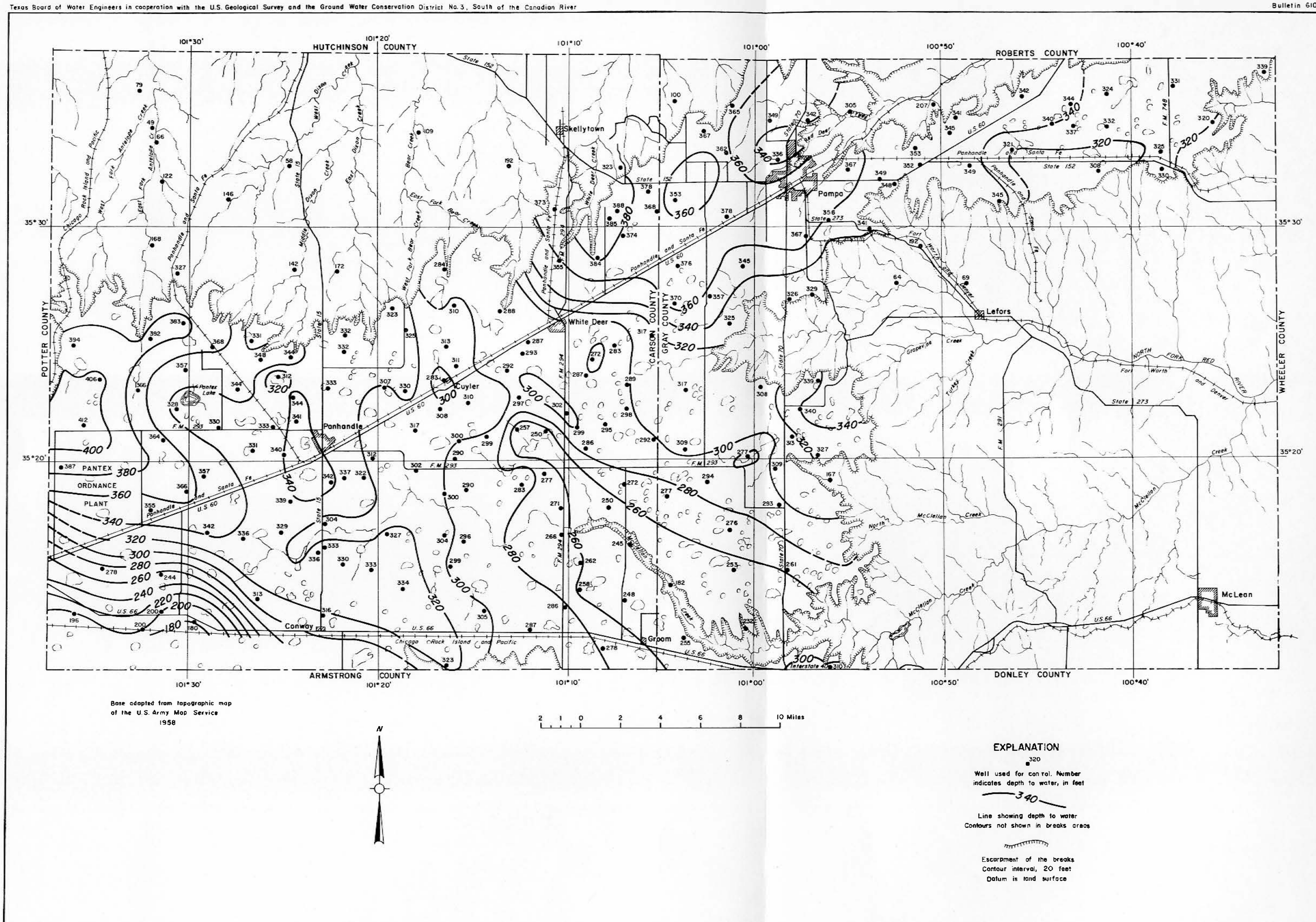

FIGURE 6. - Depth to water below land surface, Carson and Gray Counties, 1959-60

Most of the surface of the plains in Carson and Gray Counties is composed of relatively impermeable clay loam. The amount of precipitation that percolates through the soil and reaches the water table is small, probably half an inch or less per year. The large amount of water in storage in the ground-water reservoir is the result of slow accumulation over a long period of time.

The areas where the opportunities for recharge are most favorable are those where the soil is most permeable and where runoff accumulates in topographic lows. The small drainageways cut into the Ogallala formation are favorable areas of recharge, as indicated by rises in water levels in wells near streams after periods of streamflow. The effectiveness of streams as recharge facilities is further indicated by the slight ridge on the water table beneath Mc Clellan Creek in southeastern Carson and southwestern Gray Counties (figure 5). Runoff apparently infiltrates the sandy material forming the bottoms of the drainageways.

Further study is needed to determine if lakes contribute substantially to recharge in Carson and Gray Counties. The relatively impermeable silt forming the bottoms of the lakes may prevent nearly all the water from percolating into the ground. Meager records of water levels in observation wells near lakes have not shown appreciable recharge from the lakes.

Deposits of caliche within a few feet of the land surface throughout a large part of Carson and Gray Counties tend to retard the downward percolation of water, and most of the water held near the surface is ultimately consumed by evaporation or transpired by plants.

Movement of Ground Water

The movement of ground water is related to rates of recharge and discharge and the permeability of the aquifer. Ground water moves slowly from areas of recharge toward areas of discharge. Under natural conditions, water in the Ogallala formation probably moves only a few inches a day in the direction of the greatest slope of the water table. The points of natural discharge in the Carson-Gray county area are the springs and seeps in the breaks of the Canadian and Red River basins. Therefore, as shown in figure 5, ground water in the northern part of the report area moves generally northeastward toward discharge areas in the Canadian River basin. In the south-central and southeastern parts of the report area it moves more toward the east and southeast toward discharge areas in the Red River basin.

Before large amounts of water were withdrawn from the aquifer by pumping, the long-term rate of natural discharge was equal to the rate of recharge, and, consequently, the water in storage was in a state of equilibrium. When the discharge from the aquifer was materially increased by pumping, water was taken from storage in the vicinity of the pumped wells, and water levels declined in the vicinity. As the artificial discharge from the aquifer increases, the declining water levels will spread and ultimately will cause a decrease in natural discharge.

USE OF GROUND WATER

When the Carson-Gray County area was first being explored and settled, the only dependable supplies of water were the springs in the breaks below the escarpments. The campsites for early exploratory expeditions and the ruins of the Indian villages were near springs or flowing streams. The early ranchers likewise depended upon the springs for stock water.

The use of ground water largely began after the advent of the railroads in about 1886, which, in turn, stimulated the growth of towns. Ground water in Carson and Gray Counties prior to the 1920's was used principally for municipal, domestic, and stock supplies, and to supply the steam locomotives.

Industrial development in the area began about 1926 as a result of the oil and gas production in the Panhandle oil field. Since 1926, many of the original industrial wells have been replaced by larger ones, and new wells have been added. The greatest expansion in the use of water for industry was from 1940 to 1950, when about 40 percent of the wells currently in use were drilled. Since 1950, the number of industrial wells has increased more slowly until in 1960, 59 were in use in the area.

The growth of cities and their use of water has been similar to that of industry except that the greatest period of expansion has been since 1950. The establishment of the city of Amarillo well field in western Carson County and the drilling of 10 new wells for the city of Pampa have increased the number of municipal wells in operation to 57 in 1960.

Practically all the development of wells used for irrigation was a direct result of the drought, which began in 1952, only two wells having been drilled for irrigation in the area prior to 1952. The relatively great depth to water was probably a deterrent to irrigation development before the drought. The major development of irrigation began in 1953 and reached its peak in 1955, when 107 wells were put into use (figure 7). Since 1956, the number of irrigation wells has increased at a lower rate.

In 1959 there were 252 irrigation wells in use in the area; of this number, 216 were in Carson County. Based on an inventory of 203 irrigated farms in Carson County and 34 in Gray County, the average area irrigated per well was 265 acres in Carson County and 198 in Gray County. On this basis, the total area irrigated in 1959 was 64,000 acres, or about 12 percent of the irrigable land in the report area.

The total use of ground water for irrigation in the Carson-Gray County area in 1958, based on measurements of the use from about 10 percent of the irrigation wells, was estimated to be about 35,000 acre-feet. The use of water averaged about 0.6 acre-foot per acre of irrigated land and about 156 acre-feet per well.

The amount of water pumped annually for irrigation is related to the annual precipitation. Precipitation from 1957 through 1959 was adequate much of the time, and irrigation was used only to supplement the rainfall. In the spring of 1958, adequate precipitation made irrigation nearly unnecessary. Winter wheat was irrigated from some wells only from May 5 to May 12, when about an inch of rain fell in most of the area. General heavy rains of 6 to 7 inches fell over most of the area on July 3, about the time when large amounts of water usually are required for irrigating grain sorghum. Several more rains fell later in July, and only a few wells were pumped until August 1. A rather intensive period of irrigation began about August 1 and ended on September 10, when about 4 inches of rain fell throughout the area. Some wells were pumped after October 20, when winter wheat was irrigated. Based on the rate of fuel consumption by the wells tested and the total consumption by all wells, the

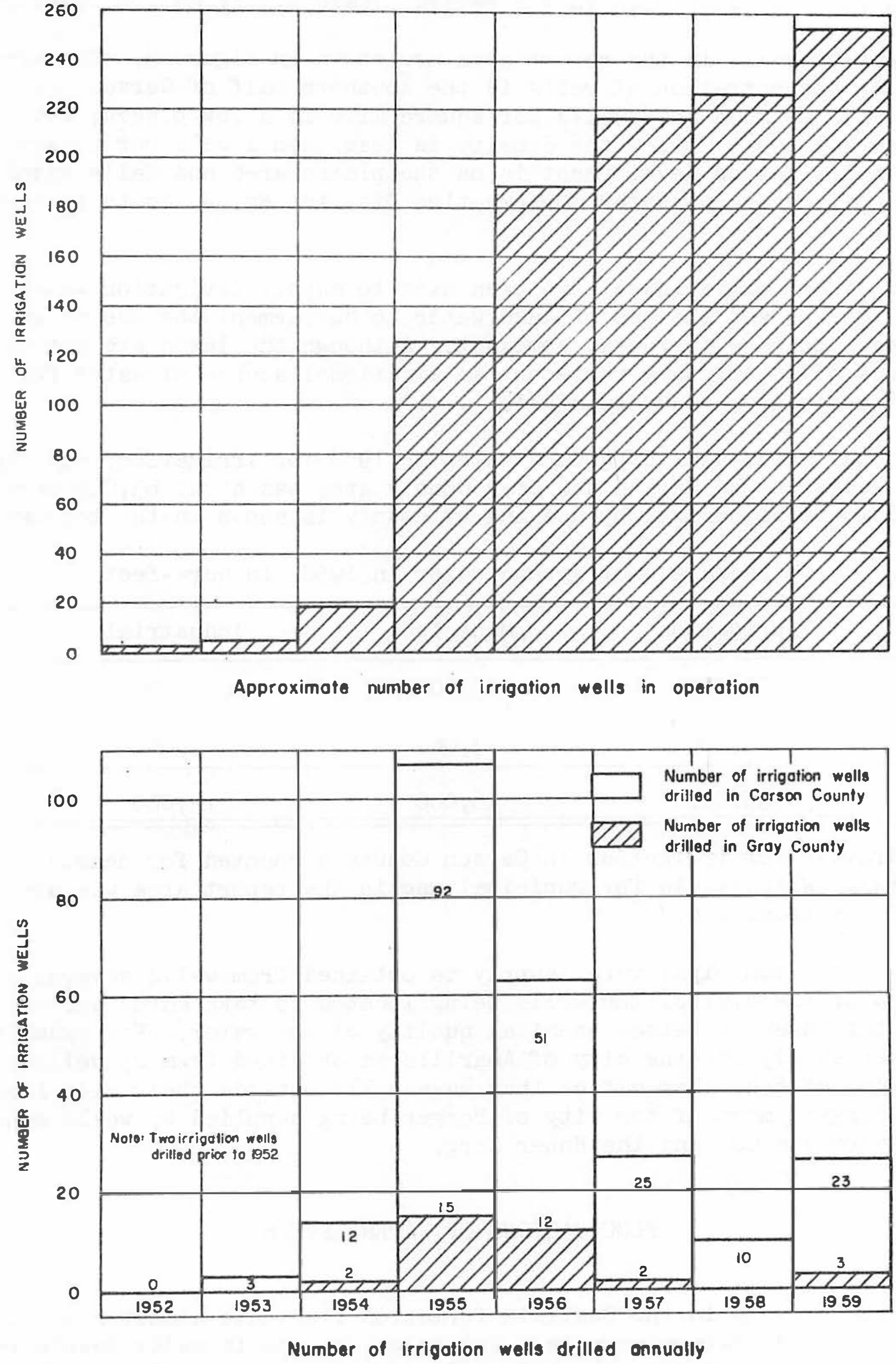

FIGURE 7. - Approximate number of irrigation wells in operation and number of irrigation wells drilled annually in Carson and Gray Counties, 1952-59

average length of time the wells were pumped in 1958 was estimated to be 54 days. Although the water requirement of 0.6 acre-foot per acre is low, it is probably near the average annual rate for the 3-year period 1957-59, when precipitation was considerably greater than in the earlier years of irrigation development.

Irrigation wells in the report area are shown in figure 3. The area having the greatest concentration of wells is the southern half of Carson County, where the density is as much as 3 wells per square mile in a few places; but over an area of several square miles the density is less than 1 well per square mile. Most of the irrigation development is on the plains area and falls within the boundaries of the Ground Water Conservation District No. 3, South of the Canadian River.

A few of the playa lakes have been used to supply irrigation water during the past 2 years, and the use of lake water to supplement the use of ground water appears to have increased somewhat. Although the lakes are not dependable sources of water, they represent an additional source of water for irrigation after periods of heavy rainfall.

The total withdrawal of ground water in 1958 for irrigation, municipal, and industrial uses in the Carson and Gray County area was about 63,000 acre-feet. The breakdown of withdrawal by use and by county is shown in the following table.

Withdrawals of ground water in 1958, in acre-feet

County	Irrigation	Municipal	Industrial	Total
Carson	30,000	13,000	9,000	52,000
Gray	5,000	3,000	3,000	11,000
Total	35,000	16,000	12,000	63,000

Withdrawals for irrigation in Carson County accounted for nearly 50 percent of the total. Withdrawals for municipal use in the report area was about 25 percent of the total use.

Much of the municipal water supply is obtained from wells several miles from the centers of the cities, the wells being located to take advantage of greater saturated thickness or better chemical quality of the water. For example, a part of the water supply for the city of Amarillo is obtained from 25 wells in Carson County. Some of the other cities that have wells outside their city limits are Pampa and Borger, most of the city of Borger being supplied by wells owned by the Phillips Petroleum Co. and the Huber Corp.

FLUCTUATIONS OF WATER LEVELS

The water levels in the Ogallala formation fluctuate almost continuously from artificial and natural causes. The major changes in water levels in the Carson-Gray County area reflect changes in storage in the aquifer. The most easily detected changes are those caused by pumping from wells. Changes in water levels due to natural recharge are shown by rises of water levels in some wells. Minor causes of fluctuations in water levels are variations in atmospheric pressure, tidal fluctuations, earthquakes, and other disturbances.

Daily fluctuations are caused by barometric-pressure changes and perhaps by tidal effects, although these are generally too small to be distinguished from daily barometric effects. Seasonal fluctuations are due to changes in rates of precipitation and evapotranspiration; however, in Carson and Gray Counties, these changes probably are masked by other factors.

Fluctuations of considerable magnitude are caused by pumping, and the effect may be observed at great distances from the pumped wells. Withdrawals of ground water cause cones of depression to form in the water table at centers of pumping. The depth of the cone of depression decreases with distance from the point of discharge. During the period the wells are being pumped, the diameters of the cones expand. When pumping ceases, the cones of depression partly fill by the lateral movement of water, filling rapidly at first, then more slowly.

Heavy pumping in Carson and Gray Counties has not spread sufficiently to affect the water levels in all areas; in fact, table 2 shows that the water levels in some wells remote from areas of heavy pumping have risen during the period of record. However, the water levels in all wells in the heavily pumped areas have declined, reflecting the effects of withdrawals of water from storage (table 3).

The long-term effects of pumping are the continued declines of water levels, as water is removed from storage--the rate of decline being related to the rate of withdrawal of water. The more or less continuous decline of water level due to pumping is well illustrated by the hydrographs of wells F-34 and G-56 in Carson County, which show a decline of about 9 feet during the period August 1954 to January 1957 (figure 8). The rate of decline in these wells probably is typical of those in most of the irrigation wells during the same period of time. The rate of decline during the drought prior to 1957 was considerably greater than that afterward, probably largely because of the decrease in pumping rate during the post-drought period.

Where heavily pumped wells are closely spaced, their cones of depressions may overlap, the pumping lifts may be increased. Figure 9 shows the effect of pumping on the water level in a nonpumping well a quarter of a mile from the pumped well. Similar effects have been observed as far as 1 mile from pumped wells.

Figure 10 shows the fluctuations of water level in Carson County well H-29, and concurrent atmospheric-pressure changes. Similar water-level fluctuations caused by atmospheric-pressure changes were recorded in wells D-8 and F-44 in Carson County. The extent of the areas in which the water levels are noticeably affected by atmospheric changes is undetermined, but in these areas, the water is probably confined by relatively impermeable materials and under artesian pressure and the water levels respond to atmospheric pressure changes.

QUALITY OF GROUND WATER

Ground water contains dissolved minerals, which determine its suitability for various uses. The minerals are dissolved from the rocks through which the water has passed. The rocks which make up the Ogallala formation were deposited by water, and the depositing water removed most of the readily soluble minerals from the rocks, leaving behind the less soluble materials. Ground water in the Ogallala formation in general has had access only to the slightly soluble minerals

Table 2.--Fluctuations of water levels in wells in areas not heavily pumped. (For locations of wells see fig. 3.)

Well	Depth to water, in feet below land surface					Change, in feet	
	1938	1954	1957	1958	1959	1938-1959	1954-1959
Carson County:							
C-7	192.0	191.1		191.0	191.8	+0.2	-0.7
C-9	108.5	110.0		108.4	109.4	-.9	+.6
D-5	335.8	324.4		322.7			
F-6		176.6		174.1	172.4		+4.2
F-8		139.8		141.2	141.7		-1.9
F-11			365.9	366.5	367.6		
G-1	366.5	365.4		360.5	354.9	+11.6	+10.5
G-2	289.7	285.0		285.8	284.2	+5.5	+.8
J-1	385.4	386.4			386.7	-1.3	-.3
J-11		279.5		278.1			
J-13		243.0		243.4	243.6		-.6
J-16		196.9		198.4	199.7		-2.8
J-23		195.5		195.3	195.5		.0
K-38	316.1	318.1		317.4	316.3	-.2	+1.8
K-42		181.0		180.1	179.8		+1.2
L-10		270.1		270.5	270.8		-.7
L-46	267.8			265.7	265.6	+2.2	
M-1	272.3	272.1		273.1	272.3	.0	-.2
M-4		254.6	253.7	253.9	253.3		+1.3
M-14	263		250.3	250.4	250.3	+13	
M-16	217.5		214.2	214.0	213.9	+3.6	

(Continued on next page)

Table 2.--Fluctuations of water levels in wells in areas not heavily pumped--Continued

Well	Depth to water, in feet below land surface					Change, in feet	
	1938	1954	1957	1958	1959	1938-1959	1954-1959
Gray County:							
A-2		307.3		306.6	306.4		+0.9
C-12		324.4		325.1	323.9		+.5
C-22		345.4		345.4	345.3		+.1
D-1		331.5		330.6	330.7		+.8
E-31		276.4		276.9	276.9		-.5
J-8		275.1		275.1	275.5		-.4
J-23		232.9		232.2	232.3		+.6
K-7		168.9		167.6	167.2		+1.7
K-10		293.2	293.9	288.2	293.2		.0
Average change ---						+3.3	+.7

Table 3.--Fluctuations of water levels in wells in
areas of heavy pumping.
(For locations of wells see fig. 3.)

Well	Depth to water, in feet below land surface						Change, in feet	
	1938	1954	1956	1957	1958	1959	1938-1959	1954-1959
Carson County:								
A-8		104.7			116.8	122.0		-17.3
E-1	144.4	163.7			168.0			
E-5		322.7			326.9			
E-11		389.3			393.2	394.4		-5.1
E-15		394.3			404.4	407.7		-13.4
E-46	369.3			375.1	380.5	384.9	-15.6	
E-59	344.6			350.7	355.5	366.3	-21.7	
F-18		304.6			310.4	311.7		-7.1
F-38			317.3	321.4	321.4	323.4		
G-42		293.8		296.5	297.5	298.9		-5.1
G-44		294.0			297.9	298.7		-4.7
G-54		287.8			293.6	294.9		-7.1
G-57		243.2		251.7	247.1	249.7		-6.5
G-65	301.7				307.4	309.8	-8.1	
G-74	278.6			288.2	287.6	292.1	-13.5	
H-5		275.2			278.8	280.5		-5.3
H-16		284.9			296.4	298.1		-13.2
J-9	354.6	353.4			355.1			
L-6	275.1	274.5		277.5	277.2	278.3	-3.2	-3.8
L-17	290.2	290.6			292.6	293.3	-3.1	-2.7

(Continued on next page)

Table 3.--Fluctuations of water levels in wells in areas of heavy pumping--Continued

Well	Depth to water, in feet below land surface						Change, in feet	
	1938	1954	1956	1957	1958	1959	1938-1959	1954-1959
Gray County:								
B-13		335.7			336.3	336.0		-0.3
B-15		350.8			351.7	351.9		-1.1
B-18		341.2			344.9	346.3		-5.1
B-31		335.7			336.3	336.0		-.3
C-6		341.2			343.6			
E-9		340.4			344.4	345.0		-4.6
F-2		364.1			367.0	367.1		-3.0
Average change ---							-10.9	-5.9

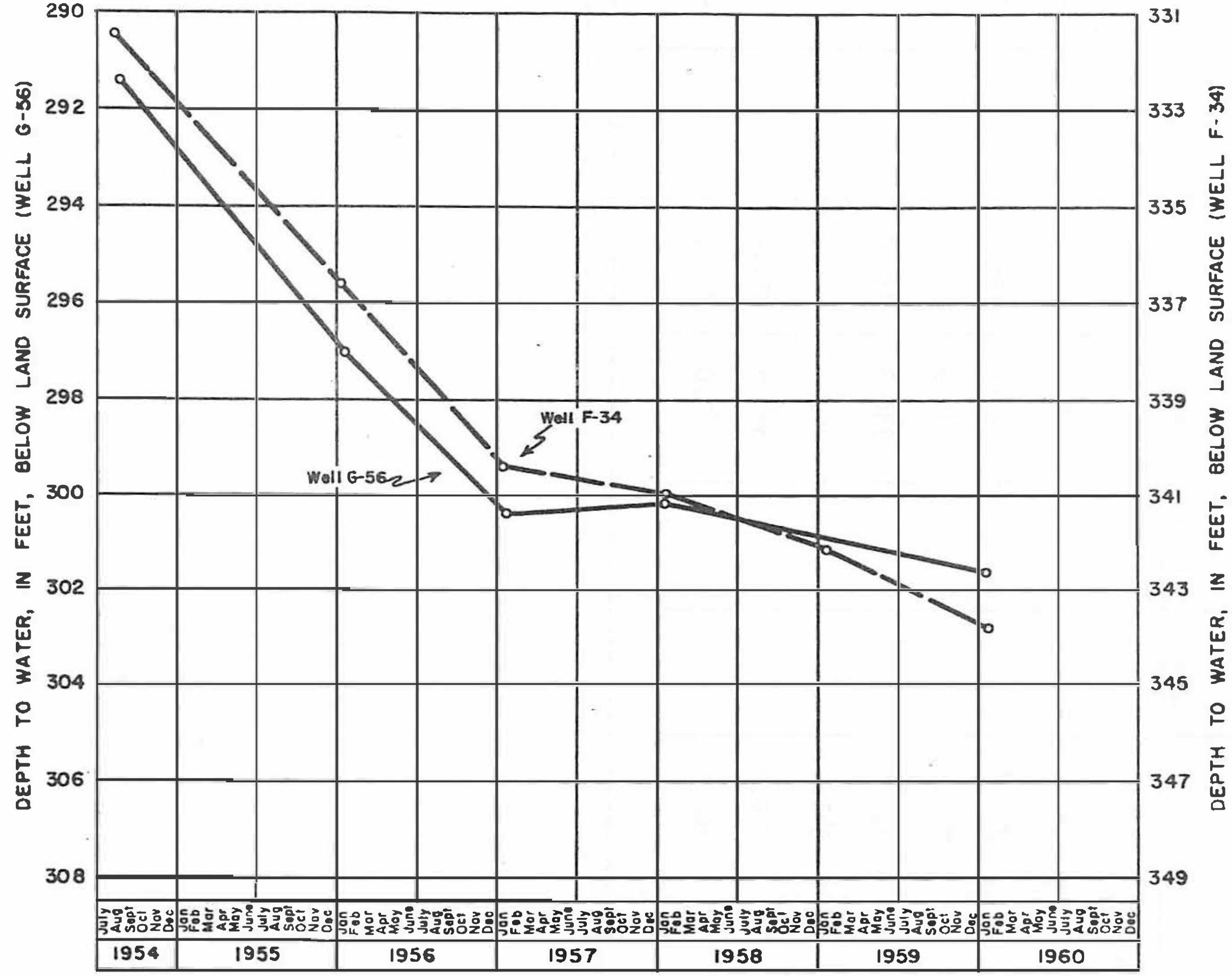

FIGURE 8. - Fluctuations of water levels in wells F-34 and G-56, Carson County

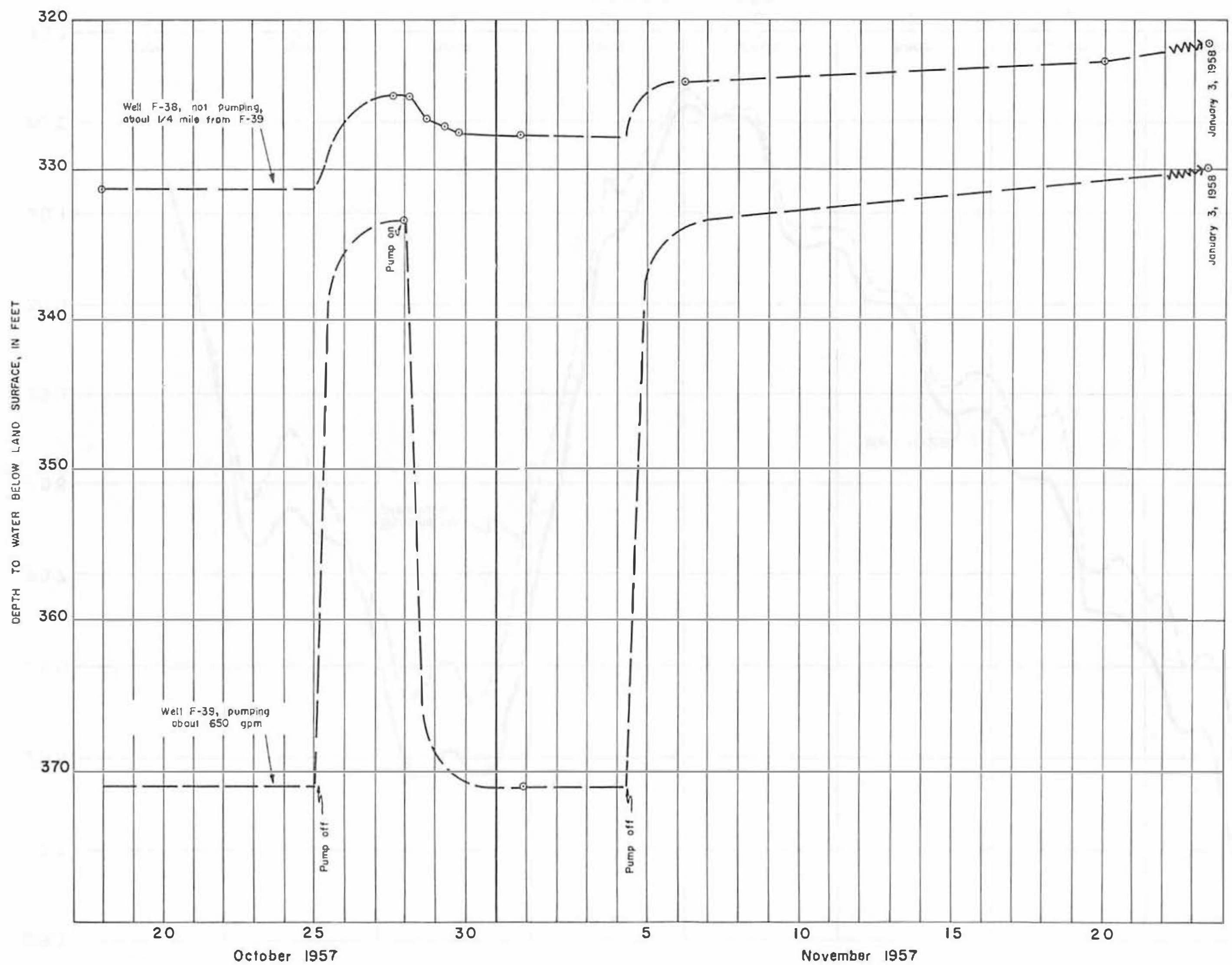

FIGURE 9. - Fluctuations of water levels in wells caused by pumping, Carson County

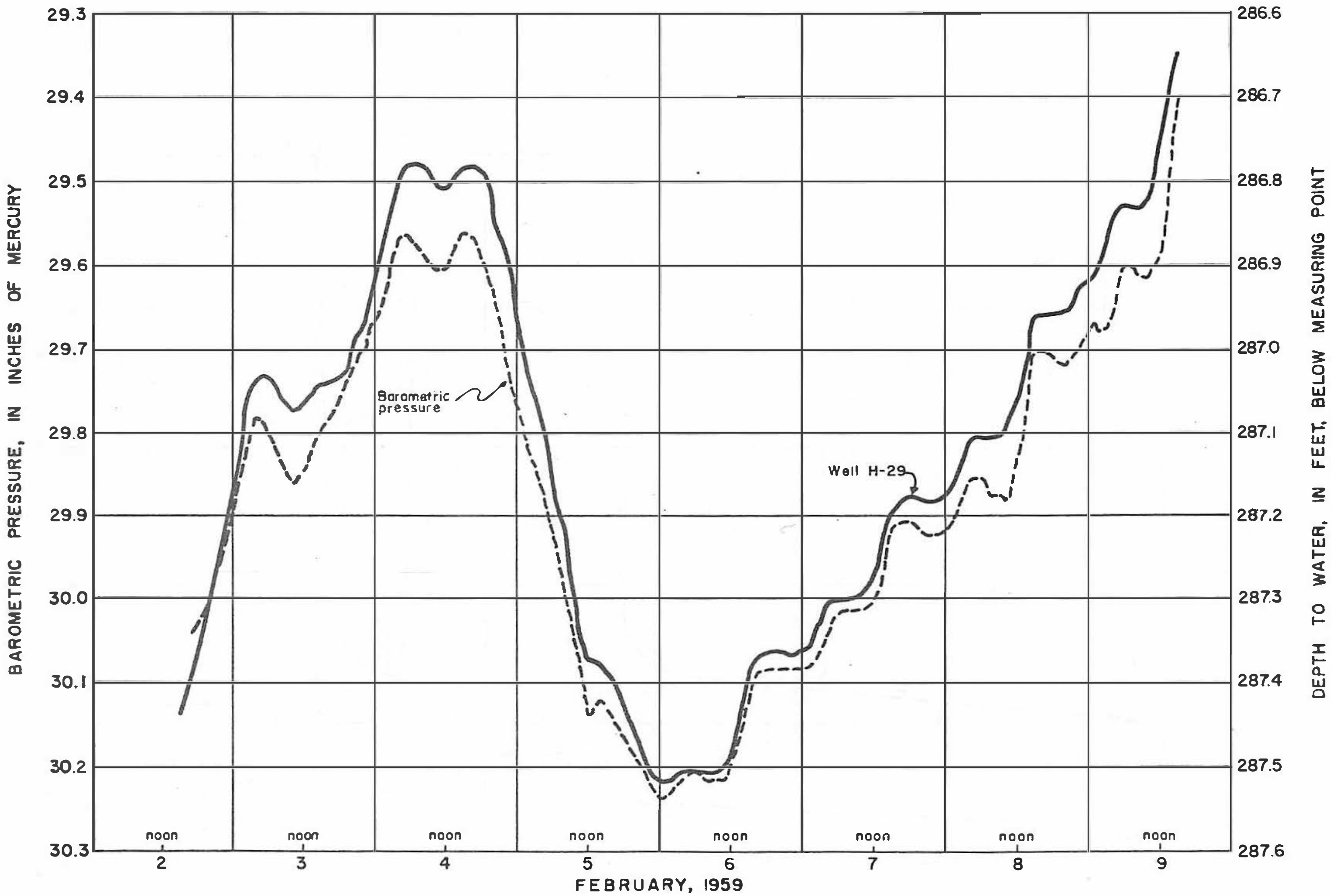

FIGURE 10. - Fluctuations of water level in well H-29 caused by atmospheric pressure, Carson County

making up the sand and gravel. As a result, the quality of water in the Ogallala formation is nearly uniform over extensive areas.

Chemical analyses by the Geological Survey of samples of water collected from wells in the area during the period 1942-59 are given in table 4. Although water from only a small fraction of the wells in the area has been analyzed, the analyses show that water suitable for most uses is widely available. The analyses indicate that water of somewhat better quality is being pumped in Carson County than in Gray County. This may be because the quality of water in parts of Gray County has been altered by infiltration of oil-field wastes, or it may be because water pumped in Gray County has been altered by being in contact with more soluble rocks. If the differences in water quality are due to waste infiltration, water quality may deteriorate further. For this reason, a more comprehensive and continuing quality-of-water study should be a part of any program of continuing ground-water studies.

Water that is hard, relatively low in dissolved solids, low in boron content, and that has a percent sodium less than 60 generally is satisfactory for continued irrigation. A system of classification for judging the quality of water for irrigation has been proposed by the U. S. Salinity Laboratory staff (1954, p. 69-82). All the analyses in table 4 indicate satisfactory irrigation water by these standards. To date, soils in the area have not been damaged by irrigating with ground water. Hence, water quality should not limit irrigation in the area, unless the water is contaminated by oil-field brine.

Water used for municipal and domestic supplies should be colorless, ordorless, palatable, and, wherever possible, meet the standards required by the U. S. Public Health Service (1946, p. 371-384) for drinking water used on interstate carriers. The following limits of concentration have been placed on some of the most common minerals found in solution:

Iron (Fe) and manganese (Mn) should not exceed 0.3 ppm (part per million)
Magnesium (Mg) should not exceed 125 ppm
Chloride (Cl) should not exceed 250 ppm
Sulfate (SO_4) should not exceed 250 ppm
Fluoride (F) must 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.

With the lone exception of the fluoride content of water from well F-11, all the analyses of water samples from wells in Carson County indicate that the water meets the above standards. High concentrations of fluoride have been observed in water from the Ogallala formation in other parts of the High Plains, but apparently fluoride is not present in excessive quantities in water in Carson and Gray Counties. Where water from a well does contain fluoride slightly in excess of the permissible maximum, it can be mixed with water from other wells so that the fluoride concentration of the mixed water is within the permissible limits. Continuous use of water containing fluoride in excess of 1.5 ppm by young children may cause permanent mottling of the teeth (Dean, Dixon, and Cohen, 1935, p. 424-442); however, the presence of fluoride in quantities slightly less than this amount tends to reduce tooth decay (Dean, Arnold, and Elvove, 1942, p. 1155-1179).

When analyzed, the water from well B-38 in Gray County contained more chloride, sulfate, and dissolved solids than the recommended maximum. The five

Table 4.--Chemical analyses of water samples from selected wells in Carson and Gray Counties

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

Well	Owner	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)		Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
																	Total	Noncarbonate				
											Carson County											
A-15	J. M. Huber Corp.	301	May 15, 1959	29	0.05	50	19	14	4.5	222	27	12	0.6	9.7	0.09	275	203	21	13	0.4	456	7.0
B-10	Phillips Petroleum Co.	535	May 7, 1959	31	a/ .00	49	20	14	4.8	232	22	13	.8	5.7	.00	274	204	14	13	.4	454	7.5
C-6	Panhandle & Santa Fe RR	418	Oct. 5, 1948	21	.05	43	23	13	4.8	220	27	13	.6	10	.06	262	202	22	12	.4	445	7.5
C-6	do	418	May 7, 1959	26	.00	44	22	13	4.0	215	30	14	.5	9.6	.01	269	200	24	12	.4	451	7.4
D-10	T. H. Barnard	517	Aug. 30, 1954	25	-	68	38	86	-	224	164	114	-	2.5	.13	620	326	142	36	2.1	1,010	7.6
D-11	do	420	do	24	-	42	32	23	-	253	29	34	-	4.0	.18	312	236	29	17	.7	550	7.7
E-25	Pantex Ordance Plant	489	Feb. 12, 1942	11	.27	39	21	36		234	29	22	.6	8.6	-	283	184	0	30	1.2	-	-
E-57	City of Amarillo	916	May 6, 1959	31	b/ .00	36	22	22	6.1	240	16	12	1.3	4.8	.03	269	180	0	20	.7	447	7.7
F-2	Phillips Petroleum Co.	376	Nov. 14, 1947	28	.06	46	22	20	8.4	250	24	18	.4	3.5	-	294	206	10	17	.6	442	8.0
F-4	do	451	do	27	.04	46	21	21	9.2	250	23	18	.4	3.5	-	292	202	0	18	.6	442	8.0
F-11	City of Amarillo	797	Feb. 14, 1953	22	.00	35	21	48	6.0	297	22	8.0	1.6	6.1	.17	333	174	0	37	1.6	515	7.8
F-34	John Kotara	-	Sept. 1, 1954	34	-	44	24	16	-	258	14	7.5	-	6.0	.09	273	208	0	14	.5	454	7.8
F-38	City of Amarillo	820	Jan. 20, 1953	17	c/ .14	33	22	50	6.2	290	35	6	1.4	6.1	.18	320	173	0	37	1.7	516	8.2
*F-45	City of Panhandle	380	June 17, 1955	42	d/	43	30	13	8.0	280	16	12	1.0	8.0	-	312	231	2	11	0.4	492	8.0
F-47	do	523	Nov. 20, 1947	7.8	0.06	40	33	15	5.2	286	16	10	1.2	7.2	-	306	236	0	12	.4	508	8.0
F-63	do	685	May 6, 1959	37	b/ .00	40	26	22	6.5	278	18	8.2	1.2	7.1	0.06	303	207	0	18	.7	497	7.7
G-16	City of White Deer	400	June 24, 1948	30	.05	41	20	26	3.2	258	18	9.0	.2	5.1	.19	285	185	0	24	.8	481	7.4
G-17	do	394	May 14, 1959	30	.04	44	19	26	5.5	258	18	11	.6	6.6	.13	288	188	0	22	.8	475	7.3
G-37	Mrs. O. W. Canady	810	Mar. 28, 1956	36	-	38	30	25	6.8	295	27	6.5	-	5.2	.18	320	218	0	19	.7	507	7.4
G-56	R. McBrayer	490	Sept. 6, 1954	35	-	38	28	24	-	282	18	7.0	-	6.0	.08	295	210	0	20	.7	488	7.6
H-21	T. D. Hodges	340	do	34	-	43	25	25	-	283	19	6.0	.8	3.5	.28	295	210	0	21	.8	493	8.2
H-22	do	440	do	34	-	38	25	43	-	297	26	7.5	-	5.6	.12	325	198	0	32	1.3	524	7.7
L-12	A. L. Stovall	438	Aug. 20, 1954	38	-	44	30	21	-	297	21	8.5	-	6.6	.13	315	233	0	16	.6	520	7.5
L-25	Mae H. Dean	600	Mar. 28, 1956	34	-	45	24	36	6.6	305	26	8.8	-	6.2	.21	337	211	0	26	1.1	555	7.4
M-12	City of Groom	508	June 24, 1948	34	.00	42	28	21	3.6	290	16	5.5	.4	3.8	.39	298	220	0	19	.6	499	7.7

See footnotes at end of table.

Table 4.--Chemical analyses of water samples from selected wells in Carson and Gray Counties--Continued

Well	Owner	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)		Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
																	Total	Noncarbonate				
Gray County																						
B-33	City of Pampa	570	Nov. 20, 1947	20	0.04	56	25	118	12	236	132	126	1.2	3.8	-	614	243	50	50	3.3	1,040	7.9
B-38	do	475	do	11	.08	72	31	278	12	228	281	312	1.2	6.0	-	1,120	307	120	65	6.9	1,890	7.8
B-44	do	528	May 15, 1959	27	.04	43	18	75	5.3	260	68	41	.9	6.2	0.24	413	182	0	46	2.4	674	7.7
G-5	City of Lefors	120	Oct. 5, 1948	21	e/ 3.8	96	17	42	3.6	214	15	144	.7	5.0	.00	514	310	134	23	1.0	834	7.5
**	City of Pampa	-	Nov. 20, 1947	12	.16	59	27	113	12	230	141	132	1.2	4.0	-	638	258	70	48	3.1	1,060	7.4

a/ Total iron 0.02 ppm.
b/ Total iron 0.00 ppm.
c/ Total iron 8.0 ppm.
d/ Total iron 0.03 ppm.
e/ Total iron.
* Well F-45, Manganese (Mn), 0.00; phosphate (PO4), 0.1.
** Composite of city wells.

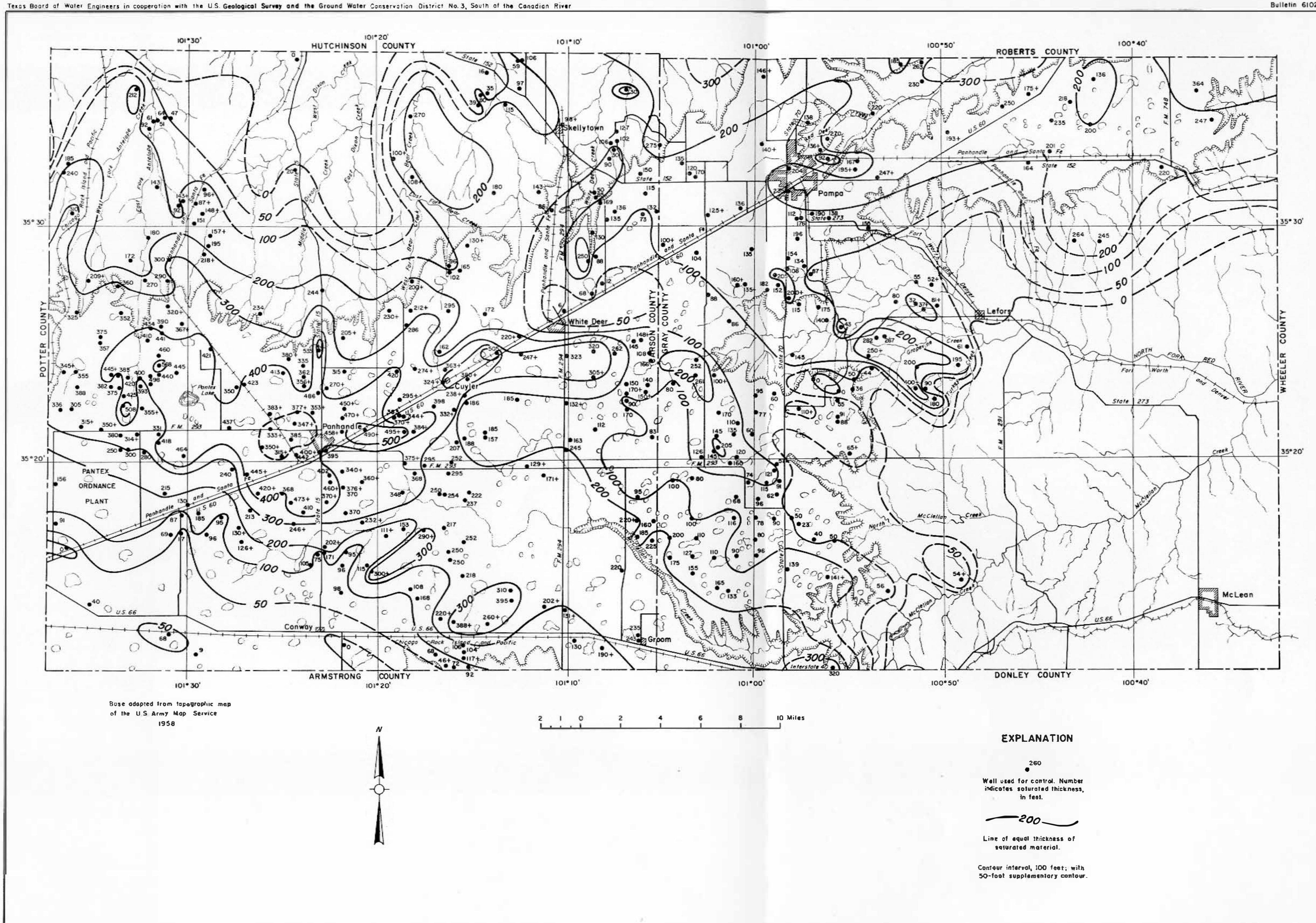

FIGURE 11. - Thickness of saturated material in Ogallala formation, Carson and Gray Counties, 1959

analyses from Gray County indicate that the quality of water being pumped in the county is not as good as that pumped in Carson County. There may be unsampled areas in Gray County where the water is poorer in quality than is indicated by the available analyses. However, standards of the Public Health Service probably can be met in the county by blending water from different wells.

Probably the single most objectionable characteristic of the water from the Ogallala formation in Carson and Gray Counties is the hardness. Hardness is a characteristic of water recognized by an increased quantity of soap required to produce lather. It is caused principally by the calcium and magnesium dissolved in the water.

Water having a hardness of 60 ppm or less is usually considered soft; water having a hardness ranging from 61 to 120 ppm is considered moderately hard, but is usually not softened in public water-treatment plants. Water having a hardness ranging from 121 to 200 ppm is considered hard and is usually softened by laundries and public water plants, which treat and filter surface water. Not many public ground-water supplies are softened. Water having a hardness exceeding 200 ppm is very hard, is decidedly scale forming, and is softened for many industrial purposes.

"Carbonate" or temporary hardness is hardness caused by calcium and mangesium equivalent to the bicarbonate and carbonate content of the water. "Noncarbonate" or permanent hardness is the remainder of the hardness. Water having noncarbonate hardness deposits harder scale, which is more difficult to remove than carbonate scale. The total and noncarbonate hardness--the carbonate hardness being the difference between the two--are given in table 4. The analyses indicate that only hard to very hard waters are being pumped from wells in the two counties, and noncarbonate hardness is generally greater in areas of higher mineralization and possible contamination by oil-field brine.

AVAILABILITY OF GROUND WATER

Amount of Water in Storage

The amount of ground water available for use in the area is represented largely by the amount of water in storage because the potential rate at which ground water may be withdrawn is much greater than the rate of replenishment. The amount of water stored in the Ogallala is related to the volume of saturated material. Figure 11 shows the approximate thickness of the saturated material throughout the report area.

When exploring for new supplies of water, the map of the thickness of saturated material should be used with caution because the type of material is not indicated, and interpretations between control points may be substantially in error. In some areas where the control points are closely spaced, the map shows abrupt changes in saturated thickness, and other such changes may occur where the control points are widely spaced. In most places, the saturated material contains enough sand and gravel so that it is capable of yielding large quantities of water to wells; however, in a few small areas, almost the entire saturated section is composed of silt and clay. For example, on the average, about 50 percent of the saturated material in the Ogallala formation consists of permeable sand and gravel. However, the saturated section of sand and gravel penetrated by 317 wells in Carson County ranges in thickness from 0 to 417 feet, and the total section of saturated material penetrated by the same wells ranges in thickness from 0 to 568 feet. Wells drilled in the clayey material yield insufficient quantities of water for irrigation, municipal, and industrial supplies but may be adequate for domestic and stock supplies.

The amount of water available from storage per unit volume is dependent on the specific yield of the material, which may be defined as the ratio, expressed in percentage, of the volume of water a formation will yield by gravity to the volume of material drained. No data are available for estimating the specific yield in Carson and Gray Counties; however, determinations made in other areas in the Southern High Plains underlain by the Ogallala formation probably can be applied in the report area.

The volume of saturated material in the Ogallala formation in the report area is estimated to be about 173,000,000 acre-feet. Based on a specific yield of 15 percent, the amount of water in storage in 1958 was about 26,000,000 acre-feet. It is not practical, however, to attempt to recover all the water. As water levels decline, yields of the wells decrease, so that it may be uneconomical to develop the lower part of the saturated section.

Of the 26,000,000 acre-feet of water, about 18,000,000 acre-feet underlies the plains area and is therefore available for irrigation. The remaining 8,000,000 acre-feet underlies the largely nonirrigable breaks area.

The area of the potentially irrigable land in Carson and Gray Counties is about eight times the size of that irrigated in 1959. Assuming that the average number of acre-feet of ground water per acre used for irrigation in 1958, a low average compared with that of some other areas, and that industrial and municipal use remain the same, full development of irrigable land would result in the annual withdrawal of at least 300,000 acre-feet in the report area.

Well Performance

The performance of a well is related to the permeability and thickness of the aquifer and the construction and development of the well. The performance may be expressed in terms of the specific capacity, which is the ratio of the yield, in gallons per minute, to the drawdown, in feet. The average and range in specific capacity of 96 irrigation wells, 36 public-supply wells, and 21 industrial wells in Carson and Gray Counties is shown in table 5.

If the specific capacities of wells are used as indications of the ability of the aquifer to yield water, the methods of construction and development of wells must be considered. Most of the irrigation wells in the report area are completed with torch-slotted casing, whereas the public supply and industrial wells generally are completed with screens and are gravel walled. The differences in the methods of construction and development of the wells are believed to account for some of the difference between the average specific capacity of the irrigation wells and that of the public supply and industrial wells. The use of proper screens offers a larger open area for the passage of water into the well, thus creating lower entrance velocities of the water, decreased drawdowns, and increased specific capacities. The use of the gravel wall and screen also allows a more thorough development of the wells, preventing the entrance of much of the sand into the well after development. The accurate placing of the perforated area of the casing opposite the coarser materials in the aquifer also effectively increases the productivity of the well.

Table 5.--Performance of wells, Carson and Gray Counties

		Use of Wells		
		Irrigation (96 wells)	Public Supply (36 wells)	Industrial (21 wells)
Specific capacity (gpm/ft)	Average	14.8	23.1	23.0
	Range	3 - 35	7 - 43	3 - 81
Yield (gpm)	Average	629	870	621
	Range	230 - 1,080	225 - 1,050	65 - 1,100
Pumping lift (ft)	Average	380	395	305
	Range	91 - 497	340 - 439	177 - 400

The capacity of the Ogallala formation to yield water varies considerably throughout the area because of differences in the permeability and thickness of the water-saturated material. These differences are reflected in the large range in the specific capacities of the wells. Most of the wells having larger specific capacities are in areas where the saturated material is thickest. Many of the public supply and industrial wells have relatively high specific capacities because, as a result of extensive ground-water explorations, they have been drilled in areas where the saturated thickness is great. The irrigation wells, on the average, have relatively low specific capacities. One reason for this is that the location of the irrigation well generally is determined by the configuration of the land surface, and ground-water explorations for irrigation wells are necessarily limited to small areas.

Table 5 shows the average pumping lift and range in 153 irrigation, public supply, and industrial wells in the report area. The average pumping lift in the industrial wells is low because several of the wells are in the topographically low breaks areas where the water levels are shallow compared to those in the plains areas.

NEED FOR FUTURE STUDIES

Continuing studies of the development of large-capacity wells and the amount of pumping are needed in the report area to determine the decrease in the ground water in storage. Records of water levels, especially in the areas remote from the heavily pumped wells, should be made to determine the extent of the dewatering of the reservoir.

Studies of the relative amount of sand and gravel in the Ogallala formation as well as data regarding the ability of the formation to transmit and store water are needed for more precise determinations of the availability of ground water. These data also may aid in estimating the rate of natural recharge to the aquifer. Pumpage data should be analyzed and related to the volume of dewatering material to determine specific yields more accurately.

Records of water levels in wells in the areas where natural recharge to the aquifer may be expected should be studies and related to climatological data to determine the amount of natural recharge and the areas where the recharge occurs. Studies should be made of the rate of depletion of water in the playa lakes compared with evapotranspiration rates in order to estimate the amount of natural recharge from the lakes. Long-term records of the quantities of water that collect in the playa lakes would show the amounts available for artificial recharge.

More chemical analyses of the water from wells are needed in certain areas to determine the extent of the more saline water and the source of the salinity. The water from some wells, particularly in areas of potential contamination, should be analyzed periodically to determine any changes in the quality of the water.

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