Geology and Ground-Water Hydrology of the Ingalls Area, Kansas

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BULLETIN 132

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By G. J. STRAMEL, CHARLES W. LANE, and WARREN G. HODSON
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GEOLOGY AND GROUND-WATER HYDROLOGY OF THE INGALLS AREA, KANSAS

By

G. J. Stramel, Charles W. Lane, and Warren G. Hodson

ABSTRACT

This report describes the geology and ground-water hydrology of a 540-square-mile area in Finney and Gray Counties, Kansas. The city of Ingalls is approximately in the center of the area, which is in the Finney lowland and High Plains physiographic provinces and is crossed by Arkansas River. The normal annual precipitation is 19.93 inches, and the mean annual temperature is 55° F.

The rocks exposed in the Ingalls area are sedimentary and range in age from Tertiary to Recent. The geology of the area is described, and cross sections show the extent of the unconsolidated deposits in the subsurface. These unconsolidated deposits are about 140 to 300 feet thick and yield water to wells for all public, domestic, stock, and most irrigation supplies in the area. The quantity of water in storage in that part of the area that is 10 miles wide and 24 miles long and lies adjacent to Arkansas River between Pierceville and Cimarron amounts to about 130,000 acre-feet in the alluvium of Arkansas River and about 2,700,000 acre-feet in the Ogallala formation beneath and adjacent to the alluvium. The ground water in most of the area is moderately hard, and the water of Arkansas River and the alluvium north of the river is very hard.

Data collected from seven aquifer tests and analyses of the data are included in this report. Three aquifer tests were made of the alluvium of Arkansas River and four of the Ogallala formation. The coefficient of transmissibility of the alluvium computed from the test data ranged from 97,000 to 180,000 gpd per foot and of the Ogallala formation from 12,000 to 61,000 gpd per foot. The storage coefficient of the Ogallala formation is about 2.5×10^{-4}.

The hydrologic and geologic data on which this report is based include records of 231 wells and test holes, logs of 89 wells and test holes, and analyses of 14 samples of water.

INTRODUCTION

Purpose and Scope of the Investigation

Large supplies of ground water are available in the Arkansas River valley between Garden City and Cimarron, Kansas. The United States Bureau of Reclamation is considering the diversion of ground water in the valley to an area northeast of Ingalls for irrigation. A preliminary study by that Bureau of what is referred to as the Ingalls irrigation project indicated that 86,000 acre-feet of ground water might be diverted from the valley to irrigate

58,000 acres in the upland. The project plan proposes pumping from wells penetrating both the alluvium of Arkansas River and the underlying Ogallala formation. Surface flow of Arkansas River would be captured by infiltration, replacing water pumped from storage within the aquifer.

Since 1937 a co-operative program to determine the availability and occurrence of ground water in Kansas has been carried on by the United States Geological Survey, the State Geological Survey, the Division of Water Resources of the State Board of Agriculture, and the Division of Sanitation of the State Board of Health. In 1955 the Bureau of Reclamation proposed that an investigation of the availability of ground water in the Arkansas Valley in the Ingalls area be made by the co-operating agencies in Kansas, and in January 1956 such an investigation was started. The results of that study are given in this report.

Objectives of the investigation included an inventory of water used for irrigation and information on depth to water, the character, thickness, and storage capacity of water-bearing materials, yields of wells, possible recharge to the alluvium from Arkansas River, recharge to the Ogallala formation from the overlying alluvium, and the quality of the ground water.

Location and Extent of the Area

The area of this investigation includes the Arkansas Valley from a point 5 miles west of Pierceville, in Finney County, to a point 7 miles east of Cimarron, in Gray County, and the adjacent upland (Fig. 1). This area, termed the *Ingalls area* in this report, comprises approximately 540 square miles (Pl. 1).

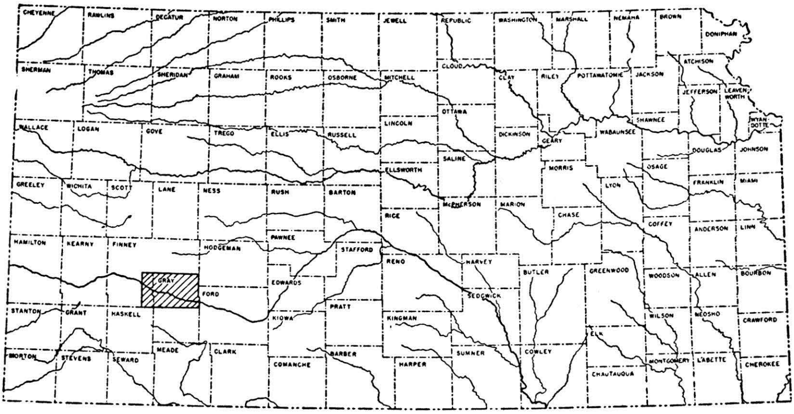

Fig. 1.—Index map showing area described in this report.

Previous Investigations

Several studies have been made that deal with the geology and ground-water resources of southwestern Kansas. The principal studies previously made are given below in chronological order.

Nettleton (1892, p. 26, app. 10) reported on the results of some underflow surveys in the Platte and Arkansas River valleys and included a discussion of the water-table configuration at Garden City. Haworth (1897) described the geology and physiography of western Kansas and included a discussion of Arkansas River. That same year he (1897a) described the results of an investigation of the underground waters of southwestern Kansas, which included the Ingalls area. A report of the Board of Irrigation Survey and Experiment to the Legislature of Kansas for the years 1895 and 1896 contained the log and water-supply data for a state-financed test well in Gray County (Sutton, 1897, p. 18). In the same report, Haworth (1897b) gave a general account of the geology of underground water in western Kansas. In 1902, Slichter (p. 68) included a hydrograph of the city well at Garden City, in a report on the motions of underground waters. Darton (1905, p. 297, 300) reported on the geology and ground-water resources of the central Great Plains and gave a general description of the water supply of Gray County, which includes most of the Ingalls area. Slichter made an intensive investigation of the underflow of Arkansas River in Finney and Kearny Counties, and reported (1906) on the velocity and origin of the underflow, fluctuations of the ground-water levels and quality of the water. He also made pumping tests on several pumping plants in the valley to determine the specific capacity of the wells and the cost of pumping. The quality and availability of water in Finney and Gray Counties were studied by Parker (1911, p. 87-90, 99, 100). Haworth (1913) described the well waters in Kansas and included in his report a brief description of Arkansas River. Theis, Burleigh, and Waite (1935) described briefly the water-bearing formations and the availability of ground water in the entire southern High Plains. Smith (1937) contributed a preliminary paper on Pleistocene gravels in southwestern Kansas in which he described gravel terraces along the Arkansas Valley, and in 1940 he described the Tertiary and Quaternary geology of southwestern Kansas, including the Ingalls area. A report of the U. S. Geological Survey published in 1940 (Water-Supply Paper 886) contained a chapter on the observation-well program in Gray County. Additional reports of this series have been published annually since that time. A report by Latta (1944) included a description of the areal geology, physiography, ground-water supply, and logs of many wells and test holes drilled in Finney and Gray counties, which include the Ingalls area.

Methods of Investigation

The investigation on which this report is based was begun in January 1956 and was completed in August 1956. An inventory was made of 75 irrigation plants in the Ingalls area. Total depth and static water level were measured with a steel tape from a fixed measuring point at the top of each well, and an estimate of well production was obtained from the owner. Additional information was obtained on the depths of and static water levels in 3 public-supply wells and 26 stock and domestic wells.

Drill cuttings were collected, at 5-foot intervals or at each formation change, from 32 test holes drilled by the Bureau of Reclamation using a portable hydraulic rotary drilling rig, and from 2 test wells drilled by a contractor for that bureau. These samples were examined and logged in the field and later studied with a binocular microscope in the laboratory; lithologic logs were then prepared. Additional information was obtained from 76 augered test holes, 35 to determine the thickness and lithology of the alluvium of Arkansas River and 41 to obtain measurements of the water level. Local well-drilling contractors supplied 13 drillers logs of wells and test holes in the area. Information was obtained from sample logs of 7 test holes drilled during the field investigation of Finney and Gray Counties (Latta, 1944). Using a spirit level, a topographic mapping crew of the Bureau of Reclamation determined the altitudes of measuring points of all wells and the land-surface altitude of all test holes.

Twelve samples of water were collected from representative wells in the area and two samples from Arkansas River. These samples were analyzed in the Water and Sewage Laboratory of the State Board of Health.

Aquifer tests were conducted in seven wells. Three of these tests made use of existing irrigation wells, of which two were in the Ogallala formation north of Arkansas River valley and one in the alluvium of Arkansas River. Four aquifer tests made use of wells drilled by private contractors for this investigation. Two of these wells were in the alluvium of Arkansas River and two were in the underlying Ogallala formation.

Field data were compiled on modified base maps prepared by the Bureau of Reclamation. Aerial photographs were used to determine locations of test holes where other methods were not accurate.

Well-Numbering System

The well and test-hole numbers used in this report give the location of wells and test holes according to General Land Office surveys and according to the following formula: township, range, section, 160-acre tract within that section, and 40-acre tract within that quarter section. The 160-acre and 40-acre tracts are designated a, b, c, and d in a counterclockwise direction beginning in the northeast quarter. If several wells or test holes are in a 40-acre tract, they are numbered serially in the order in which they were inventoried. For example, well 25-30-15cb1 is the first well inventoried in the NW¼ SW¼ sec. 15, T. 25 S., R. 30 W. (Fig. 2).

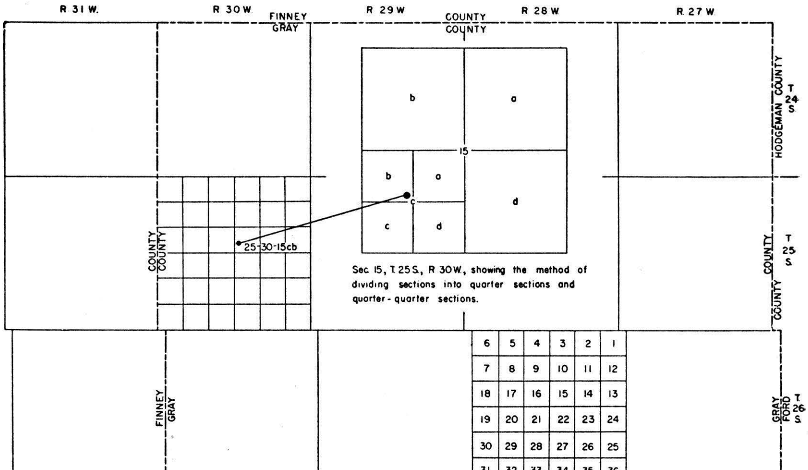

Fig. 2.—Map of Ingalls area illustrating well-numbering system used in this report.

Acknowledgments

The writers acknowledge the help of residents of the area who gave information regarding their wells, who permitted test drilling on their land, and those who permitted the use of their land and irrigation wells for aquifer tests. Appreciation is expressed to B. F. Powell, Area Planning Engineer, and his staff of the Bureau of Reclamation for assistance in planning the field investigation and in collecting basic data. Special recognition is given to Woodrow Hayes and Oscar Parker of the Bureau of Reclamation field office at Cimarron, and to Victor Pineo, John Simons, John Leathers, and Henry Blake of the Bureau's drill crew. Acknowledgment is given Orville Harold of the Soil Conservation Service and Milton N. Thomas, Gray County Agent, both from Cimarron. Records and information were obtained through the courtesy and co-operation of the following drilling companies: Gestenslager Drilling Co., Henkle and Co., Minter Drilling Co., and Western Drilling Co., all of Garden City.

The manuscript of this report has been reviewed by several members of the Bureau of Reclamation and of the Federal and State Geological Surveys; by Dwight Metzler, Director and Chief Engineer, and W. O. Hilton, Geologist, Division of Sanitation, State Board of Health; by R. V. Smrha, Chief Engineer, and George S. Knapp, Engineer, Division of Water Resources, State Board of Agriculture; and by Robert L. Smith, Executive Secretary, and W. E. Steps, Engineer, Water Resources Board.

CLIMATE

The climate of the Ingalls area is characterized by abundant sunshine, moderately low precipitation, low relative humidity, good wind movement, and a high rate of evaporation. Although summer days are hot, the heat is moderated somewhat by good wind movement and relatively low humidity. The winters are moderate, having only occasional, short periods of severe cold. The amount of precipitation and its seasonal distribution are the chief factors controlling crop growth.

According to records of the U. S. Weather Bureau, the normal annual precipitation at Cimarron is 19.93 inches, nearly 75 percent of which falls from April through September. The normal monthly precipitation is shown in Figure 3. The annual precipitation for the years of record, 1906-55, has ranged from 10.08 inches in 1934 to 39.98 inches in 1951 (Fig. 4.)

The mean annual temperature for the area is 55°F. July is the hottest month, having a mean temperature of 79.3°, and January is the coldest, having a mean temperature of 31.0°.

The average length of the growing season is 175 days. The longest growing season on record was 198 days, and the shortest was 154 days. The average date of the last killing frost in the spring is April 24, and that of the first killing frost in the fall is October 16. The latest recorded date of a killing frost in the spring was May 27, 1907, and the earliest in the fall was September 25, 1912.

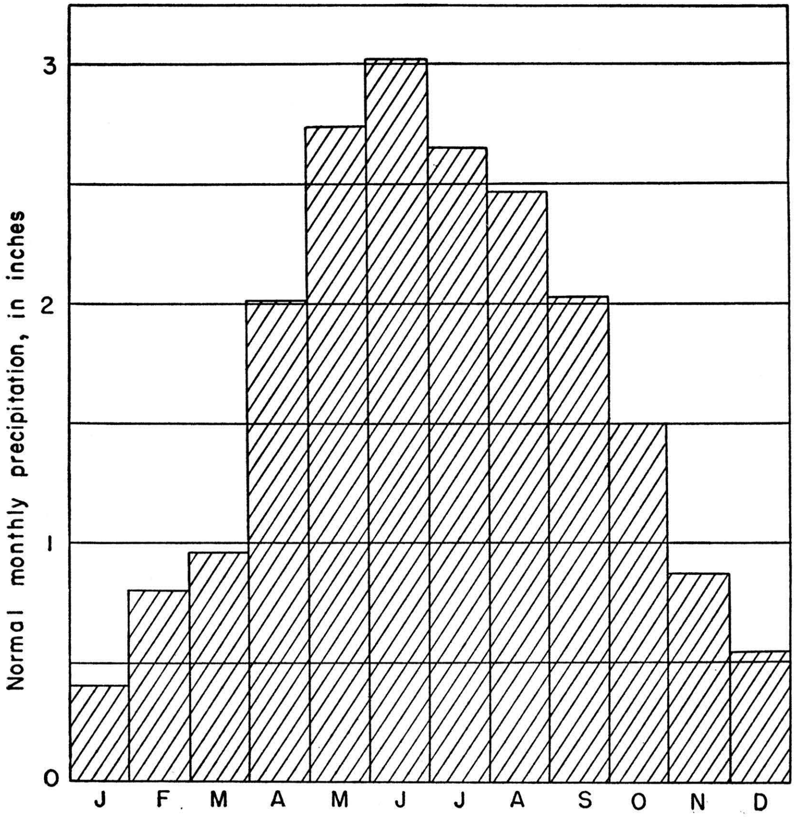

Fig. 3.—Normal monthly precipitation at Cimarron.

GENERAL GEOLOGY

Geomorphology

The Ingalls area presents several striking topographic contrasts. North of Arkansas River the valley is bordered by a continuous line of bluffs approximately 100 feet above the floodplain, which are extensively notched by deep, short draws. The upland north of the bluffs is part of the High Plains physiographic province (Schoewe, 1949) and is a relatively flat treeless plain sloping east-

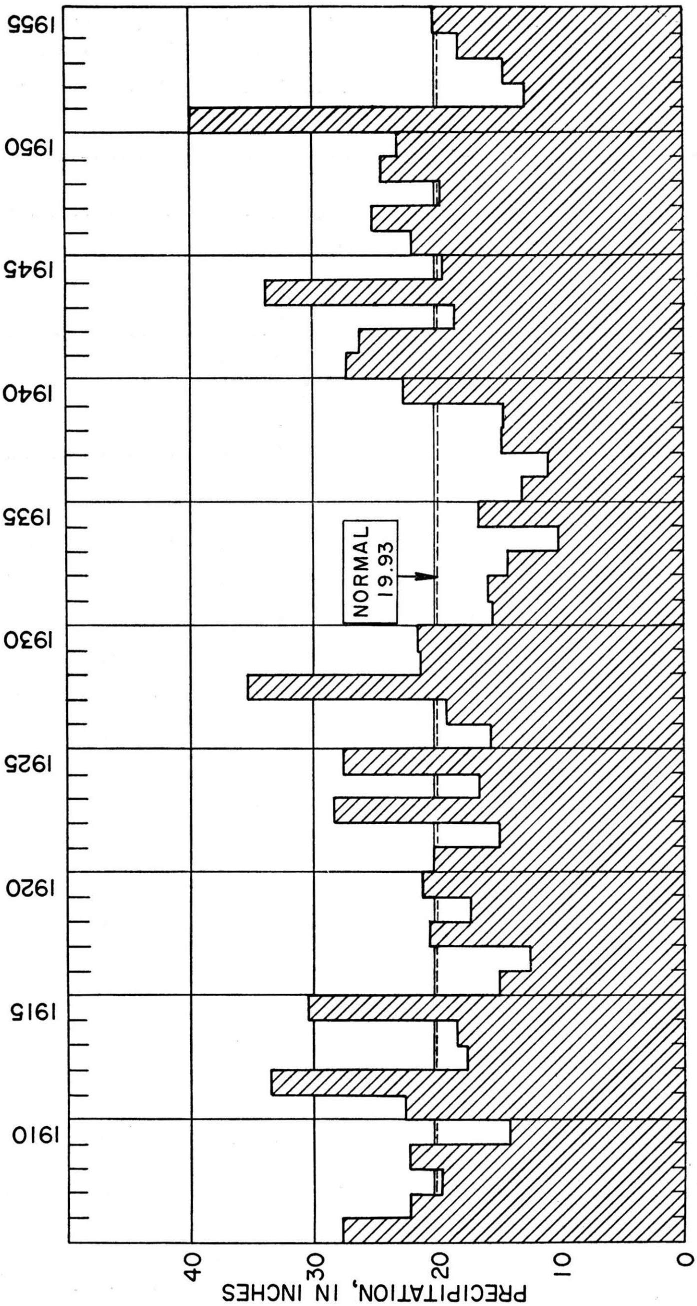

Fig. 4.—Annual precipitation at Cimarron, 1906-55.

ward about 7 or 8 feet per mile. Locally, the plain is marked by undrained depressions ranging in diameter from a few feet to about a mile.

The area south of the bluffs is in the Finney Lowland physiographic subdivision (Schoewe, 1949). This subdivision includes the floodplain of Arkansas River and the gently sloping outer valley, which is extensively mantled by dune sand and lies below the High Plains surface. Arkansas River has an eastward gradient of about 7 feet per mile. Its flood channel is 300 to 400 feet wide, but during most of the year the flow of the river is small and is confined to a narrow channel 50 to 75 feet wide.

At least two terraces flank the Arkansas River valley in this area. The lower terrace is 4 to 6 feet above the floodplain and is most noticeable north of the river. The upper terrace is 20 to 25 feet above the floodplain and is continuous along the south side of the valley. Its width is not known because it is covered by dune sand except along the scarp. Scattered terrace remnants that are probably equivalent to the upper terrace occur along the north side of the valley, notably west of Ingalls where a small draw has cut through the deposits.

The area south of the Arkansas Valley has a typical dune topography—moderate slopes and hills separated by small basins. Sand dunes extend southward a maximum of 11 miles from Ingalls and are the eastern extension of the Finney sand plain described by Smith (1940, p. 140-145, fig. 19). Most of the dunes are covered by vegetation and protected from wind action. A few are marked by blowouts, generally caused by trampling of livestock near watering and feeding places. There is no surface drainage from the sand dunes, and all precipitation accumulates in depressions until it either evaporates or seeps into the ground.

Summary of Stratigraphy *

The rocks that crop out in the Ingalls area are sedimentary and range in age from Tertiary to Recent. These rocks are underlain by shale of Cretaceous age believed to be the Carlile shale (Fig. 5). A generalized section of the geologic formations and their water-bearing properties is given in Table 1.

The oldest rock formation that crops out in the Ingalls area is the Ogallala formation (Pliocene). It is present throughout the area, but in most places is mantled by younger deposits. South of

* The classification and nomenclature of the rocks described in this report follow those of the State Geological Survey of Kansas. They differ somewhat from those used in formal reports of the U. S. Geological Survey.

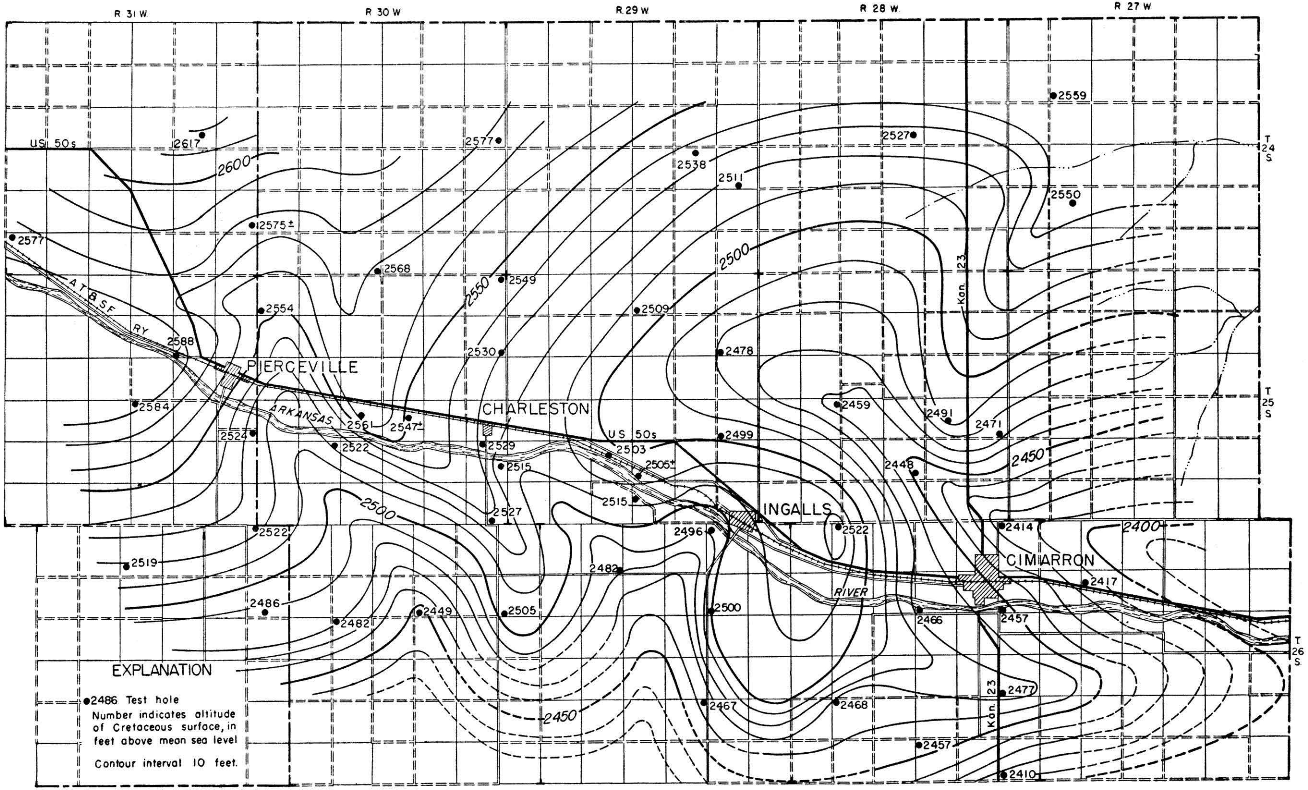

Fig. 5.—Configuration of surface of Cretaceous shale in Ingalls area.

TABLE 1.—*Generalized section of geologic formations and their water-bearing properties*

SYSTEM	Series	Group	Stage	Formation	Thickness (feet)	Character	Water supply
Quaternary	Pleistocene		Recent	Alluvium	0–40	Silt, sand, and gravel underlying flood plain.	Yields large supplies of water; supplies most domestic, stock, and irrigation wells in Arkansas Valley.
Quaternary	Pleistocene		Recent / Wisconsinan	Dune sand	0–35	Fine to coarse wind-deposited sand; contains some silt.	Lies above the water table and yields no water to wells. Serves as intake area for ground-water recharge.
Quaternary	Pleistocene	Sanborn	Wisconsinan	Terrace deposits	0–25±	Silt, sand, and gravel, poorly sorted. Extensively quarried for road metal and aggregate.	Generally lies above water table but locally supplies some stock wells and water for one irrigation system.
Quaternary	Pleistocene	Sanborn	Illinoian (?)	Undifferentiated sands and silts	0–65	Silt and fine to coarse sand. Underlies sand dunes south of Arkansas River.	Lies above water table and yields no water to wells.
Quaternary	Pleistocene	Meade	Late Kansan (?)		0–150±	Predominantly sand and gravel; contains some silt. Underlies younger Pleistocene deposits in sand-dune area.	Almost undeveloped but capable of yielding large supplies of water to wells.
Tertiary	Pliocene			Ogallala	75–300±	Calcareous silt, sand, and gravel. Underlies entire area.	Yields moderate to large supplies of water; supplies all domestic, stock, and irrigation wells north of Arkansas River Valley.
Cretaceous	Gulfian	Colorado		Carlile shale	250–300±	Dark-gray calcareous shale.	Not known to yield water to wells in this area.

Arkansas River the Ogallala formation is overlain by a thick deposit of silt, sand, and gravel, probably of late Kansan age. Overlying the thick sand and gravel south of the Arkansas Valley and overlying the Ogallala formation north of the Arkansas Valley is a sequence of water-laid sands and silts that grade upward into eolian silts and are assigned to the Sanborn group. The upper terrace south of the Arkansas Valley is probably of late Wisconsinan age and is included in the Sanborn group. Overlying the Sanborn group south of the Arkansas Valley is an extensive deposit of dune sand, which is probably of Recent age, although the dunes, in part, may be contemporaneous with the upper terrace. The alluvium and lower terrace of Arkansas River are of Recent age.

In the geologic cross sections (Pl. 2, 3) all unconsolidated deposits except the alluvium are classed as Pliocene and Pleistocene undifferentiated. No attempt was made to subdivide the Ogallala formation and the Pleistocene deposits, owing to lack of any positive evidence other than lithologic differences, although the deposits differ enough lithologically to warrant separate descriptions in the section that follows.

GEOLOGY IN RELATION TO GROUND WATER

Cretaceous System

Gulfian Series

Carlile Shale

Character.—The Carlile shale consists predominantly of dark-blue to black calcareous fissile clay shale, chalky shale, and thin beds of chalky limestone. It is composed of two members, the Fairport chalky shale below and the Blue Hill shale above, which elsewhere contains the Codell sandstone zone at the top.

The Fairport chalky shale member constitutes the lower third of the Carlile shale and consists predominantly of dark-gray to black and yellow-tan calcareous shale containing some gray limestone, flakes of calcite, and hard fine-grained concretions. The Blue Hill shale member constitutes about the upper two-thirds of the formation. The upper part of this member is exposed in a strip along Pawnee Valley several miles north of the area considered in this report. The member consists of dark-gray, bluish-black, and black noncalcareous shale containing thin seams of gypsum, selenite crystals, and in the upper part a zone of large septarian concretions.

At the top of the Carlile shale in other parts of Kansas is a sandy zone, the Codell sandstone zone, consisting of fine-grained silty sandstone and sandy shale. The Codell sandstone zone is missing in the Ingalls area and presumably was deposited but later removed by erosion before deposition of the Ogallala formation.

Distribution and thickness.—The Carlile shale does not crop out in the Ingalls area, but it underlies the area and has a maximum thickness of 300 feet (Latta, 1944). Of 32 test holes drilled by the Bureau of Reclamation, 31 penetrated a dark-gray calcareous clay shale, which is probably the Carlile shale. One test hole did not penetrate the entire thickness of younger sediments overlying the Carlile shale.

Water supply.—Because of its low permeability, the Carlile shale yields little or no water; no wells in the area are known to obtain water from it.

Tertiary System

Pliocene Series

Ogallala Formation

Character.—Unconformably overlying the Cretaceous shales is a thick sequence of clay, calcareous silt, and sand and gravel of the Ogallala formation. In general, the materials making up the Ogallala formation are poorly sorted, and the lithology changes vertically within short distances. Most studies of the Ogallala formation indicate that the deposits are lenticular, but in the relatively small Ingalls area the logs prepared from drill cuttings and used in the cross sections in Plates 2 and 3 show fair lateral continuity of beds.

Nearly all the 32 test holes drilled by the Bureau of Reclamation penetrated some clay beds in the lower half of the Ogallala formation. These beds consist of tan, gray, and greenish-gray non-calcareous clay containing streaks of silt and fine sand. The thickness of the clay beds ranges from a few inches in some places to as much as 26 feet in test hole 25-30-12dd. Several test holes penetrated 5 to 20 feet of clay.

Silts containing minor amounts of clay and much fine to medium sand compose most of the fine materials of the Ogallala formation. Beds of tan, pink, and gray silt ranging from a few inches to as much as 60 feet thick are common throughout the area. Many silt beds are heavily impregnated with calcium carbonate, which colors them gray white to light gray.

Sand is the most abundant material in the Ogallala and is found throughout the formation. Sand beds are not common, but where present they generally contain silt, are poorly sorted, and range from fine to very coarse. The sand consists predominantly of angular to subangular quartz grains but contains some feldspar grains and dark minerals. Mica is present in most sand beds.

The coarse material of the Ogallala formation is fine to coarse gravel, generally containing sand and some silt and clay. Fine to medium gravel predominates, but action of the drill during test drilling indicates the presence of very coarse gravel that was not brought to the surface by the drilling fluid. Gravel is present throughout the formation but is generally most abundant in the lower part. At or near the base of the formation it generally contains abundant pebbles of weathered Cretaceous chalk, limestone, sandstone, and ironstone, indicating local origin. Higher in the formation the gravel is arkosic, indicating a source in the Rocky Mountain area.

Caliche is common throughout the Ogallala formation and occurs as cementing material, nodules, and small pipelike concretions. Only 2 test holes drilled by the Bureau of Reclamation penetrated massive caliche; 26-31-1bb penetrated 13 feet and 26-28-1bb penetrated 12.4 feet. In both test holes the massive caliche was near the base of the formation. Thin lime-cemented zones of silt and sand a few inches to 1 foot thick were common in all test holes.

Distribution and thickness.—The Ogallala formation is exposed along the north bluff of the Arkansas River valley, and test holes penetrated it beneath younger sediments throughout the area. Because of lithologic similarity, the contact between the Ogallala formation and the overlying younger deposits was difficult to determine in test holes, and only an approximate thickness can be given for the formation in this area. Test hole 26-28-1bb penetrated more than 300 feet of material believed to be of the Ogallala formation. South of Arkansas River part of the Ogallala formation was removed by erosion during Pleistocene time, and the part remaining was subsequently covered by younger deposits. In part of the area south of the river the Ogallala formation may be less than 75 feet thick.

Water supply.—In the upland north of Arkansas River all wells obtain water from the Ogallala formation, the sands and gravels in most places being capable of yielding large supplies. Yields range from a few gallons per minute from stock and domestic wells to as much as 1,600 gpm from irrigation well 25-29-14ab. North of Arkansas Valley in the Ingalls area 21 irrigation wells produce water from the Ogallala formation. Further development of water from this formation for irrigation in the area seems feasible.

In the Arkansas River valley and the area south of the valley younger saturated deposits overlie the Ogallala formation, and only one well, 25-29-27cc2, is known to obtain water from the Ogallala. This well produces water from both the Ogallala formation and the alluvium of Arkansas River. In the vicinity of Pierceville and as far east as Charleston, clay, silt, and fine sand compose the bulk of the Ogallala formation; hence yields are not adequate for extensive irrigation, although stock and domestic supplies are available.

Quaternary System

Pleistocene Series

Meade Group

Character.—South of Arkansas River, in the area covered by dune sand, test holes penetrated a thick deposit of sand and gravel containing minor amounts of silt overlying the Ogallala formation. These deposits are not exposed in the Ingalls area, but test-hole cuttings indicate that the deposits are poorly sorted and contain abundant coarse arkosic gravel. The deposits differ from the Ogallala formation in several ways, and because they are in the same relative position as known Kansan deposits in southern Gray County (Latta, 1944; Frye, 1942) they are classified tentatively as of late Kansan age.

The fine materials in the deposits of late Kansan age consist of silt and sandy silt and are mostly in the upper part. The silt is generally tan, but where calcium carbonate is present in large quantity it ranges from gray to near white. Test hole 26-28-36cc penetrated a black silt at a depth of 89 feet that contained many fragments of fossil mollusk shells, none of which was complete enough for identification. Nearly all the silt penetrated in the Kansan deposits is calcareous, but heavy calcareous silt typical of the Ogallala formation is absent.

Sand beds in the Kansan deposits cannot be distinguished lithologically from those of the Ogallala formation. Few sand beds were penetrated in test holes, but where present they were in the upper part of the formation.

Fine to very coarse gravel containing sand and thin silt beds composes the bulk of the Kansan deposits. The gravel is made up chiefly of granite, feldspar, and quartz pebbles and, in general, is coarser than gravel penetrated in the Ogallala formation. Pebbles of sandstone, limestone, chalk, and ironstone, such as are abundant in the basal gravels of the Ogallala formation, were not present in the Kansan deposits.

Some caliche is present throughout the deposits but in very minor amounts almost confined to the upper part. A few thin lime-cemented streaks are present throughout the sand and gravel deposits but not in amounts comparable to those in the Ogallala formation.

Distribution and thickness. — The Kansan deposits probably underlie all the area south of the Arkansas River valley. If present under the younger alluvial deposits of the valley, they were not recognized during the test drilling. These deposits are topographically lower than the surface of the Ogallala formation north of the river, and if present north of Arkansas River they were not recognized.

The thickness of the Kansan deposits ranges from a featheredge near the Arkansas River valley to 147 feet (or more) near the southern edge of the Ingalls area. The maximum thickness was penetrated in test hole 26-28-29bb, where 135 feet of sand and coarse gravel was overlain by 12 feet of silt between depths of 32 and 179 feet.

Water supply.—The area south of Arkansas River that is underlain by Kansan deposits is used mostly for grazing because the sand dunes make it unsuitable for farming. As a result, few wells other than stock and domestic wells are drilled in the area, and the water in the formation is undeveloped. Only three irrigation wells are known to penetrate the formation; two of these, wells 26-31-4cc and 26-31-12cc, reportedly yielded 1,800 gpm each when test pumped. Large water supplies from wells seem to be obtainable in most of the area underlain by Kansan deposits.

Sanborn Group

No attempt has been made to subdivide the Sanborn group in the Ingalls area. The undifferentiated deposits of the Sanborn group (Table 1) described in this report are exposed in the upland north of Arkansas River and underlie the dune sand south of the river. The deposits north of Arkansas River are topographically higher and, except for some water-laid sands and silts near the base, are eolian in origin. South of Arkansas River the deposits of the Sanborn group are probably water laid.

Character.—The upland north of Arkansas River is mantled by deposits of silt, sandy silt, and sand, which are late Pleistocene in age. These deposits overlie very calcareous sandy silts of the Ogallala formation and are difficult to distinguish from the Ogallala in test-hole drill cuttings. The materials composing the Sanborn group north of Arkansas River are calcareous silt, sandy silt, and some sand. The color of the silt ranges from tan to gray tan, according to the amount of calcium carbonate present. The silts commonly become more sandy with depth and in many places grade into thin beds of fine to medium sand near the base.

South of the Arkansas Valley, in the area covered by dune sand, a sequence of silts, sandy silts, and sand of late Pleistocene age overlies deposits of gravel, sand, and silt tentatively classified as of late Kansan age. Cross section F-F′ (Plate 3) indicates two cycles of deposition, each consisting of sand that grades upward into silt. The cross sections in Plate 2 indicate that these deposits have been beveled by erosion and could have been the source of the overlying dune sand.

The fine materials composing the Sanborn group south of the Arkansas Valley consist of calcareous silt, sandy silt, and sand. The silts are tan, gray tan, gray white, and gray green, and generally grade downward into sand. The sand is generally poorly sorted, ranging from very fine to coarse, but is predominantly fine to medium. It consists principally of subangular to angular grains of quartz but contains feldspar and dark minerals. No gravel was penetrated in the Sanborn group during test drilling.

Distribution and thickness.—Deposits of the Sanborn group underlie the surface of the upland north of Arkansas River in the Ingalls area. South of the river these deposits are covered by dune sand, but they are continuous throughout the area except along the southern edge of the valley where they have been removed by erosion or covered by younger terrace deposits.

Contacts between the Sanborn group and underlying older sediments are difficult to distinguish in test holes because of similarities in lithology; therefore the thicknesses given here are only approximate. North of Arkansas River, deposits of the Sanborn group are 15 to 30 feet thick. South of the river the thickness ranges from a featheredge to as much as 65 feet but averages about 35 feet.

Water supply.—In the Ingalls area the deposits of the Sanborn group, except the terrace deposits south of Arkansas River, lie above the water table and do not yield water to wells.

Terrace Deposits

Character.—The deposits forming the prominent terrace 20 to 25 feet above the floodplain south of Arkansas River are probably of late Wisconsinan age and are included in the Sanborn group. These deposits are well exposed in gravel pits near Pierceville and Cimarron. They consist of unconsolidated crossbedded fine sand to large cobbles, which in the pit near Pierceville are overlain by sandy silt containing abundant invertebrate fossils. Sand and gravel beds are composed chiefly of subrounded to well-rounded quartz but contain some feldspar and dark minerals. Pebbles of quartz, feldspar, granite, other igneous rocks, and "mortar bed" compose the coarser gravels. Many of the pebbles in the coarse gravels are 2 to 4 inches in diameter, and some angular "mortar bed" blocks are as much as 8 inches long.

Distribution and thickness.—Terrace deposits border the floodplain of Arkansas River throughout the Ingalls area and form an almost continuous scarp along the south edge of the floodplain. Remnants of the terrace occur north of the river and are well exposed in a draw about 1.4 miles west of Ingalls. The thickness of the terrace gravels is known from two test holes: 25-31-22bb penetrated 25.5 feet of sand and gravel and 25-31-24dd penetrated 21.6 feet of sand and gravel.

Water supply.—The upper part of the terrace gravels is above the water table and does not yield water to wells. The basal part, however, is below the water table and supplies water to a few stock wells in the area. An abandoned gravel pit in the terrace deposits south of Cimarron, 26-28-14dc, has been excavated below the water table, and the water is used as an irrigation supply.

Dune Sand

Dune sand of Quaternary age mantles the area south of Arkansas Valley. It is composed predominantly of fine- to medium-grained quartz sand but contains some silt and some coarse sand. The sand forms small hills that average 30 feet in height. Most of the sand hills are covered by vegetation, but locally small areas of bare sand are subjected to wind action. Smith (1940, p. 127-128, 153-168) gives an excellent description of the dune sand in southwestern Kansas, and the reader is referred to his paper for further details.

No wells obtain water from the dune sand, because it lies above the water table. Because the sand is loose and permeable, it serves as an important catchment medium for precipitation. Although recharge to the ground-water reservoir from the sand dunes is retarded by underlying silt, the dunes hold precipitation in the area for a time sufficient to allow downward percolation that results in a recharge rate greater than in adjacent areas.

Alluvium

Character.—Deposits of Recent alluvium underlie the floodplain of Arkansas River in the Ingalls area. The deposits of the lower terrace, which stands 4 to 6 feet above the floodplain, are also classified as Recent alluvium.

The alluvium consists of stream-laid deposits that range from clayey silt to very coarse gravel. The silt and clay beds are in the upper few feet of the alluvium. These silts and clays, which range from light gray to black, are generally sandy, and locally they contain abundant invertebrate shells. The sands of the alluvium, which range from tan to gray, are composed of fine to coarse grains of quartz and minor amounts of feldspar and dark minerals. The gravels, which compose the bulk of the alluvium, range from fine to very coarse but are predominantly fine to medium. They are poorly sorted and generally contain sand. The gravels consist chiefly of subangular to rounded quartz grains. The coarser gravels are mostly well-rounded pebbles of feldspar, granite, and other igneous rocks.

Distribution and thickness.—The width of the alluvium of Arkansas Valley ranges from about 1 mile at Pierceville to 1½ miles at Cimarron, and averages approximately 1¼ miles. The thickness of the alluvium varies from place to place but averages 35 feet in the deeper parts of the fill.

Water supply.—The sands and gravels of the alluvium are the most permeable water-bearing deposits in the Ingalls area and are the source of most irrigation, stock, and domestic supplies in the valley. Yields range from a few gallons per minute from stock and domestic wells to as much as 2,500 gpm from an irrigation installation.

IRRIGATION IN THE INGALLS AREA

Extent of Irrigation

Both surface water and ground water are used for irrigation in the Ingalls area. Plate 1 shows the points of diversion of surface water from Arkansas River and the locations of irrigation wells.

According to the records of the Division of Water Resources of the State Board of Agriculture, 2,470 acre-feet of surface water from Arkansas River and 12,045 acre-feet of ground water have been appropriated in the Ingalls area; 6,415 acre-feet is pumped from wells in the Arkansas Valley and 5,630 acre-feet from wells in the upland. Of the 5,630 acre-feet, about 1,560 acre-feet is pumped from wells within 4 miles of Arkansas River, and about 4,070 acre-feet from wells 4 to 14 miles from the river.

In the Ingalls area the total amount of land irrigated is 7,420 acres, of which 1,502 acres is irrigated with surface water from Arkansas River and 5,918 acres with ground water. Of the 5,918 acres irrigated with ground water, 2,240 acres is in the Arkansas Valley, 805 acres in the upland within 4 miles of the river, and 2,873 acres in the upland 4 to 14 miles from the river.

Yields of Irrigation Wells and Types of Power Used for Pumping

The yields of irrigation wells in the Ingalls area range from about 100 to 2,500 gpm. Most of the wells are in the Arkansas River valley, and many in the alluvium constitute what are known locally as batteries of wells—3 to 5 closely spaced wells pumped by one pump. Some of these installations are driven by gasoline or diesel engines and some are driven by electric motors. The battery-type wells have a wide range in yield, which depends on the permeability of the water-bearing materials and on the number of wells connected to the system. The yield of a battery system does not always increase in proportion to the number of wells in the system. Mutual interference between the wells may reduce the average yield per well below that from any one well alone. The greater the distance between wells the less the mutual interference. Most of the battery-type systems in this area yield at least 1,500 gpm. A few shallow wells in the valley are single-cased wells pumped by electric turbines. The yields of the upland wells range from about 500 to 1,600 gpm and average about 1,000 gpm. The wells are deep and are pumped by turbine pumps, most of which are driven by diesel motors.

Depths and Diameters of Irrigation Wells

Irrigation wells in the Arkansas River valley range in depth from 25 to 50 feet and average about 30 feet; they range in diameter from 15 to 18 inches. One well (25-29-27cc2) is 180 feet deep and yields about 1,400 gpm from both the alluvium and the underlying Ogallala formation.

The upland irrigation wells range in depth from 150 to 310 feet. These wells generally are cased with 16- to 18-inch pipe and are gravel packed. Some of the wells are screened throughout the saturated water-bearing material, whereas other wells are screened only in the zones of permeable sand and gravel.

HYDROLOGIC PROPERTIES OF THE WATER-BEARING MATERIALS

The quantity of ground water that an aquifer will yield to wells depends upon the hydrologic properties of the materials in the aquifer. The principal hydrologic properties of an aquifer are its ability to transmit and to store water. The ability of an aquifer to transmit water is measured by its coefficient of transmissibility, and the ability to store water is measured by its coefficient of storage —a coefficient indicating the quantity of water that will be yielded from storage when the head is lowered.

The coefficient of transmissibility (T) of a water-bearing formation is expressed as the rate of flow of water, in gallons per day, at the prevailing temperature through a vertical strip of the aquifer 1 mile wide extending the full height of the aquifer under a hydraulic gradient of 1 foot per mile. The field coefficient of permeability (P) is expressed as the rate of flow of water, in gallons per day, at the prevailing temperature through each mile of the aquifer for each foot of thickness under a hydraulic gradient of 1 foot per mile. The field coefficient of permeability can be computed by dividing the coefficient of transmissibility by the aquifer thickness (m). The coefficient of storage of an aquifer may be defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions the coefficient of storage is practically equal to the specific yield, which is defined as the ratio of the volume of water a saturated material will yield to gravity in proportion to its own volume.

Purpose of Aquifer Tests

The well inventory and test drilling in the Ingalls area indicated several physical factors that would affect the maximum perennial yield of wells in the Arkansas Valley. These factors are the flow of Arkansas River; the thickness, areal extent, and lithology of the alluvium; the hydraulic connection between the river channel and the alluvium; the thickness, areal extent, and lithology of the Ogallala formation; and the hydraulic connection between the alluvium and the underlying Ogallala formation.

To determine the hydraulic connection between the river and the alluvium and between the alluvium and the Ogallala formation, it was necessary to determine the hydraulic constants of transmissibility, permeability, and storage of these aquifers. In addition, it was necessary to determine the vertical permeability of the Ogallala formation, as test drilling had shown that massive silt and clay confining beds were present below the alluvium and could prevent downward percolation of water from the alluvium to the Ogallala formation. Seven aquifer tests were made to determine the hydraulic constants.

Three aquifer tests were made in the alluvium. The first test was made to determine the coefficients of transmissibility and storage. The second and third tests were made not only to determine the coefficients of transmissibility and storage, but also to determine the extent of the hydraulic connection between Arkansas River and the alluvium.

Four aquifer tests were made in the Ogallala formation. Two were recovery tests made in the upland to determine the coefficient of transmissibility. Two were made in the Ogallala formation underlying the alluvium and were designed to determine not only the transmissibility and storage coefficients, but also the vertical coefficient of permeability of the Ogallala formation and the recharge from the alluvium to the underlying Ogallala formation.

Methods

The data collected during the aquifer tests were analyzed by the methods generally referred to as the Thiem method, the Theis nonequilibrium method, the Jacob modified nonequilibrium method, and the Jacob leaky-aquifer method. All these methods were used where applicable to arrive at the best interpretation of the aquifer-test data.

Thiem method.—The Thiem method is a means for determining the coefficients of transmissibility and storage on the basis of the rate of discharge of a pumped well and the drawdown in each of at least two observation wells at different known distances from the pumped well. The Thiem equation (Wenzel, 1942, p. 81), expressed in terms of transmissibility instead of permeability, is

$$T = \frac{527.7\ Q\ \log_{10} \frac{r_2}{r_1}}{s_1 - s_2}$$

where T is the coefficient of transmissibility, in gpd/ft,
Q is the rate of discharge of the pumped well in gpm,
r_1 and r_2 are the respective distances of two observation wells from the pumped well, in feet, and
s_1 and s_2 are the respective drawdowns in the two observation wells, in feet.

To apply the Thiem equation, some convenient elapsed pumping time, t, is selected after the water levels in the observation wells reach a steady rate of decline, and the drawdown, s, of each observation well is plotted against the distance, r, on semilog coordinate paper. When the values of s are plotted on the arithmetic scale and the values of r on the logarithmic scale, the data should form a straight line. From this line the change in drawdown per log cycle, Δ s, is determined, and the Thiem equation is reduced to

$$T = \frac{528\ Q}{\Delta s}$$

Using this same line and extrapolating it to the zero-drawdown axis, the storage coefficient can be calculated by the following equation

$$S = \frac{0.3\ Tt}{r_0^2}$$

where S is the coefficient of storage,
T and t are as previously defined, and
r_0 is the distance intercept on the zero-drawdown axis, in feet.

The Thiem method was used to analyze the test data on the alluvial aquifer.

The values obtained for S by the Thiem method generally are low and are not necessarily valid in short aquifer tests. Slow drainage of the aquifer may invalidate the S determination, although in some tests an approximate answer can be calculated.

Theis nonequilibrium method.—The Theis nonequilibrium method is a means for determining the coefficients of transmissibility and storage if the rate of discharge of a pumped well and the rate of change of drawdown or recovery in at least one observation well are known.

The Theis formula is

$$s = \frac{114.6\,Q}{T} \int_{u}^{\infty} \frac{e^{-u}}{u} du$$

where $u = \frac{1.87 r^2 S}{Tt}$,

s is the drawdown or recovery, in feet, at any point of observation in the vicinity of a well discharging at a constant rate,
Q is the rate of discharge of the pumped well, in gpm,
T is the coefficient of transmissibility, in gpd/ft,
r is the distance from the discharging well to the observation well, in feet,
S is the coefficient of storage expressed as a decimal fraction, and
t is the time since pumping began or stopped, in minutes.

The integral expression in the Theis formula is written symbolically as W(u) and is read as the well function of u. The integral expression cannot be integrated directly, but its value is given by the series

$$W(u) = -0.577216 - \log_e u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!}$$

Theis devised a graphical method of superposition that makes it possible to obtain a simple solution of the complex equation. If s can be measured for one value of r and several values of t, or for one value of t and several values of r, and if the discharge Q is known, then T and S can be determined. In this method a type curve is plotted on logarithmic coordinate paper. Values of W(u) are plotted against $\frac{1}{u}$ to form a type curve (Wenzel, 1942, p. 88-89). If values of s obtained in one observation well are plotted against values of t on logarithmic tracing paper to the same scale as the type curve, the curve of the observed data will be similar to the type curve. The data curve may be superposed on the type curve, the coordinate axis of the two curves being held parallel, and translated to a position that best fits the data curve to the type curve.

The selection of a match point common to both charts provides the data needed to solve the Theis equation, which in simple form reduces to

$$T = \frac{114.6\,Q\,W(u)}{s}$$

$$\text{and } S = \frac{T\,t}{1.87r^2\left(\frac{1}{u}\right)}$$

where T, S, Q, and r are as previously defined,

t and s are match-point coordinates on the data chart, and

W(u) and $\frac{1}{u}$ are match-point coordinates on the type-curve chart.

The Theis method generally gives good results where the water-bearing materials are confined; hence, the tests made in the Ogallala formation underlying the alluvium were analyzed in part by this method.

Jacob modified nonequilibrium method.—Cooper and Jacob (1946) recognized that in the series of the well function in the Theis equation the sum of the terms beyond $\log_e u$ is not significant when u becomes small. The value of u decreases as t increases and r decreases. Therefore, for large values of t and reasonably small values of r the terms beyond $\log_e u$ can be ignored. The Theis equation in its modified form becomes

$$T = \frac{264\,Q\,(\log_{10}\frac{t_2}{t_1})}{s_2 - s_1}$$

where Q and T are as previously defined,

t_1 and t_2 are two selected times since pumping started or stopped in any convenient units, and

s_1 and s_2 are the respective drawdowns or recoveries, in feet, at the noted times.

If the observed drawdowns or recoveries for each well are plotted on the arithmetic scale and the values of t are plotted on the logarithmic scale of semilog paper, the resulting plot should form a straight line if enough time has elapsed so that u has become small. The early data in this type of plot generally will plot as a curve and will be invalid. If t_1 and t_2 are chosen one log cycle apart, the Jacob modified nonequilibrium equation reduces to

$$T = \frac{264\,Q}{\Delta s}$$

where Δs is the drawdown per log cycle.

The coefficient of storage also can be determined from the same semilog plot of the observed data by the following equation:

$$S = \frac{0.3T\, t_o}{r^2}$$

where S, T, and r are as previously defined, and

t_o is the time intercept on the zero-drawdown axis, in days.

The data collected during the aquifer tests in the alluvium were analyzed, in part, by this method. The recovery data collected in the pumped wells in the Ogallala formation also were analyzed by this method.

Jacob leaky-aquifer method.—The earliest data collected during the aquifer tests of the Ogallala formation underlying the alluvium were analyzed by the Theis method. Near the end of the tests the drawdowns departed from the Theis type curve; leakage through the confining beds below the alluvium and a change in transmissibility were assumed to be the cause of the departure.

Jacob (1946) analyzed the leaky-aquifer problem and derived the following formulas and procedures for determining the coefficient of transmissibility of the artesian aquifer and the coefficient of vertical permeability of the confining bed:

$$T = \frac{229\, Q\, K_o\, (x)}{s}$$

where $x = \frac{br}{a}$ or $\frac{x}{r} = \frac{b}{a}$

and $a = \sqrt{\frac{T}{S}}$

$$b = \sqrt{\frac{P'}{m'S}}$$

$$\frac{b}{a} = \sqrt{\frac{P'}{Tm'}}$$

$$P' = \left(\frac{b}{a}\right)^2 Tm'$$

where P′ is the coefficient of vertical permeability of the confining bed, in gpd/ft^2,

m′ is the thickness of the confining bed, in feet, and

T, S, Q, r, s, are as previously defined.

Neither a nor b can be determined from field observations, but their ratio can be determined from the definition of x where

$$x = r\sqrt{\frac{P'}{Tm'}} \text{ or where } P' = Tm'\left(\frac{x}{r}\right)^2.$$

The symbol K_0 (x) is used to identify the modified Bessel function of the second kind of the zero order. A type curve is used to solve the equation.

The solution of the equations given above requires plotting the applicable field observations of s and r on logarithmic paper using the logarithmic scale adopted for the leaky-aquifer type curve. An arbitrary point is selected on the data curve, and the coordinates of this common point on both the data curve (r and s) and the type curve (K_0(x) and x) are recorded. These coordinates are then substituted in the Jacob leaky-aquifer formula to compute the coefficient of transmissibility of the artesian bed and the coefficient of vertical permeability of the leaky confining bed.

Test Results

Tests in Alluvium

Ven John.—An aquifer test was made by using an irrigation well in the SW¼ NE¼ sec. 22, T. 25 S., R. 30 W., owned by Paul Ven John. The well, 16 inches in diameter and 41 feet deep, was drilled to the base of the alluvium. The thickness of the saturated material prior to the test was 24 feet. Observation wells 1N, 2N, 3N, and 4N were constructed at distances of 30, 60, 100, and 150 feet, respectively, in a line extending north from the pumped well. The observation wells were 33, 28, 28, and 29 feet deep, respectively, and were finished with 3-foot screens. Holes were augered to a depth of 41 feet at the site of wells 1N and 4N to determine the character and depth of the alluvium. No layers of silt or clay are present in the water-bearing zone.

The well was pumped February 29, 1956, at an average rate of 440 gpm. The water levels measured during the test are given in Table 2 and are plotted against time in Figure 6; the drawdown of water level in the observation wells after 90 and 345 minutes of pumping is plotted against distance from the pumped well in Figure 7.

The coefficients of transmissibility shown in Figure 6 were determined by the Jacob modified nonequilibrium method. The co-

TABLE 2.—*Depth to water measured in pumped well and observation wells during Ven John aquifer test February 29, 1956*

Time since pumping started, in minutes	Depth to water below measuring point, in feet					Remarks
	Pumped well	Well 1N	Well 2N	Well 3N	Well 4N	
8:10 a.m.	17.30	17.02	18.42	19.70	20.24	Static
9:05	....	17.03	....	....	....	
9:15	....	....	....	....	....	Pump on
1	....	18.06	18.77	....	....	
2	....	18.06	....	19.90	....	
3	....	18.07	18.86	....	20.29	
4	26.33	....	....	....	....	
5	....	18.11	....	....	....	
6	....	....	....	....	20.31	
7	26.70	....	....	19.94	....	
9	....	....	18.97	....	20.37	
10	....	18.18	....	....	....	
11	....	....	....	20.02	....	
12	26.72	....	....	....	....	
13	....	....	18.99	....	....	
15	....	18.24	....	20.02	20.37	
17	26.72	....	19.03	....	....	
19	....	....	....	20.03	....	
20	....	18.28	....	....	20.38	
22	26.74	....	19.05	....	....	
24	....	....	....	20.05	....	
25	....	18.32	....	....	20.40	
27	26.80	....	19.10	....	....	
29	....	....	....	20.06	....	
30	....	18.35	....	....	....	
32	....	....	19.13	....	....	
34	....	....	....	20.08	....	
35	26.88	....	....	....	20.43	
37	....	....	19.16	....	....	
39	....	....	....	20.11	....	
40	....	18.41	....	....	....	
42	....	....	19.19	....	....	
45	26.91	18.43	....	20.14	20.44	
55	26.99	18.49	19.23	20.10	20.46	
65	27.00	18.53	19.26	20.20	20.48	
75	27.07	18.58	19.29	20.22	20.50	
90	27.07	18.64	19.33	20.27	20.55	
100	27.11	18.68	19.40	20.32	20.56	
120	27.12	18.73	19.43	20.34	20.58	
135	27.25	18.77	19.46	20.36	20.60	
150	27.27	18.80	19.50	20.39	20.63	
165	27.35	18.84	19.53	20.41	20.65	
195	....	....	19.60	20.48	20.70	
210	27.51	....	....	....	....	
225	....	18.98	19.66	20.50	20.73	
240	27.52	....	....	....	....	
255	27.55	19.01	19.69	20.54	20.75	
285	27.47	19.07	19.75	20.60	20.80	
315	27.55	19.12	19.79	20.63	20.81	
345	27.60	19.17	19.84	20.65	20.86	

efficients computed from data from the pumped well and observation wells 1N and 2N are thought to be correct. Larger coefficients of transmissibility were obtained from data from observation wells 3N and 4N because pumping time was insufficient for the drawdown data to attain the correct slope. Figure 7 shows the calcula-

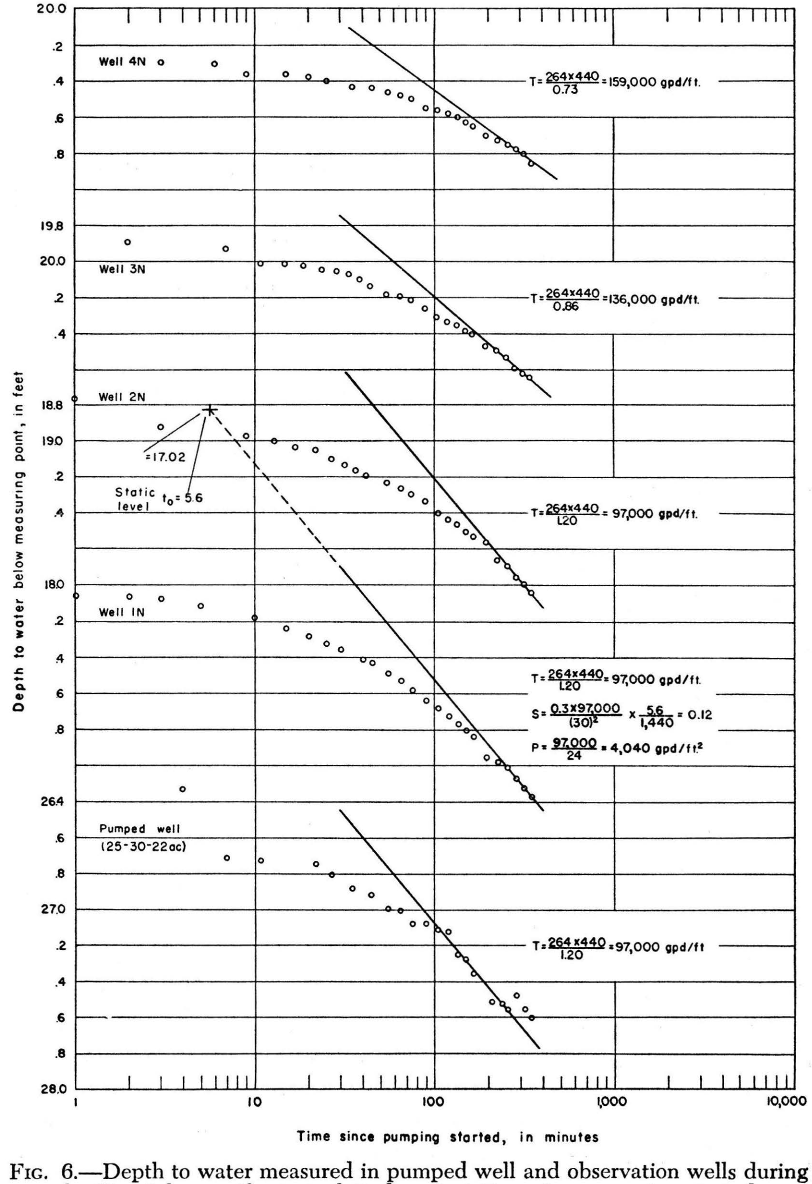

FIG. 6.—Depth to water measured in pumped well and observation wells during the Ven John aquifer test plotted against time since pumping started.

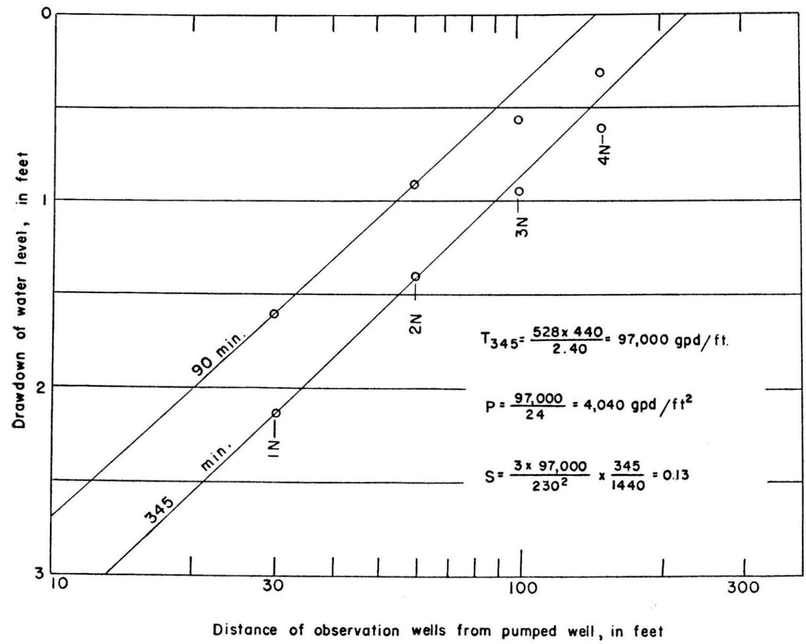

FIG. 7.—Drawdown of water levels in observation wells at 90 and 345 minutes during the Ven John aquifer test plotted against distance from pumped well.

tion for T by the Thiem method. The coefficient of transmissibility obtained by both methods was 97,000 gpd/ft, and the coefficient of permeability was about 4,040 gpd/ft.^{2}

A storage coefficient of 0.12 was obtained by the Jacob modified nonequilibrium method, and of 0.13 by the Thiem method (Fig. 6 and 7). Had the test been longer, the storage coefficient probably would have been larger than 0.13. Some drawdown occurred in all the observation wells immediately after pumping started. During the early period of the test, the aquifer acted temporarily as an artesian aquifer. The vertical permeability probably is considerably less than the horizontal permeability; the difference results in temporary artesian conditions.

The field data were not adjusted for the thinning of the aquifer during the test because it was not enough to warrant adjustment.

Renick.—An aquifer test was made to determine the permeability of the alluvial material through which Arkansas River flows and to determine whether the water could be induced to move from the river to a pumped well adjacent to it. A well to be pumped and 7 observation wells were constructed for an aquifer test in the NE¼

SE¼ sec. 25, T. 25 S., R. 30 W., on the farm of Frank Renick. The respective locations of the pumped and observation wells are shown in Figure 8. The pumped well, 16 inches in diameter, 42 feet deep, and screened with perforated pipe, was drilled to the base of the alluvium 70 feet from Arkansas River. The thickness of the saturated material prior to the test was 36 feet. Holes were augered to a

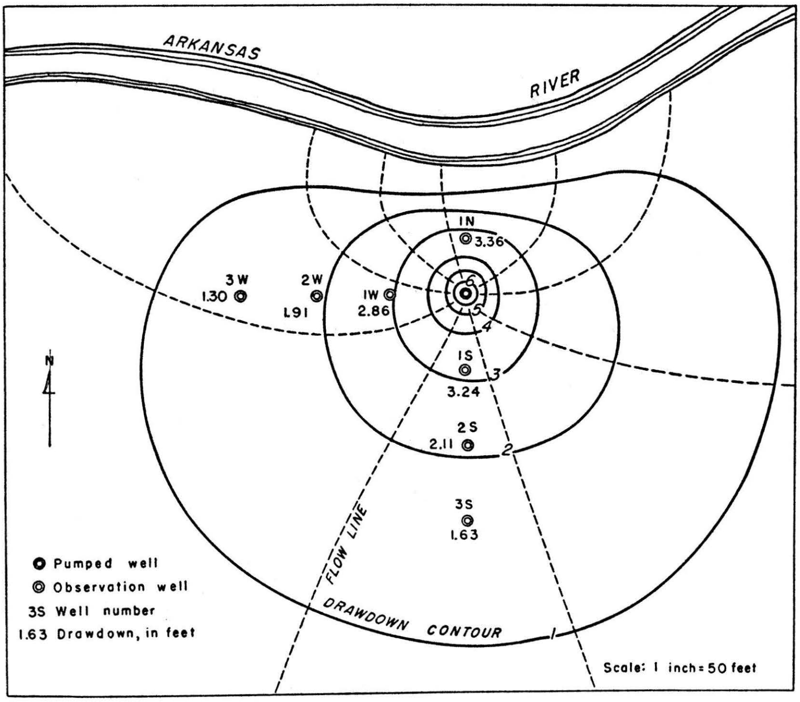

FIG. 8.—Contour map showing drawdown at end of aquifer test at Renick site (25-30-25da1).

depth of 44 feet at the site of observation wells 1S, 3S, and 3W to determine the character and depth of the alluvium. No layers of silt or clay are present in the water-bearing zone.

The well was pumped March 14 and 15, 1956, at an average rate of 1,300 gpm. Water-level measurements made in the seven observation wells are given in Table 3. Depth to water level in the observation wells is plotted against time in Figure 9, and the drawdown of water level in the observation wells west and south of the pumped well after 60, 180, and 1,020 minutes of pumping is plotted against distance from the pumped well in Figure 10. A

TABLE 3.—*Depth to water measured in observation wells during Renick aquifer test March 14-15, 1956*

Time since pumping started, in minutes	Depth to water below measuring point, in feet							Remarks
	Well 1S	Well 2S	Well 3S	Well 1W	Well 2W	Well 3W	Well 1N	
9:45 a.m.	6.20	6.10	7.98	7.21	7.92	9.37	9.72	Static
10:25	......	......	......	......	......	......	......	Pump on
1	......	6.65	8.18	......	......	9.69	11.68	
2	......	......	......	......	......	9.77	......	
2.5	7.50	......	......	......	......	......	......	
3	......	......	8.27	......	8.35	9.78	11.68	
4	......	......	......	......	......	......	11.59	Reduced speed of pump motor slightly
4.5	7.64	......	......	......	......	......	......	
5	......	6.70	......	8.61	......	9.77	11.54	
6	7.81	......	......	......	8.65	......	......	
7	......	......	......	......	......	9.87	......	
8	7.89	......	......	8.86	......	......	11.84	
9	......	......	8.33	......	......	9.87	11.84	
10	7.94	6.84	......	......	8.72	......	......	
11	......	......	......	......	......	9.87	11.93	
12	......	6.87	......	8.88	......	......	11.93	
13	7.98	......	......	......	......	......	......	
14	......	......	8.39	......	8.74	......	11.97	
15	......	......	......	9.02	......	9.89	......	
16	8.04	......	......	......	......	......	11.99	
17	......	6.90	......	......	......	......	......	
20	8.10	6.94	8.44	9.05	8.81	9.89	12.04	
25	8.15	7.00	8.49	9.10	8.87	9.93	12.09	
30	8.20	7.03	8.50	9.13	8.89	9.94	12.12	
35	8.24	7.05	8.52	9.16	8.90	9.99	12.15	
40	8.29	7.10	8.56	9.18	8.93	10.01	12.17	
45	8.32	7.13	8.57	9.21	8.97	10.04	12.22	
50	8.35	7.15	8.59	......	......	10.05	12.23	
55	8.38	7.18	8.62	9.27	9.02	10.06	12.25	
60	8.41	7.20	8.64	9.30	9.05	10.08	12.27	
65	......	......	......	9.32	9.07	......	......	
70	8.47	7.25	8.68	9.35	9.08	10.07	12.32	
75	......	......	......	......	9.11	......	......	
80	8.51	7.30	8.73	9.39	......	10.12	12.35	
85	......	......	......	......	9.15	......	......	
90	8.57	7.35	8.77	9.43	......	10.15	12.40	
95	......	......	......	......	9.19	......	......	
100	8.61	7.38	8.78	9.45	......	10.16	12.42	
110	8.65	......	......	9.49	......	10.15	12.44	
125	8.69	7.44	8.86	9.54	9.26	10.17	12.50	
140	8.74	7.48	8.89	9.58	9.29	10.21	12.53	
160	8.80	7.53	8.94	9.63	9.33	10.22	12.56	
180	8.84	7.62	8.97	9.67	9.35	10.24	12.59	
210	8.90	7.68	9.05	9.72	9.39	10.28	12.61	
240	8.95	7.71	9.09	9.75	9.45	10.31	12.66	
270	9.00	7.77	9.13	9.80	9.48	10.34	12.69	
300	9.03	7.80	9.18	......	9.51	10.38	12.73	
330	9.06	7.84	9.22	9.85	9.53	10.39	12.76	
360	9.10	7.87	9.24	9.87	9.55	10.40	12.77	

TABLE 3.—*Depth to water measured in observation wells during Renick aquifer test March 14-15, 1956—Concluded*

Time since pumping started, in minutes	Depth to water below measuring point, in feet							Remarks
	Well 1S	Well 2S	Well 3S	Well 1W	Well 2W	Well 3W	Well 1N	
420	9.15	7.92	9.33	9.92	9.60	10.44	12.83	
480	9.22	7.98	9.36	9.94	9.64	10.49	12.87	
540	9.24	8.00	9.39	10.00	9.69	10.53	12.90	
600	9.28	8.04	9.42	10.03	9.70	10.54	12.93	
660	9.31	8.07	9.46	10.05	9.72	10.57	12.95	
720	9.34	8.10	9.50	10.08	9.75	10.59	12.98	
780	9.36	8.13	9.51	10.11	9.77	10.60	13.01	
900	9.40	8.17	9.57	10.15	9.81	10.64	13.05	
1,020	9.44	8.21	9.61	10.18	9.84	10.67	13.08	

cross section of the test site before and after pumping is shown in Figure 11.

The shape of the time-drawdown curves (Fig. 9) indicates that recharge occurred during the test. If no recharge had occurred, the curves would have continued to decline until they approximated the theoretical curve shown for observation well 1S in Figure 9. In effect, the time-drawdown curves are the resultant of a curve representing drawdown caused by pumping an aquifer that has no recharge and a curve representing recovery caused by leakage from Arkansas River. The curves indicate that recharge did not occur during the early stage of the aquifer test. The downward trend of the curves representing the later stage of the test indicates that recharge was being received from Arkansas River. At the completion of the test, however, the cone of influence still was developing on the landward side, and infiltration from the river was not yet sufficient to supply the yield of the well. The curves show time lags according to the time required for recharge from the river to reach the observation wells; the time, in turn, depends on the distance of the observation wells from the river. Had the test been longer and had recharge continued to develop, the flow from the river would have continued to increase, and the proportion from storage would have continued to decrease. Eventually, nearly all the water being pumped would come from the river.

Computations of coefficients of transmissibility, permeability, and storage can be made from the time-drawdown curves only if the curves attain a constant slope prior to the beginning of recharge.

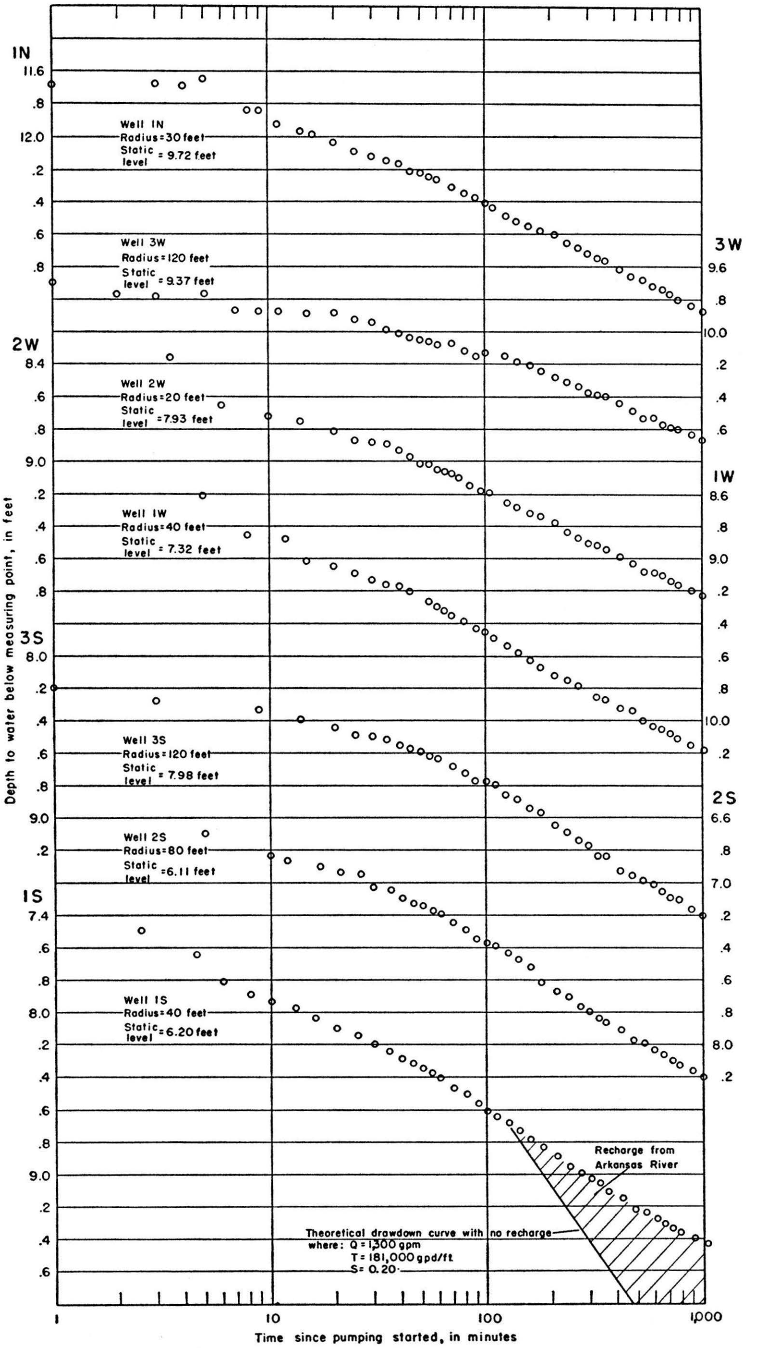

FIG. 9.—Depth to water measured in observation wells during Renick aquifer test plotted against time since pumping started (25-30-25da1).

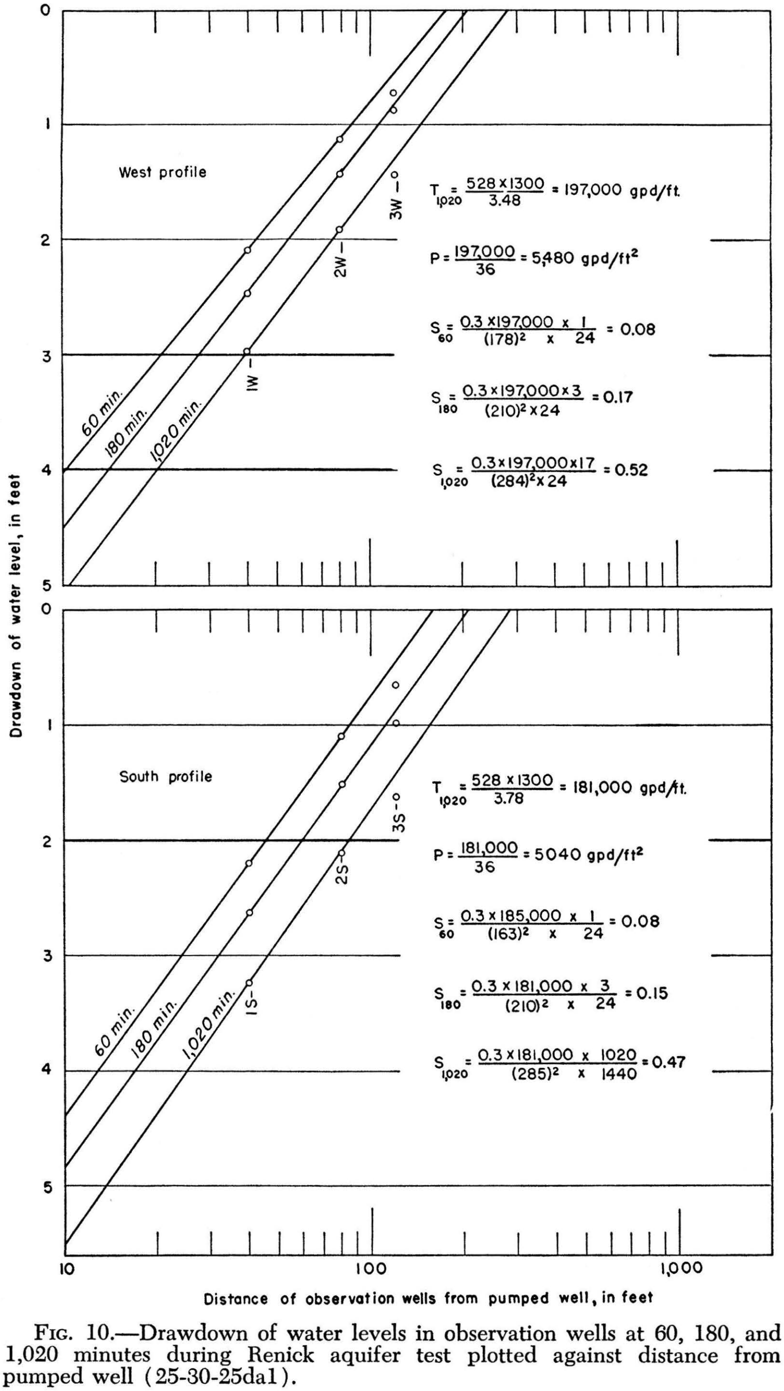

FIG. 10.—Drawdown of water levels in observation wells at 60, 180, and 1,020 minutes during Renick aquifer test plotted against distance from pumped well (25-30-25da1).

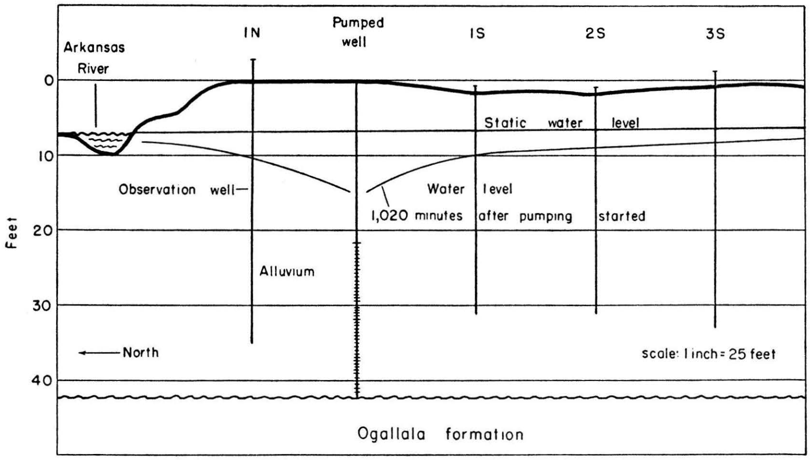

FIG. 11.—Cross section at Renick test site before and after pumping.

In this test the recharge began before the curves had time to reach a constant slope; hence the coefficients of transmissibility and storage could not be determined from these plots.

The coefficients of transmissibility, permeability, and storage shown in Figure 10 were determined by the Thiem method. The recharge that occurred during the test did not invalidate the computations of the coefficients of transmissibility and permeability, because their values depend on the slope of the line drawn through the drawdown points, and as the effect of recharge is negligible in the early part of the tests in all observation wells, the slope of the line is not changed materially. Based on data from observation wells 1S, 2S, and 3S, perpendicular to the river, after 1,020 minutes of pumping, the coefficients of transmissibility and permeability were 181,000 gpd/ft and 5,000 gpd/ft^2, respectively. Approximately the same coefficients of transmissibility and permeability were obtained from drawdown data after 60 and 180 minutes. A slightly higher coefficient of transmissibility was obtained by using data from observation wells 1W, 2W, and 3W parallel to the river than by using wells 1S, 2S, and 3S perpendicular to the river; this difference probably was caused by changes in lithology within the aquifer and partially penetrating observation wells. The lower coefficient of transmissibility obtained from these data has been used.

The storage coefficients were computed after 60, 180, and 1,020 minutes of pumping. The coefficients of 0.15 and 0.17 obtained from the 180-minute data probably were not affected much by recharge, and the error caused by recharge was small. As recharge progressed, the rate of drawdown decreased; hence the zero radius intercept was much less than it would have been if no recharge had occurred. S as computed from data from wells 1W, 2W, and 3W at the end of 1,020 minutes was 0.52. This high coefficient of storage also indicates recharge from the river. The storage coefficient of 0.17 percent is not necessarily correct, but probably is of the correct order of magnitude.

Leslie E. Mack has applied an analog field plotter to the ground-water flow during the Renick and Norbert Irsik tests. The analog plotter consists of a power source, a voltage divider having a null-point indicator and probe, and a special resistance paper. Many natural phenomena such as electrostatics, magnetostatics, heat flow, electric-current flow, and fluid flow are related in their field theory by the Laplace equation, and it can be shown that a problem in the steady-state motion of ground water is mathematically analogous to a problem in the steady-state flow of electricity. This analogy between the flow of electric current and the flow of ground water can be demonstrated with the analog field plotter by relating electrical potential to hydraulic head. A ground-water situation can be reproduced to scale by applying flow boundaries determined in an aquifer test with conductive paint on the resistance paper. Wire leads from the power supply are connected to the painted boundaries, causing a current to flow through the paper. Equipotential points then are marked by the probe and connected to form the desired contour lines.

The analog plotter was used to prepare the contour map (Fig. 8) from data collected during the Renick aquifer test. The drawdown contour lines are distorted near Arkansas River because of recharge from the river. Flow lines cross the contour lines at right angles and are shown as dashed lines. These flow lines mark the paths that particles of water would follow to the pumped well. Water that had its source in Arkansas River was moving toward the pumped well at the completion of the aquifer test. Figure 8 illustrates that water can be made to move from Arkansas River into the alluvium if the water table adjacent to the river is lowered below the river level.

Norbert Irsik.—A second aquifer test was made to determine the permeability of the alluvial material and to determine whether the water in Arkansas River would move to a pumped well. A well for the pumping test and seven observation wells were constructed in the NE¼ SW¼ sec. 28, T. 25 S., R 29 W., on the farm owned by Norbert Irsik (Fig. 12). The pumped well, 16 inches in diameter, 29 feet deep, and screened with perforated pipe, was drilled to the base of the alluvium, 135 feet from Arkansas River. The thickness

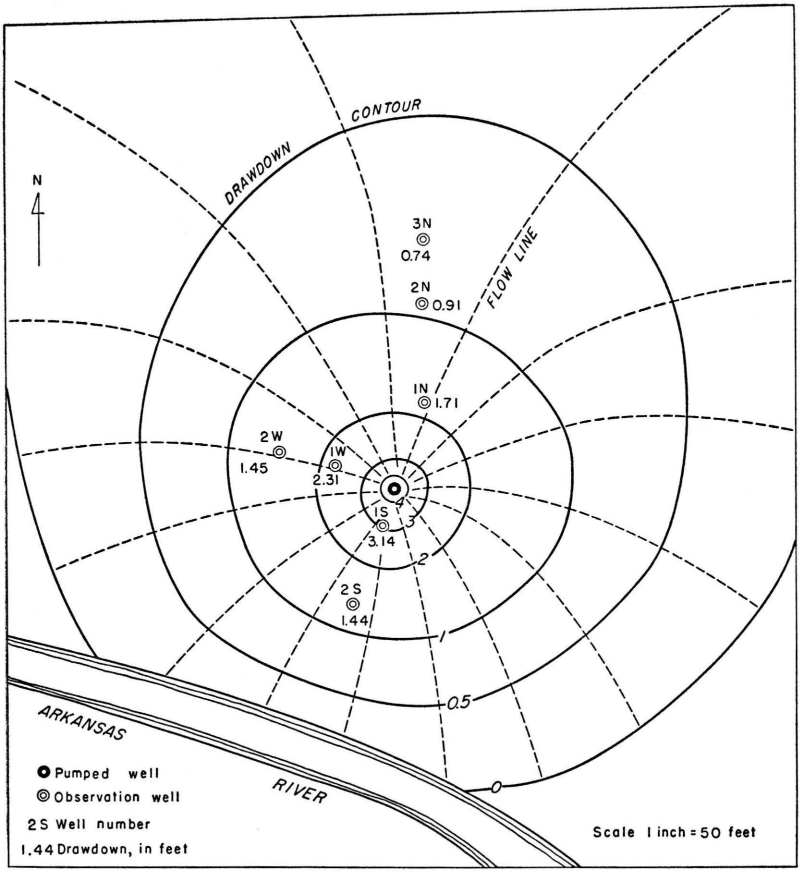

FIG. 12.—Contour map showing drawdown at end of aquifer test at Norbert Irsik site (25-29-28ca).

of the saturated material prior to the test was 22 feet; holes were augered to a depth of 35 feet at the site of observation wells 1N and 2W to determine the character and thickness of the alluvium. No layers of silt or clay are in the water-bearing zone.

The well was pumped March 21 and 22, 1956, at an average rate

Table 4. *Depth to water measured in observation wells during Norbert Irsik aquifer test on March 21-22, 1956.*

Time since pumping started, in minutes	Depth to water below measuring point, in feet							Remarks
	Well 1N	Well 2N	Well 3N	Well 1W	Well 2W	Well 1S	Well 2S	
7:45 a.m.	9.34	17.77	16.36	9.77	10.58	5.86	4.16	Static level
12:30 p.m.								Pump started
1	10.22							
2						8.21		
3		17.98						
5			16.57	11.24				
6	10.27							
7		18.02			11.21			
9			16.59			8.27		
10	10.32							
11		18.05					4.78	
12			16.60	11.31				
14					11.28			
15	10.35							
16		18.08						
17			16.62			8.34		
18							4.84	
20	10.38							
21		18.09		11.36				
22			16.63					
25	10.40				11.32			
26		18.91						
27			16.65			8.40		
28							4.92	
30	10.42							
31		18.12		11.41				
32			16.67		11.36			
40	10.47					8.46		
41		18.15					4.98	
42			16.70	11.47				
43					11.41			
50	10.50					8.52		
51		18.18					5.02	
52			16.70	11.51				
53					11.46			
60	10.54	18.20	16.72			8.56	5.07	
63				11.55	11.51			
75	10.57	18.22	16.73			8.59	5.11	
77				11.59	11.54			
90	10.61	18.25	16.75	11.63	11.56	8.63	5.16	
110	10.64	18.28	16.77	11.67	11.60	8.68	5.18	
130	10.69	18.32	16.81	11.72	11.65	8.71	5.28	
150	10.73	18.34	16.82	11.74		8.74	5.30	
180	10.77	18.39	16.87	11.80	11.69	8.79	5.36	
210	10.81	18.42	16.88	11.85	11.75	8.82	5.40	
240	10.84	18.45	16.90	11.87	11.78	8.87	5.44	
300	10.89	18.49	16.95	11.91	11.80	8.90	5.46	
390	10.94	18.54	17.00	11.99	11.87	8.93	5.53	
480	10.99	18.58	17.03	12.01	11.94	8.96	5.55	
600	11.02	18.62	17.07	12.04	11.95	8.98	5.58	
720	11.04	18.64	17.08	12.06	11.98	9.00	5.59	
900	11.05	18.68	17.10	12.08	12.03	9.00	5.60	

of 700 gpm. Water-level measurements made in the seven observation wells are given in Table 4 and are plotted against time in Figure 13; the drawdown of water level in the observation wells west and north of the pumped well after 60 and 900 minutes of pumping is plotted against distance from the pumped well in Figure 14. A cross section of the test site before and after pumping is shown in Figure 15.

The shape of the time-drawdown curves (Fig. 13) indicates that recharge occurred during the test. In general, this test had the same characteristics as the Renick test. The coefficient of transmissibility computed from data from observation wells 1N, 2N, and 3N at 900 minutes was 140,000 gpd/ft. (Fig. 14), which was lower than at the Renick site.

Recharge occurred before the drawdown data would plot at a constant slope, and the coefficients of transmissibility, permeability, and storage could not be determined from the plot in Figure 13. They were determined by the Thiem method and are shown in Figure 14. The smallest transmissibility coefficient was obtained from data from observation wells 1W and 2W at 900 minutes and was 130,000 gpd/ft. The coefficient of permeability was 5,900 gpd/ft.^{2}

At the end of the test, the water table along a line parallel to Arkansas River had a steeper slope than the water table along a line perpendicular to the river on the side of the well opposite from the river, as would be expected if river recharge occurred during the test. Had there been no recharge, the slope of the water table toward the river and parallel to the river would have been about the same.

The storage coefficients were computed from the observation-well data after 60 and 900 minutes of pumping. The coefficients obtained after 60 minutes were 0.08 and 0.09 as compared to 0.53 and 0.61 after 900 minutes. The high storage coefficients of 0.53 and 0.61 also indicate that recharge from the river occurred. None of the storage coefficients was judged to be valid.

The analog plotter was used to prepare the contour map (Fig. 12) from data collected during the Norbert Irsik aquifer test. The fact that drawdown contour lines are distorted near Arkansas River because of recharge from the river demonstrates that water can be made to move from Arkansas River into the alluvium if the water table adjacent to the river is lowered below the river level.

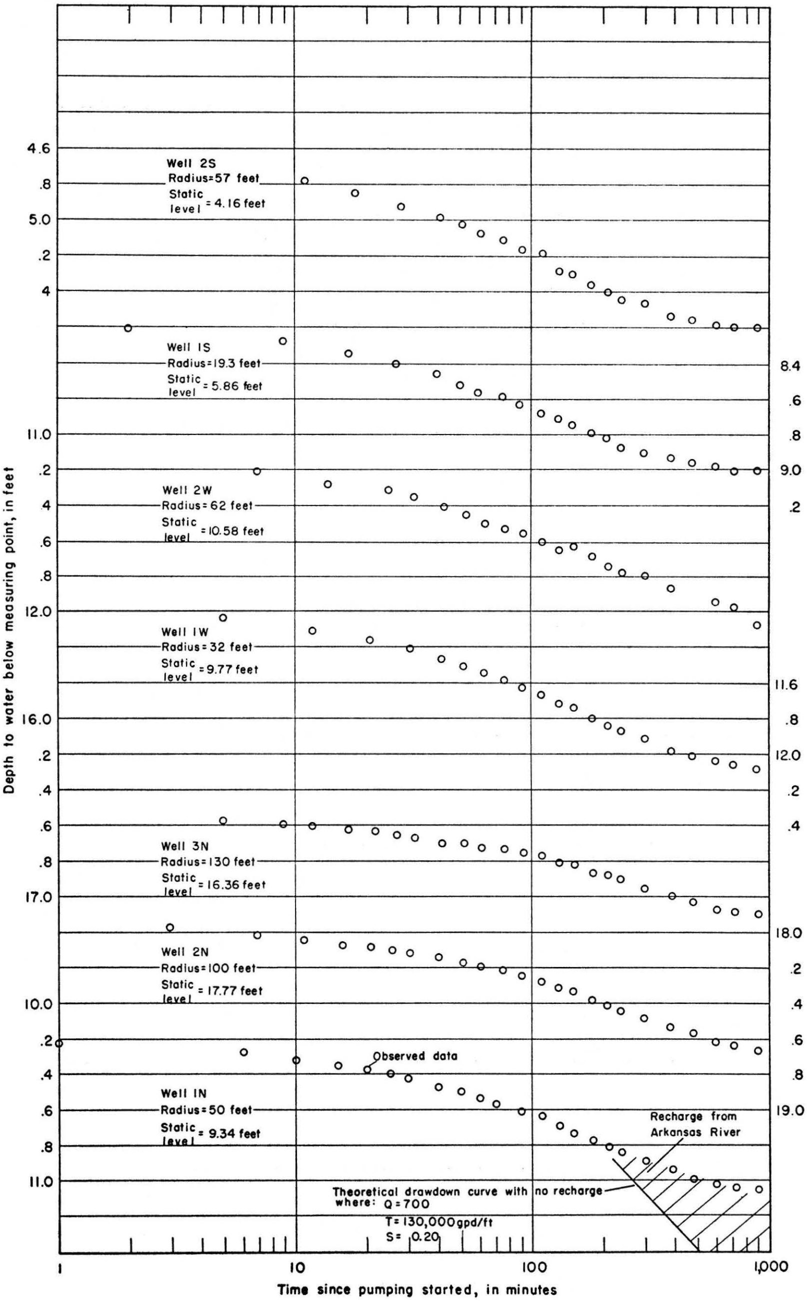

Fig. 13.—Depth to water measured in observation wells during Norbert Irsik aquifer test plotted against time since pumping started (25-29-28ca).

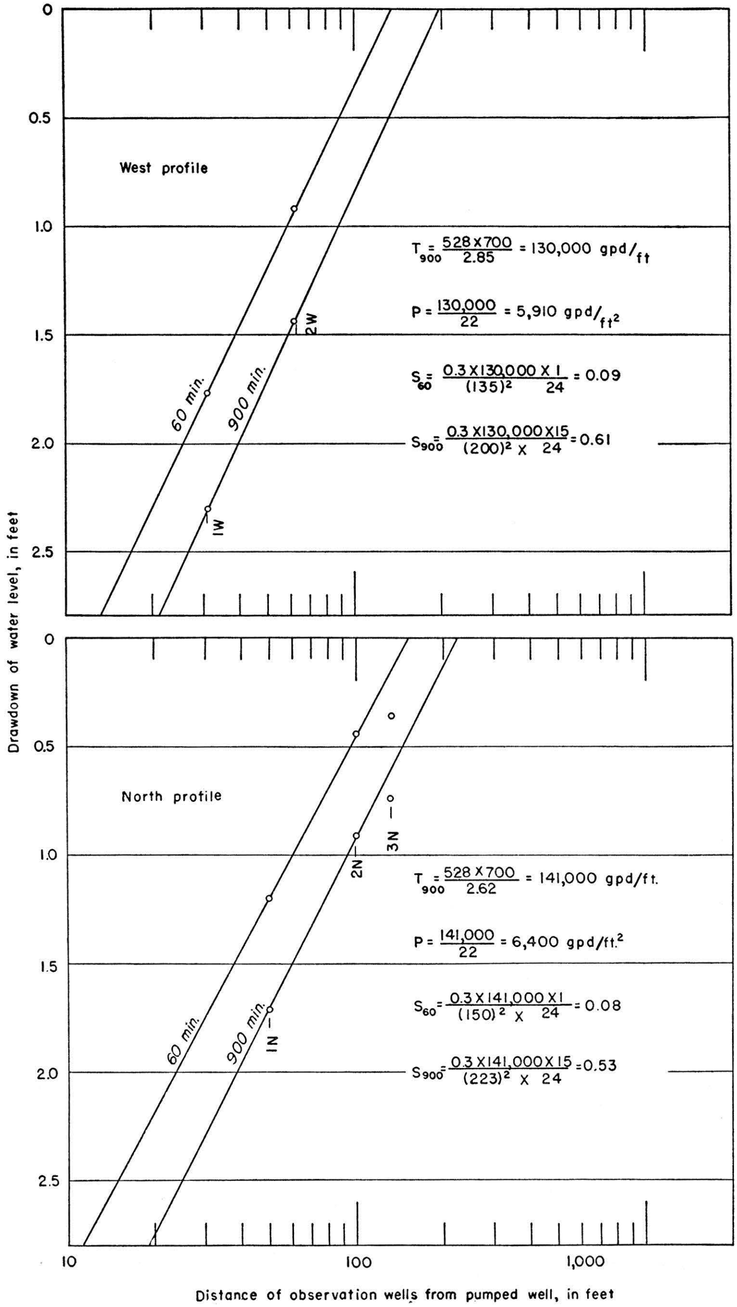

FIG. 14.—Drawdown of water levels in observation wells at 60 and 900 minutes during Norbert Irsik aquifer test plotted against distance from pumped well (25-29-28ca).

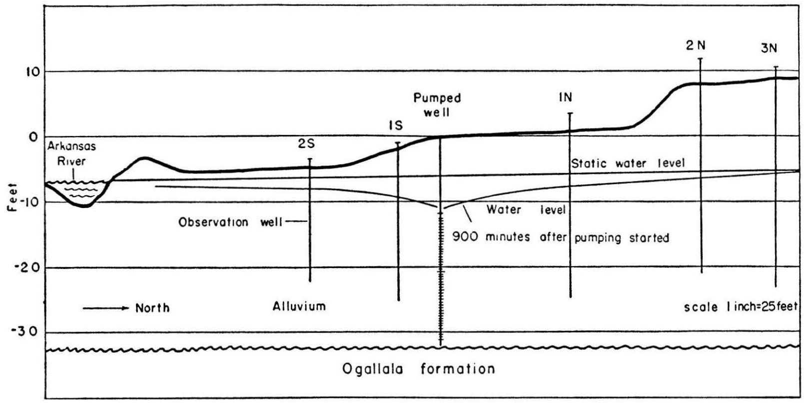

FIG. 15.—Cross section at Norbert Irsik test site before and after pumping.

Tests in Ogallala Formation Underlying Alluvium

McGehee.—A well to be pumped and seven observation wells were constructed in the SE¼ NW¼ sec. 21, T. 25 S., R. 30 W., on the farm of Myles McGehee to test the Ogallala formation underlying the alluvium. The pumped well was drilled through the Ogallala formation to a depth of 162 feet and was cased with 16-inch casing that was machine slotted at a depth of 82 to 162 feet. A 45-foot length of 26-inch surface casing was set around the 16-inch casing to seal out the water in the alluvium.

Observation wells 1N, 2N, 3N, and 4N were drilled in a line extending north from the pumped well at distances of 100, 200, 300, and 400 feet, respectively. The observation wells were completed with 2-inch casing at the same depth and were screened in the same zones as the pumped well. A 45-foot length of 6-inch surface casing was set around the 2-inch casing to seal out the water in the alluvium. The observation wells were developed by compressed air.

Three observation wells were completed in the alluvium at distances of 38, 70, and 100 feet east of the pumped well. These wells were used to note any decline of water level in the alluvium, but no decline was noted throughout the test; hence the field data have not been included in the report.

The well was pumped at an average rate of 360 gpm for 26 hours by means of a turbine pump powered by a butane motor. The yield of the well was held constant by regulating the speed of the motor.

Water-level measurements were made in the seven observation wells and the pumped well. The data obtained in the pumped well and the four observation wells finished in the Ogallala formation are given in Table 5. Water samples were taken from the pumped well at intervals during the test.

The drawdown of the water levels in the observation wells is plotted against time on semilogarithmic paper (Fig. 16); the recovery of the water levels is plotted against time on logarithmic paper (Fig. 17). The recovery of water levels in the observation wells and the pumped well is plotted against time on semilogarithmic paper (Fig. 18). The drawdown of the water levels in the observation wells at the end of the pumping period is plotted against the distances from the pumped well (Fig. 19). The computations for the coefficients of transmissibility and storage are included in the illustrations.

The coefficients of transmissibility and storage shown on Figure 17 were computed by the Theis nonequilibrium method. The recovery data fit the Theis type curve very well. The match between the type curve and the observed data defines the coefficients of transmissibility and storage of the Ogallala formation at this site. The coefficient of transmissibility of the Ogallala formation was 11,900 gpd/ft., and the coefficient of storage was about 2×10^{-4}.

The recovery data of the pumped well theoretically should plot as a straight line on semilogarithmic paper by the Jacob modified nonequilibrium method, but in this test they depart in the latter part of the recovery period (Fig. 18). The recovery data from the pumped well have been computed to show two interpretations. One interpretation gives a coefficient of transmissibility of 11,900 gpd/ft, which conforms with the answer obtained by analyzing the observation-well data. The other interpretation gives a coefficient of transmissibility of 10,700 gpd/ft, which is too low. In general, the plot of the recovery data from the pumped well has the same appearance as that from the observation wells.

Figure 16 shows that the plotted drawdown data depart from the type curve in the latter part of the test. This departure may be caused by leakage from the confining bed that overlies the artesian zone in the Ogallala formation from which water was being pumped, or it may be caused by an increase in aquifer thickness and transmissibility, or by both.

The assumed leakage that caused the observed data to depart from the type curve was analyzed by the Jacob leaky-aquifer

TABLE 5.—*Drawdown and recovery of water levels in pumped well and observation wells during McGehee aquifer test July 23-24, 1956.*

Time since pumping started, in minutes	Drawdown, in feet				
	Pumped well	Well 1N	Well 2N	Well 3N	Well 4N
1.5	....	1.29	0.13	....	....
2.5	....	2.33	0.53	....	....
3.5	....	3.24	1.03	....	....
4.5	....	4.08	1.45	....	....
5.5	....	4.86	1.83	....	....
6	....	5.25	....	....	....
7	....	6.02	2.35	1.35	0.27
8	....	6.70	2.87	....	.36
9	....	7.33	3.23	....	.59
10	....	7.86	3.59	1.73	.70
11	....	8.36	3.92	2.42	.86
12	....	8.80	4.25	2.69	....
13	....	9.28	4.52	....	1.07
14	....	9.53	4.78	....	....
15	....	9.84	5.03	....	1.33
16	....	10.12	5.25	3.47	....
17	....	10.38	5.46	3.67	1.57
18	....	10.60	5.66	3.85	....
19	....	10.80	5.83	....	....
20	....	11.02	6.02	4.13	1.90
21	....	11.17	6.27	4.27	....
22	....	11.42	6.30	4.39	2.11
23	....	11.60	6.88	4.54	....
24	42.19	....	7.16	4.67	2.29
25	....	11.91	7.31	4.77	....
26	....	....	7.53	4.87	2.32
27	....	12.22	....	4.98	....
28	....	....	7.63	5.10	2.64
29	....	12.47	....	5.20	....
30	42.92	....	7.78	5.32	2.79
31	....	12.70	....	5.41	....
32	....	....	7.91	5.49	....
33	....	12.89	....	....	....
34	....	....	8.04	....	....
35	....	13.07	....	5.75	3.04
36	....	....	8.18	....	....
37	....	13.28	....	....	....
38	....	....	8.33	....	....
39	....	13.70	....	6.07	....
40	43.73	....	8.47	6.14	3.54
42	....	....	8.62	6.25	....
44	....	13.88	8.74	6.40	....
45	....	13.96	....	....	3.86
46	....	....	8.87	6.42	....
47	....	....	....	6.51	....
48	....	14.17	....	6.64	....
49	....	....	9.04	....	....
50	44.18	....	....	6.76	4.13
51	....	14.39	....	....	....
52	....	....	9.21	....	....
54	....	14.58	....	6.97	....
55	....	....	9.37	....	4.43

TABLE 5.—*Drawdown and recovery of water levels in pumped well and observation wells during McGehee aquifer test July 23-24, 1956—Continued*

Time since pumping started, in minutes	Drawdown, in feet				
	Pumped well	Well 1N	Well 2N	Well 3N	Well 4N
57	....	14.73	....	....	....
58	....	....	9.50	7.17	....
60	44.74	14.93	9.63	....	4.63
62	....	....	....	7.37	....
64	....	15.15	....	....	....
65	....	....	9.83	7.41	4.88
68	....	15.41	....	....	....
70	....	....	10.09	7.83	5.09
72	....	15.60	....	....	....
75	....	15.74	10.29	7.94	5.31
78	46.00	....	....	....	....
80	....	15.95	10.47	8.13	5.51
85	....	16.14	10.66	8.30	5.67
90	....	16.42	10.83	8.31	5.86
95	....	16.53	11.03	8.61	6.02
100	....	16.74	11.21	8.77	6.21
105	47.26	16.89	11.38	8.94	6.36
110	....	17.01	11.54	....	....
112	....	....	....	9.09	....
115	....	17.15	....	....	6.60
117	....	....	11.75	9.25	....
120	47.39	17.32	....	....	....
123	....	....	11.89	....	....
125	....	....	....	9.46	....
127	....	....	....	....	6.94
130	....	17.52	....	....	....
133	....	....	12.13	....	....
135	47.41	....	....	9.66	....
137	....	....	....	....	7.17
140	....	17.60	12.22	....	....
145	....	....	....	9.79	7.33
150	47.52	17.97	12.41	....	....
160	....	18.15	12.64	10.12	7.64
170	....	18.32	12.78	10.39	7.81
180	47.73	18.43	12.90	10.52	8.00
195	....	18.68	13.10	10.87	8.24
210	48.55	18.93	13.29	10.97	8.45
225	....	19.15	13.47	11.18	8.64
240	48.81	19.25	13.59	11.40	8.83
260	....	19.54	13.83	11.56	9.06
280	....	19.67	13.95	11.74	9.25
300	49.34	19.83	14.08	11.91	9.45
330	....	20.00	14.25	12.13	9.70
345	49.80	....	....	....	....
360	....	20.29	14.46	12.33	10.01
390	....	20.39	14.58	12.47	10.20
405	50.09	....	....	....	....
420	....	20.60	14.73	12.67	10.36
450	....	20.78	14.88	12.86	10.58
465	50.35	....	....	....	....
480	....	20.83	14.96	12.95	10.75
510	50.93	....	....	....	....

TABLE 5.—*Drawdown and recovery of water levels in pumped well and observation wells during McGehee aquifer test July 23-24, 1956—Continued*

Time since pumping started, in minutes	Drawdown, in feet				
	Pumped well	Well 1N	Well 2N	Well 3N	Well 4N
540	....	20.96	15.12	13.17	11.03
585	51.21	....	....	....	....
600	....	21.30	15.38	13.39	11.23
660	51.39	21.58	15.59	13.60	11.50
720	....	21.67	15.68	13.77	11.66
780	51.42	21.64	15.71	13.83	11.75
900	51.80	22.21	16.10	14.27	12.15
1,020	52.10	22.28	16.16	14.36	12.37
1,140	52.49	22.44	16.33	14.56	12.55
1,260	52.84	22.64	16.48	14.73	12.73
1,380	53.32	22.97	16.83	14.92	12.76
1,500	53.47	23.19	16.90	15.10	13.12
Time since pumping stopped, in minutes	Recovery, in feet				
0.5	....	0.71	0.01	0.00	....
1	29.18	....	....	....	....
1.5	....	2.87	.33	....	....
2	32.07	....	....	.22	....
2.5	....	4.27	.98	....	0.04
3	34.02	....	....	.50	....
3.5	....	5.32	1.63	....	.16
4	35.57	....	....	.81	....
4.5	....	6.21	2.21	....	.22
5	36.77	6.59	2.55	....	.29
6	37.75	7.30	2.96	1.37	.48
7	38.55	7.87	3.40	....	.56
8	39.26	8.36	3.80	1.93	.69
9	39.83	8.81	4.14	....	.83
10	40.33	9.20	4.43	2.39	.97
11	40.79	....	....	....	....
12	41.21	9.90	5.04	2.81	1.23
13	41.57	....	....	....	....
14	41.88	10.50	5.52	3.17	1.49
15	42.16	....	....	....	....
16	....	11.01	5.95	3.64	1.73
17	42.53	....	....	....	....
18	....	11.47	6.32	3.86	1.95
19	43.05	....	....	....	....
20	....	11.85	6.65	....	2.18
21	43.56	....	....	4.28	....
22	....	....	....	....	2.42
23	....	12.38	7.09	....	....
24	44.11	....	....	4.67	2.55
26	....	12.82	7.48	....	2.64
27	44.57	....	....	5.01	....
28	....	....	....	....	2.98
29	....	13.22	7.80	....	....
30	44.98	....	....	5.33	3.06
32	....	13.59	8.12	....	....
35	45.54	13.91	8.40	5.80	3.46
40	45.98	14.39	8.80	6.23	3.81
45	46.40	14.81	9.16	6.60	4.12

TABLE 5.—*Drawdown and recovery of water levels in pumped well and observation wells during McGehee aquifer test July 23-24, 1956—Concluded*

Time since pumping started, in minutes	Recovery, in feet				
	Pumped well	Well 1N	Well 2N	Well 3N	Well 4N
50	46.72	15.18	9.48	6.85	4.46
55	47.04	15.52	9.77	7.28	4.76
60	47.22	15.82	10.03	7.52	5.02
70	47.93	16.36	10.50	8.05	5.60
80	48.25	16.82	10.89	8.47	5.02
90	48.61	17.21	11.23	8.86	5.39
105	49.04	17.73	11.68	9.36	5.93
120	49.41	18.15	12.04	9.79	6.42
140	49.83	18.62	12.46	10.28	7.00
160	50.16	19.03	12.80	10.70	7.50
180	50.44	19.36	13.09	11.11	7.92
200	50.79	....	....	....	....
210	....	19.79	13.47	11.49	8.48
240	51.05	20.11	13.75	11.86	8.93
270	51.49	20.40	13.99	12.17	9.33

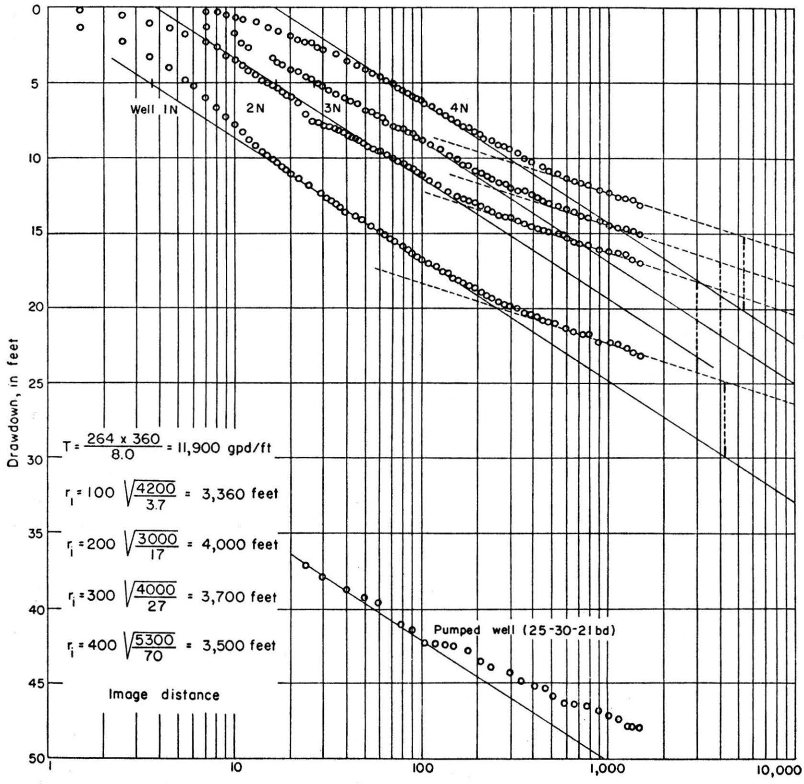

FIG. 16.—Drawdown of water levels in pumped well (25-30-21bd) and observation wells during McGehee aquifer test plotted against time since pumping started.

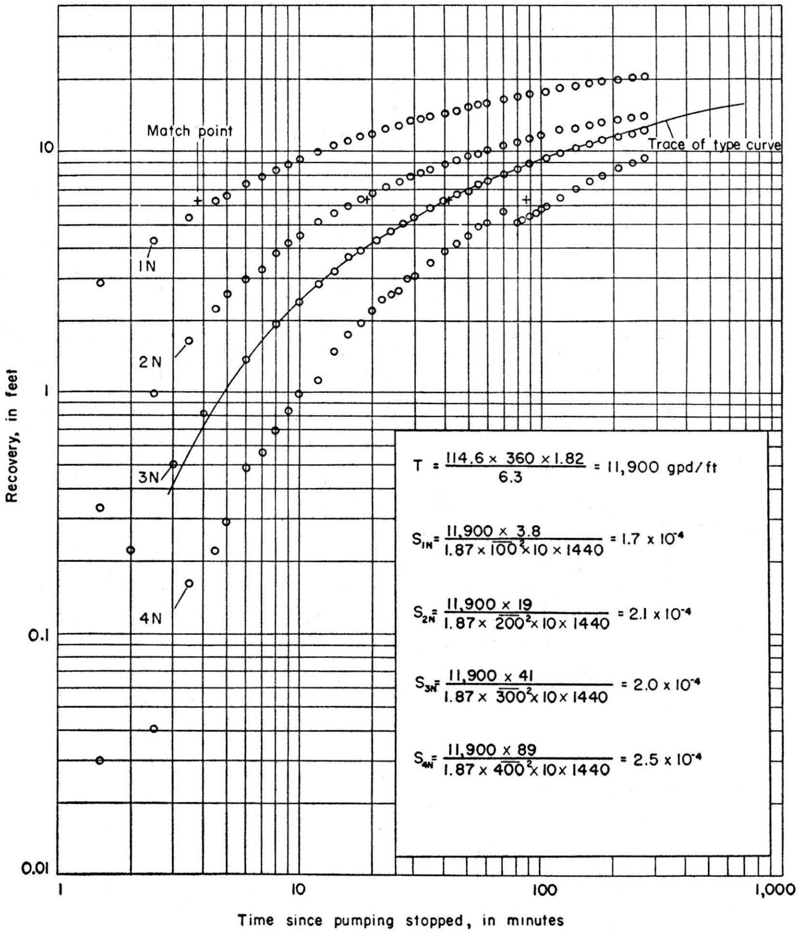

FIG. 17.—Recovery of water levels in observation wells during McGehee aquifer test plotted against time since pumping stopped (25-30-21bd).

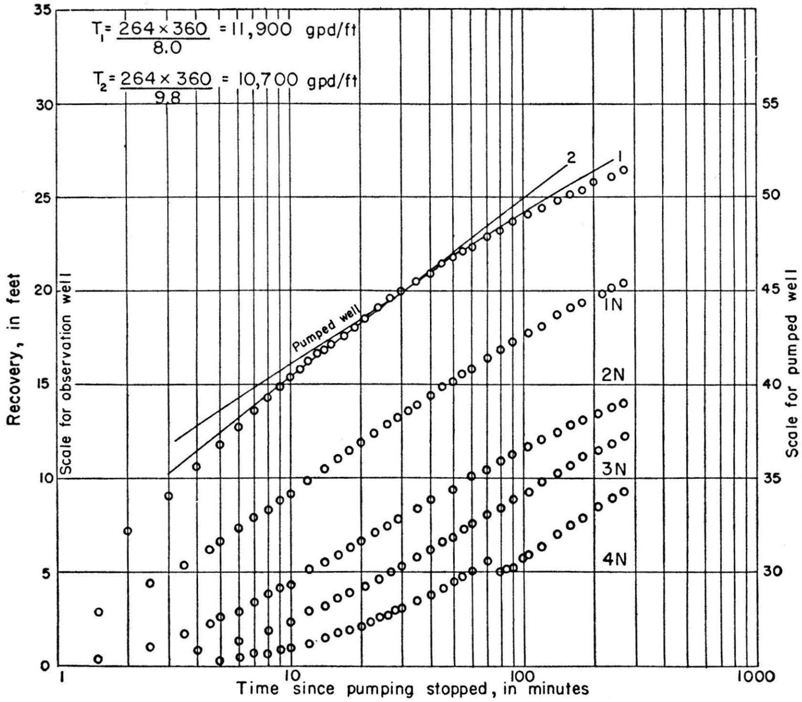

FIG. 18.—Recovery of water levels in pumped well and observation wells during McGehee aquifer test plotted against time since pumping stopped (25-30-21bd).

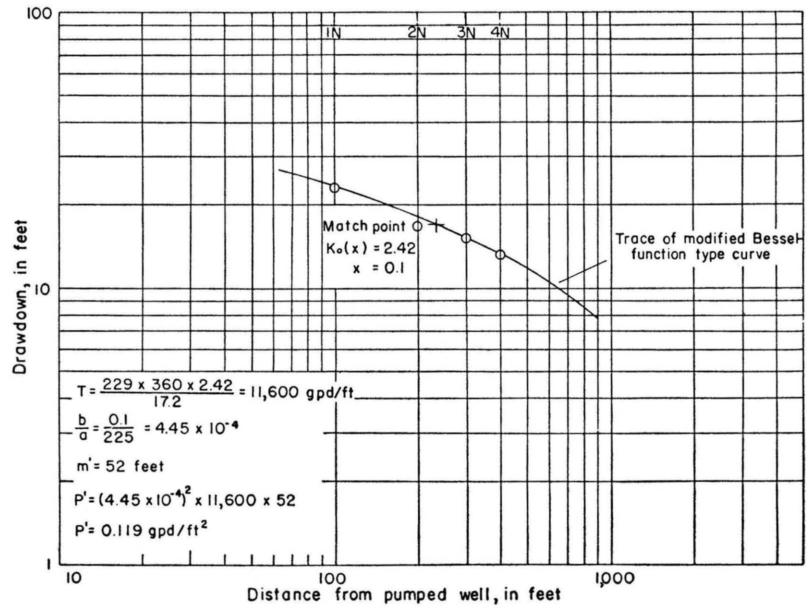

FIG. 19.—Drawdown of water levels in observation wells at end of McGehee aquifer test plotted against distance from pumped well (25-30-21bd).

method. In Figure 19 are given the computations for the coefficient of transmissibility of the artesian aquifer and the coefficient of the vertical permeability of the confining bed. If the coefficient of the vertical permeability of the confining bed, 0.119 gpd/ft.^{2}, is in error, it is probably too large. The data show that the Ogallala formation at this site has low permeability.

The upward deflection from the straight line shown in Figure 16 probably is caused by an increase in aquifer thickness. The increase is not abrupt, but is gradational over a large area, as shown by the saturated-thickness map (Fig. 20). The effective distance to a recharging "boundary" caused by a change to greater aquifer thickness and higher transmissibility can be determined by the following formula:

$$r_i = r\sqrt{\frac{t_i}{t_p}}$$

where r_i = distance from image well to observation well, in feet,
r = distance from pumped well to observation well, in feet,
t_p = time since pumping began for a particular value of s to be observed before the boundary becomes effective, in minutes, and
t_i = time since pumping began when the divergence of the drawdown curve from the straight line under the influence of the image well is equal to the value of s at t_p, in minutes.

The close clustering of the image distances given in Figure 16 implies that the recharging boundary is caused by an increase in aquifer thickness and transmissibility. The bedrock contour map (Fig. 5) and the saturated thickness map (Fig. 20) indicate that the recharging boundary is south of the pumped well.

No change in chemical quality of the water pumped from the Ogallala formation was noted during the test; hence these data have not been included in the report.

Norbert Irsik.—A well to be pumped and seven observation wells were constructed in the SE¼ NW¼ sec. 28, T. 25 S., R. 29 W., on the farm of Norbert Irsik, to test the Ogallala formation underlying the alluvium. This aquifer test was very similar to the McGehee test. The well was cased with 16-inch casing that was machine slotted at a depth of 90 to 187 feet. A 65-foot length of 26-inch surface casing was set around the 16-inch casing to seal out the water in the alluvium.

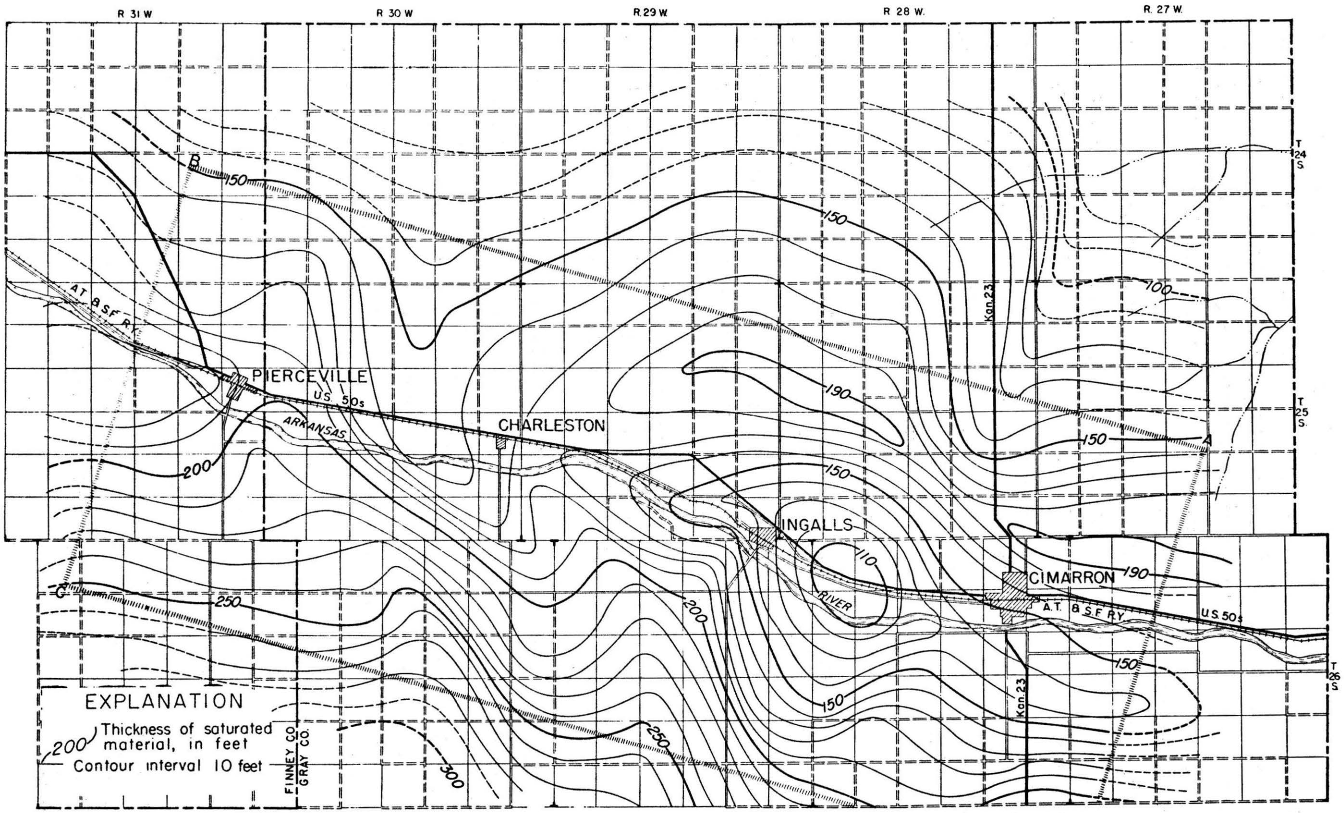

FIG. 20.—Saturated thickness of Pliocene and Pleistocene deposits in Ingalls area.

Observation wells 1W, 2W, 3W, and 4W were drilled in a line extending west from the pumped well at distances of 100, 200, 300, and 400 feet, respectively. They were completed with 2-inch casing at the same depth and were screened in the same zones as the pumped well. A 65-foot length of 6-inch surface casing was set around the 2-inch casing to seal out the water in the alluvium. The observation wells were developed by compressed air.

Three observation wells were completed in the alluvium at distances of 38, 70, and 100 feet north of the pumped well. These wells were used for measuring any decline of water level in the alluvium. As in the McGehee test, the water levels in these wells did not decline during the test; hence the data have not been included in this report.

The well was pumped at a rate of 720 gpm for 24.5 hours with the turbine pump and butane motor used in the McGehee test. Water levels were measured in the seven observation wells and the pumped well. The data obtained in the pumped well and the four observation wells finished in the Ogallala formation are given in Table 6. Water samples were taken from the pumped well at intervals during the test.

The drawdown of the water levels in the observation wells is plotted against time on semilogarithmic paper (Fig. 21). The recovery of the water levels in the observation wells is plotted against time on logarithmic paper (Fig. 22). The recovery of water levels in the observation wells and the pumped well is plotted against time on semilogarithmic paper (Fig. 23). The drawdown of water levels in the observation wells at the end of the pumping period is plotted against the distance from the pumped well (Fig. 24). The computations for the coefficients of transmissibility and storage are included in the illustrations.

The coefficients of transmissibility and storage shown in Figure 22 were obtained by the Theis nonequilibrium method. The recovery data fit the type curve very well. The match between the type curve and the observed data defines the coefficients of transmissibility and storage of the Ogallala formation at this site. The coefficient of transmissibility of the Ogallala formation was 11,700 gpd/ft, and the coefficient of storage was about 3×10^{-4}.

The recovery data of the pumped well plotted reasonably close to a straight line by the Jacob modified nonequilibrium method. The coefficient of transmissibility was slightly larger than that

TABLE 6.—*Drawdown and recovery of water levels in pumped well and observation wells during Norbert Irsik aquifer test August 8-9, 1956*

Time since pumping started, in minutes	Drawdown, in feet				
	Pumped well	Well 1W	Well 2W	Well 3W	Well 4W
1.0		1.01	0.08		
1.5					0.01
2.0		2.39	.35		
2.1				0.17	
2.5					.02
3.0		3.63	.77		
3.1				.44	
3.5					.05
4.0		4.88	1.29		
4.1				.88	
4.5					.14
5.0		5.88	1.84		
5.1				1.36	
5.5					.24
6.0		6.76	2.36	1.90	
7.0		7.44	2.85	2.46	.35
8.0		8.07	3.30	3.01	
8.5					.49
9		8.59	3.71	3.48	
9.5					.83
10		8.99	4.11	4.00	
11					1.10
12		9.91	4.87		1.28
13				5.15	1.45
14		10.68	5.49	6.40	1.63
16		11.28	6.06		1.99
18		12.00	6.58		2.33
19			7.12	6.79	2.50
20		12.81			2.67
22		13.39			3.01
23			7.85		
24		13.70		8.10	3.35
26		14.12	8.48		3.65
27				9.45	
28					3.94
29	46.34		9.00		
30		14.79		9.57	4.23
32		14.89	9.49		4.63
34		15.20			
35			9.92		
36		15.76		10.16	5.01
39		16.24			
40			10.68		5.49
41		16.52		10.90	
44		16.86			
45			11.28		5.94
46		17.14		11.55	
49	49.10	17.47			
50			11.94	12.10	6.53
51		17.68			
54		18.23			
55			12.50	12.72	7.00
56		18.51			
59	51.54	18.88			

TABLE 6.—*Drawdown and recovery of water levels in pumped well and observation wells during Norbert Irsik aquifer test August 8-9, 1956—Continued*

Time since pumping started, in minutes	Drawdown, in feet				
	Pumped well	Well 1W	Well 2W	Well 3W	Well 4W
60	....	....	12.92	13.35	7.47
62	....	19.22	....	....	....
65	....	19.50	13.24	13.73	7.91
69	....	19.86	....	....	....
70	....	....	13.73	14.30	8.31
74	52.41	20.22	....	....	....
75	....	....	14.21	14.58	8.70
79	....	20.61	....	....	....
80	....	....	14.57	15.18	9.06
85	....	20.99	14.87	15.51	9.38
90	53.80	21.42	15.28	15.92	9.72
100	54.38	22.04	16.02	16.53	10.31
110	....	22.87	16.61	17.23	10.87
115	....	23.21	....	....	....
120	55.97	23.30	17.17	17.75	11.40
135	....	24.01	17.83	18.46	12.10
150	56.60	24.66	18.37	19.36	12.69
165	....	25.16	18.80	19.71	13.20
180	57.62	25.75	19.27	20.08	13.68
200	....	26.30	19.77	20.81	14.30
220	58.74	26.82	20.22	21.34	14.79
240	....	27.09	20.76	21.77	15.18
270	59.98	28.27	21.64	22.72	15.94
300	61.05	28.84	22.11	23.15	16.54
330	61.12	29.29	22.60	23.81	17.07
360	61.70	29.75	23.01	24.15	17.53
390	61.82	30.06	23.39	24.72	17.91
420	62.35	30.46	23.63	24.89	18.27
450	63.00	30.95	24.07	25.50	18.63
495	....	31.25	24.53	25.98	19.14
540	63.48	31.76	....	26.35	19.54
600	64.75	32.31	25.36	26.99	20.06
660	....	32.86	25.86	27.50	20.48
720	65.14	33.36	26.30	28.00	21.17
780	65.95	33.56	26.58	28.15	21.37
840	66.72	34.14	27.00	28.70	21.64
900	....	34.14	27.09	28.81	22.01
960	67.02	34.58	27.46	29.18	22.22
1,080	67.16	35.14	27.95	29.66	22.73
1,200	....	35.53	28.32	30.02	23.22
1,320	....	35.44	28.35	30.02	23.34
1,350	68.33	....	....	....	....
1,380	....	36.05	28.64	30.32	23.52
1,440	68.45	36.10	28.77	30.45	23.71
1,500	....	36.24	28.84	30.55	23.79
Time since pumping stopped, in minutes	Recovery, in feet				
1	34.77	2.38	0.09	0.09	....
2	38.11	4.41	.66	.59	0.01
3	39.88	5.82	1.29	1.20	.08
4	40.91	6.95	1.88	1.83	.19
5	41.99	7.88	2.44	2.44	.35
6	42.65	....	2.95	3.01	.54
7	43.44	....	3.43	3.53	.74

TABLE 6.—*Drawdown and recovery of water levels in pumped well and observation wells during Norbert Irsik aquifer test August 8-9, 1956—Concluded*

Time since pumping started, in minutes	Recovery, in feet				
	Pumped well	Well 1W	Well 2W	Well 3W	Well 4W
8	44.08		3.92	4.05	.94
9	44.65		4.28	4.52	1.16
10	45.15	10.42	4.69	4.96	1.38
11		10.56	5.25	5.41	1.61
12	46.01	10.72	5.42	5.74	1.82
13			5.75	6.15	2.02
14	46.74	12.44	6.08	6.51	2.24
15		13.13		6.84	2.45
16	47.35	13.70	6.67	7.15	2.69
17				7.44	2.85
18	47.94		7.23	7.74	3.02
19				8.01	3.20
20	48.40	14.22	7.73	8.25	3.38
21				8.52	
22	48.91	14.77	8.21	9.00	3.74
24			8.68	9.23	4.07
25	49.55	15.43			
26			9.08	9.67	4.40
28	50.13	16.00	9.46	10.07	4.71
30		16.39	9.82	10.45	5.00
31	50.64				
32		16.76	10.16	10.79	5.29
34	51.00		10.48	11.13	5.56
35		17.26			
36			10.79	11.47	5.82
37	51.41	17.57			
38			11.09	11.77	6.07
40	51.88	18.05	11.36		6.32
42		18.29		12.07	
45	52.43	18.73	12.02		6.88
47		19.10		12.75	
50	53.00	19.29	12.60		7.40
53		19.61		13.37	
55	53.50	19.89	13.13	13.92	7.88
60	53.95	20.31	13.63	14.49	8.34
65	54.37	20.84	14.11	14.92	8.76
70	54.76	21.23	14.49	15.41	9.18
75	54.98	21.64	14.88	15.87	9.54
80	55.50		15.25	16.25	9.88
85	55.75	22.23	15.60	16.65	10.21
90	56.05	22.73	15.94	16.97	10.52
95	56.40				
100	56.65	23.39	16.53	17.59	11.10
110	57.20	23.92	17.08	18.22	11.66
120	57.75	24.56	17.59	18.72	12.12
130		24.87	18.04	19.24	12.57
140	58.50	25.34	18.47	19.70	12.99
150	58.85	25.74	18.86	20.13	13.39
160	59.23	26.12	19.23	20.52	13.76
170	59.53	26.46	19.57	20.85	14.13
180	59.84	26.79	19.89	21.23	14.39
193	60.15				

obtained from the measurements in the observation wells. The plot of the recovery data from the pumped well has the same general appearance as that from the observation wells.

Figure 21 shows that the plotted curve of the drawdown data departs from the type curve for the latter part of the test. This departure may be caused by leakage from the confining bed that overlies the Ogallala formation from which water was being pumped, or by an increase in aquifer thickness and transmissibility, or both. The leakage phenomenon was analyzed by the Jacob

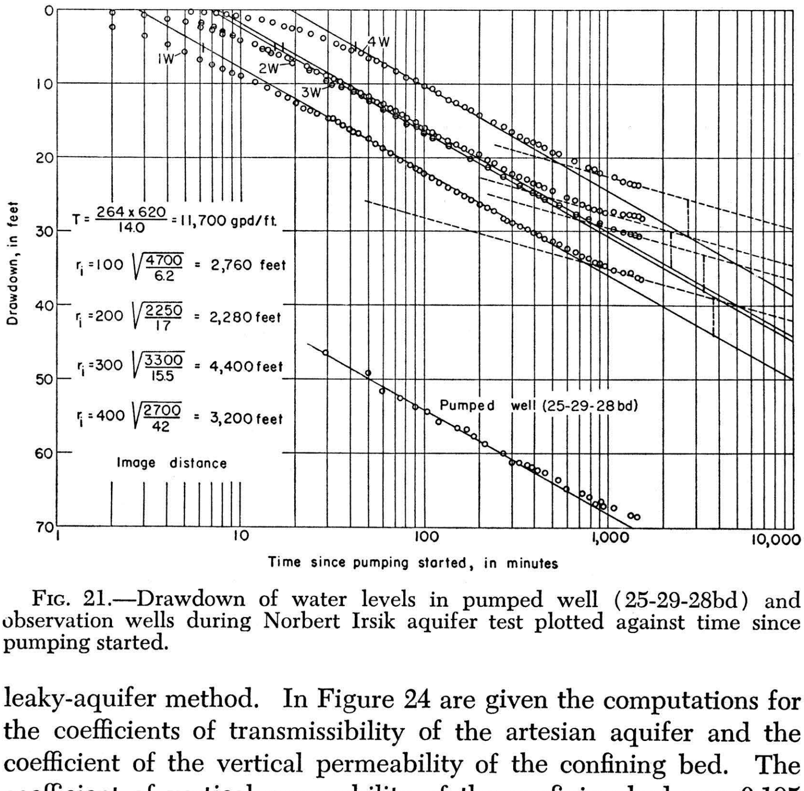

FIG. 21.—Drawdown of water levels in pumped well (25-29-28bd) and observation wells during Norbert Irsik aquifer test plotted against time since pumping started.

leaky-aquifer method. In Figure 24 are given the computations for the coefficients of transmissibility of the artesian aquifer and the coefficient of the vertical permeability of the confining bed. The coefficient of vertical permeability of the confining bed was 0.195 gpd/ft^2.

The upward deflection from the straight line shown in Figure 21 probably is caused by an increase in aquifer thickness to the south. The image arc distances computed for the Norbert Irsik test were not as consistent as those computed in the McGehee test, which

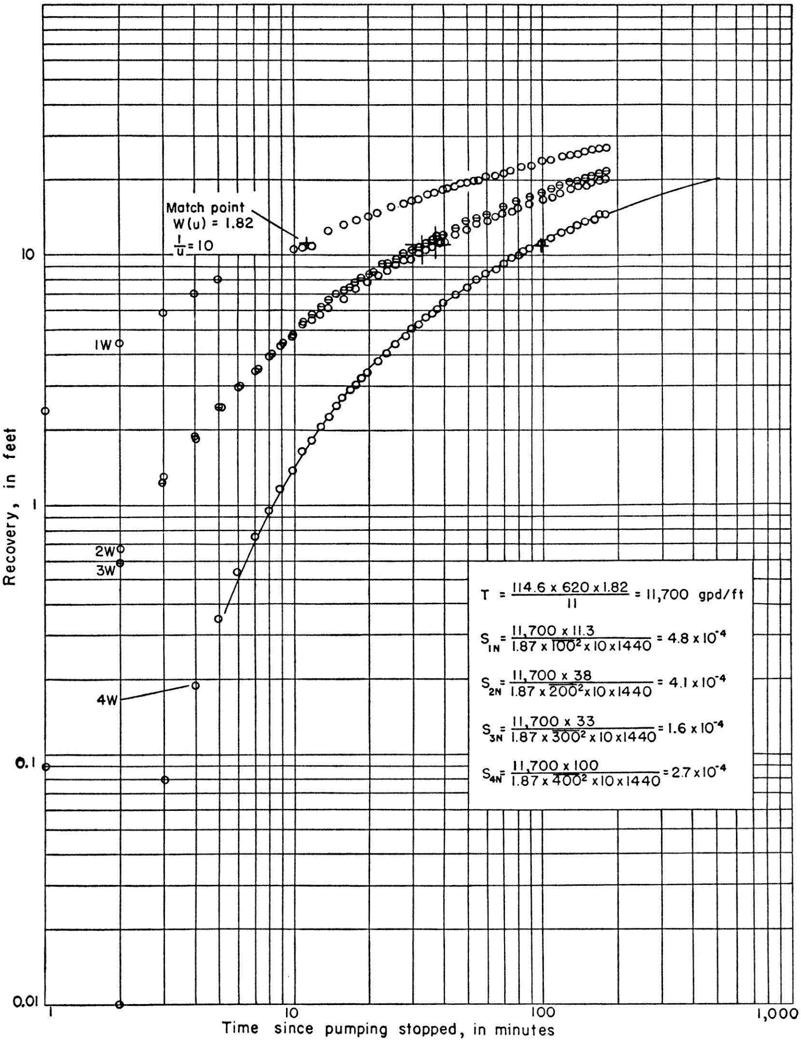

FIG. 22.—Recovery of water levels in observation wells during Norbert Irsik aquifer test plotted against time since pumping stopped (25-29-28bd).

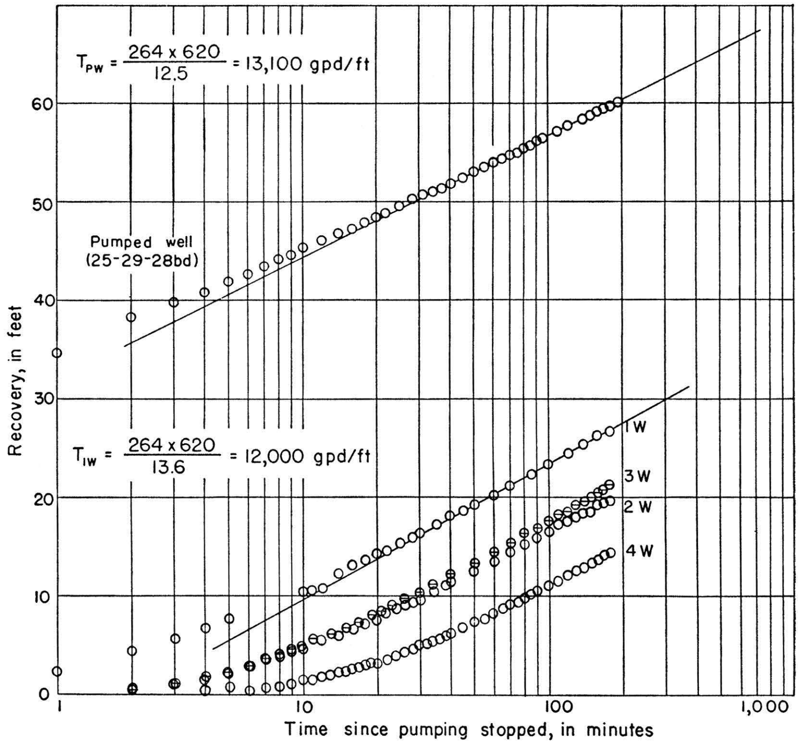

FIG. 23.—Recovery of water levels in pumped well (25-29-28bd) and observation wells during Norbert Irsik aquifer test plotted against time since pumping stopped.

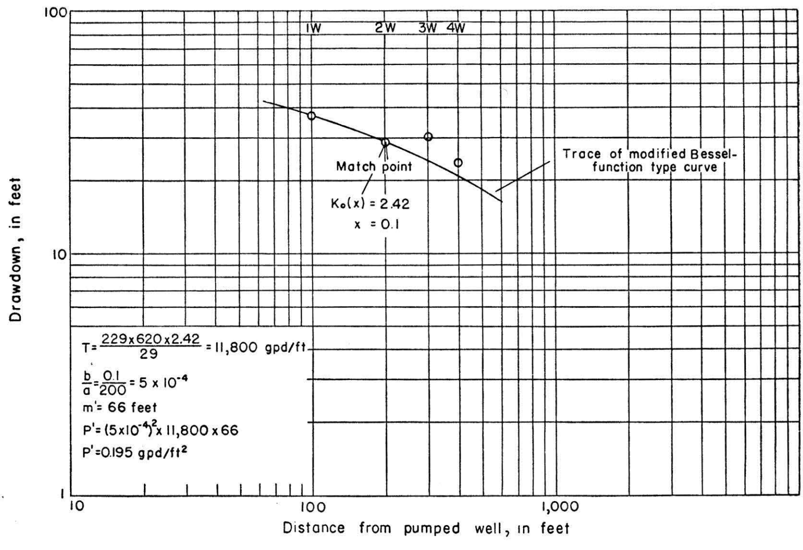

FIG. 24.—Drawdown of water levels in observation wells at end of Norbert Irsik aquifer test plotted against distance from pumped well (25-29-28bd).

probably were caused by a change in the lithology of the Ogallala formation.

No change in chemical quality of the water pumped from the Ogallala formation was noted during the test.

Tests in Ogallala Formation in the Upland

Clark.—An aquifer test of the Ogallala formation was made by pumping an irrigation well in the NE¼ SW¼ sec. 32, T. 24 S., R. 30 W., on the farm leased by Lester Clark. The well, cased with 16-inch pipe, is 303 feet deep and completely penetrates the Ogallala formation. It is gravel packed, and the casing is slotted throughout the saturated thickness of 165 feet. The well was pumped March 5, 1956, for 4 hours at a rate ranging from 1,370 gpm at the start of the test to 1,142 gpm at the end of the test, and averaging about 1,200 gpm. All water-level measurements were made in the pumped well, as no observation wells were available.

The water-level measurements made during the recovery period are listed in Table 7 and are plotted against time in Figure 25. The

TABLE 7.—*Depth to water measured in pumped well during Clark aquifer test March 5, 1956*

Time since pumping started, in minutes	Depth to water below measuring point, in feet	Time since pumping stopped, in minutes	Depth to water below measuring point, in feet
8:05 a.m.	140.65 (Static)	36	150.30
8:30	Pump started	40	149.84
11:55	202.02	45	149.34
12:00	Pump stopped	50	148.88
Time since pumping stopped, in minutes		55	148.49
		60	148.13
		65	147.80
2	162.20	70	147.51
5	159.63	75	147.24
8	157.32	80	147.01
10	156.25	90	146.56
12	155.38	100	146.19
14	154.65	110	145.85
16	154.05	120	145.58
18	153.47	130	145.32
20	152.98	140	145.08
22	152.53	150	144.88
24	152.16	170	144.52
26	151.82	180	144.36
28	151.45	200	144.10
30	151.13	220	143.86
33	150.71	240	143.64

recovery data during the latter stage of the recovery period plotted as a curve. The earlier data plotted as a straight line and were used to compute the coefficiencts of transmissibility and permeability. By the Jacob modified nonequilibrium method of computation, the coefficient of transmissibility was 29,400 gpd/ft, and the coefficient of permeability was 178 gpd/ft.[2]

Theoretically, the recovery data should plot as a straight line. They depart from a straight line possibly because of the lenticular structure of the water-bearing deposits in the Ogallala formation. The lower water-bearing zones have higher heads than the upper zones. Thus, during the recovery period of a well, the water comes first from all water-bearing zones. When the water level has recovered to that of the head in the zone of lowest head, the water begins to move laterally to zones of lower head and the rate of water-level recovery slows down. Consequently, the plot develops curvature as shown in Figure 25.

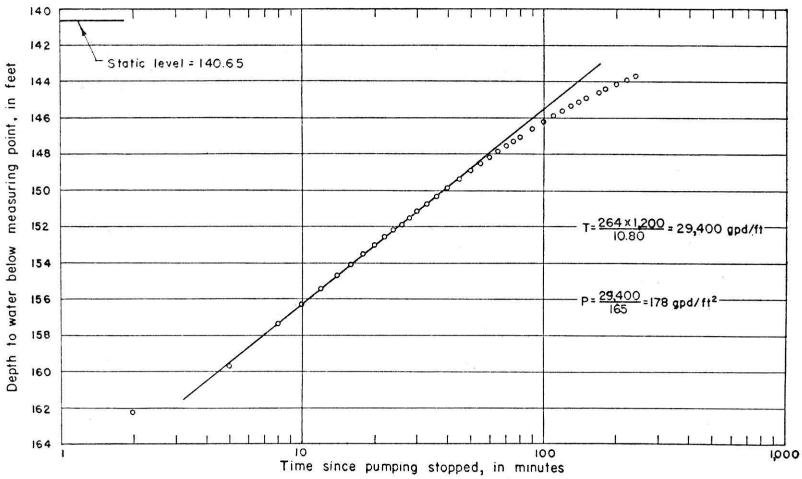

FIG. 25.—Depth to water measured in pumped well (24-30-32ca) during Clark aquifer test plotted against time since pumping stopped.

The static water level in a well penetrating and open to the full section of the Ogallala formation is not necessarily the piezometric level of any particular zone but is the resultant head of all the different zones. The differences in head indicate that the vertical permeability of the Ogallala is slight. The vertical movement of water from one permeable zone to another is retarded by less permeable zones within the Ogallala formation. In some places, these clay or silt zones may have such a low permeability that practically no water moves vertically.

C. Irsik.—An aquifer test was made using an irrigation well in the NW¼ NE¼ sec. 14, T. 25 S., R. 29 W., on a farm owned by Clarence Irsik. The well is cased with 16-inch pipe, is 308 feet deep, and completely penetrates the Ogallala formation. It is gravel packed, and the casing is slotted throughout the saturated thickness of the formation, which is 200 feet. It was pumped April 11, 1956, at an average rate of 1,600 gpm for about 2 hours. Water-level measurements were made in the pumped well, as no observation wells were available.

Measurements made during the recovery period are listed in Table 8 and are plotted against time in Figure 26. The recovery

TABLE 8.—*Depth to water measured in pumped well during C. Irsik aquifer test April 11, 1956*

Time since pumping started, in minutes	Depth to water below measuring point, in feet	Time since pumping stopped, in minutes	Depth to water below measuring point, in feet
8:15 a.m.	107.30 (Static)	35	111.21
8:50	Pump started	40	111.02
9:30	157.04	45	110.73
10:52	157.50	50	110.50
11:00	Pump stopped	55	110.28
Time since		60	110.13
pumping stopped,		70	109.82
in minutes		80	109.57
2	119.66	95	109.28
4	117.69	110	109.04
6	116.39	155	108.57
8	115.47		
10	114.79		
12	114.24		
14	113.80		
16	113.38		
19	112.90		
22	112.50		
25	112.16		
30	111.69		

data departed from a straight line during the latter stage of the recovery period. The earlier data plotted as a straight line and were used to compute the coefficients of transmissibility and permeability. By the Jacob modified nonequilibrium method, the coefficient of transmissibility was 61,000 gpd/ft, and the coefficient of permeability was about 305 gpd/ft^2.

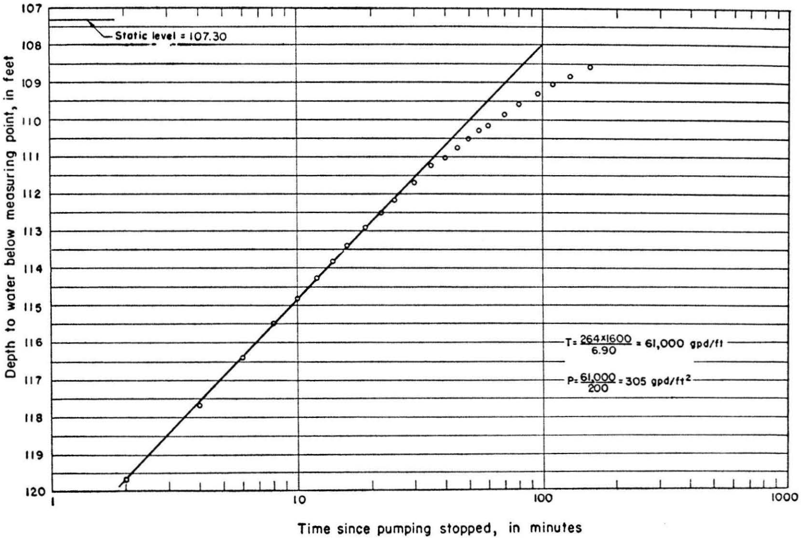

FIG. 26.—Depth to water measured in pumped well (25-29-14ab) during C. Irsik aquifer test plotted against time since pumping stopped.

SUMMARY OF AQUIFER TESTS

The coefficients of transmissibility computed from data collected during the Ven John, Renick, and Norbert Irsik aquifer tests of the alluvium were 97,000, 181,000, and 130,000 gpd/ft, and the coefficients of permeability were 4,040, 5,040, and 5,910 gpd/ft^2. The lowest permeability was near the north edge of the alluvium, and the two highest were near the center of the alluvium. The average coefficient of permeability was 5,000 gpd/ft^2. The storage coefficients obtained from the tests of the alluvium were invalid because of slow drainage and river recharge, and a storage coefficient of 0.20 for the alluvium has been assumed.

The coefficient of transmissibility of the Ogallala formation as determined by both the McGehee and Norbert Irsik tests was about 12,000 gpd/ft; the coefficients of storage were about 2×10^{-4} and 3×10^{-4}, respectively. These two tests showed artesian conditions in the Ogallala formation; however, near the end of the tests a recharging boundary was noted. Leakage through the confining roof or an increase in aquifer thickness, or both, may have had the effect of a recharging boundary. The evidence from well logs supports both interpretations.

The coefficients of transmissibility obtained in the Clark and C. Irsik aquifer tests were 29,000 and 61,000 gpd/ft. The reliability of the pumped-well-recovery data collected in the McGehee and Norbert Irsik Ogallala tests provides assurance that the coefficients of transmissibility obtained in the Clark and C. Irsik tests are of the right order of magnitude.

The tests show that there is better material in the Ogallala formation at the Clark and C. Irsik test sites than at the McGehee and Norbert Irsik test sites. The Clark well is on the flank of a bedrock channel and the C. Irsik well in the middle of a bedrock channel, and in both places the lower zones contain permeable sands and gravels. Thus, the saturated thickness and transmissibility are greater than at the McGehee and Norbert Irsik sites. The McGehee well and the Norbert Irsik well are both above a bedrock high. As a result, the saturated thickness is less, and the water-bearing section does not contain the permeable sands and gravels of the lower zones.

The performances of these four wells also indicate the differences in the hydrologic properties of the Ogallala formation at the test sites. The C. Irsik well had a yield of 1,600 gpm and a drawdown of 50.2 feet after being pumped about 2 hours. The Clark well had an average yield of 1,200 gpm and a drawdown of 61.4 feet after being pumped 4 hours. The McGehee well had a yield of only 360 gpm and a drawdown of 53.5 feet after being pumped 26 hours. The Norbert Irsik well had a yield of 620 gpm and a drawdown of 68.5 feet after 24½ hours.

The coefficients of transmissibility and storage obtained from data collected during the tests of the Ogallala formation indicate that pumping effects will be noted at great distances in relatively short periods of time. Wells screened in both the alluvium and the Ogallala formation should have yields of 1,000 gpm per well as long as there is a sufficient saturated thickness of the alluvium. When the alluvium becomes dewatered, the yields of wells will drop sharply.

Application of Aquifer-Test Data

Alluvium

In the Arkansas River valley, the water table slopes toward the river most of the time, and ground water consequently slowly discharges into the river. Water that is being discharged from the alluvium can be intercepted by wells before it reaches the river, and, by pumping water from storage, the gradient of the water table can be reversed so that water will move from the river toward the pumped wells. Infiltration can be induced by pumping wells near the river. The amount of water that can be obtained by induced infiltration will be determined principally by the permeability of the river bottom, by the permeability and thickness of the water-bearing materials between the river and the wells, by the quantity of flow and stage of the stream, and by the distance from the river to centers of pumping.

Water being pumped from the alluvium near Arkansas River will be replaced in part by water from the river. If pumping continues long enough, a condition of steady-state flow will result, and most or all of the water pumped will be derived from the river. Caution should be exercised in applying the coefficients of transmissibility as determined by the aquifer tests. Although recharge from the river does occur, there may be times when the stream bed is too narrow or too impermeable to allow all the available water in the river to infiltrate the aquifer even if storage space is provided below the river. As a result, some of the available stream flow may move out of the area where infiltration is needed.

The amount of infiltration that will occur in a given area will vary according to the hydraulic gradient from the river to the place of storage. After a period of no streamflow, the rate of infiltration directly below the river may be very high initially when streamflow

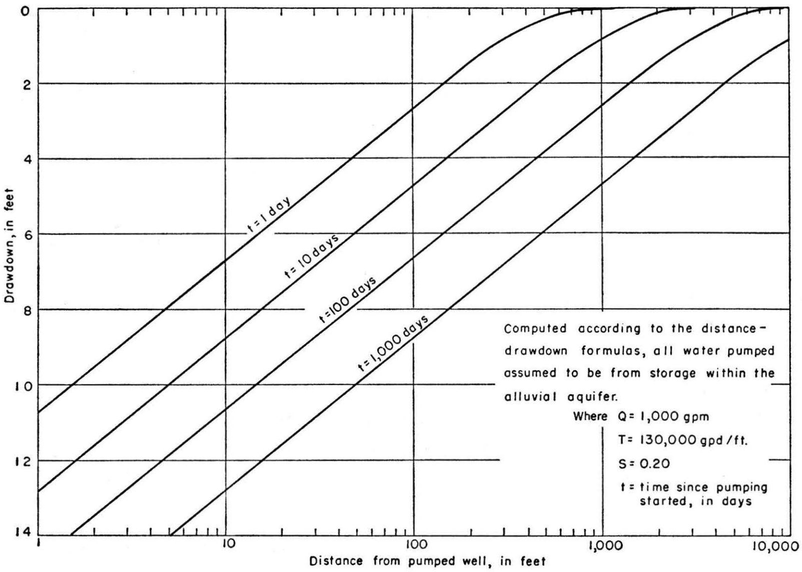

FIG. 27.—Drawdown of water level in alluvium at any distance from pumped well after pumping has begun.

becomes available. As a mound of water builds up beneath the river and spreads, the gradient away from the river will diminish. As a result, the rate of infiltration from the river will continue to decline as water is put back in storage, and some of the aquifer, which will be dewatered as a result of pumping during drought periods, may never be recharged with water from the river unless provision is made to divert water into those areas.

The coefficients of transmissibility and storage of the alluvium provide data for computing yield and optimum spacing of wells in the alluvium. Figure 27 shows that, after 1,000 days of pumping at a rate of 1,000 gpm, the drawdown at a distance of 1,000 feet from the pumped well will be 4.7 feet, and that measurable drawdown

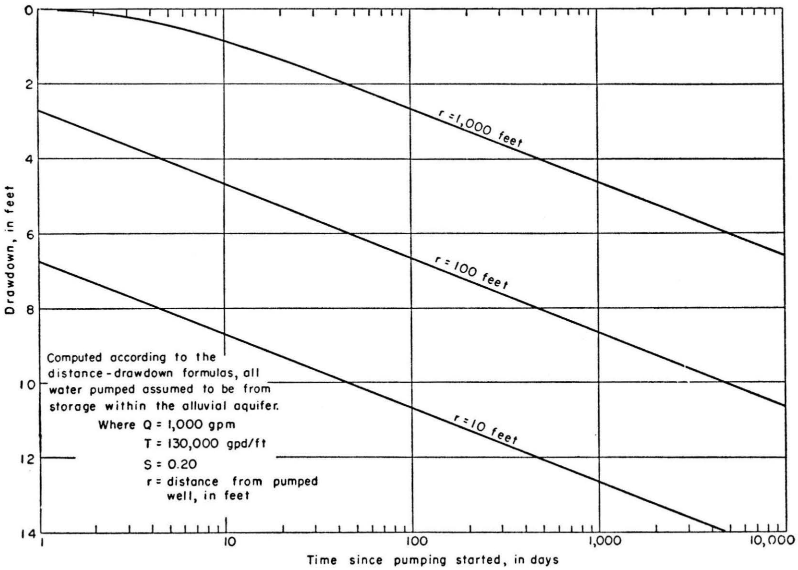

FIG. 28.—Drawdown of water level in alluvium at any time after pumping has begun.

will be noted at increasingly greater distances as pumping continues. Figure 28 shows the rate of decline caused by pumping. The drawdown in a well 1,000 feet from a well pumping 1,000 gpm for 100 days will be about 2.7 feet and for 1,000 days will be about 4.7 feet.

The drawdowns in Figures 27 and 28 were computed on the assumption that all water pumped came from storage in the alluvium and are given to show only the general magnitude caused by pumping. Any well placed near Arkansas River will receive recharge from it, and consequently, as long as there is water in the river, the drawdowns will be less than those shown in Figures 27 and 28. If a well is placed farther from the river and nearer the valley wall, however, the drawdowns in wells may be greater than those shown, because the alluvium pinches out. In computing declines caused by pumping from the alluvium, both the recharging effect of Arkansas River and the discharging boundary effect of the valley wall must be considered.

Ogallala Formation

The computations for drawdown in the Ogallala formation are based on the assumption that all water pumped came from storage. The drawdowns are too large because the effect of leakage and changes in lithology within the Ogallala formation have not been computed, but they show the general magnitude of decline. Figure 29 shows, under the assumed conditions specified, the drawdown of water level at any distance from a pumped well after 1, 10, 100, and 1,000 days. The data indicate that the cone of influence will spread rapidly in response to pumping in the Ogallala formation. After 100 days of pumping at a rate of 500 gpm, the

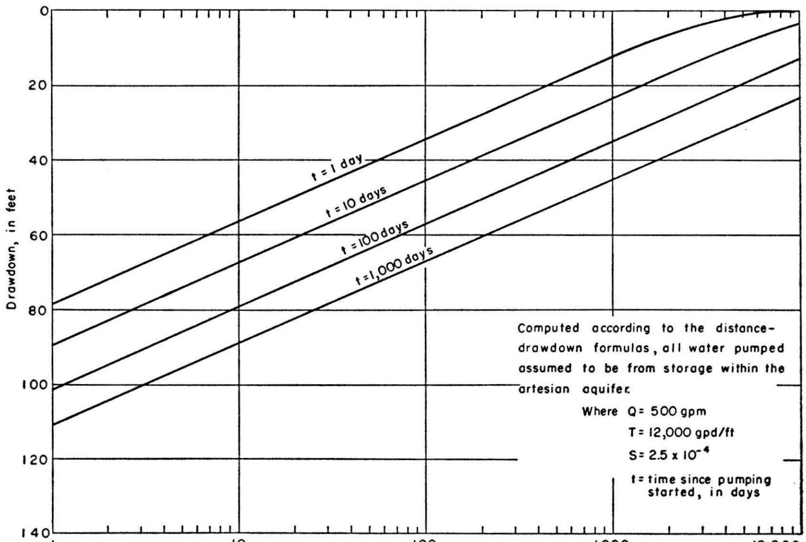

FIG. 29.—Drawdown of water level in Ogallala formation at any distance from pumped well after pumping has begun.

drawdown at a distance of 1,000 feet will be about 35 feet. Large yields from wells cannot be maintained in the area between Pierceville and Ingalls where the permeability of the Ogallala formation is low. Also, wells pumping from the Ogallala formation in this area will seriously interfere with each other unless spaced at considerable distances. Where wells mutually interfere, the drawdown at any one point will be the sum of the drawdowns produced by each well. Pumping lifts will increase and yields will decline. Figure 30 shows the rate of decline caused by pumping. A well

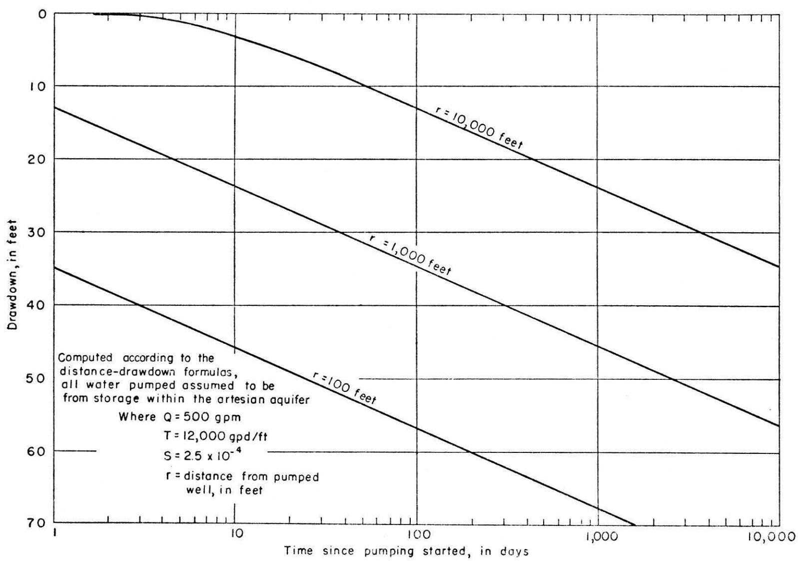

FIG. 30.—Drawdown of water level in Ogallala formation at any time after pumping has begun.

pumping 500 gpm for 10 days will cause about 24 feet of decline at a distance of 1,000 feet from the pumped well, and after 1,000 days it will cause 46 feet of decline.

WATER TABLE AND MOVEMENT OF GROUND WATER

The depth to the water table in the Ingalls area ranges from about 5 to 140 feet below the land surface. The Arkansas River valley is a shallow-water area where the depth to the water table is generally less than 30 feet and, in much of the area, particularly south of the river, less than 10 feet. North of the river the water table is slightly deeper.

The depth to the water table in the dune-sand area ranges from about 10 to 80 feet below the land surface and may range widely within relatively short distances because of local relief of the dune topography. In the upland north of Arkansas River, the depth to the water table in the Ogallala formation ranges from about 90 to 140 feet.

Plate 1 shows the configuration of the water table in the Ingalls area by means of water-table contours. The slope of the water table determines the rate and direction of movement of ground water; the movement is always down slope at right angles to the water-table contours, as shown in Plate 1 by light dashed lines referred to as "flow lines". In the Ingalls area it is generally eastward.

The unequal additions of water to the ground-water reservoir and the differences in permeability of the water-bearing materials are probably the most significant reasons why the shape of the water table is irregular. Ground water in the Ingalls area moves generally toward Arkansas River, and the water table as shown by the contours has a tendency to steepen as it approaches the river. This steepening is apparent south of Ingalls.

Discharge of ground water into Arkansas River is the only discharge into a stream in the area, and it affects the slope of the water table near the river. The slope of the water table toward the river from the north is less than the slope from the south. If the transmissibility of the water-bearing materials is equal, the greater slope from the south indicates that more water is draining to Arkansas River from the dune-sand area south of the river. Ground water discharges perennially into Arkansas River from the south. At times during the irrigation season, the water table on the north side of the river is lowered enough by pumping to induce some infiltration of river water into the ground-water reservoir.

The slope of the water table ranges from about 30 feet to about 3 feet per mile, and it averages about 8 feet per mile. The average gradient of Arkansas River is 7 feet per mile. The quantity of ground water moving through a given cross-sectional area of water-bearing material can be calculated from the following formula:

$$Q = pAv = PIA,$$

where: Q = the quantity of water,
p = the porosity of the material,
P = the coefficient of permeability,
v = the velocity of the ground water,
I = the hydraulic gradient, and
A = the cross-sectional area.

The approximate rate of movement of water through the water-bearing materials is calculated by applying the above formula transposed as follows:

$$v = \frac{PI}{p}$$

If P is expressed as gpd/ft^2 (Meinzer's unit), I in feet per mile, and p in percent, then v, in feet per day, is given by the following formula:

$$v = \frac{PI}{395p}$$

In the alluvial deposits the hydraulic gradient is about 8 feet per mile, the porosity is about 30 percent, and aquifer tests indicate that the average permeability is about 5,000 gpd/ft^2; therefore, the average velocity of the ground water is

$$v = \frac{5{,}000 \times 8}{395 \times 30} = 3.4 \text{ feet per day.}$$

Owing to the high permeability of the alluvium, ground water moves readily through the water-bearing material in the valley.

The rate of movement of the water in the Ogallala formation, however, is slower than in the alluvium. In the Ogallala the average gradient is about 8 feet per mile, the porosity is about 30 percent, and aquifer tests indicate that the permeability averages about 200 gpd/ft^2. Hence, the velocity of the ground water in the Ogallala formation is:

$$v = \frac{200 \times 8}{395 \times 30} = \begin{matrix}\text{0.14 foot per day, or} \\ \text{1.6 inches per day}\end{matrix}$$

Thus, in material of low permeability the velocity of ground water becomes very low. Even in material of high permeability the velocity of ground water is relatively low as compared to that of surface water. Low ground-water velocity explains why the water table under the sand dunes had not declined greatly in 1956 even after 4 years of drought. Water-table contours south of the river indicate also that in many places the vertical permeability beneath the dune sand is low. Logs of test holes show that beds of silt underlie much of the dune sand and retard the downward percolation of water. After periods of heavy precipitation, a semiperched water table exists under at least parts of the dune area. The horizontal permeability of the terrace deposits is probably very high, and water that enters the dune-sand area discharges at the base of the terrace as seepage springs, thus helping to recharge the alluvium.

AVAILABILITY OF GROUND WATER

The availability of ground water in the Ingalls area depends on the quantity of water in storage in the ground-water reservoir, recharge from precipitation, and flow of Arkansas River. Streamflow records have been studied by the Bureau of Reclamation and therefore have not been discussed in this report. The quantity of water in storage and the quantity of recharge are discussed below.

Quantity of Water in Storage

The saturated-thickness map (Fig. 20), prepared by superposing the water-table contour map (Pl. 1) on the bedrock contour map (Fig. 5) and drawing contours through points of equal thickness, shows that the saturated materials in the area have a minimum thickness of 110 feet. The deposits are thinnest in the northeastern part of the area and thickest in the southwest. The saturated thickness beneath the Arkansas valley ranges from about 110 to 200 feet.

The total volume of saturated material in the alluvium, Kansan deposits, and Ogallala formation in the area designated A-B-C-D on Figure 20 has been computed as about 28,000,000 acre-feet. The alluvium is about 1¼ miles wide, has an average thickness of 35 feet, and contains about 670,000 acre-feet of the saturated material. The Kansan deposits and Ogallala formation together contain somewhat more than 27,000,000 acre-feet of the saturated material.

The specific yield, the amount of water that will drain out of saturated material by gravity, has been estimated as 20 percent for the alluvium and 10 percent for the Kansan deposits and Ogallala formation. On the basis of a specific yield of 20 percent, the total amount of water available in the alluvium is about 130,000 acre-feet; on the basis of a specific yield of 10 percent, the total amount of water available in the Kansan deposits and Ogallala formation is about 2,700,000 acre-feet. Thus, a total of about 2,800,000 acre-feet of water would be available if the area A-B-C-D were drained completely. Obviously only a part of this quantity could be recovered practicably. In the Arkansas Valley the yields of wells screened in both the alluvium and the Ogallala formation would diminish very sharply if the alluvium were drained, because the Ogallala formation is much less permeable than the alluvium.

The 670,000 acre-feet of saturated alluvium lies along 24 miles of the valley length; thus there is about 28,000 acre-feet of saturated volume per mile of valley length. If 11 miles of valley length is used, as considered by the Bureau of Reclamation, there would be in this reach about 310,000 acre-feet of saturated alluvium. On the basis of a specific yield of 20 percent, the amount of water available from storage in the alluvium in the 11 miles of valley is about 62,000 acre-feet.

Recharge From Precipitation

The normal annual precipitation at Cimarron is 19.93 inches. Of the total precipitation, a part runs off directly on the surface, a part is evaporated, a part is transpired by plants from the zone of soil moisture, and a small part moves downward to the zone of saturation.

All recharge to the aquifer in the Ingalls area is derived from precipitation that falls within the area or areas to the west. Once the water becomes a part of the main ground-water body, it moves down gradient perpendicular to the water-table contours (Pl. 1) to points of discharge.

The amount of water added to or discharged from the ground-water reservoir is reflected in the fluctuations of the water levels in wells (Fig. 31). From 1940 through 1951 precipitation at Cimarron was above normal, and the trend of the water levels was upward during most of that period.

The water level in well 24-31-27c, which is in the Ogallala formation, rose steadily during the 1940's and had reached a record-high stage by November 1953. Owing to drought conditions since that time, the water level had declined about 5 feet by December 1955. In general, the hydrograph of this well shows that the amount of water in storage in 1956 was about the same as at the beginning of the period of record, but that during the period there has been some recharge and discharge. The amount of recharge probably is small, owing to the depth to water and the relatively impermeable material above the water table.

Although runoff from the upland north of the river is small, most of the water that infiltrates the ground is later evaporated or transpired by plants. The annual rate of recharge to the Ogallala formation is generally reported to be less than half an inch per year (Theis, 1937). Sufficient data are not available to determine the recharge in this area, however, and until such time as an accurate figure can be determined, a value of less than half an inch a year is assumed.

The hydrographs of two wells (26-29-36dc and 26-29-7cb) in the dune-sand area south of Arkansas River are shown in Figure 31. The dune sands are very permeable and readily absorb the precipi-

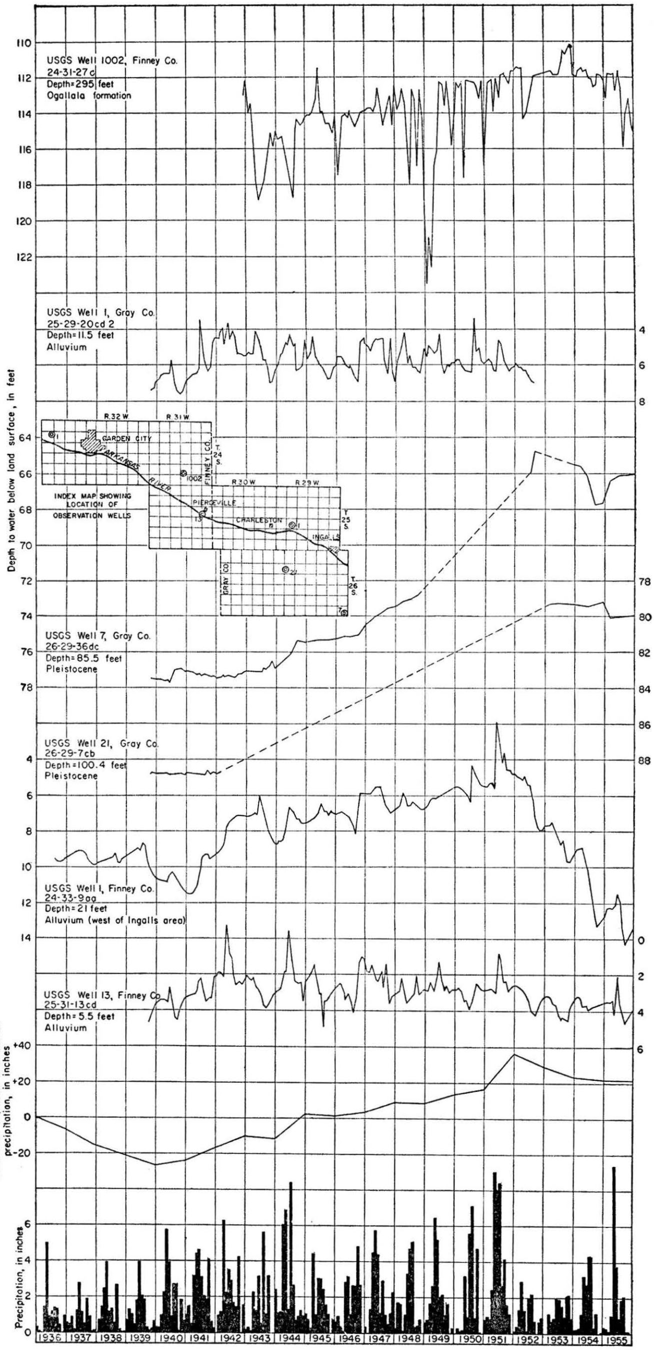

FIG. 31.—Five hydrographs showing fluctuations of water table in Ingalls area, one typical hydrograph at Garden City, and precipitation and cumulative departure from normal at Cimarron.

tation that falls in the area. Much of the precipitation percolates downward rapidly and escapes evaporation and transpiration. After 1943 the water levels under the dunes rose steadily until they attained a record high in 1951. Since 1951 the rainfall has been deficient, and during much of that period the water levels have declined; nevertheless at the end of 1955 they were as much as 10 feet higher than at the end of the drought period in the 1930's.

The accumulation of ground water under the sand dunes and the slow release of that water to Arkansas River provide much of the increase in river flow between Pierceville and Cimarron. Data are not available to determine the amount of recharge in the dune sands, but it is much more than in the upland north of the river.

Much of the precipitation that falls on the valley alluvium readily passes through the porous soil and percolates downward to the water table. The water levels in the valley respond quickly to recharge but also recede sharply after recharge periods because the permeable alluvium allows water to move readily toward the river. The hydrographs of three wells (25-29-20cd2, 25-31-13cd, and 24-33-9aa) in the alluvium of the Arkansas Valley are given in Figure 31 and show the fluctuations of water level caused by recharge and discharge. They also show some interference from irrigation pumping and some rises and declines caused by rises and declines of Arkansas River.

When the water table is lowered below river stage by heavy pumping, Arkansas River is a source of recharge to alluvial deposits. During the irrigation season, pumping causes a drawdown of water levels in the valley on the north side of the river. During heavy pumping, the water level in the alluvium is lower than the river stage, and water from the river moves northward toward centers of pumping. Although considerable water is discharged into the alluvium from the dune sands and terrace deposits, probably little water moves into the alluvium from the Ogallala formation north of Arkansas River.

Considerable recharge occurs in irrigated fields from water that percolates through the sandy soil and back to the water table. The percentage of return water from irrigation is not known, but it probably amounts to as much as 20 percent. Most irrigation in the valley is by ditch irrigation and flooding. Considerable loss of water by downward percolation results generally from these methods of irrigation.

Additional Development of Water Supplies from Wells

The amount of water that can be pumped perennially from an underground reservoir depends not only on the amount of water in storage in the reservoir and the amount of recharge, but also on the ability of the reservoir to release water to wells.

Sufficient saturated material is available in the Ingalls area for the development of irrigation wells in most of the area. In part of the upland, however, wells having large yields cannot be developed from the Ogallala formation because of the low permeability locally. Well 25-29-14ab, one of the best irrigation wells pumping from the Ogallala formation in the upland, is 308 feet deep and yields 1,600 gpm. In general, the water-bearing materials become thinner east of this well, but sufficient saturated material is available to yield satisfactory supplies for some additional irrigation wells, if it contains permeable beds.

In the dune-sand area south of Arkansas River, the water-bearing materials are thick and fairly permeable, and many wells having yields of about 1,500 gpm can be developed. Little irrigation development has taken place south of Arkansas River, but the area is capable of supplying much additional water.

Many thousands of acre-feet of water have been pumped from the alluvium in the Arkansas valley in the last 50 years, and present data indicate that water is available for much additionl pumping. Fluctuations of the water table in the Arkansas valley are influenced by use of the water for irrigation, but for the most part these are seasonal. To prevent overdevelopment, wells should be spaced so as to minimize mutual interference. Single-cased wells of good construction can be expected to yield as much as 1,000 gpm, and a battery of shallow wells, as much as 3,000 gpm. If declines of water levels in the valley alluvium are regionally great, the yields from wells can be expected to decline also, because the saturated alluvial material in the valley is relatively thin.

Arkansas River is cut into the alluvium and is hydraulically connected to the water in the alluvium. Therefore, the possibility of developing additional supplies from the alluvium is very closely related to the discharge of Arkansas River. In general, the water table slopes toward the river, and ground water discharges into the stream. This seepage of ground water into the river constitutes the streamflow during periods of drought. Water that is now being discharged into the river can be intercepted by wells. If enough

TABLE 9.—*Analyses of water from wells and river in Ingalls area*

Analyzed by H. A. Stoltenberg. Dissolved constituents given in parts per million*

Well Number	Location	Depth, feet	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	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)	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate
	T. 24 S., R. 30 W.																		
24-30-32ca...	NE SW sec. 32....	303	Ogallala formation...	4-11-56	......	528	31	0.37	92	31	34	224	186	28	1.3	15	357	184	173
	T. 25 S., R. 29 W.																		
25-29-14ab...	NW NE sec. 14...	308	do..................	4-11-56	......	523	29	.06	84	33	39	227	178	30	0.9	17	345	186	159
25-29-27cd...	SE SW sec. 27....	15	Alluvium...........	4-10-56	......	1,530	14	.14	194	62	208	251	822	68	1.0	40	739	206	533
	T. 25 S., R. 30 W.																		
25-30-19ad...	SE NE sec. 19....	15	do..................	4-10-56	......	1,580	12	8.9	168	71	246	288	858	80	1.1	0.8	711	236	475
25-30-19dd2..	SE SE sec. 19.....	15	do..................	4-10-56	......	168	13	.08	37	6.2	13	144	11	6	.4	10	118	118	0
25-30-22ac...	SW NE sec. 22....	41	do..................	4-10-56	......	700	23	.08	119	38	51	218	296	37	.8	28	453	179	274
25-30-24ca1..	NE SW sec. 24....	16.5	do..................	4-10-56	......	880	24	.29	120	52	87	232	391	47	1.3	44	513	190	323
25-30-25bc...	SW NW sec. 25...	15	do..................	4-10-56	......	258	23	.05	58	10	18	221	25	9	.6	5.3	186	181	5
	T. 25 S., R. 31 W.																		
25-31-13ca2..	NE SW sec. 13....	180	Ogallala formation...	4-10-56	......	274	20	.10	45	15	29	202	50	9	.7	4.9	174	166	8
25-31-24bb...	NW NW sec. 24...	....	Arkansas River.....	4-10-56	......	1,770	13	.49	213	76	245	248	1,000	85	.9	8.8	844	204	640
	T. 26 S., R. 28 W.																		
26-28-11bd1..	SE NW sec. 11....	205	Ogallala formation...	6- 3-54	......	261	20	.08	49	9.3	22	189	35	9	.6	2.6	160	155	5
	T. 26 S., R. 29 W.																		
26-29-2ac....	SW NE sec. 2.....	....	Arkansas River.....	4-10-56	......	1,480	14	.37	182	63	205	244	814	74	.8	7.1	713	200	513
26-29-22aa**	NE NE sec. 22....	86.5	Pleistocene deposits..	12- 9-40	......	234	......	1.3	60	10	13	202	20	13	.3	15	190	166	24
	T. 26 S., R. 30 W.																		
26-30-1bc**..	SW NW sec. 1....	70	do..................	12-10-40	......	233	......	.15	59	9.8	15	208	22	10	.4	13	188	170	18

* One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.
** Kansas Geological Survey Bulletin 55.

water is pumped from storage, the water-table gradient will be reversed, and water will flow from the river toward areas of pumping. Hydrogeologic conditions are excellent for induced infiltration throughout the length of the river in the Ingalls area, and the alluvium can be made to function as a surface reservoir. The Renick and Norbert Irsik aquifer tests of the alluvium indicate that water can move readily from the river to a pumped well. The amount of induced infiltration will be limited by streamflow. How much of the total flow of the river can be salvaged is primarily a problem of design and of existing water rights, as possibly all base flow in the river could be captured. It is very doubtful, however, that all the flood flows could be captured by pumping from wells, as a large percentage of the floodwaters doubtless will move out of the area unless held or diverted by dams and levees.

CHEMICAL CHARACTER OF WATER IN THE INGALLS AREA

The chemical character of ground water is indicated by 12 analyses of water samples collected from wells in the Ingalls area and by two samples of water from Arkansas River. The analyses (Table 9) were made by H. A. Stoltenberg, Chemist, in the Water and Sewage Laboratory of the State Board of Health. The results of the analyses are given in parts per million; factors for converting parts per million of mineral constituents to equivalents per million are given in Table 10.

TABLE 10.—*Factors for converting parts per million of mineral constituents to equivalents per million*

Cation	Conversion factor	Anion	Conversion factor
Ca^{++}	0.0499	HCO_3^-	0.0164
Mg^{++}	.0822	SO_4^{--}	.0208
Na^+	.0435	Cl^-	.0282
		NO_3^-	.0161
		F^-	.0526

The dissolved solids in water samples from the Ingalls area ranged from 168 to 1,770 ppm. The concentrations were relatively low in samples of ground water from the Ogallala formation, ranging from 261 to 528 ppm. Two samples of ground water from the Pleistocene deposits south of Arkansas River in the sand dune area contained small amounts of dissolved solids (233 and 234 ppm), and two samples from the alluvium south of the river also contained small amounts (168 and 258 ppm). Conversely, samples collected from the alluvium north of the river contained large amounts of dissolved solids (ranging from 700 to 1,580 ppm). The concentration of dissolved solids in ground water in the alluvium north of the river became increasingly greater toward the river. The two samples of water from Arkansas River contained large amounts of dissolved solids and were very similar to samples from the alluvium a short distance north of the river.

The total hardness of water samples from the Ingalls area ranged from 118 to 844 ppm. Samples of water from Arkansas River were high in total hardness, especially noncarbonate hardness, because of the large content of calcium and magnesium sulfates. Samples of water from wells 25-30-19ad and 25-29-27cd, approximately 400 feet north of Arkansas River, were very similar in both carbonate and noncarbonate hardness to samples from Arkansas River (25-31-24bb and 26-29-2ac). Water in the Ogallala formation and in the Pleistocene and alluvial deposits south of Arkansas River is much softer than water from the river.

The sulfate content of the water samples ranged from 11 to 1,000 ppm. With the exception of the samples from Arkansas River and the samples from the alluvium north of the river, the water in the Ingalls area was low to moderate in sulfate content. The iron content of the water samples ranged from 0.05 to 8.9 ppm, but only five samples contained more than 0.3 ppm of iron. The fluoride content ranged from 0.3 to 1.3 ppm; the nitrate content, from 0.8 to 44 ppm; and the chloride content, from 6 to 85 ppm.

In general, the analyses indicate that water from the Ogallala formation and the alluvium and Pleistocene deposits south of the river is of relatively good quality. The water in Arkansas River at low flow and in the alluvium north of the river is of relatively poor quality.

North of the river considerable ground water is pumped from the alluvium during the irrigation season; this pumpage results in a lowering of water levels. As a result, water from the river, which is of poor quality, moves northward from the river to areas of pumping. Figure 32 shows graphically the mineral constituents of water from wells and Arkansas River and indicates that water of poor quality from Arkansas River is the source of the water of poor quality in the alluvium north of the river.

Water samples from wells 25-30-19ad and 25-29-27cd, about 400 feet north of Arkansas River, and from Arkansas River at Pierceville

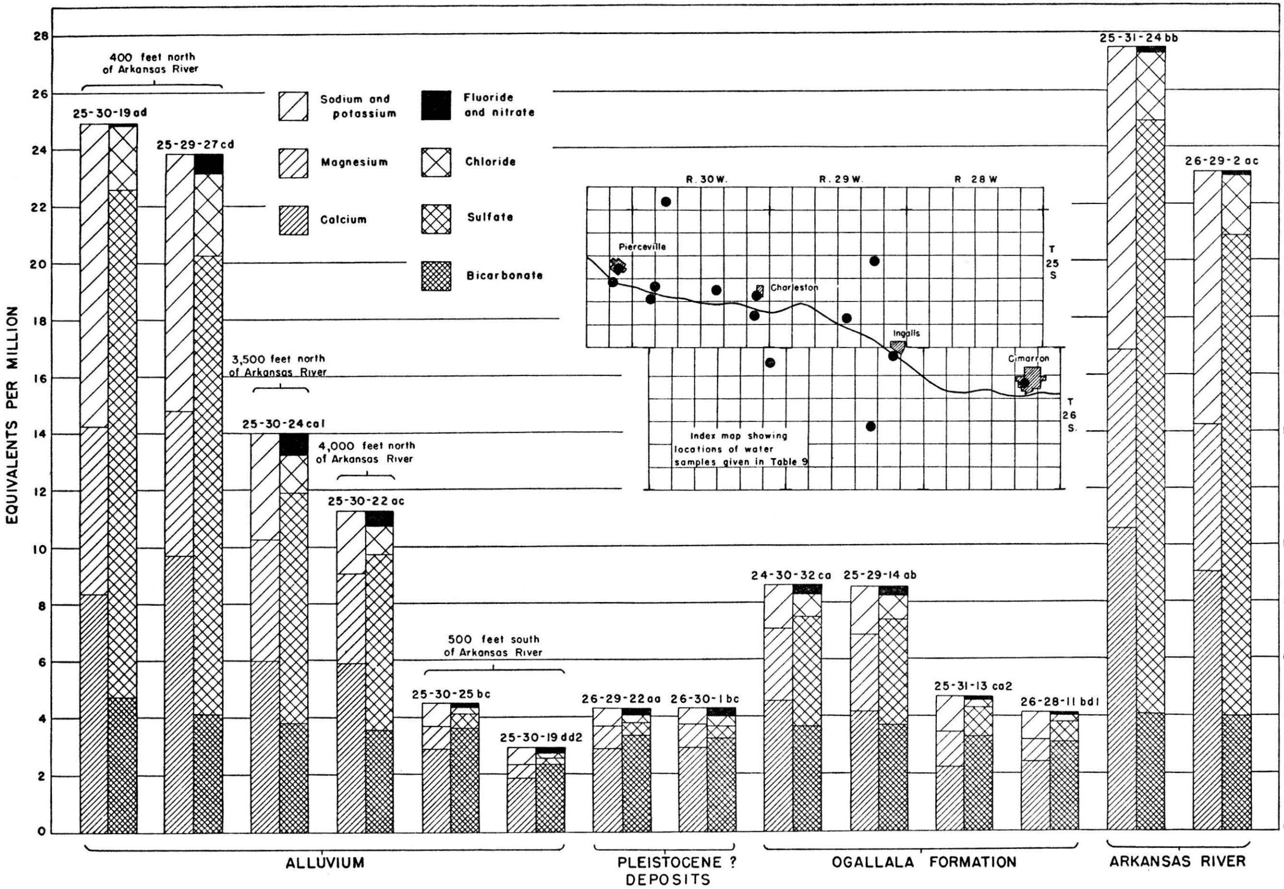

FIG. 32.—Graphic representation of analyses of water from wells and Arkansas River in Ingalls area.

(25-31-24bb) and at Ingalls (26-29-2ac) are very similar in chemical quality (Fig. 32). The river sample taken at Ingalls is slightly better in quality than the river sample taken at Pierceville. Discharge of ground-water of good quality from the south probably dilutes the water in the river between Pierceville and Ingalls and accounts for the improved quality. Water in the river at the time of the sample collections was derived from ground-water discharge. The waters sampled from the two wells near the north bank of the river also differed slightly in quality.

Water samples from wells 25-30-24ca1 and 25-30-22ac are similar in quality. Both wells derive water from the alluvium. They are about 3,500 and 4,000 feet north of the river, respectively, and are near the north edge of the valley; water from Arkansas River has affected the quality very little, owing to dilution by recharge from precipitation and by inflow from the Ogallala formation to the north.

Water samples from wells 25-30-25bc, 25-30-19dd2, 26-29-22aa, and 26-30-1bc are similar in quality. These wells derive water from the alluvium, terrace deposits, and Pleistocene deposits south of the river where, in general, the quality is good. The ground-water gradient south of the river is for the most part toward the river, and water that moves into the alluvium south of the river is of good quality.

Water samples from wells 24-30-32ca and 25-29-14ab are similar in quality. These two wells obtain water from the Ogallala formation in the upland north of the river. Figure 32 shows that this water is better in quality than water in the alluvium north of the river but not so good as water in the alluvium south of the river.

Water samples from wells 25-31-13ca2 and 26-28-11bd1 are similar in quality. These two wells obtain water from the Ogallala formation underlying alluvium that contains water of poor quality. Water in the alluvium has been cased off in both wells, and the water obtained is of better quality than water from the Ogallala formation in the upland and is of about the same quality as water obtained south of the river. This suggests that most of the water in the Ogallala formation under the river moves from the dune-sand area and that the Ogallala formation below the valley alluvium contains confining layers.

Chemical Constituents in Relation to Irrigation

The evaluation of water with regard to its suitability for irrigation is based on methods outlined in Agricultural Handbook 60 of the U. S. Department of Agriculture (Richards and others, 1954).

Soil that was originally nonsaline and nonalkali may become unproductive if excessive soluble salts or exchangeable sodium are allowed to accumulate because of improper irrigation and soil-management practices or inadequate drainage. If the amount of water applied to the soil is not in excess of the amount needed by plants, water will not percolate downward below the root zone, and an accumulation of mineral matter will form at that point. Likewise, impermeable soil zones near the surface can retard the downward movement of water and cause waterlogging of the soil and deposition of salts.

The characteristics of an irrigation water that seem to be most important in determining its quality are the total concentration of soluble salts and the relative activity of sodium ions in exchange reactions. For purposes of diagnosis and classification, the total concentration of soluble salts can be expressed in terms of electrical conductivity, which is a measure of the ability of the inorganic salts in solution to conduct an electrical current. The electrical conductivity can be determined accurately in the laboratory, or approximately by multiplying the total equivalents per million of calcium, magnesium, sodium, and potassium by 100, or by dividing the parts per million of total dissolved solids by 0.64. Water having an electrical conductivity of less than 750 micromhos per centimeter is generally satisfactory for irrigation insofar as the salt content is concerned, although salt-sensitive crops such as strawberries, green beans, and red clover may be adversely affected by water having an electrical conductivity of more than 250 micromhos per centimeter. Water in the range of 750 to 2,250 micromhos per centimeter is widely used, and satisfactory crop growth is obtained under good management and favorable drainage conditions, but saline conditions will develop if leaching and drainage are inadequate. Water having a conductivity of about 2,250 micromhos per centimeter has seldom been used successfully.

The sodium-adsorption ratio (SAR) of a water, which relates to the adsorption of sodium by the soil, may be determined by the formula

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

in which the ionic concentrations are expressed in equivalents per million. The sodium-adsorption ratio may be determined also by use of the nomogram shown in Figure 33. In using the nomogram, the concentration of sodium, expressed in equivalents per million, is plotted on the left-hand scale (A), and the concentration of calcium plus magnesium, expressed in equivalents per million, is plotted in reverse on the right-hand scale (B). The point at which a line connecting these two points intersects the sodium-adsorption-

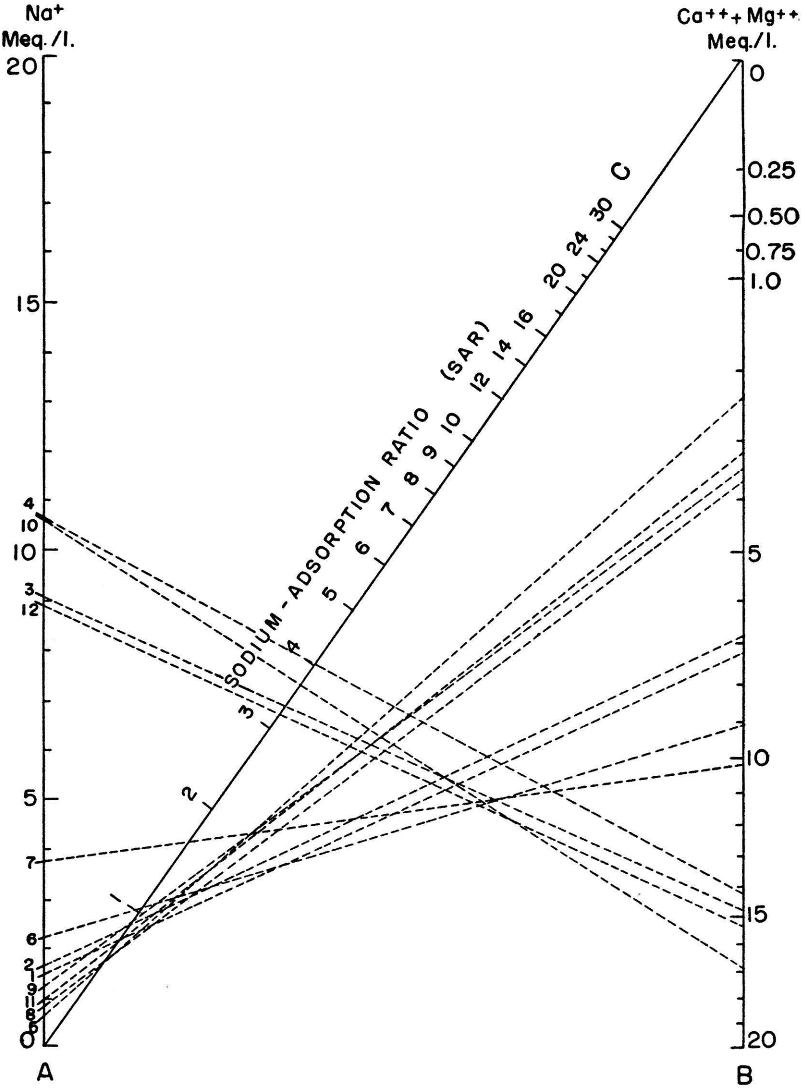

FIG. 33.—Nomogram for determining sodium-adsorption ratio of water.

ratio scale (C) determines the sodium-adsorption ratio of the water. When the sodium-adsorption ratio and the electrical conductivity of a water are known, the suitability of the water for irrigation can be determined by graphically plotting the values on the diagram shown in Figure 34. Table 11 lists the sodium-adsorption

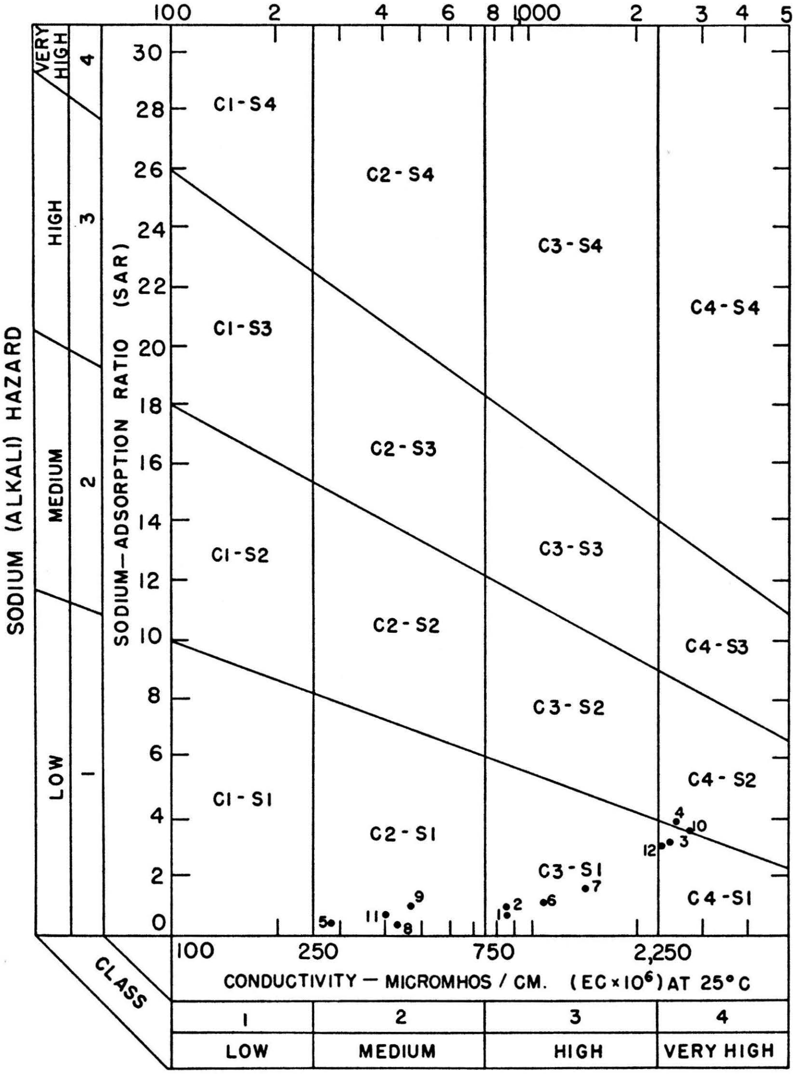

FIG. 34.—Classification of irrigation waters in the Ingalls area. (After Richards)

TABLE 11.—*Index numbers of samples shown in Figures 33 and 34 and sodium-adsorption ratio (SAR) and conductivity for which analyses are given in Table 9.*

WELL NUMBER	Number used in figures 33 and 34	SAR	Approximate conductivity
24-30-32ca	1	0.7	850
25-29-14ab	2	.9	850
25-29-27cd	3	3.3	2,400
25-30-19ad	4	4.0	2,470
25-30-19dd2	5	.5	275
25-30-22ac	6	1.0	1,100
25-30-24ca1	7	1.7	1,400
25-30-25bc	8	.5	425
25-31-13ca2	9	.9	450
25-31-24bb	10	3.7	2,750
26-28-11bd1	11	.7	400
26-29-2ac	12	3.2	2,300

ratios and approximate electrical conductivities of the 12 water samples plotted on Figures 33 and 34.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of developing harmful levels of exchangeable sodium. Medium-sodium water (S2) can be used safely on coarse-textured or organic soils having good permeability, but it will present an appreciable sodium hazard in certain fine-textured soils, especially those not leached thoroughly. High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management such as good drainage, thorough leaching, and addition of organic matter. Very high sodium water (S4) is generally unsatisfactory for irrigation unless special action is taken, such as addition of gypsum to the soil.

Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Crops of moderate salt tolerance, such as potatoes, corn, wheat, oats, and alfalfa, can be irrigated with C2 water without special practices. High-salinity water (C3) cannot be used on soils with restricted drainage. Very high salinity water (C4) can be used only on certain crops and then only if special practices are followed.

In the diagram for the classification of irrigation waters in the Ingalls area (Fig. 34), samples 25-31-24bb and 26-29-2ac collected from Arkansas River and samples collected from wells 25-29-27cd and 25-30-19ad, a short distance north of the river, are classed as of very high salinity (C4). The rest of the samples had a medium to high salinity hazard. All but one sample (4) had a low sodium hazard, however.

RECORDS OF WELLS AND TEST HOLES

Descriptions of 231 wells and test holes in the Ingalls area are given in Table 12. All reported information was obtained from the owner or tenant and is given in feet. Measured depths of wells and depths to water levels are given in feet and tenths below land surface. The well-numbering system is explained on page 13. The locations of wells and test holes are shown on Plate 1.

TABLE 12.—*Records of wells and test holes in the Ingalls area*

Well no. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (4)	Use of water (5)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (6)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 23 S., R. 28 W.															
23-28-34dd	SE SE sec. 34		Dr		4			Ogallala formation	Cy, N	N	Top of cement platform	1.3	2736.2	81.4	1-20-56	
	T. 24 S., R. 27 W.															
24-27-6ab	NW NE sec. 6	Sam Davison	Dr		16			do.	T, B	I	Pump base	0.3	2700.8	65.1	1-16-56	
24-27-6bb	NW NW sec. 6	Rufus Wood	Dr		16			do.	T, B	I	do.	1.3	2708.0	68.0	1-16-56	Reported yield 600.
24-27-8cc	SW SW sec. 8	Dale Davison	Dr	138				do.	T, B	I	do.	0.2	2697.2	60.6	1-16-56	Recently pumped. Driller's log.
24-27-14ab	NW NE sec. 14	Herman Werner	Dr		14			do.	T, B	I	do.	0.3	2654.1	68.0	1-16-56	
24-27-24bd	SE NW sec. 24	Clarence Sapp	Dr		16			do.	T, E	I	do.	0.5	2653.1	73.4	1-16-56	
24-27-29ac	SW NE sec. 29		Dr	155.0	4			do.	N	N	Land surface	0.0	2703.0			Driller's log.
24-27-29bc	SW NW sec. 29	Les Sapp	Dr	155	16			do.	T, B	I						Reported yield 800.
	T. 24 S., R. 28 W.															
24-28-15dd	SE SE sec. 15	State Geol. Survey	Dr	617.0	4			do.	N	N	Land surface	0.0	2742.4			Sample log from Kansas Geol. Survey Bull. 55.
24-28-21d	SE sec. 21	Clara Timken	Dr					do.	T	I						
24-28-24bb	NW NW sec. 24	G. Bowser	Dr	95	6			do.	Cy, W	N	Top of pipe clamp	0.8	2719.6	77.0	11-10-40	From Kansas Geol. Survey Bull. 55.
24-28-35cc	SW SW sec. 35	Leonard Burkhart	Dr	196	16			do.	T, B	I	Top of casing	1.6	2738.4	94.0	1-24-56	Reported yield 450.
24-28-36ac	SW NE sec. 36	Art Schartz	Dr	163	16			do.	T, D	I	Pump base	0.9	2721.0	85.4	1-12-56	Reported yield 280.
	T. 24 S., R. 29 W.															
24-29-18cc	SW SW sec. 18	Nicholson	Dr	220				do.			Land surface	0.0	2814.0	125	1-19-56	Driller's test hole.
24-29-23ba1	NE NW sec. 23	George Loewen	Dr	235.0	4			do.	N	N	do.	0.0	2772.0			Driller's log.
24-29-23ba2	NE NW sec. 23	do.	Dr	232	16			do.	T, D	I	Pump base	0.2	2772.6	95.0	1-13-56	Two wells.
24-29-24dc1	SW SE sec. 24	Rudy Loewen	Dr	256.0	4			do.	N	N	Land surface	0.0	2766.0			Driller's log.
24-29-24dc2	SW SE sec. 24	do.	Dr	217.0	16			do.	T, D	I	Top of breather hole	1.0	2767.4	89.1	1-13-56	Recently pumped.
24-29-28aa	NE NE sec. 28	G. M. Kerr	Dr	121	5			do.	Cy,W,H	N	Top of casing, east side	0.2	2797.0	109.5	11-18-40	From Kansas Geol. Survey Bull. 55.

	T. 24 S., R. 30 W.															
24-30-8cc....	SW SW sec. 8.....	Harold Wolf......	Dr	240	16	......	....	do.............	T, D	I	Top of breather hole	0.6	2869.9	141.0	1-13-56	Reported yield 1000.
24-30-13dd..	SE SE sec. 13.....	State Geol. Survey	Dr	250.0	4	......	....	do.............	N	N	Land surface..	0.0	2819.2	....	....	Sample log from Kansas Geol. Survey Bull. 55.
24-30-28cd...	SE SW sec. 28....	Oliver Armstrong..	Dr	300	8	......	....	do.............	T, E	I	do.........	0.0	2852.8	120	1-13-56	Two wells.
*24-30-32ca...	NE SW sec. 32....	Lester Clark......	Dr	303	16	......	....	do.............	T, B	I	Inspection hole in pump, west side....	2.0	2876.9	138.0	1-13-56	Used for aquifer test; measured yield 1200.
24-30-33dd..	SE SE sec. 33.....	U. S. Bureau of Reclamation....	Dr	290	4	......	....	do.............	N	N	Land surface..	0.0	2854.5	....	....	Sample log.
	T. 24 S., R. 31 W.															
24-31-14d...	SE sec. 14........	....	Dr	280	4	......	....	do.............	N	N	do.........	0.0	2881.9	....	....	Driller's log from Kansas Geol. Survey Bull. 55.
24-31-17dc...	SW SE sec. 17....	R. G. Morris.....	Dr	290.0	16	......	....	do.............	T, D	I	Pump base...	0.2	2904.2	121.2	1-19-56	Reported yield 1200.
24-31-20ab..	NW NE sec. 20...	do............	Dr	310	16	......	....	do.............	T, D	I	do.........	0.6	2904.6	121.5	1-19-56	do
24-31-25dd..	SE SE sec. 25.....	U. S. Bureau of Reclamation....	Dr	229.4	4	......	....	do.............	N	N	Land surface..	0.0	2864.7	....	....	Sample log.
24-31-27c....	SW sec. 27.......	U. S. Army.......	Dr	295	16	......	....	do.............	T, E	P	....	......	....	....	....	U.S.G.S. observation well 1002.
24-31-31b...	NW sec. 31.......	State Geol. Survey	Dr	220.0	4	......	....	Alluvium and Ogallala formation	N	N	Land surface..	0.0	2791.2	....	....	Sample log from Kansas Geol. Survey Bull. 55.
24-31-34ab..	NW NE sec. 34...	John Moler.......	Dr	280	16	......	....	Ogallala formation	T, D	I	do.........	1.1	2880.6	120.2	1-19-56	Reported yield 1540.
	T. 25 S., R. 27 W.															
25-27-12bb..	NW NW sec. 12...	J. G. Kornelson...	Dr	72	5	......	....	do.............	N	N	Top of casing	0.3	2652.5	55.2	11-14-40	From Kansas Geol. Survey Bull. 55.
25-27-22dd..	SE SE sec. 22.....	E. L. Feasler.....	Dr	117.8	6	......	....	do.............	Cy, W	D, S	Lower edge of hole in pump base.......	1.3	2695.2	102	1-20-56	
	T. 25 S., R. 28 W.															
25-28-20aa...	NE NE sec. 20....	U. S. Bureau of Reclamation....	Dr	299.7	4	......	....	do.............	N	N	Land surface..	0.0	2757.2	....	....	Sample log.
25-28-23cb1	NW SW sec. 23...	C. H. Powell......	Dr	258.0	4	......	....	do.............	N	N	do.........	0.0	2748.0	....	....	Driller's log.
25-28-23cb2	NW SW sec. 23...	do............	Dr	257	16	......	....	do.............	T, G	I	Pump base...	0.3	2748.5	112.5	1-12-56	
25-28-24dd..	SE SE sec. 24.....	U. S. Bureau of Reclamation....	Dr	259.7	4	......	....	do.............	N	N	Land surface..	0.0	2728.3	112.3	3-20-56	Sample log.
25-28-27dd..	SE SE sec. 27.....	State Geol. Survey	Dr	310.0	4	......	....	do.............	N	N	do.........	0.0	2751.1	....	....	Sample log from Kansas Geol. Survey Bull. 55.

TABLE 12.—*Records of wells and test holes in the Ingalls area*—Continued

Well no. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing	Principal water-bearing bed		Method of lift (4)	Use of water (5)	Measuring point			Depth to water level below land surface, feet (6)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
							Character of material	Geologic source			Description	Distance above land surface, feet	Height above mean sea level, feet			
	T. 25 S., R. 29 W.															
25-29-3cc	SW SW sec. 3	U. S. Bureau of Reclamation	Dr	289.5	4			Ogallala formation	N	N	Land surface	0.0	2793.7			Sample log.
25-29-12cc	SW SW sec. 12	do.	Dr	289.8	4			do.	N	N	do.	0.0	2765.8			do
*25-29-14ab	NW NE sec. 14	Clarence Irsik	Dr	308	16			do.	T, D	I	Pump base	0.5	2776.8	105.3	1-11-56	Used for aquifer test; measured yield 1600.
25-29-19cc	SW SW sec. 19	State Geol. Survey	A	9.0	4			Alluvium	N	O	Land surface	0.0	2694.0	4.1	2- 6-56	
25-29-20ca	NE SW sec. 20	Mr. Hewes	Dr	44.4	14			do.	Cf, E	I	Top of board platform	0.7	2695.9	13.7	1-12-56	
25-29-20cd1	SE SW sec. 20	do.						do.	Cf, B	I	Water surface	-6.0	2679.6		1-12-56	Gravel pit; altitude is water surface.
25-29-20cd2	SE SW sec. 20	G. A. Hard	Dr	11.5	5.5			do.	Cy, W	N	Top of casing, south side					U.S.G.S. observation well 1.
25-29-24cc	SW SW sec. 24	U. S. Bureau of Reclamation	Dr	277.6	4			Ogallala formation	N	N	Land surface	0.0	2774.0			Sample log.
25-29-27cc1	SW SW sec. 27	Norbert Irsik	Dr	173.0	4			do.	N	N	do.	0.0	2675.0			Driller's log.
25-29-27cc2	SW SW sec. 27	do.	Dr	180	16			Alluvium and Ogallala formation	T, E	I	do.	0.0	2674.7			Measured yield 1400.
*25-29-27cd	SE SW sec 27	do.	Dr	15	4			Alluvium	Cy, W	S						
25-29-28bb	NW NW sec. 28	State Geol. Survey	A	19.0	4			do.	N	O	Land surface	0.0	2690.3	15.5	2- 6-56	
25-29-28bd	SE NW sec. 28	U. S. Bureau of Reclamation	Dr	187.0	16			Ogallala formation	T, B	O	do.	0.0	2690.0	17.0	8- 8-56	Used for aquifer test; water level in Ogallala formation. Sample log.
25-29-28ca	NE SW sec. 28	State Geol. Survey	Dr	29.0	16			Alluvium	T, G	O	do.	0.0		7.0	3-21-56	Used for aquifer test; driller's log.
25-29-28cd	SE SW sec. 28	Charles Sturtevant	Dr	15	5			do.	Cy, W	S	Top of casing	1.0	2677.0	4.3	2- 9-56	
25-29-28da	NE SE sec. 28	State Geol. Survey	A	19.0	4			do.	N	O	Land surface	0.0	2681.9	12.3	2- 4-56	
25-29-30da	NE SE sec. 30	do.	A	9.0	4			do.	N	O	do.	0.0	2688.5	6.5	2- 9-56	
25-29-32aa1	NE NE sec. 32	Charles Sturtevant	Dr	28.0	14			do.	Cf, G	I	Top of board platform	0.0	2682.1	7.0	1-11-56	Reported yield 1600.

25-29-32aa2	NE NE sec. 32	State Geol. Survey	A	9.0	4			do	N	O	Land surface	0.0	2679.3	5.4	2- 9-56	
25-29-33cb	NW SW sec. 33	do	A	24.0	4			do	N	O	do	0.0	2700.0	13.6	2- 9-56	
25-29-33cc	SW SW sec. 33	do	A	24.0	4			do	N	O	do	0.0	2704.7	15.5	2- 9-56	
25-29-34aa	NE NE sec. 34	do	A	19.0	4			do	N	O	do	0.0	2672.0	12.9	2- 4-56	
25-29-34bc	SW NW sec. 34	U. S. Bureau of Reclamation	Dr	166.3	4			Ogallala formation	N	N	do	0.0	2679.4			Sample log.
25-29-34dd	SE SE sec. 34		Dr	11.5	6			Alluvium	Cy, W	S	Pump base	1.0	2664.7	6.0	1-11-56	
25-29-35cd	SE SW sec. 35	George Giesbrecht	Dr	26.5	2			do	Cf, G	I	Top of casing	2.5	2663.8	6.5	1-11-56	
25-29-35da	NE SE sec. 35	State Geol. Survey	A	29.0	4			do	N	O	Land surface	0.0	2665.2	11.2	2- 4-56	
25-29-35dc	SW SE sec. 35	George Giesbrecht	Dr	22.0	12			do	Cf, G	I	Top of casing	2.5	2660.4	5.5	1-11-56	
25-29-36dc	SW SE sec. 36	State Geol. Survey	A	23.0	4			do	N	N	Land surface	0.0	2673.3			Driller's log.
	T. 25 S., R. 30 W.															
25-30-1aa	NE NE sec. 1	U. S. Bureau of Reclamation	Dr	285.0	4			Ogallala formation	N	N	do	0.0	2832.2			Sample log.
25-30-6cc	SW SW sec. 6	do	Dr	304.0	4			do	N	O	do	0.0	2853.9	114.9	3-20-56	do
25-30-12dd	SE SE sec. 12	do	Dr	300.1	4			do	N	N	do	0.0	2825.5			do
25-30-17cd	SE SW sec. 17	State Geol. Survey	A	24.0	4			Alluvium	N	O	do	0.0	2741.5	19.2	2- 6-56	
25-30-17dc	SW SE sec. 17		Dr		4				Cy, W	S	Top of 1¼ in. pipe	3.7	2748.6	24.4	1-19-56	
25-30-18cb	NW SW sec. 18	State Geol. Survey	A	19.0	4			Alluvium	N	O	Land surface	0.0	2748.6	15.8	2- 6-56	
25-30-18dc	SW SE sec. 18	do	A	24.0	4			do	N	O	do	0.0	2747.1	19.1	2- 6-56	
*25-30-19ad	SE NE sec. 19	Nell Wallace	Dr	15.0	4			do	Cy, W	S						
25-30-19cd	SE SW sec. 19	State Geol. Survey	A	13.0	4			do	N	O	Land surface	0.0	2740.7	11.8	2- 7-56	
25-30-19dd1	SE SE sec. 19	E. E. Porter	Dr	35	16			do	Cf, B	I						
*25-30-19dd2	SE SE sec. 19	do	Dr	15	6			do	Cy, W	S						
25-30-20bb	NW NW sec. 20	Andrew Larson	Dr	42.0	18			do	Cf, E	I	Top of casing	2.1	2735.6	10.1	1-13-56	Battery of five wells.
25-30-20bc1	SW NW sec. 20	do	Dr	46.0	18			do	Cf, B	I	do	1.3	2734.6	9.3	2- 6-56	Battery of five wells. Reported yield 2500.
25-30-20bc2	SW NW sec. 20	do	Dr	46.0	18			do	Cf, B	I	do	1.3		9.3	2- 6-56	Battery of five wells.
25-30-20dd	SE SE sec. 20	Mr. Wartman	Dr	35	16			do	Cf, B	I						
25-30-21bb	NW NW sec. 21	Myles McGehee	Dr	35	16			do	Cf, E	I	Steel rim	-1.0	2727.2	9.5	1-11-56	Battery of five wells; reported yield 1500.
25-30-21bd	SE NW sec. 21	U. S. Bureau of Reclamation	Dr	162.0	16			Ogallala formation	T, B	O	Land surface	0.0	2723	10.0	7-23-56	Used for aquifer test; water level in Ogallala formation. Sample log.
25-30-21cb	NW SW sec. 21	State Geol. Survey	A	44.0	4			Alluvium	N	O	do	0.0	2723.7	6.5	2- 6-56	
25-30-22aa	NE NE sec. 22	do	A	29.0	4			do	N	O	do	0.0	2731.3	25.2	2- 6-56	
*25-30-22ac	SW NE sec. 22	Paul Ven John	Dr	41	16			do	T, E	I	Pump base	0.8	2723.1	14.7	1-11-56	Four individual wells; measured east well. Reported average yield 400; driller's log. Used for aquifer test.

TABLE 12.—*Records of wells and test holes in the Ingalls area—Continued*

Well no. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (4)	Use of water (5)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (6)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 25 S., R. 30 W.															
25-30-22cb	NW SW sec. 22	Frank Renick	Dr	32.0	16			Alluvium	Cf, E	I	Top of casing	0.3	2725.0	12.8	1-12-56	Driller's log.
25-30-23ac	SW NE sec. 23	State Geol. Survey	A	29.0	4			do	N	O	Land surface	0.0	2725.0	24.3	2- 6-56	
*25-30-24ca1	NE SW sec. 24	Frank Renick	Dr	16.5	6			do	Cy, W	S						
25-30-24ca2	NE SW sec. 24	State Geol. Survey	A	62.0	4			do	N	N	Land surface	0.0	2711.8			Driller's log.
25-30-24ca3	NE SW sec. 24	do	A	59.0	4			do	N	N	do	0.0	2709.3			do
25-30-24ca4	NE SW sec. 24	do	A	19.0	4			do	N	O	do	0.0	2709.3	14.3	2- 6-56	
25-30-24cd1	SE SW sec. 24	do	A	49.0	4			do	N	N	do	0.0	2703.5			Driller's log.
25-30-24cd2	SE SW sec. 24	do	A	59.0	4			do	N	N	do	0.0	2699.4			do
25-30-25ba1	NE NW sec. 25	do	A	54.0	4			do	N	N	do	0.0	2699.5			do
25-30-25ba2	NE NW sec. 25	do	Dr	220.0	4			Ogallala formation	N	N	do	0.0	2698.2			Sample log from Kansas Geol. Survey Bull. 55.
25-30-25ba3	NE NW sec. 25	do	A	53.0	4			Alluvium	N	N	do	0.0	2699.8			Driller's log.
*25-30-25bc	SW NW sec. 25	Frank Renick	Dr	15	6			do	Cy, W	S						
25-30-25bd1	SE NW sec. 25	State Geol. Survey	A	41.0	4			do	N	N	Land surface	0.0	2701.5			Driller's log.
25-30-25bd2	SE NW sec. 25	do	A	53.0	4			do	N	N	do	0.0	2700.8			do
25-30-25ca1	NE SW sec. 25	do	A	55.0	4			do	N	N	do	0.0	2701.3			do
25-30-25ca2	NE SW sec. 25	do	A	55.0	4			do	N	N	do	0.0	2701.6			do
25-30-25cc	SW SW sec. 25	Frank Renick	Dr	15	6			do	Cy, W	S	Top of pipe clamp	1.0	2702.3	4.7	2- 8-56	
25-30-25cd	SE SW sec. 25	State Geol. Survey	A	70.0	4			do	N	N	Land surface	0.0	2701.7			Driller's log.
25-30-25da1	NE SE sec. 25	U. S. Bureau of Reclamation	Dr	42.0	16			do	T, G	O	do	0.0		6.0	3-14-56	Used for aquifer tests; driller's log.
25-30-25da2	NE SE sec. 25	do	Dr	186.8	4			Alluvium and Ogallala formation	N	N	do	0.0	2697.0			Sample log.
25-30-26db	NW SE sec. 26	State Geol. Survey	A	49.0	4			Alluvium	N	O	do	0.0	2704.9	6.1	2- 8-56	
25-30-27ca	NE SW sec. 27	do	A	15.0	4			do	N	O	do	0.0	2714.9	7.7	2- 7-56	
25-30-27da	NE SE sec. 27	do	A	9.0	4			do	N	O	do	0.0	2709.7	5.6	2- 7-56	
25-30-28ad	SE NE sec. 28	do	A	13.0	4			do	N	O	do	0.0	2720.0	10.9	2- 7-56	
25-30-28ba	NE NW sec. 28	do	A	9.0	4			do	N	O	do	0.0	2719.5	5.7	2- 7-56	
25-30-29aa	NE NE sec. 29	U. S. Bureau of Reclamation	Dr	210.0	4			Alluvium and Ogallala formation	N	N	do	0.0	2722.7			Sample log.

25-30-30aa	NE NE sec. 30	State Geol. Survey	A	9.0	4			Alluvium	N	O	do	0.0	2730.8	5.9	2- 7-56	
25-30-30bc	SW NW sec. 30	do	A	40.0	4			do	N	O	do	0.0	2758.5	19.4	2- 7-56	
25-30-30cc	SW SW sec. 30		Dr		6			Pleistocene deposits or Ogallala formation	Cy, W	S	Top of plate on casing	3.0	2769.7	24.4	2- 7-56	
25-30-36ba	NE NW sec. 36	State Geol. Survey	A	35.0	4			Alluvium	N	N	Land surface					Driller's log.
25-30-36cd	SE SW sec. 36		Dr		5			Pleistocene deposits and Ogallala formation	Cy, W	S	Top of plate on casing	4.3	2728.0	25.6	2- 9-56	
25-30-36dc	SW SE sec. 36	U. S. Bureau of Reclamation	Dr	209.3	4			Ogallala formation	N	N	Land surface	0.0	2735.2			Sample log.
	T. 25 S., R. 31 W.															
25-31-11cc	SW SW sec. 11	Clay Weldon	Dr	49.0	14			Alluvium	T, E	I	Pump base	0.6	2765.3	23.7	1-13-56	Reported yield 500; driller's log.
25-31-13ba	NE NW sec. 13	State Geol. Survey	A	68.0	4			do	N	N	Land surface	0.0	2762.0			Driller's log.
25-31-13bc	SW NW sec. 13	Clay Weldon	Dr	24.6	16			do	Cf, E	I	Top of casing	0.4	2752.7	13.9	1-13-56	Battery of five wells.
25-31-13bd	SE NW sec. 13	State Geol. Survey	A	69.0	4			do	N	N	Land surface	0.0	2755.4			Driller's log.
25-31-13ca1	NE SW sec. 13	John Husband	Dr	26.0				do	Cf, B	I	Top of casing	1.5		9.0	2- 7-56	Battery of three wells.
*25-31-13ca2	NE SW sec. 13	Pierceville Jr. High School	Dr	180				Ogallala formation	T, E	P						
25-31-13ca3	NE SW sec. 13	State Geol. Survey	A	58.0	4			Alluvium	N	N	Land surface	0.0	2744.2			Driller's log.
25-31-13ca4	NE SW sec. 13	do	A	58.0	4			do	N	N	do	0.0	2744.2			do
25-31-13cc	SW SW sec. 13	do	A	40.0	4			do	N	N	do	0.0	2742.6			do
25-31-13cd	SE SW sec. 13	Ed Wehrley	Du	5.5	24			do	N	N						U.S.G.S. observation well 13.
25-31-15bb	NW NW sec. 15	Gerald Beach	Dr	60.4	14			do	T, E	I	Pump base	0.1	2757.9	5.0	1-13-56	
25-31-15dd	SE SE sec. 15	State Geol. Survey	A	9.0	4			do	N	O	Land surface	0.0	2753.2	4.6	2- 7-56	
25-31-22bb	NW NW sec. 22	U. S. Bureau of Reclamation	Dr	204.5	4			Ogallala formation	N	N	do	0.0	2783.7			Sample log.
25-31-23aa	NE NE sec. 23	State Geol. Survey	A	14.0	4			Alluvium	N	O	do	0.0	2745.3	5.6	2- 7-56	
25-31-23ab	NW NE sec. 23	do	A	9.0	4			do	N	O	do	0.0	2748.4	3.1	2- 7-56	
25-31-24bb1	NW NW sec. 24	do	A	48.0	4			do	N	N	do	0.0	2745.8			Driller's log.
25-31-24bb2	NW NW sec. 24	do	A	27.0	4			do	N	N	do	0.0	2743.7			do
25-31-24bb3	NW NW sec. 24	do	A	43.0	4			do	N	N	do	0.0	2743.3			do
25-31-24bc1	SW NW sec. 24	do	A	68.0	4			do	N	N	do	0.0	2745.1			do.
25-31-24bc2	SW NW sec. 24	do	A	68.0	4			do	N	N	do	0.0	2746.5			do
25-31-24dc	SW SE sec. 24	do	A	29.0	4			do	N	O	do	0.0	2759.0	18.8	2- 7-56	
25-31-24dd	SE SE sec. 24	U. S. Bureau of Reclamation	Dr	229.0	4			Ogallala formation	N	N	do	0.0	2748.3			Sample log.
25-31-35db	NW SE sec. 35		Dr	61.4	4			Alluvium	Cy, W	S	Top of cement platform	2.3	2803.7	48.7	1-18-56	
	T. 26 S., R. 27 W.															
26-27-2cc	SW SW sec. 2	Gerald Langton	Dr	265				Ogallala formation	T, B	I	Pump base	0.5	2696.8	125.8	1-16-56	Reported yield 1000.
26-27-7bb	NW NW sec. 7	Ross Miller	Dr	250	24			do	T, G	I	do	1.0	2625.6	28.0	1-10-56	Reported yield 1300.

TABLE 12.—*Records of wells and test holes in the Ingalls area*—*Continued*

Well no. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (4)	Use of water (5)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (6)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
26-27-8bc	SW NW sec. 8	U. S. Bureau of Reclamation	Dr	179.1	4			Alluvium and Ogallala formation	N	N	Land surface	0.0	2594.4	7.4	3-20-56	Sample log.
26-27-9cc	SW SW sec. 9	R. L. Salmons	Dr	40	16			Alluvium	Cf, N	I	Top of casing	1.8	2588.4	7.2	1-17-56	
26-27-10cc	SW SW sec. 10	Mr. Kenober	Dr	32	15			do	N	I	do	2.6	2579.3	6.0	1-17-56	Portable centrifugal pump used.
26-27-10cd	SE SW sec. 10	do	Dr		16			do	N	I	do	3.4	2577.6	6.2	1-17-56	do
26-27-13bc	SW NW sec. 13	C. E. Butcher	Dr		16			do	Cf, G	I	Cement wall 5.6 feet above casing	1.6	2568.2	9.2	1-17-56	Battery of four wells.
26-27-14cd	SE SW sec. 14	Ralph Monical	Dr		12			do	Cf, G	I	Top of casing	0.2	2572.8	7.6	1-17-56	
26-27-14dc	SW SE sec. 14	John Keach	Dr					do	N	I	do	0.5	2571.7	8.9	1-17-56	Portable centrifugal pump used.
26-27-15ac	SW NE sec. 15		Dr		16			do	N	I	do	2.0	2574.3	5.3	1-17-56	do
26-27-15cb	NW SW sec. 15	Jess Nichols	Dr	33	12			do	N	I	do	1.6	2576.6	5.2	1-17-56	do
26-27-15db	NW SE sec. 15	do	Dr	32	12			do	N	I	do	1.6	2574.1	5.0	1-17-56	do
26-27-18ca	NE SW sec. 18	State Geol. Survey	A	9.0	4			do	N	O	Land surface	0.0	2598.6	5.9	2- 9-56	
26-27-23ab	NW NE sec. 23	Ralph Monical	Dr		15			do	Cf, B	I	Board platform	0.0	2572.3		1-17-56	
26-27-24ab	NW NE sec. 24	Enerson Koehn	Dr	22.6				do	Cf	I	Top of casing	0.7	2559.4	4.7	1-17-56	Reported yield 600.
26-27-24ac	SW NE sec. 24	do	Dr	28				do		I	do	-3.0	2558.9	7.6	1-17-56	Reported yield 600.
26-27-28cc	SW SW sec. 28	Federal Land Bank	Dr	52.5	4				Cy, H		do	0.5	2640.9	48.0	11-14-40	From Kansas Geol. Survey Bull. 55.
	T. 26 S., R. 28 W.															
26-28-1bb	NW NW sec. 1	U. S. Bureau of Reclamation	Dr	329.6	4			Ogallala formation	N	O	Land surface	0.0	2742.0	130.0	3-20-56	Sample log
26-28-5bb	NW NW sec. 5	do	Dr	249.8	4			do	N	N	do	0.0	2764.0			do
26-28-6cc	SW SW sec. 6	Leo Almstead	Dr	41.3	18			Alluvium	Cf, B	I	Top concrete wall	0.1	2655.4		1-11-56	Reported yield 1400.
26-28-6db	NW SE sec. 6	do	Dr		6			do	Cy, W	S	Pump pipe	3.8	2660.7	26.0	1-10-56	
26-28-6dd	SE SE sec. 6	do	Dr	17.1				do	Cf, G	I		-3.0	2633.9	7.0	1-11-56	
26-28-9ad	SE NE sec. 9	State Geol. Survey	A	24.0	4			do	N	O	Land surface	0.0	2636.0	21.0	2- 3-56	
26-28-9bb	NW NW sec. 9	do	A	14.0	4			do	N	O	do	0.0	2633.2	13.4	2- 3-56	
26-28-10ac	SW NE sec. 10	F. Luther	Dr	60.2				do	T, E	I	Pump base	0.6	2632.2	19.4	1-10-56	

26-28-10bc	SW NW sec. 10	do.	Dr	55.5				do.	T, E	I	do.	0.0	2637.3	23.7	1-10-56	
26-28-10cc	SW SW sec. 10	State Geol. Survey	Dr	210.0	4			Alluvium and Ogallala formation	N	N	Land surface	0.0	2621.8			Sample log from Kansas Geol. Survey Bull. 55.
26-28-10da	NE SE sec. 10	G. A. Egbert	Dr	40.6				Alluvium	Cf, E	I	Top of casing	0.5	2622.4	15.1	1-10-56	
26-28-11bb	NW NW sec. 11	Ivan Davison	Dr	50.5				do.	T, E	I	Pump base	0.7	2637.1	29.2	1-11-56	
26-28-11bc	SW NW sec. 11	G. A. Egbert	Dr	28.5				do.	N	I	Top of concrete wall	0.0	2630.5	22.6	1-10-56	Not being used.
26-28-11bd1	SE NW sec. 11	City of Cimarron	Dr	205				Ogallala formation	T, E	P						
26-28-11bd2	SE NW sec. 11	G. A. Egbert	Dr	44.1	20			Alluvium	Cf, E	I	Top of curb	1.5	2629.5	22.5	1-10-56	Reported yield 2250.
26-28-11ca1	NE SW sec. 11	Leo Leatherwood	Dr	27.0	16			do.	Cf, E	I	do.	1.8	2618.1	11.4	1-11-56	
26-28-11ca2	NE SW sec. 11	State Geol. Survey	A	53.0	4			do.	N	N	Land surface	0.0	2612.0			Driller's log.
26-28-11dc	SW SE sec. 11	do.	A	47.0	4			do.	N	N	do.	0.0	2609.8			do
26-28-12ab	NW NE sec. 12	John Geisbrecht	Dr		16			do.	Cf	I	Top of concrete wall	0.1	2630.4	33.3	1-10-56	
26-28-12ad	SE NE sec. 12	Dallas Egbert	Dr	44.6	14			do.	Cf	I	Land surface	0.0	2614.8		1-10-56	Battery of four wells; reported yield 1700.
26-28-12bc1	SW NW sec. 12	Oliver Van Dine	Dr	46.5				do.	N	I		1.0	2621.8	22.7	1-10-56	Battery of two wells.
26-28-12bc2	SW NW sec. 12	Sam Robbins	Dr	35.0				do.	Cf, E	I	Top of board curb	1.0	2619.8		1-10-56	do
26-28-12cc	SW SW sec. 12	U. S. Bureau of Reclamation	Dr	149.0	4			Alluvium and Ogallala formation	N	N	Land surface	0.0	2605.1			Sample log.
26-28-13cb	NW SW sec. 13	State Geol. Survey	A	9.0	4			Alluvium	N	O	do.	0.0	2609.6	5.4	2- 9-56	
26-28-14ab	NW NE sec. 14	Wiley Cruisinberry	Dr	30.0	14			do.	Cf, G	I	Top of casing	1.0	2610.1	5.2	1-10-56	
26-28-14ac	SW NE sec. 14	do.	Dr	35.0				do.	Cf, G	I	Top of concrete curb	1.0	2611.5	5.2	1-11-56	
26-28-14ba	NE NW sec. 14	State Geol. Survey	A	63.0	4			do.	N	N	Land surface	0.0	2610.3			Driller's log.
26-28-14bb	NW NW sec. 14	do.	A	9.0	4			do.	N	O	do.	0.0	2611.6	5.1	2- 9-56	
26-28-14bd1	SE NW sec. 14	do.	A	61.0	4			do.	N	N	do.	0.0	2609.8			Driller's log.
26-28-14bd2	SE NW sec. 14	do.	A	57.0	4			do.	N	N	do.	0.0	2609.8			do
26-28-14ca	NE SW sec. 14	do.	A	26.0	4			do.	N	N	do.	0.0	2616.9			do
26-28-14db	NW SE sec. 14	Clyde Shnofle	Dr	25	16			do.	Cf, G	I	Top of casing	1.0	2610.3	4.0	1-11-56	Battery of two wells.
26-28-14dc	SW SE sec. 14	Charles B. Steele						Terrace deposits	Cf, G	I	Water surface		2615.4		3-56	Gravel pit; altitude is water surface.
26-28-16aa	NE NE sec. 16	State Geol. Survey	A	9.0	4			Alluvium	N	O	Land surface	0.0	2621.1	4.6	2- 9-56	
26-28-16ab	NW NE sec. 16	do.	A	9.0	4			do.	N	O	do.	0.0	2624.7	4.3	2- 9-56	
26-28-16cb	NW SW sec. 16	do.	A	24.0	4			do.	N	O	do.	0.0	2655.8	18.8	2- 9-56	
26-28-17aa	NE NE sec. 17	do.	A	9.0	4			do.	N	O	do.	0.0	2630.6	7.4	2- 9-56	
26-28-21bc	SW NW sec. 21	do.	A	39.0	4			do.	N	O	do.	0.0	2677.9	35.5	2- 9-56	
26-28-23aa	NE NE sec. 23	Kerr Sand Co.						Terrace deposits		I	Water surface		2615.5		3-56	Gravel pit; altitude is water surface.
26-28-24cc	SW SW sec. 24	U. S. Bureau of Reclamation	Dr	178.3	4			Ogallala formation	N	O	Land surface	0.0	2648.4	29.4	3-20-56	Sample log.
26-28-24da	NE SE sec. 24	Charles B. Steele	Dr	40	24			Terrace deposits	Cf, G	I	Top of concrete curb	0.0	2626.3	19.2	1-11-56	

TABLE 12.—*Records of wells and test holes in the Ingalls area*—*Concluded*

Well no. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (4)	Use of water (5)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (6)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 26 S., R. 28 W.															
26-28-29bb	NW NW sec. 29	U. S. Bureau of Reclamation	Dr	235.0	4	.....	.....	Ogallala formation	N	O	Land surface	0.0	2699.9	48.9	3-20-56	Sample log.
26-29-33b	NW sec. 33	V. C. Shafer	Dr	.....	.....	.....	.....	.....	T	I	.....	.....	.....	.....	.....	Deep well.
26-28-34bb	NW NW sec. 34	State Geol. Survey	Dr	220.0	4	.....	.....	Terrace deposits and Ogallala formation	N	N	Land surface	0.0	2671.5	.....	.....	Sample log from Kansas Geol. Survey Bull. 55.
26-28-36cc	SW SW sec. 36	U. S. Bureau of Reclamation	Dr	279.3	4	.....	.....	Ogallala formation	N	O	do.	0.0	2687.2	63.2	3-20-56	Sample log.
	T. 26 S., R. 29 W.															
26-29-1bb	NW NW sec. 1	State Geol. Survey	A	24.0	4	.....	.....	Alluvium	N	O	Land surface	0.0	2662.6	17.6	2-4-56	
26-29-1db	NW SE sec. 1	Leo Almstead	Dr	37.2	16	.....	.....	do.	Cf, B	I	Concrete wall	.....	2655.2	15.2	1-11-56	
26-29-2aa1	NE NE sec. 2	State Geol. Survey	A	68.0	4	.....	.....	do.	N	N	Land surface	0.0	2661.6	.....	.....	Driller's log.
26-29-2aa2	NE NE sec. 2	do.	A	68.0	4	.....	.....	do.	N	N	do.	0.0	2655.5	.....	.....	do
26-29-2ac	SW NE sec. 2	do.	A	68.0	4	.....	.....	do.	N	N	do.	0.0	2656.3	.....	.....	do
26-29-2bb	NW NW sec. 2	U. S. Bureau of Reclamation	Dr	163.0	4	.....	.....	Ogallala formation	N	N	do.	0.0	2655.4	.....	.....	Sample log.
26-29-2ca1	NE SW sec. 2	State Geol. Survey	A	68.0	4	.....	.....	Alluvium	N	N	do.	0.0	2651.3	.....	.....	Driller's log.
26-29-2ca2	NE SW sec. 2	do.	A	10.0	4	.....	.....	do.	N	O	do.	0.0	2658.7	7.3	2-9-56	
26-29-2cb	NW SW sec. 2	do.	A	68.0	4	.....	.....	do.	N	N	do.	0.0	2653.6	.....	.....	Driller's log.
26-29-2cc	SW SW sec. 2	do.	A	68.0	4	.....	.....	do.	N	N	do.	0.0	2658.5	.....	.....	do.
26-29-5dd	SE SE sec. 5	U. S. Bureau of Reclamation	Dr	243.0	4	.....	.....	Ogallala formation	N	O	do.	0.0	2721.5	35.5	3-20-56	Sample log.
26-29-6cc	SW SW sec. 6	.....	Dr	90	.....	.....	.....	Pleistocene deposits or Ogallala formation	Cy, W	S	Top of 2 in. pipe	2.5	2773.0	66.3	1-11-56	
26-29-7cb	NW SW sec. 7	C. M. Davis	Dr	100.4	6	.....	.....	do.	Cy, W	S	Top of pipe clamp	1.0	2785.6	79.0	1-18-56	U.S.G.S. observa- well 21.
26-29-10aa	NE NE sec. 10	State Geol. Survey	A	34.0	4	.....	.....	Alluvium	N	O	Land surface	0.0	2688.7	20.6	2-9-56	
26-29-11cc	SW SW sec. 11	U. S. Bureau of Reclamation	Dr	214.6	4	.....	.....	Ogallala formation	N	N	do.	0.0	2713.2	40.0	3-20-56	Sample log.

*26-29-22aa..	NE NE sec. 22....	Federal Land Bank	Dr	86.5	5			Pleistocene deposits or Ogallala formation	Cy, H	D						From Kansas Geol. Survey Bull. 55.
26-29-27aa...	NE NE sec. 27....	U. S. Bureau of Reclamation....	Dr	264.4	4			Ogallala formation	N	N	Land surface..	0.0	2728.0	51.0	3-19-56	Sample log.
26-29-36dc...	SW SE sec. 36....	P. Brietenbach....	Dr	85.5	5.5			Pleistocene deposits or Ogallala formation	Cy, N	N	Top of pipe clamp......	1.0	2734.7	72.7	1-18-56	U.S.G.S. observation well 7.
	T. 26 S., R. 30 W.															
*26-30-1bc....	SW NW sec. 1....	H. A. Jones......	Dr	70	3			Terrace deposits...	Cy, W	D, S						From Kansas Geol. Survey Bull. 55.
26-30-6cd....	SE SW sec. 6.....	Morris Johnson...	Dr	125	16				T, G	I	Discharge pipe	3.0	2800.2	61.1	1-11-56	
26-30-10cc...	SW SW sec. 10....	U. S. Bureau of Reclamation....	Dr	339.4	4			Ogallala formation	N	N	Land surface..	0.0	2786.0			Sample log.
26-30-12cc...	SW SW sec. 12....	do............	Dr	299.1	4			do.......	N	N	do.........	0.0	2796.5			do
26-30-17bb..	NW NW sec. 17...	do............	Dr	299.3	4			do............	N	N	do.........	0.0	2779.4			do
26-30-18aa...	NE NE sec. 18....	E. Welch.........	Dr	63.2	2			Pleistocene deposits	Cy, W	N	Top of pump jacket, east side.......	4.2	2785.7	50.15	1-18-56	
	T. 26 S., R. 31 W.															
26-31-1bb...	NW NW sec. 1....	U. S. Bureau of Reclamation....	Dr	269.0	4			Ogallala formation	N	O	Land surface..	0.0	2783.9	38.9	3-21-56	Sample log.
26-31-4cc....	SW SW sec. 4.....	Lowell McGaw....	Dr	140	16				T, B	I	Pump base...	0.5	2818.9	54.5	1-19-56	Reported test yield 1800; driller's log. Plugged back from 200 ft.
26-31-12cc...	SW SW sec. 12....	O. E. Hutton.....	Dr	161	16				T, B	I	do.........	0.7	2805.5			Reported yield 1800.
26-31-12cd...	SE SW sec. 12....	U. S. Bureau of Reclamation....	Dr	318.0	4			Ogallala formation	N	N	Land surface..	0.0	2796.1			Sample log.

1. An asterisk (*) before a well number indicates that analysis of water is given in Table 9.
2. A, auger hole; Dr, drilled well; Du, dug well.
3. Reported depths below the land surface are given in feet, measured depths are given in feet and tenths below measuring points.
4. Type of pump: Cf, centrifugal; Cy, cylinder; N, none; T, turbine.
   Type of power: B, butane; D, diesel; E, electric; G, gas engine; H, hand operated; W, windmill.
5. I, irrigation; N, none; O, observation; P, public; S, stock.
6. Measured depths to water level are given in feet, tenths, and hundredths; reported depths to water level are given in feet.

LOGS OF TEST HOLES AND WELLS

The logs of 89 test holes and wells are given on the following pages; the locations of these wells are shown on Plate 1.

24-27-8cc. *Drillers log of irrigation well in SW¼ SW¼ sec. 8, T. 24 S., R. 27 W., drilled by C. W. Henkle Co., 1948. Surface altitude, 2,697 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Soil	1	1
Clay, yellow	1	2
Silt, hard	3	5
Clay, yellow	16	21
Clay, white; cemented streaks	15	36
Sand, limy, soft	9	45
Clay, sandy, yellow	3	48
Sand, cemented	6	54
Clay, sandy, yellow	32	86
Gravel, fine; cemented streaks	17	103
Clay, yellow	7	110
Gravel, medium, loose; some "lime"	22	132
Clay, yellow	6	138
CRETACEOUS—Gulfian		
Carlile Shale (?)		
Shale, blue	2	140

24-27-29ac. *Drillers log of test hole in SW¼ NE¼ sec. 29, T. 24 S., R. 27 W., drilled by E. W. Henkle Co., 1946. Surface altitude, 2,703.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Soil	2	2
Clay, yellow	7	9
Sand, fine	7	16
Clay, yellow	16	32
Clay, limy; streaks of caliche	20	52
Clay, sandy; cemented streaks	6	58
Sand, cemented	8	66
Clay, sandy, pink	7	73
Gravel, fine	4	77
Clay, sandy, brown	15	92
Gravel, clay streaks	8	100
Gravel	8	108
Clay	2	110
Gravel	34	144
Mortar bed	1	145
Gravel	8	153
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale	2	155

24-28-15dd. *Sample log of test hole 18 at SE cor. sec. 15, T. 24 S., R. 28 W., Gray County, drilled by State and Federal Geological Surveys, 1941. Surface altitude, 2,742.4 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, tan	0.5	0.5
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, tan; contains scattered sand and gravel	16.5	17
Silt and sand, fine, tan; contains limy nodules	14	31
Silt, sandy, limy, tan	24	55
Caliche, silty, light gray to white	5	60
Silt, sandy, limy, tan to white	4.5	64.5
Caliche, hard, light tan to light gray	1.5	66
Sand, fine to medium, cemented, tan	6	72
Sand and gravel; brown	2	74
Silt, sand, and gravel; cemented; gray	5	79
Sand and gravel; brown	4	83
Gravel, medium to coarse, cemented	7	90
Silt and sand, fine, limy, tan to reddish brown	21	111
Caliche, soft, light gray; silt and sand, fine; limy	3	114
Gravel, medium to coarse, brown	16	130
Silt, sand, and gravel	11	141
Caliche, light gray and tan; silt and fine sand; limy,	4	145
Silt and sand, fine, limy, light gray to white	6	151
Silt and clay, silty, yellow tan	7	158
Sand and gravel; brown	5	163
Silt, sandy, tan	27	190
Sand, fine, to fine gravel, limy, silty, tan	20	210
Silt and sand, fine, limy, tan	5.5	215.5
CRETACEOUS—Gulfian		
Carlile shale		
Fairport shale member		
Shale, calcareous, black	4.5	220
Shale, calcareous, dark gray to black; thin calcite veins	6	226
Greenhorn (?) limestone		
Shale, calcareous, light gray and black; contains 5-inch bed of blue-gray bentonite at 261 feet	46	272
Shale, silty, sandy, calcareous, black	18	290
Shale, calcareous, silty, dark gray to black; contains few thin beds of blue-gray bentonite and calcite,	57	347
Shale, calcareous, silty, light gray to white; contains interbedded hard black shale	3	350
Graneros shale—Kiowa (?) shale		
Shale, noncalcareous, blue gray; contains few thin beds of dark-gray sandstone	23	373
Shale, noncalcareous, silty, light gray to black; contains pyrite	6.5	379.5
Sandstone, hard, dark gray	.5	380
Shale, noncalcareous, silty, light to medium gray	20	400

	Thickness, feet	Depth, feet
Shale, noncalcareous, silty, light gray, and shale, sandy, gray	20	420
Shale, noncalcareous, dark gray, and shale, silty and sandy, light gray	50	470
Shale, noncalcareous, sandy, light gray	25	495
Shale, noncalcareous, sandy, dark brown to black	5	500
Shale, sandy, laminated, light to dark gray and yellow	10	510
Shale, noncalcareous, dark gray; contains some medium-gray and orange-tan silty clay	26	536
Shale, noncalcareous, dark gray; contains some light-gray silty shale and brown sandy shale	24	560
Shale, noncalcareous, light to medium gray; contains sand, mineral charcoal, and some red clay	57	617

24-29-23ba1. *Drillers log of test hole in NE¼ NW¼ sec. 23, T. 24 S., R. 29 W., drilled by E. W. Henkle Co., 1953. Surface altitude, 2,772.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Topsoil	3	3
Subsoil	3	6
Clay	20	26
Clay, sandy, limy; some cemented streaks	18	44
Mortar bed	1	45
Clay, sandy	47	92
Sand, fine; clay streaks	18	110
Sand, fine to coarse; clay streaks	18	128
Clay	4	132
Sand, fine; clay streaks	15	147
Sand, fine to medium; clay streaks	6	153
Clay	2	155
Sand, fine to coarse; clay streaks	7	162
Mortar bed	1	163
Sand, fine to coarse; clay streaks	3	166
Clay, streaks of fine sand	14	180
Sand, fine to medium; clay streaks	12	192
Clay; sand streaks	3	195
Sand, fine; clay streaks	29	224
Clay	10	234
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale	1	235

24-29-24dc1. *Drillers log of test hole in SW¼ SE¼ sec. 24, T. 24 S., R. 29 W., drilled by E. W. Henkle Co., 1952. Surface altitude, 2,766.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Topsoil	2	2
Subsoil	2	4

	Thickness, feet	Depth, feet
Clay	16	20
Caliche	31	51
Sand, fine to coarse; clay streaks; cemented streaks,	18	69
Clay, sandy; cemented streaks	10	79
Clay, sandy	31	110
Sand, fine; clay streaks	8	118
Clay	4	122
Sand, fine to coarse; clay streaks	20	142
Clay, sandy, limy; cemented streaks	20	162
Clay; sand streaks	6	168
Clay	17	185
Clay, sandy; sand streaks; cemented streaks	30	215
Clay	27	242
Clay; sand streaks	13	255
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale	1	256

24-30-13dd. *Sample log of test hole 19 at SE cor. sec. 13, T. 24 S., R. 30 W., Gray County, drilled by State and Federal Geological Surveys, 1941. Surface altitude, 2,819.2 feet.*

	Thickness, feet	Depth, feet
Soil, dark brown	1	1
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt and sand, fine, limy, tan and light brown	19	20
Silt and sand, fine, limy, reddish tan to yellow tan; contains caliche	23	43
Silt and sand, fine, limy, cemented	5	48
Sand, coarse, to coarse gravel	12	60
Sand, coarse, to fine gravel, cemented	5.5	65.5
Sand, coarse, to coarse gravel	4.5	70
Sand, fine, tan	3	73
Sand, coarse, to coarse gravel; contains thin cemented zones	23	96
Gravel, fine, cemented	2.5	98.5
Silt and sand, fine, limy, tan	1.5	100
Sand, fine, to coarse gravel; partly cemented	31	131
Silt and sand, fine, tan	19	150
Silt, sand, gravel, and caliche	11	161
Sand, coarse, to medium gravel	11	172
Silt and sand, fine, tan	11	183
Sand, coarse, to coarse gravel	27	210
Gravel, fine to coarse; composed mostly of white to light-gray limestone pebbles	14	224
Clay, noncalcareous, yellow and gray	18	242

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Carlile shale		
Fairport shale member		
Shale, calcareous, dark gray	8	250

24-30-33dd. *Sample log of test hole 32 drilled by U. S. Bureau of Reclamation April 1956, in SE cor. sec. 33, T. 24 S., R. 30 W. Surface altitude, 2,854.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, dark gray brown	2	2
Silt, calcareous, tan gray	7.5	9.5
Silt, sandy, very calcareous, pink tan to tan gray	15.5	25
Silt, sandy, very calcareous, gray white	9	34
Silt, sandy, calcareous, pink tan	17.5	51.5
Sand, fine to very coarse; contains some silt and some lime-cemented streaks	8.5	60
Sand, fine to coarse, and fine to coarse gravel; contains some lime-cemented streaks near base	19	79
Silt, sandy, calcareous, light gray tan	3	82
Sand, fine to coarse, and fine to medium gravel	13	95
Sand, fine to coarse; contains some calcareous gray-tan silt streaks and some lime-cemented streaks	13	108
Silt, sandy, calcareous, pink tan	3.5	111.5
Sand, fine to coarse, and fine gravel	8.5	120
Silt, very sandy, calcareous, pink tan	1	121
Sand, fine to coarse; contains some fine gravel and some tan silt and clay streaks	24	145
Silt, sandy, very calcareous, gray white to gray tan,	17	162
Sand, fine to medium; contains some silt streaks	5	167
Silt, sandy, calcareous, light tan; contains some sand streaks and some lime-cemented streaks	9.5	176.5
Sand, fine to coarse; contains some calcareous tan silt streaks	23.5	200
Silt, very clayey, calcareous, tan; contains some sand streaks	7	207
Clay, silty, sandy, calcareous, tan	3	210
Sand, fine to coarse; contains some clayey calcareous tan silt streaks and silty tan clay streaks at 215 to 217 and 253 to 255 feet	60	270
Sand, fine to coarse, and fine gravel; contains some silt streaks and much Cretaceous-derived material,	16.5	286.5
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	3.5	290

24-31-14d. *Drillers log of irrigation well 162 of H. Harms in SE¼ sec. 14, T. 24 S., R. 31 W. Surface altitude, 2,881.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Soil and "gyp"	50	50
Sand and rock	30	80
Clay, sandy	15	95
Clay, tough	5	100
Sand, fine	5	105
Clay, sandy	25	130
Sand	13	143
Rock	2	145
"Gyp", sandy	25	170
Clay, tough	15	185
Gravel, water bearing	20	205
Clay	2	207
Gravel	58	265
CRETACEOUS—Gulfian		
Carlile shale		
Fairport shale member		
Clay, yellow, sticky	15	280

24-31-25dd. *Sample log of test hole 1 drilled by U. S. Bureau of Reclamation January 1956, in SE cor. sec. 25, T. 24 S., R. 31 W. Surface altitude, 2,864.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, calcareous, gray	3	3
Silt, sandy, calcareous, light tan	7.7	10.7
Sand, fine to medium, very silty, calcareous, light tan	4.3	15
Silt, very sandy, calcareous, pink tan to brown	14.4	29.4
Sand, fine to coarse, and fine to coarse gravel at base; contains some tan calcareous silt streaks and lime-cemented streaks	45	74.4
Silt, very sandy, calcareous, tan to brown	15	89.4
Sand, fine to coarse; contains streaks of tan calcareous silt	10	99.4
Sand, fine to coarse, and fine to medium gravel; contains some calcareous tan silt streaks and lime-cemented streaks	15	114.4
Silt, very sandy, slightly calcareous, tan	5	119.4
Sand, fine to coarse; contains much calcareous, pink-tan silt and some fine gravel at base	10	129.4
Silt, very sandy, tan to brown; contains hard calcareous streaks	15	144.4

	Thickness, feet	Depth, feet
Sand, fine to coarse; contains some calcareous tan silt streaks and lime-cemented streaks	10	154.4
Silt, very sandy, calcareous, light tan	5	159.4
Sand, fine to coarse; contains many streaks of calcareous tan silt, brown clay streaks at 159.4 to 164.4 feet, and some lime-cemented streaks	50	209.4
Silt, very sandy, calcareous, light tan	10	219.4
Sand, fine to coarse, and fine gravel; contains many Cretaceous-derived pebbles and streaks of tan silt and silty clay	10	229.4

24-31-31b. *Sample log of test hole 9 in NW¼ sec. 31, T. 24 S., R. 31 W., Finney County, drilled by State and Federal Geological Surveys, 1941. Surface altitude, 2,791.2 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, dark	2	2
QUATERNARY—Pleistocene		
Recent—Alluvium		
Silt and sand, fine, light tan and light gray	4	6
Gravel, fine to very coarse; contains some sand and cobbles	31	37
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt and sand, fine, tan and light gray; contains lime-cemented bed at 41 to 43 feet	12	49
Sand and gravel, poorly sorted, brown	17	66
Silt and sand, fine, tan; contains thin lenses of coarser sand and gravel	12	78
Sand, fine, lime cemented, tan	5	83
Sand, fine, limy; contains thin cemented beds	7	90
Silt and sand, fine, limy, tan and light gray	9.5	99.5
Sand, fine, tan to brown; contains cemented zones and white and yellow chalk and limestone pebbles	20.5	120
Silt and sand, fine, tan; contains some clay	17	137
Sand, medium, to medium gravel; contains caliche fragments and yellow chalk pebbles	26	163
Silt, clayey, sandy, tan	3	166
Sand, medium, to medium gravel	3	169
Silt, clayey, tan	6	175
Sand, medium, to fine gravel; contains chalk pebbles	28	203
Silt and sand, fine, tan and gray	5.5	208.5
Sand, medium, to fine gravel, brown	5.5	214
CRETACEOUS—Gulfian		
Carlile shale		
Fairport (?) shale member		
Shale, silty, yellow tan; contains hard sandstone concretions	3.5	217.5
Shale, calcareous, dark gray	2.5	220

25-28-20aa. *Sample log of test hole 23 drilled by U. S. Bureau of Reclamation March 1956, in SE cor. NE¼ NE¼ sec. 20, T. 25 S., R. 28 W. Surface altitude, 2,757.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, gray brown	2	2
Silt, calcareous, tan; contains some sand near base,	12.7	14.7
Silt, very calcareous, gray tan; contains some sand near base	15	29.7
Silt, sandy, very calcareous, light pink gray to pink tan	35	64.7
Sand, fine to coarse; contains fine to coarse gravel at 74.7 to 89.7 feet, some calcareous tan silt streaks, and some lime-cemented streaks	25	89.7
Silt, clayey, sandy, calcareous, pink tan	5	94.7
Sand, fine to coarse; contains some fine gravel at 99.7 to 104.7 and 114.7 to 119.7 feet, some calcareous tan silt streaks, and some lime-cemented streaks	55	149.7
Silt, sandy, very calcareous, gray tan; contains sand streaks and some lime-cemented streaks	20	169.7
Sand, fine to coarse; contains some calcareous clayey tan silt streaks	5	174.7
Silt, calcareous, gray tan; contains some tan clay streaks and some sand streaks	10	184.7
Sand, fine to coarse; contains some fine gravel at 189.7 to 199.7 feet and some calcareous tan silt streaks	50	234.7
Sand, fine to coarse, and fine gravel; contains some calcareous clayey tan silk streaks and much Cretaceous-derived material	63.3	298
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	1.7	299.7

25-28-23cb1. *Drillers log of test hole in NW¼ SW¼ sec. 23, T. 25 S., R. 28 W., drilled by E. W. Henkle Co., 1953. Surface altitude, 2,748 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Topsoil	2	2
Subsoil	2	4
Clay, silty	31	35
Clay, limy	5	40
Clay, sandy	12	52
Clay, sandy, limy; cemented streaks	17	69
Mortar bed	6	75
Clay, sandy, limy	7	82
Sand, fine to medium	6	88
Sand, cemented	7	95
Sand, fine to medium	23	118
Clay, sandy, sand streaks	19	137

	Thickness, feet	Depth, feet
Sand, fine to medium, clay streaks	19	156
Clay, sandy, limy	8	164
Clay, cemented streaks	12	176
Mortar bed	1	177
Sand, fine	3	180
Mortar bed	6	186
Sand, fine to coarse, clay streaks	14	200
Clay	4	204
Sand, fine, clay streaks	15	219
Clay, sand streaks	8	227
Sand, fine to medium; clay streaks	13	240
Sand, fine to coarse, clay streaks	14	254
Clay	3	257
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale	1	258

25-28-24dd. *Sample log of test hole 25 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. SE¼ SE¼ sec. 24, T. 25 S., R. 28 W. Surface altitude, 2,728.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, gray	4.5	4.5
Silt, light tan	5.2	9.7
Silt, sandy, calcareous, light tan	20	29.7
Silt, very sandy, very calcareous near base, gray tan to pink tan; contains some sand streaks and some lime-cemented streaks	47.8	77.5
Sand, fine to coarse, and fine to medium gravel; contains some calcareous tan silt streaks near base and some lime-cemented streaks	42.2	119.7
Silt, very sandy, calcareous, pink tan to tan	17.8	137.5
Sand, fine to very coarse; contains some calcareous tan silt streaks	12.2	149.7
Silt, sandy, calcareous, pink tan to gray tan	40	189.7
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt and clay streaks and some Cretaceous-derived material	25	214.7
Silt, clayey, sandy, calcareous, tan	5	219.7
Sand, fine to coarse; contains some clayey tan silt streaks	15	234.7
Sand, fine to coarse, and fine gravel; contains some clayey tan silt and much Cretaceous-derived material	23	257.7
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	2	259.7

25-28-27dd. *Sample log of test hole 20 at SE cor. sec. 27, T. 25 S., R. 28 W., Gray County, drilled by State and Federal Geological Surveys, 1941. Surface altitude, 2,751.1 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, dark brown	2	2
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, tan to red brown; contains scattered sand and gravel	8	10
Silt and sand, fine, limy, light tan to red brown; contains caliche nodules	45.5	55.5
Silt and sand, fine, lime cemented, soft, white to light tan, and caliche	9.5	65
Sand, fine, red tan, gray, and yellow, and caliche	15	80
Sand, fine, to coarse gravel, loose; contains cemented zones	17.5	97.5
Sand, fine, limy, light tan	2.5	100
Silt and sand, fine, light tan; contains scattered coarse sand and gravel	10	110
Sand, fine to medium, tan; contains scattered gravel and caliche	10	120
Sand, fine, to fine gravel, silty	30	150
Silt, sand, and gravel, limy, tan	24	174
Sand, fine, pink tan	6	180
Sand, fine, limy, light tan; contains some coarse sand, fine gravel, and caliche	7	187
Silt and sand, fine, limy, white to light tan, and caliche	8	195
Sand, gravel, and caliche	25	220
Silt and sand, fine, tan	10	230
Sand, fine, to fine gravel, silty	40	270
Sand, fine, to medium gravel	15	285
Silt, sandy, light tan	5	290
Silt and sand, fine, clayey, tan to light brown	13	303
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, light to dark gray and dark brown; contains thin crystalline calcite veins	7	310

25-29-3cc. *Sample log of test hole 14 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. sec. 3, T. 25 S., R. 29 W. Surface altitude, 2,793.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, gray brown	1	1
Silt, sandy at base, calcareous, tan	8	9
Silt, sandy, very calcareous, light gray tan	22	31
Silt, sandy, very calcareous, pink gray to gray tan; contains some lime-cemented streaks	21.5	52.5

	Thickness, feet	Depth, feet
Sand, fine to coarse, and fine to medium gravel; contains some sandy gray-tan clay at 62.5 to 66 feet,	15.5	68
Silt, sandy, calcareous, light gray tan	2	70
Sand, fine to coarse, and fine gravel; contains some lime-cemented streaks	27	97
Silt, sandy, calcareous, clayey, pink tan	9	106
Sand, fine to coarse, and some fine gravel	45.5	151.5
Silt, very sandy, very calcareous, light pink gray	11.5	163
Sand, fine to medium; contains some calcareous pink-tan silt streaks	6.5	169.5
Silt, very sandy, calcareous, pink tan; contains some fine gravel	8	177.5
Sand, fine to coarse, and fine gravel; contains some calcareous gray-white clay	14.5	192
Silt, sandy, calcareous, gray green to tan; contains some clay	24	216
Sand, fine to coarse; contains some fine gravel near base and some calcareous gray-green clay streaks,	23.5	239.5
Clay, silty, calcareous, tan; contains some fine to coarse sand streaks	5	244.5
Sand, fine to coarse, and fine gravel; contains calcareous silty gray-tan clay streaks at 249.5 to 269.5 feet and much Cretaceous-derived material,	40.5	285
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	4.5	289.5

25-29-12cc. *Sample log of test hole 22 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. sec. 12, T. 25 S., R. 29 W. Surface altitude, 2,765.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, dark gray	1.3	1.3
Silt, calcareous, tan gray	6.7	8
Silt, very sandy, calcareous, gray tan	16.8	24.8
Silt, very sandy, very calcareous, gray tan to pink tan,	32.7	57.5
Sand, fine to coarse, and fine gravel; contains some tan silt	13.5	71
Silt, sandy, calcareous, gray tan	3.8	74.8
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks and some lime-cemented streaks	30	104.8
Silt, sandy, calcareous, light tan	5	109.8
Sand, fine to coarse; contains some fine gravel and some calcareous tan silt streaks	11.2	121
Silt, very sandy, calcareous, red tan	8.8	129.8
Sand, fine to coarse; contains much calcareous tan silt	5	134.8

	Thickness, feet	Depth, feet
Silt, very sandy, very calcareous, red tan to gray tan; contains tan clay streaks at 144.8 to 168 feet and sand streaks at 153 to 154.8 feet	33.2	168
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks	19	187
Silt, sandy, calcareous, light tan	6	193
Sand, fine; contains much calcareous tan silt	10	203
Silt, clayey, sandy, calcareous, light tan	5	208
Sand, fine to medium; contains some calcareous tan silt streaks	11.8	219.8
Silt, clayey, sandy, calcareous, light tan	6.7	226.5
Sand, fine to coarse; contains fine gravel at 254.8 to 272.5 feet, some clayey tan silt streaks, and much Cretaceous-derived material	46	272.5
Silt, sandy, calcareous, light gray tan	1.5	274
Sand, fine to coarse	3.5	277.5
Silt, very sandy, calcareous, light gray tan	2.3	279.8
Sand, fine to coarse, silty; contains some lime-cemented streaks	8.2	288
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	1.8	289.8

25-29-24cc. *Sample log of test hole 21 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. sec. 24, T. 25 S., R. 29 W. Surface altitude, 2,774.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, gray brown	1	1
Silt, sandy, very calcareous near base, light tan to gray tan	17	18
Silt, sandy, very calcareous, pink tan to gray tan; contains some sand streaks and some lime-cemented streaks	45	63
Sand, fine to coarse, and fine to medium gravel; contains some silty tan clay streaks at 85.1 to 103 feet	40	103
Silt, very sandy, calcareous, gray tan to tan	17.1	120.1
Sand, fine to coarse; contains fine gravel at 145 to 198 feet, some calcareous tan silt streaks, and some lime-cemented streaks	78	198.1
Silt, clayey, very sandy, calcareous, gray tan	12	210.1
Sand, fine to coarse; contains some silty tan clay streaks near top and some fine gravel	26.9	237
Silt, very clayey, sandy, calcareous, light gray tan to tan	18.1	255.1
Sand, fine to coarse; contains some silt	5	260.1
Silt, clayey, very sandy, very calcareous, gray tan; contains some lime-cemented streaks	15	275.1

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	2.5	277.6

25-29-27cc1. *Drillers log of test hole in SW cor. sec. 27, T. 25 S., R. 29 W., drilled by E. W. Henkle Co. Surface altitude, 2,675 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Soil and clay	10	10
Gravel	47	57
Clay, yellow	10	67
Clay, sandy, sand streaks	48	115
Sand, loose	3	118
Clay	12	130
Clay, sandy	10	140
Clay, sand streaks	8	148
Clay	5	153
Sand and gravel, loose	7	160
Clay, cemented sand streaks	4	164
Sand and gravel	6	170
Rock	3	173

25-29-28bd. *Sample log of test well in SE¼ NW¼ sec. 28, T. 25 S., R. 29 W., drilled July 1956 by Western Drilling Co. Surface altitude, 2,690.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Silt, sandy, gray	3	3
Sand, fine to coarse, and fine gravel	3	6
Silt, sandy, calcareous, light tan	5	11
Sand, fine to coarse, and fine to coarse gravel and cobbles; silt streak at 17 to 18 feet	23	34
TERTIARY—Pliocene		
Ogallala formation		
Clay, silty, sandy, slightly calcareous, tan	5	39
Sand, fine to coarse, and fine gravel; contains some silt and clay streaks; lower part partly cemented,	14	53
Sand, fine to coarse, and fine gravel, silty	9	62
Silt, sandy, calcareous, tan	10	72
Sand, fine to coarse, silty, partly lime cemented	8	80
Clay, sandy, silty, tan	5	85
Silt, sandy, very clayey, calcareous, tan; contains some sand streaks	16	101
Sand, fine to medium	1	102
Silt, very sandy, calcareous, tan; contains gray and tan clay	24	126
Sand, fine to coarse, and fine gravel; contains some tan silt	11	137
Silt, sandy, clayey, calcareous, tan	4	141
Sand, fine to coarse, and fine to medium gravel; contains some silt streaks	7	148
Silt, sandy, calcareous, light gray tan	9	157

	Thickness, feet	Depth, feet
Sand, fine to coarse, and fine to medium gravel; contains much Cretaceous-derived material	8	165
Silt, very sandy, calcareous, light tan	10	175
Sand, fine to coarse, and fine gravel, very silty; contains much Cretaceous-derived material	7	182
Clay, silty, calcareous, light tan	2	184
Sand, fine to coarse, and fine gravel, very silty, calcareous, lime cemented	3	187
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	3	190

25-29-28ca. *Drillers log of test well in NE¼ SW¼ sec. 28, T. 25 S., R. 29 W., 135 feet north of Arkansas River, drilled March 1956 by Gestenslager Drilling Company.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Silt, sandy, tan	4	4
Sand and gravel	23	27
Gravel and sand	2	29
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine to coarse, silty, cemented	6	35

25-29-34bc. *Sample log of test hole 15 drilled by U. S. Bureau of Reclamation March 1956, in SW¼ NW¼ sec. 34, T. 25 S., R. 29 W. Surface altitude, 2,679.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Sand, fine, silty, brown	1	1
Silt, sandy, calcareous, gray tan	3	4
Silt, clayey, black	2.5	6.5
Sand, fine to coarse, and fine to medium gravel	23.5	30
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, very sandy, calcareous, clayey in upper part, gray tan	9.1	39.1
Sand, fine to coarse, and fine to medium gravel; contains some silty tan calcareous clay streaks and some lime-cemented streaks	20	59.1
Clay, silty, sandy, gray to tan; contains some sand streaks	20	79.1
Sand, fine to coarse; contains some silty tan clay and some lime-cemented streaks	5	84.1
Clay, silty, sandy, gray to tan; contains some sand streaks	15	99.1
Silt, sandy, calcareous, light tan gray; contains some tan clay streaks	10	109.1

	Thickness, feet	Depth, feet
Clay, silty, sandy, calcareous, light tan	15	124.1
Silt, very clayey, sandy, calcareous, light tan	5.9	130
Sand, fine to coarse; contains some light-tan clayey silty streaks	14.1	144.1
Sand, fine to coarse; contains some fine gravel and some tan silt; contains cemented streaks near base and much Cretaceous-derived material	20	164.1
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	2.2	166.3

25-29-36dc. *Log of test hole augered by State Geological Survey, March 1956, in SW¼ SE¼ sec. 36, T. 25 S., R. 29 W., 1,800 feet north of Arkansas River. Surface altitude, 2,673.3 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Cinders, soil, road fill	2	2
Silt, clayey, brown	6	8
Silt, reddish brown; contains calcareous nodules	9	17
Sand and coarse gravel	3	20
Sandstone, well cemented	3	23

25-30-1aa. *Sample log of test hole 13 drilled by U. S. Bureau of Reclamation March 1956, in NE cor. sec. 1, T. 25 S., R. 30 W. Surface altitude, 2,832.2 feet.*

QUATERNARY AND TERTIARY Undifferentiated Pleistocene and Ogallala (Pliocene)	Thickness, feet	Depth, feet
Silt, sandy, gray brown	2	2
Silt, sandy, calcareous in lower part, tan	10	12
Silt, sandy, very calcareous, tan to pink and gray tan,	53	65
Sand, fine to coarse, and fine gravel; contains some lime-cemented streaks	9	74
Silt, sandy, calcareous, tan to pink and gray tan; contains some sand streaks	17	91
Sand, fine to coarse, and fine gravel, silty	5	96
Silt, very sandy, calcareous, light gray tan; contains some lime-cemented sand streaks	6	102
Sand, fine to very coarse; contains some fine gravel at base, some calcareous tan silt streaks, and some lime-cemented streaks	45.5	147.5
Silt, sandy, very calcareous, gray tan to pink tan	28.5	176
Sand, fine to coarse; contains some calcareous tan silt streaks and some lime-cemented streaks	18	194
Silt, sandy, calcareous, light gray tan	3	197
Sand, fine to coarse, and fine gravel	3	200
Silt, sandy, calcareous, gray tan	4	204
Sand, fine to coarse, and fine to medium gravel; contains some Cretaceous-derived material	7	211
Silt, sandy, calcareous, tan	1.5	212.5

	Thickness, feet	Depth, feet
Sand, fine to coarse at base; contains some calcareous tan silt streaks	36.5	249
Clay, silty, sandy, tan	2	251
Sand, fine to coarse, and fine gravel; contains some silty tan clay streaks near base and much Cretaceous-derived material	32.5	283.5
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	1.5	285

25-30-6cc. *Sample log of test hole 2 drilled by U. S. Bureau of Reclamation February 1956, in SW cor. sec. 6, T. 25 S., R. 30 W. Surface altitude, 2,853.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, light gray	2	2
Silt, sandy, calcareous, light tan	12.4	14.4
Sand, very fine to fine, silty	5	19.4
Silt, sandy, very calcareous, gray white	5	24.4
Silt, very sandy, calcareous, pink tan	5	29.4
Sand, fine to coarse; contains streaks of very calcareous pink-tan silt	10	39.4
Silt, very sandy, very calcareous in upper part, white to pink tan	15	54.4
Sand, fine to coarse; contains some silt and clay streaks and lime-cemented streaks	15	69.4
Sand, fine to coarse, and fine to medium gravel; contains streaks of calcareous tan silt and some cemented streaks near base	30	99.4
Sand, fine to coarse, and some fine gravel near base; contains some silt streaks	20	119.4
Silt, very sandy, calcareous, light tan; contains some sand streaks	10	129.4
Sand, fine to coarse; contains some fine to medium gravel at base and some calcareous tan silt and clay streaks	20	149.4
Silt, sandy, very calcareous, gray tan to tan; contains some tan clay streaks at 164.4 to 169.4 feet	35	184.4
Sand, fine to coarse; contains some fine gravel at base and some calcareous tan silt and clay streaks,	40	224.4
Silt, sandy, calcareous, tan; contains some tan clay streaks and thin streaks of sand and fine gravel	10	234.4
Sand, fine to medium; contains streaks of calcareous clayey tan silt	10	244.4
Silt, very sandy, clayey, calcareous, gray tan	5	249.4
Sand, fine to coarse; contains some fine gravel, some tan clayey silt streaks, and some Cretaceous-derived pebbles	15	264.4
Silt, very sandy, calcareous, gray tan	10	274.4

	Thickness, feet	Depth, feet
Sand, fine to coarse; contains some fine gravel, some tan sandy calcareous silt and clay streaks, some lime-cemented streaks, and some Cretaceous-derived pebbles	22.8	297.2
Clay, silty, calcareous, light gray tan	2.8	300
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	4	304

25-30-12dd. *Sample log of test hole 12 drilled by U. S. Bureau of Reclamation March 1956, in SE cor. sec. 12, T. 25 S., R. 30 W. Surface altitude, 2,825.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, gray brown	1.5	1.5
Silt, sandy, calcareous, light tan	13.6	15.1
Silt, sandy, very calcareous, pink tan to gray tan; contains some sand streaks	33	48.1
Sand, fine; contains much calcareous tan silt	10	58.1
Silt, very sandy, calcareous, tan gray	2	60.1
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks in lower half and some lime-cemented streaks	46	106.1
Silt, very sandy, calcareous, pink tan	4	110.1
Sand, fine to coarse; contains some fine gravel at 117 to 120 and at 142 to 145 feet, lime-cemented streaks near base, and some calcareous silt streaks,	52	162.1
Silt, very sandy, calcareous, tan gray	6	168.1
Sand, fine to medium; contains some calcareous tan silt streaks and some lime-cemented streaks	7	175.1
Silt, sandy, clayey, calcareous, tan gray; contains some lime-cemented streaks	5	180.1
Sand, fine to medium; contains some calcareous silt streaks	2	182.1
Silt, sandy, clayey, calcareous, gray tan to pink tan,	14	196.1
Sand, fine to medium; contains some calcareous silt	5	201.1
Silt, sandy, clayey in upper part, calcareous, gray tan	9	210.1
Sand, fine to coarse; contains some calcareous gray-tan silt streaks in upper part and some lime-cemented streaks	28	238.1
Clay, sandy, silty, gray green and tan	6	244.1
Sand, fine to coarse; contains some silty clay streaks,	10	254.1
Clay, sandy, silty, calcareous, gray green and tan; contains some sand streaks	26	280.1
Sand, fine to coarse, and fine gravel near base; contains some silty tan clay streaks, some lime-cemented streaks and much Cretaceous-derived material	15.4	295.5

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	4.6	300.1

25-30-21bd. *Sample log of test well in SE¼ NW¼ sec. 21, T. 25 S., R. 30 W., drilled July 1956, by Western Drilling Co. Surface altitude, 2,723 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Silt, sandy, gray	3	3
Silt, slightly calcareous, black	5	8
Sand, fine to coarse, and fine to very coarse gravel	30	38
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine to coarse, and gravel, lime cemented	1	39
Silt, sandy, calcareous, gray tan; partly cemented with lime near base	11	50
Sand, fine to coarse, and fine to medium gravel, silty; contains some lime-cemented streaks	10	60
Silt, sandy, calcareous, clayey, light tan to tan; contains some sand streaks	30	90
Sand, fine to coarse, and fine gravel; contains some silt streaks	10	100
Silt, sandy, calcareous, clayey, tan	20	120
Sand, fine to coarse, and much calcareous tan silt	15	135
Silt, sandy, calcareous, clayey, tan	15	150
Sand, fine to coarse, and fine gravel, very silty, lime-cemented	12	162
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	33	195

25-30-22ac. *Drillers log of irrigation well in SW¼ NE¼ sec. 22, T. 25 S., R. 30 W., drilled by E. W. Henkle Co., 1947. Surface altitude, 2,722.3 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Clay	8	8
Sand	10	18
Clay	2	20
Sand	18	38
Sand, cemented	2	40
Sand	9	49
Clay	11	60
Caliche	7	67
Sand, cemented	3	70
Sand	2	72
Caliche	11	83
Clay	25	108
Sand	10	118
Clay, sandy	57	175

25-30-22cb. *Drillers log of test hole for irrigation well in NW¼ SW¼ sec. 22, T. 25 S., R. 30 W., drilled by E. W. Henkle Co., 1947. Surface altitude, 2,724.7 feet.*

Quaternary and Tertiary—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Clay and sand	23	23
Sand	23	46
Clay	16	62
Rock	11	73
Sand	11	84
Clay	15	99
Sand, fine	22	121
Clay	29	150
Sand	5	155
Clay	24	179

25-30-24ca2. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 24, T. 25 S., R. 30 W., 4,100 feet north of Arkansas River. Surface altitude, 2,711.8 feet.*

Quaternary and Tertiary—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, black	1	1
Silt, sandy, tan	3	4
Sand, fine	2	6
Silt, sandy, tan	10	16
Sand, fine, gray; contains much silt	3	19
Gravel and sand	41	60
Silt and very fine sand, tan	2	62

25-30-24ca3. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 24, T. 25 S., R. 30 W., 3,400 feet north of Arkansas River. Surface altitude, 2,709.3 feet.*

Quaternary and Tertiary—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Sand, fine to coarse, silty; contains some limy nodules	4	4
Silt, sandy, tan	6	10
Sand, fine to coarse, tan	9	19
Gravel and sand	39	58
Silt and very fine sand, tan	1	59

25-30-24cd1. *Log of test hole augered by State Geological Survey March 1956, in SE¼ SW¼ sec. 24, T. 25 S., R. 30 W., 2,900 feet north of Arkansas River. Surface altitude, 2,703.5 feet.*

Quaternary and Tertiary—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Sand, fine; contains some black silt	1	1
Sand, fine, tan	3	4
Silt, tan	1	5
Sand, fine to coarse, yellow	1	6
Sand, fine to coarse, reddish brown	1	7
Gravel and sand	41	48
Silt, tan	1	49

25-30-24cd2. *Log of test hole augered by State Geological Survey March 1956, in SE¼ SW¼ sec. 24, T. 25 S., R. 30 W., 2,500 feet north of Arkansas River. Surface altitude, 2,699.4 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	2	2
Sand, fine, tan	1	3
Silt, gray	2	5
Sand, yellow	1	6
Sand and gravel, silty, gray	9	15
Gravel and sand, tan	42	57
Silt, tan	2	59

25-30-25ba1. *Log of test hole augered by State Geological Survey March 1956, in NE¼ NW¼ sec. 25, T. 25 S., R. 30 W., 1,900 feet north of Arkansas River. Surface altitude, 2,699.5 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	4	4
Sand and gravel, tan	15	19
Gravel, fine to medium	26	45
Sand, cemented	3	48
Silt, tan	6	54

25-30-25ba2. *Sample log of test hole 21 at NE cor. NW¼ sec. 25, T. 25 S., R. 30 W., Gray County, drilled by State and Federal Geological Surveys, 1941. Surface altitude, 2,698.2 feet.*

	Thickness, feet	Depth, feet
Soil, brown	1	1
QUATERNARY—Pleistocene		
Recent—Alluvium		
Sand, fine, silty, tan	1	2
Sand, coarse, to very coarse gravel	41	43
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt and sand, fine yellow tan; contains caliche and lime-cemented nodules	19	62
Sand, fine, hard, cemented	2.5	64.5
Silt and sand, fine, clayey, yellow tan; contains caliche and "mortar bed" fragments in upper part	18.5	83
Sand, fine, to fine gravel; contains some yellow-tan silty and sandy clay	27	110
Silt, fine sandy, yellow tan, and blocky, silty clay; contains scattered sand and gravel	20	130
Sand, fine, to coarse gravel; contains thin lenses of sandy silt	30	160
Sand, fine, silty, tan and gray, and sand and gravel containing pebbles of limestone and yellow shale,	9	169

CRETACEOUS—Gulfian	Thickness, feet	Depth, feet
Carlile shale		
Fairport shale member		
Shale, silty and fine sandy, calcareous, dark gray,	26	195
Shale, silty and fine sandy, light and medium gray, and shale, sandy, hard, dark gray	1.5	196.5
Shale, silty and fine sandy, calcareous, dark gray,	3.5	200
Shale, silty and sandy, calcareous, light to dark gray; contains thin bed of blue-gray bentonite and calcite	10	210
Shale, sandy, hard, calcareous, dark gray	10	220

25-30-25ba3. *Log of test hole augered by State Geological Survey March 1956, in NE¼ NW¼ sec. 25, T. 25 S., R. 30 W., 1,500 feet north of Arkansas River. Surface altitude, 2,699.8 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	2	2
Silt, black	3	5
Sand, fine, yellow	2	7
Sand and gravel	44	51
Silt, tan	2	53

25-30-25bd1. *Log of test hole augered by State Geological Survey February 1956, in SE¼ NW¼ sec. 25, T. 25 S., R. 30 W., 500 feet north of Arkansas River. Surface altitude, 2,701.5 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	4	4
Sand, fine to coarse	15	19
Gravel and sand	19	38
Silt (determined from action of the auger)	3	41
Sand and gravel (no sample)		

25-30-25bd2. *Log of test hole augered by State Geological Survey March 1956, in SE¼ NW¼ sec. 25, T. 25 S., R. 30 W., 400 feet south of Arkansas River. Surface altitude, 2,700.8 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	2	2
Sand, silty, gray	2	4
Sand and gravel	5	9
Gravel and sand	42	51
Silt, tan	2	53

25-30-25ca1. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 25, T. 25 S., R. 30 W., 900 feet south of Arkansas River. Surface altitude, 2,701.3 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	2	2
Silt, black, waxy	3	5
Sand, fine, yellow	3	8
Sand and gravel	37	45

	Thickness, feet	Depth, feet
Sand, fine to coarse, silty	7	52
Silt, tan	3	55

25-30-25ca2. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 25, T. 25 S., R. 30 W., 1,400 feet south of Arkansas River. Surface altitude, 2,701.6 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	3	3
Sand, fine, silty	4	7
Clay, green	3	10
Sand, fine to coarse, greenish	8	18
Sand and gravel, silty, gray	6	24
Sand and gravel	29	53
Silt, tan	2	55

25-30-25cd. *Log of test hole augered by State Geological Survey March 1956, in SE¼ SW¼ sec. 25, T. 25 S., R. 30 W., 1,900 feet south of Arkansas River. Surface altitude, 2,701.7 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	2	2
Sand, very fine	1	3
Silt, black, waxy	1	4
Clay, green	3	7
Clay, blue green	5	12
Sand and gravel, silty, tan	28	40
Sand, fine to coarse, very silty, gray	30	70

25-30-25da1. *Drillers log of test well in NE¼ SE¼ sec. 25, T. 25 S., R. 30 W., 75 feet south of Arkansas River, drilled March 1956 by Gestenslager Drilling Co.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Silt, sandy, tan	4	4
Sand and gravel, very coarse	38	42
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine to coarse, cemented	2	44

25-30-25da2. *Sample log of test hole 31 drilled by U. S. Bureau of Reclamation March 1956, in NW cor. NE¼ SE¼ sec. 25, T. 25 S., R. 30 W. Surface altitude, 2,697.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Sand, fine, very silty, gray	4.5	4.5
Sand, fine to coarse, and fine to coarse gravel	35.5	40
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine to coarse, and fine to medium gravel; contains some silt and some lime-cemented streaks	16	56

	Thickness, feet	Depth, feet
Silt, sandy, very calcareous, light gray to gray tan; contains some sand and gravel streaks	28.3	84.3
Sand, fine to coarse, and fine gravel; contains some calcareous silty tan clay streaks	10	94.3
Silt, clayey, very sandy, calcareous, tan; contains some sand streaks	15	109.3
Sand, fine to coarse; contains some calcareous tan silt streaks	10	119.3
Silt, clayey, very sandy, calcareous, light gray tan	10	129.3
Sand, fine to coarse; contains many calcareous tan silt streaks	5	134.3
Silt, clayey, sandy, calcareous, gray tan; contains some sand and gravel streaks	5	139.3
Sand, fine to coarse, and fine gravel; contains some silty tan clay streaks and much Cretaceous-derived material	25	164.3
Silt, sandy, calcareous, light tan; contains some sand and gravel streaks	5	169.3
Sand, fine to coarse, and fine gravel; contains some tan silt streaks and much Cretaceous-derived material	12.7	182
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	4.8	186.8

25-30-29aa. *Sample log of test hole 5 drilled by U. S. Bureau of Reclamation February 1956, in NE cor. sec. 29, T. 25 S., R. 30 W. Surface altitude, 2,722.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Sand, fine to medium, very silty, gray	2	2
Sand, fine to coarse	8	10
Sand, fine to coarse, and fine to coarse gravel	12.5	22.5
Silt, very sandy, calcareous, clayey, light tan	8.5	31
Sand, fine to coarse, and fine to medium gravel	1.5	32.5
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, calcareous, gray tan	4.5	37
Sand, fine to coarse, and fine gravel; contains some silt streaks	13	50
Sand, fine to coarse; contains streaks of gray-tan to tan calcareous silt at top and at base	32	82
Silt, very sandy, calcareous, pink tan to gray tan at base; contains some sand streaks and some lime-cemented streaks	33	115
Sand, fine to coarse, and some fine gravel	6	121
Silt, very sandy, calcareous, gray tan	9	130
Sand, fine to coarse; contains some tan silt streaks and some clay near base	20	150

	Thickness, feet	Depth, feet
Silt, very sandy, calcareous, gray tan; contains some tan clay streaks near base	30	180
Sand, fine to coarse, and some fine gravel; contains calcareous tan silt streaks at top, tan clay streaks near base, and some Cretaceous-derived pebbles,	10	190
Sand, fine to coarse, and fine to medium gravel; contains much Cretaceous-derived material	11	201
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	9	210

25-30-36ba. *Log of test hole augered by State Geological Survey March 1956, in NE¼ NW¼ sec. 36, T. 25 S., R. 30 W., 2,700 feet south of Arkansas River in sand dunes.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Sand, fine to coarse, gray	3	3
Sand, fine, yellow	2	5
Sand, fine to coarse; contains much coarse gravel	8	13
Sand and gravel; contains some silt	6	19
Silt, sandy, tan	16	35

25-30-36dc. *Sample log of test hole 11 drilled by U. S. Bureau of Reclamation March 1956, in SE cor. SW¼ SE¼ sec. 36, T. 25 S., R. 30 W. Surface altitude, 2,735.2 feet.*

QUATERNARY AND TERTIARY	Thickness, feet	Depth, feet
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine to medium, very silty, brown	7	7
Silt, sandy, calcareous, light gray	2.3	9.3
Silt, sandy, tan	5	14.3
Silt, sandy, calcareous, gray tan	5	19.3
Sand, fine to coarse, and fine to medium gravel	16.2	35.5
Silt, sandy, calcareous, pink tan to gray tan at base,	23.8	59.3
Sand, fine to coarse, and fine gravel, silty	5	64.3
Silt, sandy, calcareous, light gray tan	7.7	72
Sand, fine to coarse; contains some fine gravel, some calcareous tan silt streaks, and some lime-cemented streaks	13	85
Silt, sandy, calcareous, gray tan	4.3	89.3
Sand, fine to coarse; contains some fine gravel at base, some sandy tan silt, and some lime-cemented streaks	10	99.3
Silt, sandy, clayey, gray tan; contains some sand streaks	7.7	107
Clay, silty, calcareous, gray and tan	7.3	114.3
Sand, fine to coarse; contains many calcareous silty tan clay streaks	37	151.3
Clay, silty, calcareous, gray tan	3	154.3

	Thickness, feet	Depth, feet
Sand, fine to coarse; contains some fine to medium gravel, many calcareous tan silt streaks, and much Cretaceous-derived material	53.7	208
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	1.3	209.3

25-31-11cc. *Drillers log of test hole for irrigation well in SW cor. sec. 11, T. 25 S., R. 31 W. Drilled by E. W. Henkle Co., 1948. Surface altitude, 2,765.3 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Soil	5	5
Clay, yellow, some gravel	9	14
Gravel, medium to coarse, loose	28	42
Clay, yellow	2	44
Gravel, medium to coarse	9	53
Clay, sandy, yellow, some caliche and gravel	23	76
Clay, yellow	9	85
Sand, fine	11	96
Clay, yellow, tight	15	111
Sand, fine, silty	26	137
Clay, sandy, yellow	22	159
Gravel, fine	18	177
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, blue	4	181

25-31-13ba. *Log of test hole augered by State Geological Survey March 1956, in NE¼ NW¼ sec. 13, T. 25 S., R. 31 W., 4,200 feet north of Arkansas River. Surface altitude, 2,762.0 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, yellowish gray	6	6
Silt, light gray, tough, very calcareous	4	10
Clay, greenish to yellowish gray, compact	3	13
Sand, fine to medium, silty	2	15
Sand, fine to medium; contains black clay layers	3	18
Sand, fine to coarse	13	31
Clay	1	32
Sand, coarse, silty, clayey	6	38
Sand, coarse, silty; contains cemented zones	30	68

25-31-13bd. *Log of test hole augered by State Geological Survey March 1956, in SE¼ NW¼ sec. 13, T. 25 S., R. 31 W., 3,000 feet north of Arkansas River. Surface altitude, 2,755.4 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, yellow; contains gray-white caliche nodules	12	12
Sand, coarse; contains some fine gravel	7	19
Sand, coarse; contains some silt and fine sand	4	23
Gravel, fine, and coarse sand	46	69

25-31-13ca3. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 13, T. 25 S., R. 31 W., 1,100 feet north of Arkansas River. Surface altitude, 2,744.2 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, road fill	3	3
Gravel, fine to medium, and coarse sand	44	47
Gravel and sand; contains clay zones	1	48
Gravel	7	55
Clay, sandy, silty	3	58

25-31-13ca4. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 13, T. 25 S., R. 31 W., 2,000 feet north of Arkansas River. Surface altitude, 2,744.2 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Sand, medium, brown, well sorted	3	3
Sand, coarse; contains some fine gravel	5	8
Gravel, fine to medium; contains coarse sand	45	53
Gravel, fine to medium; contains some cemented zones	5	58

25-31-13cc. *Log of test hole augered by State Geological Survey March 1956, in SW¼ SW¼ sec. 13, T. 25 S., R. 31 W., 500 feet north of Arkansas River. Surface altitude, 2,742.6 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Soil	1	1
Sand, silty, brown	3	4
Sand and gravel, silty	5	9
Sand and gravel	30	39
Clay (determined from action of drill)	1	40

25-31-22bb. *Sample log of test hole 3 drilled by U. S. Bureau of Reclamation February 1956, in NW cor. sec. 22, T. 25 S., R. 31 W. Surface altitude, 2,783.7 feet.*

QUATERNARY—PLEISTOCENE	Thickness, feet	Depth, feet
Terrace deposits		
Sand, fine to coarse, silty	5	5
Sand, fine to coarse, and fine gravel, coarse at base,	20.5	25.5
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, calcareous, pink tan to gray tan; contains some lime-cemented streaks	9	34.5
Sand, fine to medium; contains some gray-tan calcareous silt streaks	5	39.5
Silt, sandy, calcareous, gray tan to tan; contains some sand streaks	20	59.5
Sand, fine to coarse; contains some streaks of silty tan clay	5	64.5

	Thickness, feet	Depth, feet
Sand, fine to coarse, and fine to medium gravel; contains some calcareous tan silt streaks at 79.5 to 96.5 feet	32	96.5
Silt, sandy, calcareous, gray tan	1.5	98
Sand, fine to coarse; contains streaks of calcareous gray-tan to tan silt and clay	31.5	129.5
Silt, very sandy, tan gray to tan; contains some tan clay at base	10	139.5
Sand, fine to coarse, and fine gravel; some tan silt and clay streaks and many Cretaceous-derived pebbles	30	169.5
Silt, sandy, calcareous, pink tan; contains some sand streaks	11.5	181
Silt, sandy, very calcareous, tan gray; contains many clay streaks	19	200
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	4.5	204.5

25-31-24bb1. *Log of test hole augered by State Geological Survey March 1956, in NW¼ NW¼ sec. 24, T. 25 S., R. 31 W., 300 feet south of Arkansas River. Surface altitude, 2,745.8 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, road fill	3	3
Sand, coarse	5	8
Sand, coarse; contains some medium gravel	20	28
Gravel, fine, sandy; contains some medium and coarse gravel	8	36
Gravel; contains hard zones	2	38
Gravel, fine to medium	7	45
Siltstone, clayey, calcareous, tough	3	48

25-31-24bb2. *Log of test hole augered by State Geological Survey March 1956, in NW¼ NW¼ sec. 24, T. 25 S., R. 31 W., 600 feet south of Arkansas River. Surface altitude, 2,743.7 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, road fill	2	2
Sand, medium to coarse, and fine gravel	6	8
Gravel, fine, and coarse sand	18	26
Clay, sandy, reddish brown	1	27

25-31-24bb3. *Log of test hole augered by State Geological Survey March 1956, in NW¼ NW¼ sec. 24, T. 25 S., R. 31 W., 750 feet south of Arkansas River. Surface altitude, 2,743.3 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Sand	3	3
Sand, coarse, and fine gravel	5	8
Gravel, fine to medium, sandy	34	42
Clay, sandy, calcareous, light gray to white	1	43

25-31-24bc1. *Log of test hole augered by State Geological Survey March 1956, in SW¼ NW¼ sec. 24, T. 25 S., R. 31 W., 1,100 feet south of Arkansas River. Surface altitude, 2,745.1 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Soil, road fill	2	2
Sand, fine to medium, clayey	2	4
Sand, medium to coarse; contains much fine to medium gravel	14	18
Cemented zone (determined from action of drill)	1	19
Gravel, medium to coarse, sandy	4	23
Sand and gravel, cemented	30	53
Gravel and sand; contains thin cemented zones	15	68

25-31-24bc2. *Log of test hole augered by State Geological Survey March 1956, in SW¼ NW¼ sec. 24, T. 25 S., R. 31 W., 1,400 feet south of Arkansas River. Surface altitude, 2,746.5 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	3	3
Silt, clayey, and fine sand	5	8
Sand, coarse; contains some fine gravel	5	13
Gravel, fine to medium; contains some sand	24	37
Hard zone (no samples)	1	38
Sand, fine to coarse, and fine gravel	13	51
Gravel, medium to fine	2	53
Gravel, medium to fine; contains tough streaks	15	68

25-31-24dd. *Sample log of test hole 4 drilled by U. S. Bureau of Reclamation February 1956, in NE cor. SE¼ SE¼ sec. 24, T. 25 S., R. 31 W. Surface altitude, 2,748.3 feet.*

QUATERNARY—Pleistocene	Thickness, feet	Depth, feet
Terrace deposits		
Sand, fine to coarse, silty	2	2
Silt, sandy, calcareous, gray	2.4	4.4
Sand, fine to coarse, and fine to coarse gravel; contains many cobbles of caliche	17.2	21.6
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, calcareous, light tan	2	23.6
Sand, fine to coarse; contains some fine gravel, a streak of calcareous tan silt, and some lime-cemented streaks	31.4	55
Silt, sandy, calcareous, gray tan to tan	9	64
Sand, fine to coarse; contains some calcareous tan silt streaks and some lime-cemented streaks	5	69
Silt, very sandy, calcareous, pink tan; contains some lime-cemented streaks	15	84
Sand, fine to coarse; contains fine gravel in upper part and some calcareous tan silt streaks	25	109
Silt, very sandy, very calcareous, gray tan to tan; contains some lime-cemented streaks	20	129

	Thickness, feet	Depth, feet
Sand, fine to coarse; contains some fine gravel, some calcareous tan silt streaks, and some lime-cemented streaks	15	144
Silt, very sandy, calcareous, light tan; contains some sand streaks and some tan clay streaks near base,	30	174
Sand, fine to coarse, silty	5	179
Silt, very sandy, calcareous, tan; contains some clay streaks at 189 feet	20	199
Sand, fine to coarse; contains some fine gravel at base, some calcareous tan silt streaks, and many Cretaceous-derived pebbles	15	214
Silt, sandy, calcareous, tan; contains some Cretaceous-derived pebbles	10	224
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	5	229

26-27-8bc. *Sample log of test hole 27 drilled by U. S. Bureau of Reclamation March 1956, in NW cor. SW¼ NW¼ sec. 8, T. 26 S., R. 27 W. Surface altitude, 2,594.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Silt, very sandy, gray brown	2.5	2.5
Silt, sandy, calcareous, gray	2.5	5
Sand, fine to coarse, and fine to coarse gravel	30.3	35.3
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, very sandy, calcareous, pink tan to gray tan; contains some clay streaks at 59.1 to 69.1 feet and some sand streaks	38.8	74.1
Sand, fine to coarse; contains some clayey tan silt streaks	11.9	86
Silt, very clayey, sandy, calcareous, gray tan to tan,	30	116
Clay, silty, sandy, calcareous, gray tan; contains some sand streaks	8.1	124.1
Sand, fine to coarse; contains some silty tan clay streaks	15	139.1
Sand, fine to coarse, and fine gravel; contains some tan silt near base and much Cretaceous-derived material	37.9	177
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	2.1	179.1

26-28-1bb. *Sample log of test hole 26 drilled by U. S. Bureau of Reclamation March 1956, in NW cor. sec. 1, T. 26 S., 28 W. Surface altitude, 2,742.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, gray brown	1	1
Silt, calcareous, tan gray	4	5

	Thickness, feet	Depth, feet
Silt, sandy, calcareous, gray tan to tan	20.6	25.6
Silt, sandy, calcareous, pink tan to gray tan	34	59.6
Sand, fine, silty	3	62.6
Silt, very sandy, very calcareous, light gray to pink tan; contains some sand streaks and some lime-cemented streaks	24.9	87.5
Sand, fine to coarse, and fine to coarse gravel; contains some lime-cemented streaks	5.5	93
Silt, sandy, calcareous, light tan; contains some lime-cemented streaks	3.5	96.5
Sand, fine to coarse, and fine gravel, silty; contains some lime-cemented streaks	6.5	103
Silt, sandy, calcareous, pink tan to gray tan; contains some sand streaks	21.6	124.6
Sand, fine to coarse, silty; contains some lime-cemented streaks	11.4	136
Silt, sandy, calcareous, red tan; contains some sand streaks	8.6	144.6
Sand, fine to coarse; contains some calcareous tan silt streaks	30	174.6
Silt, sandy, very calcareous, light tan gray; contains some lime-cemented streaks	15	189.6
Sand, fine to medium; contains many calcareous tan silt streaks	27.4	217
Silt, clayey, sandy, calcareous, tan	2	219
Sand, fine to medium; contains some calcareous tan silt streaks	12	231
Silt, clayey, very sandy, calcareous, tan	13.6	244.6
Clay, silty, calcareous, tan; contains some sand streaks	5	249.6
Sand, fine to coarse; contains some clayey tan silt streaks	10	259.6
Silt, clayey, calcareous, green tan; contains some sand streaks	5	264.6
Sand, fine to coarse; contains some silty gray-tan clay streaks and some lime-cemented streaks	15	279.6
Sand, fine to coarse, and fine gravel; contains some tan silt and some Cretaceous-derived material	15	294.6
"Mortar bed", lime-cemented silt and sand, light tan	12.4	307
Silt, clayey, sandy, calcareous, light gray tan; contains some lime-cemented streaks	7.6	314.6
Sand, fine to coarse, and fine gravel; contains some silty tan clay streaks and much Cretaceous-derived material	10	324.6
Clay, silty, sandy, light brown	3	327.6
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	2	329.6

26-28-5bb. *Sample log of test hole 24 drilled by U. S. Bureau of Reclamation March 1956, in NE cor. NW¼ NW¼ sec. 5, T. 26 S., R. 28 W. Surface altitude, 2,764.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, gray brown	1.3	1.3
Silt, sandy, calcareous, tan	8.5	9.8
Silt, very sandy, very calcareous, pink tan to gray tan	28.2	38
Sand, fine, very silty, calcareous, brown	5.5	43.5
Silt, very sandy, very calcareous, pink tan to gray tan	24.5	68
Sand, fine to coarse, and fine to medium gravel; contains some tan silt	9	77
Silt, very sandy, calcareous, light tan	16	93
Sand, fine to coarse, and fine gravel	3	96
Silt, very sandy, calcareous, pink tan	11	107
Sand, fine to coarse, silty; contains some lime-cemented streaks	14	121
Silt, sandy, calcareous, light gray tan	7	128
Sand, fine to coarse	5	133
Silt, very clayey, sandy, calcareous, gray tan	6.8	139.8
Sand, fine to coarse	26.7	166.5
Silt, sandy, very calcareous, gray white	8.3	174.8
Sand, very fine to fine, very silty; contains some lime-cemented streaks	20	194.8
Silt, very clayey, sandy, calcareous, light gray tan	17.7	212.5
Sand, fine to coarse; contains some tan silt and clay,	27.3	239.8
Clay, silty, sandy, calcareous, gray tan	2.2	242
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	7.8	249.8

26-28-10cc. *Sample log of test hole 22 at SW cor. sec. 10, T. 26 S., R. 28 W., Gray County, drilled by State and Federal Geological Surveys, 1941. Surface altitude, 2,621.8 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, dark	0.5	0.5
QUATERNARY—Pleistocene		
Recent—Alluvium		
Sand, fine to medium, limy, gray	4.5	5
Gravel, medium to very coarse; contains pebbles as much as an inch in diameter	35	40
Sand, fine, to coarse gravel, brown	19.5	59.5
TERTIARY—Pliocene		
Ogallala formation		
Silt and sand, fine, lime cemented, gray	3.5	63
Sand and gravel, limy, gray	4	67
Sand, fine to coarse, silty, tan and light gray	33	100

	Thickness, feet	Depth, feet
Silt and sand, fine, limy, tan	10	110
Sand, fine, to fine gravel, silty	20	130
Sand, coarse, to coarse gravel; contains granules and pebbles of limestone and sandstone	26	156
CRETACEOUS—Gulfian		
Carlile shale (?)		
Clay, silty, calcareous, yellow tan	7.5	163.5
Shale, dark gray to black; contains a few hard calcite veins	4.5	168
Shale, hard, light gray to white, and shale, calcareous, black	32	200
Shale, calcareous, light to dark gray and black; contains thin bed of light-blue bentonite	10	210

26-28-11ca2. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 11, T. 26 S., R. 28 W., 1,200 feet north of Arkansas River. Surface altitude, 2,612 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Soil, road fill	4	4
Sand, medium, brown	2	6
Sand, fine to coarse; contains some gravel	18	24
Gravel, fine to coarse, silty and sandy	13	37
Sand and gravel, silty and clayey, light pinkish gray,	8	45
Sand, clay, and silt, tough	8	53

26-28-11dc. *Log of test hole augered by State Geological Survey March 1956, in SW¼ SE¼ sec. 11, T. 26 S., R. 28 W., 300 feet north of Arkansas River. Surface altitude, 2,609.8 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, yellowish gray	4	4
Sand, coarse, and fine to medium gravel	15	19
Gravel, medium to coarse, sandy, clean	26	45
Cemented layers (determined from action of drill),	2	47

26-28-12cc. *Sample log of test hole 28 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. sec. 12, T. 26 S., R. 28 W. Surface altitude, 2,605.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Silt, very sandy, dark gray	3	3
Sand, fine to coarse, and fine to coarse gravel	33.5	36.5
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, sandy, calcareous, pink tan to gray tan; contains some lime-cemented streaks	32.5	69
Sand, fine to coarse; contains some tan clay streaks near base and some calcareous tan silt streaks	50	119

	Thickness, feet	Depth, feet
Silt, clayey, sandy, calcareous, gray tan; contains some sand streaks and some lime-cemented streaks	10	129
Sand, fine to coarse, very silty	5	134
Silt, clayey, sandy, very calcareous, light tan gray; contains some lime-cemented streaks	14.3	148.3
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	0.7	149

26-28-14ba. *Log of test hole augered by State Geological Survey March 1956, in NE¼ NW¼ sec. 14, T. 26 S., R. 28 W., 600 feet south of Arkansas River. Surface altitude, 2,610.3 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, road fill	4	4
Sand, medium to coarse, and brown clay	2	6
Gravel, medium to coarse, sandy	48	54
Sand, medium, silty; contains some gravel	7	61
Clay and silt, sandy, pinkish gray	2	63

26-28-14bd1. *Log of test hole augered by State Geological Survey March 1956, in SE¼ NW¼ sec. 14, T. 26 S., R. 28 W., 1,800 feet south of Arkansas River. Surface altitude, 2,609.8 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, road fill	2	2
Sand, medium to coarse; contains much gravel	11	13
Gravel, fine to medium, sandy	11	24
Sand, medium to coarse, silty, clayey	12	36
Sand, cemented	15	51
Sandstone; contains hard and soft layers	10	61

26-28-14bd2. *Log of test hole augered by State Geological Survey March 1956, in SE¼ NW¼ sec. 14, T. 26 S., R. 28 W., 3,000 feet south of Arkansas River. Surface altitude, 2,609.8 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, road fill, black	4	4
Clay, plastic, yellow	1	5
Gravel, medium to coarse, sandy	45	50
Sandstone; contains cemented layers	6	56
Sandstone, clayey, tough, pinkish gray	1	57

26-28-14ca. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 14, T. 26 S., R. 28 W., 4,300 feet south of Arkansas River. Surface altitude, 2,616.9 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Soil	3	3
Sand, fine to medium	22	25
Sandstone, clayey, tough, cemented	1	26

26-28-24cc. *Sample log of test hole 29 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. sec. 24, T. 26 S., R. 28 W. Surface altitude, 2,648.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine to medium, silty	4	4
Silt, sandy, gray brown	1.5	5.5
Silt, calcareous, light gray tan	5	10.5
Silt, very sandy, calcareous, gray tan	13.8	24.3
Sand, fine to coarse, and fine to coarse gravel; contains a few calcareous tan silt streaks	100	124.3
Silt, very clayey, sandy, calcareous in lower part, tan to gray tan; contains some sand streaks	35	159.3
Sand, fine to coarse, very silty	2.7	162
Silt, sandy, very calcareous, light tan gray; contains some clay streaks and some lime-cemented streaks	9.5	171.5
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	6.8	178.3

26-28-29bb. *Sample log of test hole 17 drilled by U. S. Bureau of Reclamation March 1956, in NW cor. sec. 29, T. 26 S., R. 28 W. Surface altitude, 2,699.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, very silty, brown	1.5	1.5
Silt, sandy, gray brown	2.9	4.4
Silt, sandy, calcareous, light gray tan	3.6	8
Sand, fine to medium	24.5	32.5
Silt, sandy, very calcareous, light gray to tan; contains some sand streaks	11.9	44.4
Sand, fine to coarse, and fine to coarse gravel; contains some calcareous tan silt streaks	135	179.4
Silt, sandy, calcareous, pink tan	17.1	196.5
Silt, sandy, calcareous, light gray to tan; contains some tan clay stıeaks	7.9	204.4
Sand, fine to coarse, and fine gravel; contains some calcareous silt and much Cretaceous-derived material	11.1	215.5
Silt, sandy, calcareous, pink tan to gray tan; contains some lime-cemented streaks near base, and some sand streaks	16.5	232
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	3	235

26-28-34bb. *Sample log of test hole 23 at NW cor. sec. 34, T. 26 S., R. 28 W., Gray County, drilled by State and Federal Geological Surveys, 1941. Surface altitude, 2,671.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Dune sand		
Soil, sandy, dark	3	3
Sand, fine, silty, brown	7	10
Terrace gravels		
Sand, medium, to fine gravel, brown; contains snails and shell fragments	10	20
Silt to coarse sand, tan	4	24
Sand, medium, to medium gravel, brown	6	30
Sand, coarse, to very coarse gravel, poorly sorted	48	78
TERTIARY—Pliocene		
Ogallala formation		
Silt and sand, fine, limy, light gray	3	81
Sand, coarse, to very coarse gravel	22	103
Gravel, fine to very coarse, brown	37	140
Silt and sand, fine, tan to buff; contains some gravel	43	183
Gravel, fine to coarse, brown	17	200
Silt and sand, fine to coarse, tan	10	210
Silt and sand, limy, light gray	5	215
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, black	5	220

26-28-36cc. *Sample log of test hole 30 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. sec. 36, T. 26 S., R. 28 W. Surface altitude, 2,687.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, silty, light brown	4	4
Silt, calcareous, light tan	10.3	14.3
Silt, very sandy, tan	15	29.3
Sand, fine to coarse; contains some tan silt	15	44.3
Silt, very sandy, light tan to tan gray, very calcareous at base	21.7	66
Sand, fine to coarse, and fine to coarse gravel; contains some calcareous tan and black silt	23.3	89.3
Silt, sandy, very calcareous, light tan gray to pink tan	35	124.3
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks	12.7	137
Silt, clayey, sandy, calcareous, tan gray; contains some lime-cemented streaks	12.3	149.3
Sand, fine to coarse; contains some calcareous gray silt streaks	5	154.3
Clay, silty, sandy, calcareous, gray tan	5	159.3

	Thickness, feet	Depth, feet
Silt, clayey, sandy, calcareous, gray tan; contains some lime-cemented streaks	10	169.3
Sand, fine to very coarse; contains some silt	15	184.3
Silt, sandy, calcareous, pink tan; contains some sand streaks	15	199.3
Sand, fine to coarse; contains some calcareous tan silt streaks	5	204.3
Silt, sandy, calcareous, light tan; contains some fine sand streaks	7.7	212
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks, much Cretaceous-derived material, and some lime-cemented streaks	65.5	277.5
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	1.8	279.3

26-29-2aa1. *Log of test hole augered by State Geological Survey March 1956, in NE¼ NE¼ sec. 2, T. 26 S., R. 29 W., 1,300 feet north of Arkansas River. Surface altitude, 2,661.6 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Soil, silty	1	1
Clay, silty, reddish brown	9	10
Sand, medium to coarse	7	17
Gravel, fine to coarse, sandy, pinkish gray	33	50
Sand, fine to medium; contains hard and soft layers,	9	59
Sand and gravel	9	68

26-29-2aa2. *Log of test hole augered by State Geological Survey March 1956, in NE¼ NE¼ sec. 2, T. 26 S., R. 29 W., 500 feet north of Arkansas River. Surface altitude, 2,655.5 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, yellowish gray	4	4
Sand, fine to medium	14	18
Gravel, medium to coarse, sandy	44	62
Cemented layers; drills slowly, no samples	4	66
Clay, silty, yellow; contains some fine sand	2	68

26-29-2ac. *Log of test hole augered by State Geological Survey March 1956, in SW¼ NE¼ sec. 2, T. 26 S., R. 29 W., 500 feet south of Arkansas River. Surface altitude, 2,656.3 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, road fill	3	3
Sand, fine to medium	5	8
Gravel, medium to coarse; contains much sand	57	65
Clay, yellowish gray	3	68

26-29-2bb. *Sample log of test hole 20 drilled by U. S. Bureau of Reclamation March 1956, in NE cor. NW¼ NW¼ sec. 2, T. 26 S., R. 29 W. Surface altitude, 2,655.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent—Alluvium		
Sand, fine, very silty, brown	1.5	1.5
Silt, sandy, clayey, calcareous, dark gray	1.5	3
Sand, fine to coarse, and fine to coarse gravel	30	33
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Silt, clayey, sandy, tan; contains some lime-cemented streaks	6.5	39.5
Sand, fine to coarse, and fine to medium gravel; contains some tan silt and clay streaks and some lime-cemented streaks	34.7	74.2
Silt, sandy, clayey, calcareous, gray tan; contains some sand streaks	10	84.2
Sand, fine to coarse; contains fine gravel at 84.2 to 94.2 feet, some calcareous gray-tan silt streaks, and some silty tan clay streaks	25	109.2
Silt, sandy, clayey, calcareous, gray tan; contains some sand streaks	10	119.2
Clay, silty, sandy, calcareous, gray tan; contains some sand streaks	20	139.2
Sand, fine to coarse; contains some tan silt in upper part and some Cretaceous-derived material	20	159.2
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	3.8	163

26-29-2ca1. *Log of test hole augered by State Geological Survey March 1956, in NE¼ SW¼ sec. 2, T. 26 S., R. 29 W., 1,900 feet south of Arkansas River. Surface altitude, 2,651.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Soil and silt	1	1
Sand, medium to coarse, brown	7	8
Gravel, medium to coarse, sandy	18	26
Gravel, fine, sandy	22	48
Gravel, medium to coarse	3	51
Sand, fine to medium; contains some silt and gravel (hard and loose cemented layers)	14	65
Hard zone (no samples)	3	68

26-29-2cb. *Log of test hole augered by State Geological Survey March 1956, in NW¼ SW¼ sec. 2, T. 26 S., R. 29 W., 2,900 feet south of Arkansas River. Surface altitude, 2,653.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Silt	3	3
Sand, fine	3	6

	Thickness, feet	Depth, feet
Gravel, coarse to medium	26	32
Silt and sand, medium (drilled slow)	8	40
Sand, medium to coarse; contains some gravel and silt	26	66
Clay, silt, and fine to medium sand	2	68

26-29-2cc. *Log of test hole augered by State Geological Survey March 1956, in SW¼ SW¼ sec. 2, T. 26 S., R. 29 W., 4,000 feet south of Arkansas River. Surface altitude, 2,658.5 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt, sandy, road fill	2	2
Sand, medium to coarse; contains some fine gravel and silt	31	33
Sand and gravel; contains hard layers at 40 feet	32	65
Hard zone at 65 feet (no samples)	3	68

26-29-5dd. *Sample log of test hole 16 drilled by U. S. Bureau of Reclamation March 1956, in SE cor. sec. 5, T. 26 S., R. 29 W. Surface altitude, 2,721.5 feet.*

QUATERNARY AND TERTIARY

Undifferentiated Pleistocene and Ogallala (Pliocene)	Thickness, feet	Depth, feet
Sand, fine, very silty, brown	16	16
Silt, sandy, calcareous, gray to tan	8	24
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks	21.5	45.5
Silt, sandy, calcareous, gray tan to pink tan; contains some sand streaks near base	18.5	64
Sand, fine to coarse; contains fine gravel near base and some calcareous gray-tan silt streaks	11	75
Silt, sandy, calcareous, pink tan	8	83
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks	6	89
Silt, sandy, calcareous, pink tan to gray; contains some sand streaks	15	104
Sand, fine to coarse; contains some calcareous gray-tan silt and tan clay streaks and some lime-cemented streaks	24	128
Clay, silty, sandy, calcareous, light gray tan	6	134
Sand, fine, silty	2	136
Clay, silty, sandy, calcareous, light gray tan; contains some lime-cemented streaks	13	149
Sand, fine to coarse, and fine gravel; contains some calcareous tan clayey silt streaks	10	159
Clay, sandy, light gray tan; contains some calcareous tan silt streaks	5	164
Sand, fine to coarse, and fine gravel; contains some silty tan clay streaks	5	169

	Thickness, feet	Depth, feet
Clay, silty, sandy, calcareous, gray tan; contains some sand streaks	20	189
Sand, fine to coarse, and fine to medium gravel; contains some silty tan clay streaks and much Cretaceous-derived material	43	232
Silt, sandy, calcareous, light gray tan; contains some clay	2	234
Sand, fine to coarse, and fine gravel; contains much calcareous clayey silt and much Cretaceous-derived material	6	240
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	3	243

26-29-11cc. *Sample log of test hole 19 drilled by U. S. Bureau of Reclamation March 1956, in SW cor. sec. 11, T. 26 S., R. 29 W. Surface altitude, 2,713.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, silty, gray tan	1.5	1.5
Silt, very sandy, gray	1.5	3
Sand, fine to medium	21.7	24.7
Silt, sandy, very calcareous, gray tan; contains some sand streaks	10	34.7
Sand, fine to coarse, and fine gravel; contains some calcareous tan silt streaks	27.3	62
Silt, sandy, very calcareous, gray tan to pink tan; contains some sand streaks	17.7	79.7
Sand, fine to very coarse; contains fine to medium gravel near base, some calcareous gray and tan silt streaks, and some lime-cemented streaks	25	104.7
Silt, sandy, very calcareous, tan; contains some tan clay	10	114.7
Sand, fine to coarse; contains many calcareous sandy tan silt streaks	15	129.7
Silt, very clayey, tan; contains some fine to coarse sand streaks	5	134.7
Sand, fine to coarse; contains some fine to medium gravel at 144.7 to 149.7 feet and some calcareous clayey gray to tan silt streaks	25	159.7
Silt, clayey, sandy, calcareous, gray tan; contains some sand streaks	5	164.7
Sand, fine to coarse; contains some calcareous sandy tan silt streaks	5	169.7
Clay, silty, sandy, tan	5	174.7

	Thickness, feet	Depth, feet
Sand, fine to coarse; contains some fine to medium gravel at 179.7 to 194.7 feet, many silty tan clay streaks, many lime-cemented streaks near base, and much Cretaceous-derived material	39	213.7
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, gray	0.9	214.6

26-29-27aa. *Sample log of test hole 18 drilled by U. S. Bureau of Reclamation March 1956, in NE cor. sec. 27, T. 26 S., R. 29 W. Surface altitude, 2,728.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, very silty, gray brown	9.4	9.4
Silt, sandy, very calcareous, gray tan	10	19.4
Sand, fine to medium; contains some sandy tan silt streaks	17.6	37
Silt, sandy, very calcareous, gray tan	12.4	49.4
Sand, fine to medium; contains some calcareous gray-tan silt	10	59.4
Silt, very sandy, calcareous, light tan	5	64.4
Sand, fine to coarse, and fine to medium gravel; contains some calcareous sandy tan silt streaks	90	154.4
Silt, sandy, calcareous, gray; contains some sand and gravel streaks	5	159.4
Sand, fine to coarse, and fine gravel; contains some calcareous gray and tan silt streaks and some lime-cemented streaks	10	169.4
Silt, sandy, very calcareous, pink tan	10	179.4
Sand, fine to medium; contains much calcareous pink-tan silt	10	189.4
Silt, sandy, very calcareous, pink tan	5	194.4
Sand, fine to coarse, and fine to medium gravel; contains some tan silt and much Cretaceous-derived material	15	209.4
Silt, sandy, very calcareous, pink tan; contains some sand streaks	5	214.4
Sand, fine to medium; contains some calcareous tan silt streaks	10	224.4
Silt, very sandy, calcareous, pink tan to tan; contains some sand streaks	13.6	238
Sand, fine to coarse, and fine to medium gravel; contains some calcareous tan silt and much Cretaceous-derived material	23	261
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, gray	3.4	264.4

26-30-10cc. *Sample log of test hole 9 drilled by U. S. Bureau of Reclamation February 1956, in SW cor. sec. 10, T. 26 S., R. 30 W. Surface altitude, 2,786.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, silty, brown	5	5
Silt, sandy, gray brown	3.5	8.5
Sand, fine, silty	1.5	10
Silt, sandy, calcareous, tan to gray tan near base	19.4	29.4
Sand, fine to medium; contains some silt streaks	10	39.4
Silt, sandy, calcareous, light gray tan	5	44.4
Sand, fine to coarse; contains some calcareous tan silt streaks	11.6	56
Sand, fine to coarse, and fine gravel; contains some silt and some lime-cemented streaks	10.5	66.5
Silt, sandy, calcareous, light gray tan	2.9	69.4
Sand, fine to coarse, and fine gravel; contains some tan calcareous silt streaks and some clay streaks	55	124.4
Sand, fine to very coarse; contains tan clay streaks at 133 to 134.4 feet and some calcareous tan silt streaks	26.6	151
Silt, very sandy, very calcareous, pink tan	3.4	154.4
Sand, fine to coarse; contains some fine gravel near base and some tan silt streaks	10	164.4
Silt, sandy, very calcareous, light gray tan	2.6	167
Sand, fine to coarse; contains some tan silt streaks	10	177
Silt, sandy, calcareous near base, gray tan; contains many clay streaks at 179.4 to 189.4 feet	22.4	199.4
Sand, fine to coarse; contains some tan clay streaks,	20	219.4
Silt, sandy, calcareous, tan; contains many tan clay streaks	21.6	241
Sand, fine to very coarse; contains some lime-cemented streaks and some tan clay streaks	6	247
Silt, sandy, calcareous, light gray tan	14	261
Sand, fine to coarse, silty; contains some lime-cemented streaks	8.4	269.4
Sand, fine to coarse, and fine gravel; contains some silty tan clay streaks and much Cretaceous-derived material	21.6	291
Clay, very silty, sandy, calcareous, light gray tan	5	296
Sand, fine to coarse, and fine gravel; contains some silty tan clay streaks and much Cretaceous-derived material	31	327
Clay, silty, tan	2.4	329.4
Sand, fine to coarse, and fine gravel, very silty, cemented; contains much Cretaceous-derived material	7.6	337
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	2.4	339.4

26-30-12cc. *Sample log of test hole 10 drilled by U. S. Bureau of Reclamation February 1956, in SE cor. SW¼ SW¼ sec. 12, T. 26 S., R. 30 W. Surface altitude, 2,796.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, very silty, brown	3.5	3.5
Silt, sandy, calcareous, gray tan	4.5	8
Sand, fine to coarse; contains many tan silt streaks	21.1	29.1
Silt, sandy, calcareous at base, tan to gray tan at base	16.9	46
Sand, fine to medium; contains much calcareous tan silt in upper part	19	65
Silt, sandy, calcareous, light gray tan to pink tan	17	82
Sand, fine to coarse, and fine to coarse gravel; contains many calcareous tan silt streaks and some tan clay streaks	107.1	189.1
Silt, sandy, calcareous, gray tan	5	194.1
Sand, fine to coarse; contains some fine gravel at base and a few calcareous tan silt streaks	15	209.1
Silt, sandy, calcareous, gray tan to pink tan; contains some sand streaks, some lime-cemented streaks at 261.5 to 267.5 feet, and much tan clay at 267.5 to 273 feet	63.9	273
Sand, fine to coarse, and fine to coarse gravel; contains some silty tan clay streaks, lime-cemented streaks, and much Cretaceous-derived material	18.5	291.5
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	7.6	299.1

26-30-17bb. *Sample log of test hole 8 drilled by U. S. Bureau of Reclamation February 1956, in NW cor. sec. 17, T. 26 S., R. 30 W. Surface altitude, 2,779.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine to medium, very silty, calcareous at base, brown	5	5
Silt, sandy, calcareous, gray to tan	9.3	14.3
Silt, sandy, green gray	3.7	18
Sand, fine; contains some medium to coarse sand	4	22
Silt, very sandy, calcareous, tan gray	6	28
Sand, fine to coarse, silty	2	30
Silt, sandy, calcareous, light gray tan	7	37
Sand, fine to coarse, and fine gravel	5.5	42.5
Silt, sandy, light gray tan	6	48.5
Sand, fine to coarse, and fine to medium gravel; contains some silt and some cemented streaks	29.5	78
Clay, sandy, silty, light brown and gray	2	80

	Thickness, feet	Depth, feet
Sand, fine to coarse, and fine gravel; contains some silt near base and lime-cemented streaks	26	106
Silt, very sandy, calcareous, light tan to gray tan; contains some tan clay at 109 to 119.3 feet	22	128
Sand, fine to coarse, and fine gravel; contains some lime-cemented streaks	11.3	139.3
Silt, sandy, very calcareous, light gray tan; contains some lime-cemented streaks	25	164.3
Sand, fine to coarse; contains some calcareous tan silt streaks	15	179.3
Silt, very sandy, clayey, calcareous, light tan	5.7	185
Sand, fine to coarse, and fine gravel	3	188
Silt, sandy, calcareous, gray tan; contains much tan clay	13	201
Sand, fine to coarse, and fine gravel; contains some lime-cemented streaks	13.3	214.3
Silt, sandy, calcareous, clayey, gray tan	16.7	231
Sand, fine to coarse; contains fine gravel near base and is very silty at 231 to 239.3 feet	15	246
Silt, sandy, calcareous, light gray tan	9	255
Sand, fine to coarse, and fine to medium gravel; contains some silty clay near base, some cemented streaks, and much Cretaceous-derived gravel	41	296
Silt, sandy, very calcareous, light tan gray	1.5	297.5
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	1.8	299.3

26-31-1bb. *Sample log of test hole 6 drilled by U. S. Bureau of Reclamation February 1956, in NE cor. NW¼ NW¼ sec. 1, T. 26 S., R. 31 W. Surface altitude, 2,783.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, very silty, gray	2	2
Silt, very sandy, clayey, gray	4	6
Silt, very sandy, light tan	3	9
Sand, very fine, grading to coarse at base	8	17
Silt, sandy, very calcareous, pink tan	6	23
Sand, fine to coarse; contains tan clayey silt streaks at 34 to 39 feet and some fine gravel at 43 to 49 feet	26	49
Sand, fine to coarse, and much fine to coarse gravel; contains some sandy tan silt streaks at 69 to 84 feet	48	97
Silt, sandy, calcareous, gray tan	2	99

	Thickness, feet	Depth, feet
Sand, fine to coarse, and fine to medium gravel; contains some sandy tan silt streaks	15	114
Silt, sandy, calcareous, tan; contains some sand streaks	5	119
Sand, fine to coarse; contains many calcareous tan silt streaks	10	129
Silt, very sandy, calcareous, clayey, gray tan; contains some lime-cemented streaks	18	147
Sand, fine to coarse, and fine gravel; contains some silt	5	152
Silt, very sandy, calcareous, light tan	6	158
Sand, fine to coarse; contains much calcareous tan silt	21	179
Sand, fine to medium, silty	5	184
Silt, sandy, calcareous, gray tan	6	190
Sand, fine to coarse; contains much calcareous tan silt and some lime-cemented streaks	19	209
Silt, very sandy, calcareous, gray tan to light tan; contains some tan clay streaks near base and some sand streaks	20	229
Sand, fine to coarse, and fine gravel, silty	4	233
Silt, calcareous, gray tan; contains some sand and fine gravel streaks	6	239
Sand, fine to coarse, silty; contains some lime-cemented streaks and some Cretaceous-derived pebbles	3	242
Silt, very sandy, calcareous, light gray tan	7	249
"Mortar bed", lime-cemented silt, sand, and gravel, tan white; contains many Cretaceous-derived pebbles	13	262
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	7	269

26-31-4cc. *Drillers log of irrigation well in SW¼ SW¼ sec. 4, T. 26 S., R. 31 W., drilled by Minter Drilling Co. Surface altitude, 2,818.9 feet.*

QUATERNARY AND TERTIARY—Pleistocene and Pliocene	Thickness, feet	Depth, feet
Silt	52	52
Sand and gravel, coarse, limy clay streaks	10	62
Clay, sandy	2	64
Sand and gravel, some clay	16	80
Clay, sandy; sand and gravel streaks	5	85
Sand, fine, and some gravel, clay streaks	24	109
Caliche, hard	1	110
Sand and gravel, cemented streaks	11	121

	Thickness, feet	Depth, feet
"Mortar" bed, very sandy	3	124
Sand and gravel, loose	6	130
Sand and gravel, clay streaks	6	136
Clay, sandy, cemented streaks	3	139
Clay, sandy, sand, and gravel streaks	12	151
Sand and gravel, loose	2.5	153.5
"Mortar" bed	1	154.5
Sand and gravel, limy, loose	8.5	163
Clay, sandy, thin sand streaks	7	170
Sand, fine, cemented streaks	5	175
Sand and gravel, cemented streaks at 185 to 190 and 195 to 200 feet	25	200

26-31-12cd. *Sample log of test hole 7 drilled by U. S. Bureau of Reclamation February 1956, in SW cor. SE¼ SW¼ sec. 12, T. 26 S., R. 31 W. Surface altitude, 2,796.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Undifferentiated Pleistocene and Ogallala (Pliocene)		
Sand, fine, very silty, gray	2	2
Silt, sandy, light to dark tan	22	24
Silt, sandy, calcareous, light gray tan	2	26
Sand, fine to medium	3	29
Silt, very sandy, very calcareous, gray tan	15	44
Sand, fine to coarse, and fine to medium gravel	10	54
Silt, sandy, calcareous, light tan	5	59
Sand, fine to coarse; contains some fine to medium gravel at base	10	69
Silt, very sandy, calcareous, tan gray	5	74
Sand, fine to coarse, and fine gravel; contains some silt at base and some lime-cemented streaks	17	91
Silt, very sandy, calcareous, gray tan	2	93
Sand, fine to coarse, and fine gravel, silty	7	100
Silt, sandy, calcareous, tan; contains some lime-cemented sand streaks	11	111
Sand, fine to coarse, and fine to medium gravel; contains some cemented streaks	22	133
Silt, sandy, very calcareous, pink tan to gray tan	18	151
Sand, fine to coarse; contains lime-cemented streaks,	2	153
Silt, sandy, very calcareous, gray tan	13	166
Sand, fine to very coarse, silty	7	173
Silt, sandy, calcareous, tan; contains some brown clay streaks	6	179
Sand, fine to coarse, and fine gravel; contains some calcareous clayey tan silt streaks	22	201
Silt, sandy, calcareous, clayey, tan	23	224

	Thickness, feet	Depth, feet
Sand, fine to coarse; contains some calcareous tan silt streaks	9	233
Silt, sandy, calcareous, gray tan	2	235
Sand, fine to coarse, and fine gravel, contains much Cretaceous-derived gravel	14	249
Silt, very sandy, very calcareous, light gray tan	10	259
Sand, fine to coarse, and fine gravel; contains much clayey tan silt at 259 to 269 and 279 to 284 feet and some lime-cemented streaks	35	294
Silt, very sandy, very calcareous, light tan; contains some sand and streaks of Cretaceous-derived gravel near base	16.5	310.5
CRETACEOUS—Gulfian		
Carlile shale (?)		
Shale, calcareous, dark gray	7.5	318

REFERENCES

COOPER, H. H., JR., and JACOB, C. E. (1946) A generalized graphical method for evaluating formation constants and summarizing well-field history: Am. Geophys. Union Trans., v. 27, p. 526-534, fig. 1-5, table.

DARTON, N. H. (1905) Preliminary report on the geology and underground-water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, p. 1-409, fig. 1-18, pl. 1-72 (incl. maps).

FRYE, J. C. (1942) Geology and ground-water resources of Meade County, Kansas: Kansas Geol. Survey Bull. 45, p. 1-152, fig. 1-13, pl. 1-12.

HAWORTH, ERASMUS (1897) Physiography of western Kansas: Kansas Univ. Geol. Survey, v. 2, p. 11-49.

——— (1897a) Underground waters of southwestern Kansas: U. S. Geol. Survey Water-Supply Paper 6, p. 1-65, pl. 1-12.

——— (1897b) The geology of underground water in western Kansas: Kansas Board of Irrigation Survey Report 1895-1896, p. 49-114, fig. 7-11.

——— (1913) Special report on well waters in Kansas: Kansas Univ. Geol. Survey Bull. 1, p. 1-110, fig. 1-9, pl. 1-6.

JACOB, C. E. (1946) Radial flow in a leaky artesian aquifer: Am. Geophys. Union Trans., v. 27, no. 2, p. 198-205, fig. 1-3.

——— (1946a) Drawdown test to determine effective radius of artesian well: Am. Soc. Civil Engineers Proc., v. 72, no. 5, p. 629-646.

LATTA, B. F. (1944) Geology and ground-water resources of Finney and Gray Counties, Kansas: Kansas Geol. Survey Bull. 55, p. 1-272, fig. 1-21, pl. 1-12.

NETTLETON, C. W. (1892) Artesian and underflow investigations—Final report of the Chief Engineer to the Secretary of Agriculture (with accompanying maps, profiles, diagrams, and additional papers): U. S. 42d Cong., 1st sess. S. Ex. Doc. 41, pt. 2, p. 1-116, map, profiles, tables.

PARKER, H. N. (1911) Quality of the water supplies of Kansas: U. S. Geol. Survey Water-Supply Paper 273, p. 1-375, fig. 1 (map), pl. 1.

RICHARDS, L. A., and others (1954) Diagnosis and improvement of saline and alkali soils: U. S. Dept. Agr., Agr. Handbook No. 60, p. 1-160.

SCHOEWE, W. H. (1949) The geography of Kansas; Part II, Physical geography: Kansas Acad. Sci. Trans., v. 52, p. 261-333, fig. 12-55.

SLICHTER, C. S. (1902) The motions of underground waters: U. S. Geol. Survey Water-Supply Paper 67, p. 1-106, pl. 1-8.

——— (1906) The underflow in Arkansas valley in western Kansas: U. S. Geol. Survey Water-Supply Paper 153, p. 1-90, fig. 1-24, pl. 1-3.

SMITH, H. T. U. (1937) Preliminary notes on Pleistocene gravels in southwestern Kansas: Kansas Acad. Sci. Trans., v. 40, p. 283-291, fig. 1 [1938].

——— (1940) Geologic studies in southwestern Kansas: Kansas Geol. Survey Bull. 34, p. 1-244, fig. 1-22, pl. 1-34.

SUTTON, W. B. (1897) Introduction: Rept. Board of Irrigation Survey and Experiment for 1895 and 1896 to the Legislature of Kansas, p. 1-48, fig. 1-6.

THEIS, C. V. (1937) Amount of ground-water recharge in the southern High Plains: Am. Geophys. Union Trans., p. 564-568.

———, BURLEIGH, H. P., and WAITE, H. A. (1935) Ground-water in the southern High Plains: U. S. Dept. Interior, Memorandum for the press, Oct. 30, p. 1-4, map.

U. S. WEATHER BUREAU, Climatological data: U. S. Dept. Commerce.

U. S. GEOLOGICAL SURVEY, Water levels and artesian pressure in observation wells in the United States; Part 3, North-central States: Issued annually as Water-Supply Papers.

WENZEL, L. K. (1942) Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U. S. Geol. Survey Water-Supply Paper 887, p. 1-192, fig. 1-17, pl. 1-6.

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