Geology and Ground-Water Resources of Cloud County, Kansas

By

CHARLES K. BAYNE and KENNETH L. WALTERS

WITH A SECTION ON CERAMIC MATERIALS

By

NORMAN PLUMMER

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BULLETIN 139

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By

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With a Section on Ceramic Materials by Norman Plummer

Prepared by the State Geological Survey of Kansas and the United States Geological Survey, with the co-operation of the Division of Sanitation of the Kansas State Board of Health, and the Division of Water Resources of the Kansas State Board of Agriculture.

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GEOLOGY AND GROUND-WATER RESOURCES OF CLOUD COUNTY, KANSAS

By Charles K. Bayne and Kenneth L. Walters

ABSTRACT

This report describing the geography, geology, and ground-water resources of Cloud County, Kansas, is based on hydrologic and geologic information obtained in the field during the fall of 1953 and the summer of 1954. The field data are given in tables; they include records of 170 wells, chemical analyses of water from 57 representative wells, and logs of 76 test holes. In addition, 100 holes were augered to determine the depth to water.

Cloud County has an area of about 711 square miles and in 1950 had a population of 16,104. The county lies in the Dissected High Plains section of the Great Plains physiographic province. Most of it is drained by Republican and Solomon Rivers. A small part is drained by Chapman Creek. The normal annual precipitation at Concordia is 25.24 inches, and the mean annual temperature is 53.8° F. Agriculture is the principal occupation in the county.

The rocks that crop out in Cloud County are sedimentary and range in age from Cretaceous to Recent. The oldest formation exposed in the county is the Dakota Formation. The youngest Cretaceous formation exposed in the county is the Carlile Shale. The Ogallala Formation, of Tertiary age, is present as small remnants in a few places. The Cretaceous rocks are mantled in many places by unconsolidated continental deposits of fluviatile and eolian origin representing four stages of the Pleistocene Epoch.

The unconsolidated sand and gravel deposits of Pleistocene age form the principal aquifers in the county. These deposits are best developed in the valley of Republican River. The Dakota Formation yields moderate quantities of water, but Cretaceous rocks overlying the Dakota Formation yield very little water in the county. Where it is deeply buried the Dakota Formation contains salty water, which is being discharged into the valley fill of Republican River near Concordia.

Ground water in the area is recharged principally from local precipitation; underflow from adjacent areas contributes significantly, however. Ground water is discharged mainly by seepage into streams and by transpiration by plants; there is some discharge by underflow across the eastern boundary of the county. All municipal and industrial water supplies and most domestic and stock supplies are obtained from wells. Irrigation from wells is practiced extensively in the valley of Republican River, and to a lesser extent in the Solomon River valley.

INTRODUCTION

Purpose of Investigation

A program of investigation of the ground-water resources of Kansas was begun in 1937 by the United States Geological Survey and the State Geological Survey of Kansas with the co-operation of the Division of Sanitation of the State Board of Health and the Division of Water Resources of the State Board of Agriculture.

The investigation of that part of Cloud County that lies within the Republican Valley was integrated with the program of the Interior Department for development of the Missouri River basin. The investigation of Cloud County began in August 1953 and is similar to other investigations that have been completed or are being made in other counties in Kansas. The present status of investigations is shown in Figure 1.

Ground water is one of the principal natural resources of Cloud County. Nearly all public, domestic, and industrial water supplies and many stock water supplies are obtained from wells. The use of ground water for irrigation is increasing and probably will continue to increase at an accelerated rate. At the present rate of withdrawal the danger of seriously depleting the ground-water supply or of impairing the quality of the water by encroachment of saline waters is slight, but an adequate understanding of the quality and quantity of the available ground-water supply is needed to aid in future development.

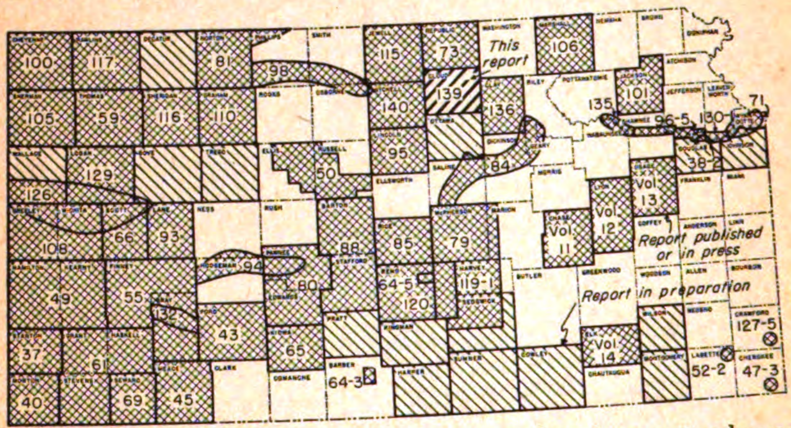

FIG. 1.—Index map of Kansas showing area discussed in this report and areas for which ground-water reports have been published or are in preparation.

LOCATION AND EXTENT OF AREA

Cloud County is in north-central Kansas, in the second tier of counties from the north border of the state and just east of the center of the state. The county contains 20 townships from T. 5 to T. 8 S., and from R. 1 to R. 5 W. and includes an area of 711 square miles. The location of Cloud County is shown in Figure 1.

Previous Investigations

The principal studies of the geology and ground-water resources of north-central Kansas that have a bearing on Cloud County are mentioned below. Specific references are cited at appropriate places in the text by author and date, and are given under References at the end of the report.

The geology of the Upper Cretaceous in Kansas was described by Logan in 1897. Darton (1905) made reference to wells in north-central Kansas in a preliminary report of the geology and ground-water resources of the central Great Plains. Haworth (1913) prepared a report on well waters in Kansas in which he discussed the availability of ground water in the Republican River valley. A report by Wing (1930) of the geology of Cloud and Republic Counties was the first detailed report on this area. Moore and others (1940) prepared a generalized report on the ground-water resources of Kansas. A detailed report on the outcrop area of the Dakota Formation was made by Plummer and Romary (1942). Fishel (1948) prepared a report on the ground-water resources of Republic County and northern Cloud County, which included data from about the northern fourth of Cloud County. A report describing the geology and engineering construction materials in Cloud County was prepared by Buck and others (1951). Schoewe (1952) prepared a report on the coal resources of the Dakota Formation in which the occurrence of coal in Cloud County is discussed.

Methods of Investigation

In all, 2 months in the fall of 1953, 3 months in the summer of 1954, and 1 month in the fall of 1955 was spent in Cloud County collecting the data upon which this report is based. Geology was mapped in the field on aerial photographs from field observations and stereoscopic study of aerial photographs. Data were transferred from the photographs to a base map by means of a focalmatic projector.

Data on the total depth, depth to water, yield, and character of the water-bearing material of 170 wells (Table 16) were collected. Test holes were bored with a power auger at 150 locations; 100 were bored in alluvial or terrace material to obtain depth-to-water measurements included in Table 16 and 50 were bored to obtain geologic information. Forty-four test holes were drilled with a hydraulic-rotary drilling machine owned by the State Geological Survey of Kansas and operated by E. L. Reavis and William Gellinger to obtain geologic information. Logs of test holes were prepared in the field and modified later after microscopic study of the drill cuttings in the laboratory. Level parties headed by Woodrow W. Wilson and E. L. Reavis determined the altitudes of wells and test holes by means of a plane table and alidade. Fifty-seven samples of water from wells and test holes were collected and were chemically analyzed by Howard Stoltenberg, chemist in the Water and Sewage Laboratory of the Kansas State Board of Health. (Table 3.)

Well-Numbering System

In this report the well, auger-hole, and test-hole numbers accord with the General Land Office system of land classification. The component parts of a well number are the township number, range number, section number, and three lowercase letters indicating respectively the quarter section, quarter-quarter section, and the quarter-quarter-quarter section. The lowercase letters are assigned in a counterclockwise direction beginning in the northeast quarter of each section or subdivision. For example, well 6-2-30dad (Fig.

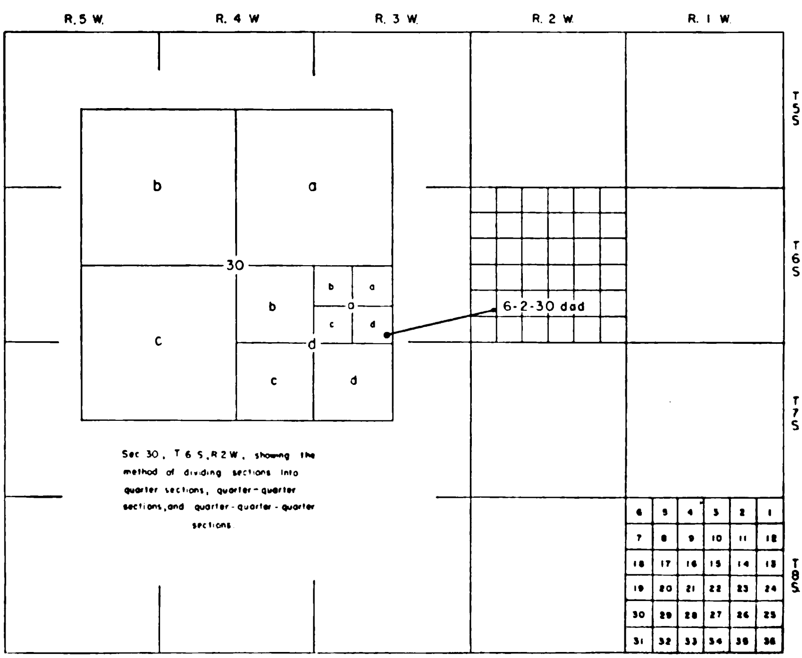

Fig. 2.—Map of Cloud County illustrating well-numbering system used in this report.

2) is in the SE¼ NE¼ SE¼ sec. 30, T. 6 S., R. 2 W. If there are two or more wells within the same quarter-quarter-quarter section they are numbered serially according to the order in which they are inventoried.

Acknowledgments

Appreciation is expressed to the many residents of Cloud County who supplied information and aided in the collection of field data. Special acknowledgment is given the officials of the many cities who provided information about their water supplies. Acknowledgment is made also of the information supplied by George Cox, J. G. Lassey, and Carl Thoman, well drillers in Cloud County. Franklin Day, W. T. Wright, and James Doorman co-operated in permitting use of their irrigation wells for aquifer tests.

The manuscript of this report was reviewed by several members of the Federal Geological Survey and the State Geological Survey; by Robert Smrha, Chief Engineer, and George S. Knapp, Engineer, of the Division of Water Resources, Kansas State Board of Agriculture; and by Dwight Metzler, Director and Chief Engineer, and Willard O. Hilton, Geologist, of the Division of Sanitation, Kansas State Board of Health.

GEOGRAPHY

Topography and Drainage

Cloud County lies in the Dissected High Plains section of the Great Plains physiographic province (Schoewe, 1949). The topography represents several types: high flat upland areas resembling the High Plains farther west, gently rolling areas on the Dakota Formation dotted with many mounds or buttes, the broad flat valleys of Solomon and Republican Rivers, and a belt of deeply dissected uplands between the upland and river valleys. Topographically subordinate but important in a ground-water study are the broad flat terraces in the valleys and also the salt marshes in northwestern Cloud County, which affect the quality of water.

The lowest points in Cloud County, about 1,300 feet above sea level, are in the southwestern part of the county along Solomon River and in the northeastern part of the county along Republican River. The highest point is about 1,700 feet, in south-central Cloud County on the divide between Solomon and Republican Rivers.

Approximately two-thirds of Cloud County is drained by Republican River. This stream rises in Colorado and flows generally

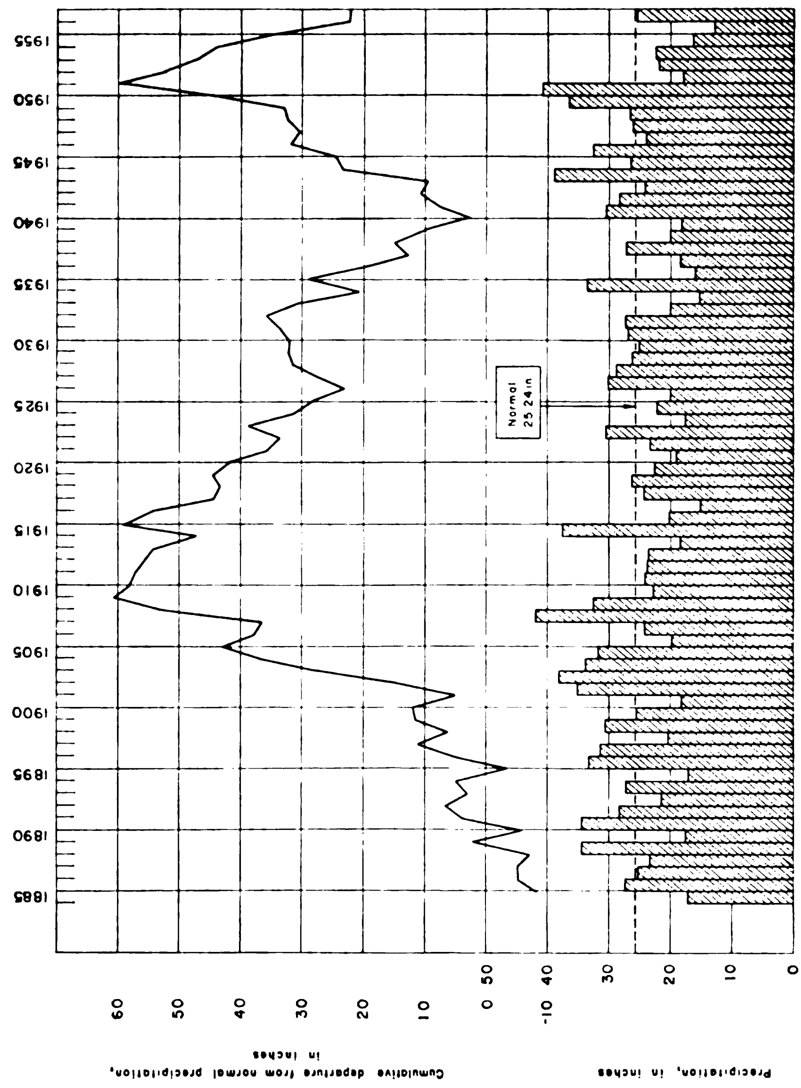

FIG. 3.—Annual precipitation and cumulative departure from normal at Concordia.

eastward through Colorado and Nebraska to about the northwest corner of Republic County, Kansas, then bends southeastward to join Smoky Hill River at Junction City to form Kansas River. In Cloud County, tributary streams that enter Republican River from the north rise in Republic County, and those that enter from the south rise in the upland between Solomon and Republican Rivers. The major tributary to Republican River in the county is Buffalo Creek, which rises in Jewell County and flows eastward to its junction with Republican River just west of Concordia.

Most of the southern third of Cloud County is drained by Solomon River. This river rises in Thomas County and flows eastward to Cloud County, then southeast to its junction with Smoky Hill River at Solomon, Kansas. About 35 square miles in southeastern Cloud County is drained by Chapman Creek, which is a tributary to Smoky Hill River.

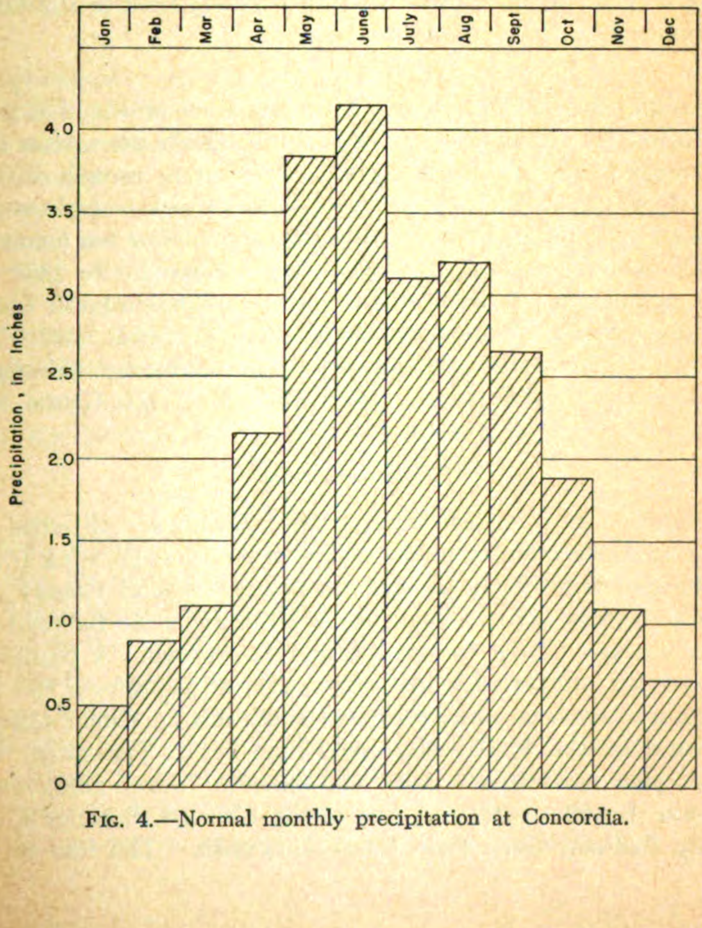

FIG. 4.—Normal monthly precipitation at Concordia.

Climate

The U. S. Weather Bureau has maintained a precipitation gage at Concordia since 1885. The normal annual precipitation recorded at Concordia is 25.24 inches. The annual precipitation and the cumulative departure from normal for the period of record beginning in 1885 are shown graphically in Figure 3. The annual precipitation has ranged from 15.28 inches in 1934 to 41.88 inches in 1908.

About three-quarters of the precipitation falls during the 6-month period (April through September) that is favorable for growing crops. The normal monthly precipitation at Concordia is shown in Figure 4.

The mean annual temperature at Concordia is 53.8° F. The growing season in Cloud County has ranged from 134 to 220 days and averages 186 days. The latest date of a killing frost in the spring is May 19; the earliest date of a killing frost in the fall is September 27.

Population

According to the 1950 census the population of Cloud County was 16,104, an average density of 22.6 inhabitants per square mile as compared with 23.1 for the state. The census records show a gradual decline in the population of Cloud County of about 100 persons a year in the last 20 years. Urban population has increased steadily while the rural population has decreased. In 1930 the urban population was 8,250 and the rural population 9,756, but in 1950 the urban population was 10,671 and the rural, 5,433. The principal cities and their populations as reported by the 1950 census are: Concordia, 7,175; Clyde, 1,067; Miltonvale, 911; Glasco, 803; Jamestown, 494; and Aurora, 221.

Transportation

Cloud County has good transportation facilities. All cities are served by one or more railroads. A line of the Chicago, Rock Island and Pacific Railway Co. crosses northeastern Cloud County and serves the city of Clyde. A line of the Missouri Pacific Railroad Co. passes through Clyde, Concordia, and Jamestown. A branch at Yuma serves northern Cloud County, and at Jamestown the line branches to serve northwestern and southwestern Cloud County. The Missouri Pacific Railroad again branches at Jamestown, one branch going southwest to Beloit and the other branch going northwest into Jewell County. A line of the Chicago, Burlington and Quincy Railroad Co. terminates at Concordia. The line of the

Atchison, Topeka and Santa Fe Railway Co. passes through Miltonvale and Concordia. A branch line of the Union Pacific Railway Co. from Clay Center in Clay County terminates at Miltonvale, and another branch line of the Union Pacific Railway Co. crosses southwestern Cloud County, passing through Glasco.

In addition to the railroads, State and Federal highways cross Cloud County from north to south and from east to west, offering easy access to the area by automobile and truck. U. S. Highway 81 through Concordia is one of the important north-south highways through the county. U. S. Highway 24 crosses southern Cloud County through Miltonvale and Glasco. Kansas Highway 9 passes through Clyde and Concordia and thence southwest to Beloit, and Kansas Highway 28 from Concordia through Jamestown serves northwestern Cloud County. All state highways are hard surfaced and many county roads are graveled. Most township roads are graded.

Agriculture

Agriculture is the chief occupation in Cloud County. Wheat, corn, oats, sorghums, and tame hay are the principal crops grown, and many cattle, hogs, and poultry are raised. In the valley areas corn, sorghums, and alfalfa are the principal crops; in the uplands wheat, oats, and other cereal grains are the principal crops. The dissected areas between the valleys and uplands are principally pasture. About 90 percent of the 455,040 acres of land area in Cloud County is used for agriculture. Of the total land area in the county in 1955, 27 percent was planted to wheat, 12 percent to sorghums, 6 percent to corn, 3 percent to oats, 7 percent to tame hay, and 1 percent to other crops, and 34 percent was wild hay land and pasture.

Mineral Resources

Construction Materials

Parts of almost all the geologic formations in Cloud County can be used for some type of construction. The principal uses and the geologic source of construction materials in Cloud County are discussed in the following paragraphs.

Concrete aggregate.—Aggregate for concrete consists of fragments of hard, durable minerals or rocks of sand and gravel size. The constituent particles should be free from adherent particles or coatings that would interfere with the bonding between the aggregate particles and the cement. A great quantity of sand and gravel for concrete aggregate is available from the Recent alluvium of Republican River. Limestone gravel from the Crete Formation in southwestern Cloud County along the edge of the Solomon River valley is composed of hard crystalline limestone pebbles in a finer matrix predominantly composed of quartz sand. In the basal part of the formation the particles are free of adherent materials and constitute a potential source of aggregate. These deposits are terrace remnants along the present valley walls and are not extensive.

Materials for the manufacture of lightweight aggregate are available from parts of the Dakota Formation, the Graneros Shale, and the silts of the Peoria and Loveland Formations. Such uses are discussed more fully under ceramic materials. Silica-cemented sandstones of the Dakota Formation are available in very small quantity in the county for crushed stone aggregate.

Road metal.—Surfacing material consisting of crushed stone or gravel can be produced in large quantities in Cloud County. The sand and gravel from the alluvium of Republican River are available in great quantity for road metal. The limestone gravel from the Crete Formation is available in lesser quantity but is used extensively in the area. A small quantity of silica-cemented "quartzite" of the Dakota Formation and some iron-cemented sandstone can be crushed for road metal. The Greenhorn Limestone is used extensively for road metal, but it has a tendency to form dust in dry weather.

Mineral filler.—Large quantities of silt for mineral filler are available from the Peoria and Loveland Formations, and probably also from the silts of the terrace deposits in the major valleys.

Riprap.—The quartzitic sandstones of the Dakota Formation are suitable for use as riprap, but these deposits are not extensive. The iron-cemented sandstones of the Dakota Formation, the supply of which is more extensive, can be used if the degree of cementation is great enough. The Greenhorn Limestone is not suitable for riprap because it rapidly disintegrates through freeze-and-thaw action.

Structural stone.—Structural stone is any hard dense rock that can be quarried and cut to the desired size and shape. Materials in Cloud County that meet these requirements include parts of the Greenhorn Limestone and the Dakota Formation. The Fencepost Limestone bed at the top of the Pfeifer Shale member of the Greenhorn Limestone is an ideal building stone. The stone is soft and easily quarried in a fresh exposure but "case hardens" after quarrying, and it weathers well. The "Shell-rock limestone bed" at the top of the Jetmore Chalk member also is used as a structural stone, but does not improve on weathering as does the Fencepost bed. The cemented sandstone of the Dakota Formation has been used as structural stone, but owing to uneven cementation of the sandstone it does not weather as well as limestones from the Greenhorn Limestone.

Ceramic Raw Materials

By Norman Plummer

In Cloud County the Dakota Formation is the only important source of clays suitable for use in the ceramic industries. Between 1938 and 1940, 117 samples of clay were obtained from 50 localities in the Dakota Formation in Cloud County. Ceramic tests and a detailed description of the types of clay available were reported (Plummer and Romary, 1947). From some of the more valuable deposits many samples have been collected and tested since 1940.

In Kansas, the clays of the Dakota Formation contain kaolinite as the dominant clay mineral and minor amounts of illite. Owing to the fact that kaolinite is refractory and white firing, the clays of the Dakota Formation fire to relatively light colors ranging from nearly white to buff unless contaminated by iron oxides. Those containing iron minerals fire to colors ranging from dark buff to deep red. The refractory quality of the kaolinite is sufficient to assure resistance to high temperature, although finely divided quartz and other impurities are mixed with it. Such clays are called fire clays. In Cloud County these fire clays range from Low Duty refractories having a pyrometric-cone equivalent of not less than cone 19 (2806° F.) to High Duty refractories having a pyrometric-cone equivalent of not less than cone 31½ (3090° F.).

The lighter firing clays range in type from ball clay (an extremely plastic, fine-grained, white- to ivory-firing refractory clay) to very siliceous fire clay. The intermediate types, ranging from plastic fire clay to moderately siliceous fire clay, are most abundant and the most extensively used.

Cloud County has one brick plant, Cloud Ceramics, southeast of Concordia, which uses clay from three pits in the Janssen Clay member of the Dakota Formation. This company manufactures face brick ranging from light ivory to purplish red. During 1955 this plant shipped 1,130 carloads of brick. The capacity of Cloud Ceramics was doubled early in 1957 when a large tunnel kiln and an additional factory unit were put in operation.

A plastic fire clay mined from a pit north of Miltonvale was used by the Miltonvale Potteries, Inc., before the plant ceased operations. A small tonnage of clay is still being taken from this pit and sold to small potteries and to schools. Ball clay and plastic fire clay are being sold also from a deposit near the south line of the county in the SW¼ sec. 32, T. 8 S., R. 2 W. At present most of the clay is shipped to schools, amateur potters, and small commercial potteries. Several carloads of clay have been used in the past by the Ludowici-Celadon Co. of Coffeyville, Kansas, in the manufacture of insulating fire brick, kiln furniture, and glazed structural blocks.

Coal

More than 40 percent of the lignite mined in central Kansas was produced from the Dakota Formation in Cloud County (Schoewe, 1952). The Dakota Formation is the surface rock over all or nearly all of 11 of the 20 townships in the county. Test drilling indicates that lignite is present at some level in the Dakota Formation under nearly all the county. Some of these lignite deposits are too thin to have commercial value, some are too deeply buried, and some are of very poor quality.

Coal was mined in Cloud County as early as 1855 at the now abandoned village of Minersville on the county line northeast of Concordia, and coal was mined in this area more or less continuously until 1940. The coal is about 24 inches thick and occurs in two beds separated by about 4 inches of impure coal. The coal lies about 20 feet below the contact between the Dakota and Graneros formations.

Early maps of the area and reports of residents indicate that coal was mined at other localities in the county but on a much smaller scale. Production figures for coal mined in the county are incomplete but indicate that the largest annual amount, 18,000 tons, was produced in 1884. Schoewe (1952) estimates that the original reserves of coal amounted to 5,300,000 tons and that the reserves as of July 1952 amounted to 5,200,000 tons. Inasmuch as all known coal beds in the county are less than 3 feet thick, the known reserves are classed as marginal reserves.

GEOLOGY

Summary of Stratigraphy *

The rocks that crop out in Cloud County are sedimentary and range in age from Cretaceous (Gulfian) to Recent. Their areal distribution is shown on Plate 1, and their stratigraphic relation is shown on Plate 3. A generalized section of the geologic formations is given in Table 1.

The oldest rocks exposed in Cloud County are nonmarine Cretaceous rocks of the Dakota Formation. Overlying the Dakota Formation without apparent disconformity are Cretaceous marine deposits of the Graneros Shale, Greenhorn Limestone, and Carlile Shale, successively. In western Cloud County, in an upland position near the divide between the major streams, Tertiary (Pliocene) deposits classified as the Ogallala Formation crop out in two small areas. Eolian deposits included in the Sanborn Group (Pleistocene) are widely distributed in the upland and along valley walls. Along the major streams these eolian silts are underlain by stream-deposited silts and sands, which are in a "high terrace" position with respect to the valleys and are classified as Illinoian in age in this report. Along Solomon and Republican Rivers and many of their principal tributaries are terrace deposits of Wisconsinan age. These deposits are locally important sources of ground water. Alluvium along Solomon River forms only a narrow belt adjacent to the stream channel, but the alluvium bordering Republican River has considerable width.

In places in the valleys of Republican River and Buffalo Creek where the deposits extend to the greatest depth, locally derived gravel, sand, and silt classified as Kansan in age underlie the Wisconsinan terrace deposits and alluvium. In local areas along Republican River the prevailing southerly winds have formed dunes, which lie on both Wisconsinan terrace deposits and alluvium.

Geologic History

Pre-Pleistocene Geologic History

The oldest rocks exposed in Cloud County are the clay shales and sandstones of the Dakota Formation, which is thought to be late middle Cretaceous in age. The history of geologic events that preceded their deposition is known partly from deep tests for oil in the county and partly from surface exposures of rocks, deeply

* The geologic classification and nomenclature of this report follow the usage of the State Geological Survey of Kansas and differ somewhat from those of the U. S. Geological Survey.

TABLE 1.—*Generalized section of geologic formations in Cloud County* *

System	Series	Group	Stage	Stratigraphic unit	Thickness	Character	Water supply
Quaternary	Pleistocene		Recent	Dune sand	0–50	Sand, fine to medium, quartz, and some silt.	Generally above water table, but yields small quantities of water to a few wells.
				Alluvium	0–130	Clay, silt, sand, and gravel, unconsolidated.	Yields large quantities of water to wells.
		Sanborn	Wisconsinan	Terrace deposits	0–125	Clay, silt, sand, and gravel, stream deposited; coarser materials generally in lower part of deposits.	Yield large quantities of water to wells.
				Peoria Formation	0–10	Silt, eolian, mantling upland and older terrace deposits along major streams.	Above water table and yields no water to wells.
			Illinoian	Loveland Formation	0–10	Silt, eolian, mantling upland and in places older terrace deposits along major streams.	Above water table and yields no water to wells.
				Crete and Loveland Formations undifferentiated	0–75	Silt and clay, waterlaid, containing minor amounts of sand and gravel; generally more gravel near base.	Yield small to moderate quantities of water to wells.
				Crete Formation	0–30	Sand, gravel, and silt in terrace position along some major streams. Gravel is principally limestone.	Lies generally above water table, but yields small quantities of water to wells where below water table.
		Meade	Kansan	Sappa Formation / Grand Island Formation	0–60	Sand and gravel, locally derived, overlain by silt and clay. Occurs in deeper parts of Republican River valley.	Water generally of poor quality; high chloride content in part of county.
Tertiary	Pliocene			Ogallala Formation	0–1	Deposits of "Algal limestone" of very small areal extent.	Yields no water to wells.

Cretaceous	Gulfian	Colorado Group	Carlile Shale	Fairport Shale member	0–30	Shale, thin bedded, calcareous, capping high upland in west-central part of county.	Lies above water table and yields no water to wells.
			Greenhorn Limestone	Pfeifer Shale member	80–90	Limestones and shales, thin bedded, chalky; thin streaks of bentonite.	Yields small quantities of hard water to a few wells.
				Jetmore Chalk member			
				Hartland Shale member			
				Lincoln Limestone member			
			Graneros Shale		20–40	Clay and fissile shale, noncalcareous, black and olive drab.	Yields no water to wells in county.
			Dakota Formation	Janssen Clay member	25–400 ±	Clay, shale, siltstone, and sandstone; some lignite.	Yields moderate to large quantities of water of good quality to wells in most of county. High chloride content locally.
				Terra Cotta Clay member			
	Comanchean		Kiowa Shale				
Permian	Leonardian	Sumner Group	Wellington Formation		300–400	Clay, gray shale, and a few beds of limestone and chert.	Yields no water to wells in county.

*** The stratigraphic nomenclature is that of the State Geological Survey of Kansas.**

buried in Cloud County, that crop out east of the area. The Precambrian crystalline rocks are the oldest rocks beneath Cloud County and are the basement rocks upon which later sedimentary rocks have been laid down. These rocks have not been penetrated in test wells in Cloud County but have been penetrated in surrounding areas. The Precambrian rocks were subjected to a long period of erosion; the seas then covered the rocks intermittently, depositing limestone and shale during parts of Cambrian, Ordovician, Silurian, Devonian, and Mississippian time. The thickness of these deposits totals nearly 2,000 feet. Just before but more especially after Mississippian deposition, the rocks were gently folded along a line extending from Nemaha County southward through Sumner County. This fold is named the Nemaha Anticline; its axis passes about 50 miles east of Cloud County. Upward folding along the anticline was accompanied by downwarping on the flanks. This downwarping on the west flank created a large syncline known as the Salina Basin. The post-Mississippian folding elevated the area above sea level, starting a long period of erosion during which nearly all the sediments were removed from the highest part of the anticline. In Cloud County part of the sequence was beveled, all the Mississippian rocks being removed in northeastern Cloud County. Subsequently, the area again was covered by the sea, and Pennsylvanian and Permian rocks were deposited. This deposition was followed by another long period of erosion, which lasted through Triassic, Jurassic, and early Cretaceous time. During this period upper Permian deposits were removed, if they had ever been deposited, and the surface rock in Cloud County at the beginning of Cretaceous deposition was the Wellington Formation.

Cretaceous deposition in Cloud County began with the marine Kiowa Shale, which was followed successively by the nonmarine Dakota Formation and the marine Graneros Shale, Greenhorn Limestone, and Carlile Shale. By the end of Cretaceous time the sea withdrew, and the environment has been continental since that time.

During most of Tertiary time the area was eroded, and great quantities of Cretaceous rocks were removed, leaving a beveled eastward-sloping surface. About 500 feet of Cretaceous rocks remain in western Cloud County, but in parts of eastern Cloud County only about 100 feet of Cretaceous rocks remain. During Pliocene time streams from the Rocky Mountains area deposited as much as 300 feet of sand, gravel, and silt over western Kansas. Eastward these deposits (Ogallala Formation) thin, and in Cloud County only the uppermost rocks are present. Probably they were never more than a few feet thick and consisted of "Algal limestone" containing grains of sand.

Pleistocene Geologic History

The events that shaped the present topographic features began after the deposition of the "Algal limestone" and the beginning of Pleistocene erosion. During early Pleistocene time streams formed on the sloping plain and began to cut into the underlying rocks.

The Pleistocene is divided into four glacial and four interglacial stages. The Nebraskan was the first glacial stage and was followed chronologically by the Aftonian (interglacial) Stage, the Kansan (glacial) Stage, the Yarmouthian (interglacial) Stage, the Illinoian (glacial) Stage, the Sangamonian (interglacial) Stage, the Wisconsinan (glacial) Stage, and the Recent, which in Kansas usage is regarded as an interglacial stage.

No deposits of Nebraskan age were recognized in Cloud County. Streams in the county during Nebraskan time possibly headed not far to the west of Cloud County, and did not carry heavy loads of silt and sand from the Tertiary deposits farther west. Therefore, during the Nebraskan Stage the streams probably were incising their channels, and minor deposits have been removed by later erosion.

During Aftonian and early Kansan time, the streams in Cloud County continued to incise their channels, and the valleys probably were relatively deep and averaged about 2 miles wide (Pl. 3). Buffalo Creek or Marsh Creek probably was the principal stream, and that part of the present Republican River extending from the mouth of Buffalo Creek to Republic City was a tributary to Buffalo Creek. The ancestral Republican River did not flow through Cloud County during early Kansan time. It entered Kansas near its present location and flowed southeastward to about Republic City, thence northeastward across Republic County, and re-entered Nebraska near Chester, Nebraska (Lohman *in* Fishel, 1948, p. 29). The ancestral Republican River carried a heavy load of sand and gravel, a part of which was deposited in the channel.

The absence in the Republican Valley in Cloud County of arkosic deposits like those in the ancestral valley, which are known to be Kansan in age, indicates that the present drainage pattern in Cloud County was not established until very late Yarmouthian or early Illinoian time. Basal deposits in the Republican Valley in Cloud County principally are locally derived materials because the drainage system headed not far west and did not arise in arkosic materials. The deposits are not thick, probably because the gradient of the streams was relatively steep.

During Yarmouthian or early Illinoian time, the streams in Cloud County again incised their channels and partly removed the Kansan deposits. In late Illinoian time, the streams widened their channels and deposited sediments. Illinoian deposits in the Solomon Valley consist mostly of locally derived sand and gravel and minor amounts of silt, but the presence of some arkosic gravel indicates that Solomon River was a trunk stream carrying material eroded from Tertiary deposits farther west. Illinoian deposits in the Republican Valley are thick water-laid silts containing imbedded gravel; in most places a thin bed of gravel lies at the base of the Illinoian deposits.

After, and in part contemporary with, Illinoian fluvatile deposition, eolian silts were deposited over a part of the upland of Cloud County. These late Illinoian and Sangamonian deposits are overlain by younger eolian silts of early Wisconsinan age, which lie upon Illinoian terrace deposits but not upon the Wisconsinan terrace deposits.

Beginning in the Wisconsinan stage, the early Illinoian deposits were partly removed, and stream channels were deepened to a point below the deepest Illinoian deposits and were later partly backfilled with deposits of sand, gravel, and silt.

During Recent time the streams have remained in their present channels. In early Recent time the Wisconsinan deposits were removed in places, the channel being cut below the Wisconsinan incision. Since this cutting cycle the streams have deposited material in the channels until at present the surface of the alluvial deposits is only about 12 feet lower than the surface of the Wisconsinan deposits.

Locally in the Republican valley prevailing winds have built up dunes on the alluvium and Wisconsinan terrace deposits. These dunes are the youngest deposits in the valleys, except for the alluvium in the active channels of the streams.

GROUND WATER

Principles of Occurence

The rocks and surficial deposits that form the crust of the earth generally are not solid but contain many open spaces, called voids or interstices. It is in these spaces that water is present below the surface of the earth and from some of which, those in the zone of saturation, a part of it is recovered through springs and wells. There are many kinds of rocks and they differ greatly in the number, size, shape, and arrangement of their interstices and therefore in their water-bearing properties. The occurrence of ground water in any region, therefore, is determined by the geology of the region.

The interstices of rocks range in size from pores of microscopic dimensions to openings several feet wide, and they can be divided into two classes, primary and secondary. The primary or original interstices, of which the commonest are pores in fragmental rocks such as sand and sandstone, were formed when the rock was deposited. The secondary interstices, the commonest of which are fractures, were formed by the different processes that affected the rock after deposition. In Cloud County all the water-bearing rocks are sedimentary rocks, and the openings that hold the water are either the open spaces between the grains of the rocks, which are primary interstices, or joints, crevices, and openings along bedding planes that have resulted from deformation of the rocks, which are secondary interstices.

The amount of water that can be stored in a rock depends upon its porosity. Porosity is expressed quantitatively as the percentage of the total volume of the rock that is occupied by interstices. When all interstices in a rock are filled with water the rock is said to be saturated. The amount of water that a saturated rock will yield to the pull of gravity is known as the specific yield. The amount of water that a given rock can hold is determined by its porosity, but the rate at which it will yield water to wells is determined by its permeability. The permeability of a rock is its ability to transmit water under a hydraulic gradient and is measured by the rate at which it will transmit water through a unit cross section under a unit loss of head per unit of distance. Beds of clay or shale may have a high porosity, but because the interstices are very small, may transmit little or no water and may be regarded as impervious. Rocks differ greatly in their permeability, according to the number and size of their interstices and the degree to which the interstices are interconnected.

Source

In Cloud County ground water is derived from precipitation in the form of rain or snow that falls on the county or on nearby areas. Part of the precipitation becomes surface runoff to streams; a large part of the precipitation is absorbed by the soil, from which much of it evaporates directly or is absorbed by vegetation and later evaporated into the atmosphere. The rest percolates slowly downward through the soil and underlying strata until it reaches the water table, where it joins the body of ground water in what is known as the zone of saturation. This is the zone saturated with water under hydrostatic pressure.

The ground water percolates slowly through the rocks in directions determined by the geology, topography, and geologic structure until it is discharged eventually through wells and springs or by evaporation and transpiration in areas where the water table is shallow.

Artesian Conditions

Artesian conditions may exist where a water-bearing bed is overlain by an impermeable or nearly impermeable bed that dips from its outcrop toward the discharge area. At the outcrop of the water-bearing bed, water percolates downward to the water table and then moves downdip beneath the impermeable bed ("confining bed"). The hydrostatic pressure of the ground water is due to the weight of the water at higher levels in the aquifer. The pressure head of water at a given point in an aquifer is its hydrostatic pressure expressed as the height of a column of water that can be supported by the pressure. The pressure head is the height that a column of water will rise in a tightly cased well that has no discharge. If the pressure in the aquifer is sufficient to lift the column of water above the top of the aquifer, artesian conditions are said to exist. A well will not flow at the surface unless the difference in height of the aquifer between the outcrop and the point of discharge is sufficient to develop a pressure equal to the weight of the column of water in the well plus the head loss caused by friction within the aquifer. To put it in another way, the head must be sufficient to raise the water above the land surface at the well.

One flowing artesian well was found in Cloud County. This well (8-1-13ad) is in a valley and flows a small quantity of water of very good quality from the Dakota Formation; the recharge area is probably the nearby upland. An oil test well drilled many years ago in the valley of Solomon River about 1 mile south of Glasco reported a strong artesian flow. No record of the head of the artesian flow or of the quality of water from this well was made. Logan (1897, p. 213) reported an artesian well having a head of 12 feet in the salt marsh near Wayne and Talmo in Republic County. Although only one flowing artesian well was found in Cloud County, probably most of the deep aquifers in the Dakota Formation are under artesian pressure, but the water does not flow at the surface because the artesian head is insufficient to raise the column of water in a well above the land surface.

The Water Table

The water table is defined as the upper surface of the zone of saturation in a porous rock (Meinzer, 1923). Where the upper surface is intersected by an impermeable rock, the water table is interrupted and artesian conditions exist. If an aquifer lies above an impermeable bed, the water contained in the aquifer may be perched and the surface of this water may be a perched water table.

The water table is not a plane surface, but is generally a sloping surface, which has irregularities caused by differences in permeability of water-bearing materials, by unequal additions to or withdrawals from the aquifer, and by topographic features. The water table is not stationary, but fluctuates in response to additions of water to or withdrawals of water from storage. Plate 2 shows the location of wells and test holes in Cloud County in which the depth to water was measured, the altitude of the water surface with respect to sea level, and contours on the water table. The water table is shown in the valley and in the upland. In the upland only those wells that were drilled into the deeper part of the Dakota Formation were used in drawing the water-table contours, inasmuch as water in the Greenhorn Limestone and very shallow water in the Dakota Formation seem to be perched or semiperched.

The shape and slope of the water table in Cloud County are shown on Plate 2 by means of contours. Each point on the water table on a given contour is at the same altitude, and the water-table contours show the configuration of the water surface just as contours on a topographic map show the configuration of the land surface. The ground water moves downslope in a direction at right angles to the contours.

In the major valleys in Cloud County the water-table contours are relatively widely spaced, indicating a downstream slope of the water table of about 5 feet per mile. Along the edges of the valleys the contours, as they enter the valley from the upland, curve sharply upstream. This indicates that water is entering the valley from the upland.

In the upland the contours are more closely spaced, indicating a steeper slope on the surface of the ground-water body. The steepest slopes lie just east and south of the outcrop of the Greenhorn Limestone and where the Dakota Formation is composed principally of sandstones on the outcrop. The steeper slopes are probably due in part to recharge in these areas. A west-northwest-trending ground-water divide crosses the county from a point near the northwest corner of T. 6 S., R. 5 W., to the northeast corner of T. 8 S., R. 1 W. Ground water from storage moving north from this divide is discharged into the drainage system of Republican River, and ground water moving south from this divide is discharged into the drainage system of Solomon and Smoky Hill Rivers. The highest point on the water table is near the northwest corner of T. 8 S., R. 2 W. This point lies on the ground-water divide, and water moves east and west as well as north and south from this point. Recharge conditions at this point are ideal and probably account at least in part for the high water table. A southwest-trending trough or saddle extends from the northeast corner of T. 6 S., R. 4 W., to a point near the southwest corner of T. 7 S., R. 5 W. Water moves toward this trough from the southeast and the northwest. This trough seems to have an important bearing on the quality of water in the area, as the water west of this trough is of poor quality whereas water nearly everywhere to the east is of good quality. Water of good quality probably moves generally westward into the trough, whereas water of poor quality moves southeastward toward the trough through the deeply buried Dakota Formation from the northwest. Waters moving into the trough mix and move down the plunge of the trough to discharge into the Solomon River valley.

The rate and direction of ground-water movement are controlled by the geology. The Dakota Formation is composed of much finer-grained materials than the alluvium and terrace deposits in the valleys, and the water-table contours shown on Plate 2 are more closely spaced in the upland than in the valleys. Movement of water through the fine material is slower than in coarse material, as it takes steeper slopes to move a given quantity of water through the fine deposits.

The water table generally reflects the surface topography. The slope of the water table in a valley is approximately equal to the slope of the land surface. Where the valley grades into the upland, the slope of the water table is steeper under the valley walls than it is in the center of the valley. This is apparent in Cloud County, as along Republican River east of Concordia (Pl. 2). Topographic slope is the chief cause of slope of the water table in the upland in Cloud County, but differences in permeability and recharge also are effective.

The water table does not remain stationary, but fluctuates vertically, as does the water level of a surface reservoir. The amount of rise and decline of the water table depends upon the amount of recharge to the ground-water body and the amount of discharge from it. When the amount of recharge exceeds the amount of discharge in the ground-water reservoir the water table rises, and when discharge exceeds recharge it declines.

Factors that tend to raise the water level are precipitation that percolates downward to the ground-water reservoir, the water that moves into the ground-water body from streams, and water entering the county by subsurface movement. Principal factors tending to cause decline of the water table are the loss of water to streams through seepage, discharge through evaporation and transpiration, discharge through pumping wells, and subsurface movement out of the county. The rise or decline of the water table over any area usually is not uniform but varies locally, owing to variation in the factors causing rise or decline. Figure 5 is a hydrograph of three wells in the Republican River valley showing rise and decline in the water table and the relation of this rise and decline to the cumulative departure from normal precipitation in the same general area. The general trend of the hydrographs is similar to the graph of the cumulative departure from normal precipitation; minor differences are caused by factors other than precipitation, local difference in permeability probably being the principal factor.

Ground-Water Recharge

The addition of water to the zone of saturation is known as ground-water recharge. Ground-water recharge in Cloud County is derived from precipitation within the county, from influent streams, and from subsurface movement from adjacent areas.

Recharge from Precipitation

Most ground-water recharge in Cloud County is derived from precipitation, which averages about 25 inches annually in the county. When the amount of precipitation absorbed by the soil is greater than the amount that can be retained there by capillary forces, the excess moves down to the zone of saturation. Usually the soil is nearly depleted of moisture by the end of the growing season, owing to evaporation and transpiration, and soil moisture must be replaced before water can move down to the zone of saturation. The amount of water that becomes recharge depends

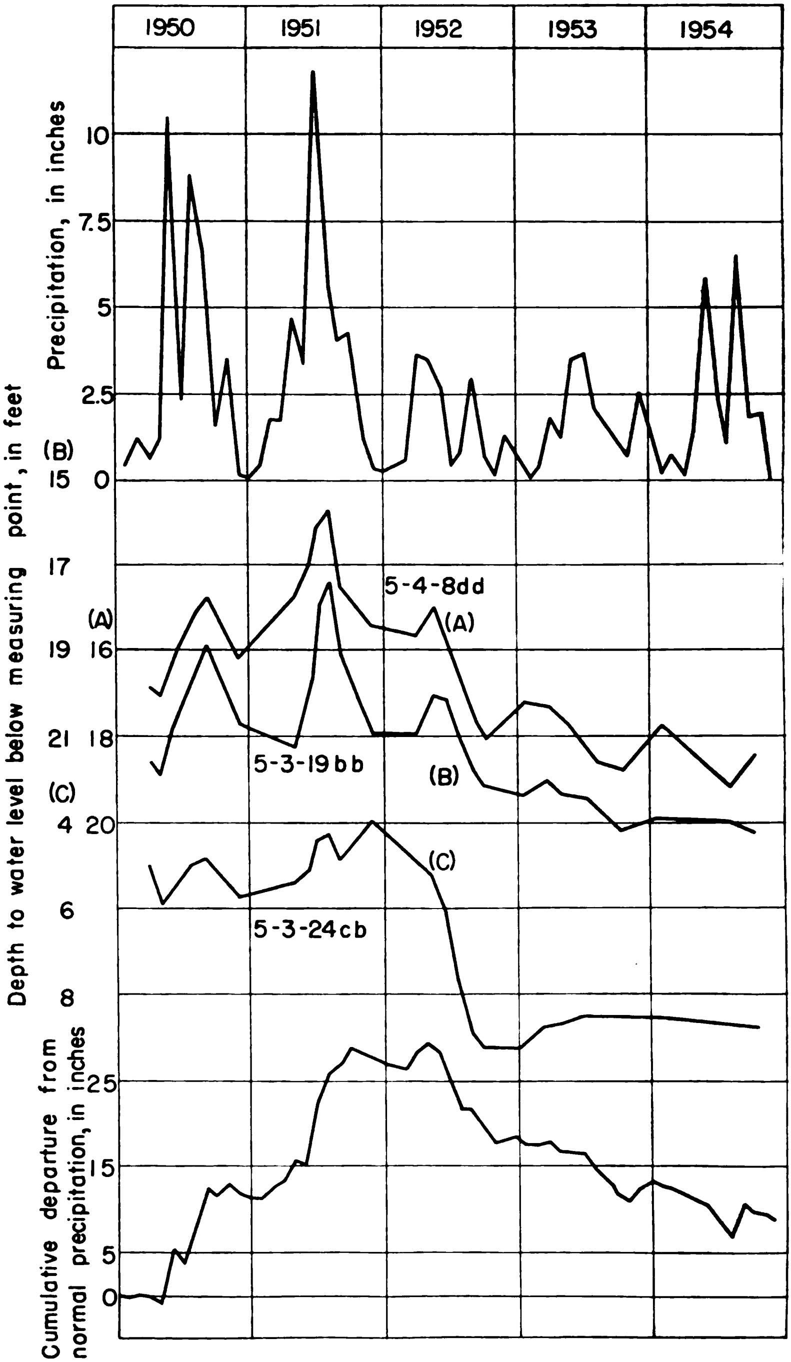

FIG. 5.—Hydrographs of three wells in Republican River valley, and graphs of precipitation and cumulative departure from normal precipitation at Concordia.

upon the soil type and the underlying material through which the water must pass to reach the zone of saturation. Thus, the sandy soils of the alluvial deposits and the sandstones of part of the Dakota Formation absorb and transmit more water than the clay soils of parts of the the Dakota Formation and loess-covered areas of the upland.

The hydrographs of the three wells and the graphs of monthly precipitation and cumulative departure from normal (Fig. 5) indicate that precipitation and fluctuations of the water table correlate closely. These wells are in the alluvial and terrace deposits of the Republican River valley. In the uplands of the county the slopes on the water table (Pl. 2) are steepest where the thick sandstone deposits of the Dakota Formation crop out. As the water table tends to be most uniform and flat where permeability of the materials is greatest, the steep slopes on the water table where the Dakota Formation crops out can be accounted for by recharge.

Seepage from Streams and Ponds

Two factors determine whether a stream will recharge the ground-water reservoir; first, the water surface in the stream must be above the water table, and second, the material between the stream channel and the ground-water reservoir must be sufficiently permeable to permit movement of water from the stream into the reservoir. The perennial streams in Cloud County probably contribute a considerable quantity of water to the ground-water reservoir in the valleys when the stage of the stream is above the water table. The valley deposits are relatively permeable, as indicated by the cross sections in Plate 3, and admit water freely. The normal gradient of the water table in the valleys is toward the streams, but this gradient is relatively small, and only a slight rise in the streams causes a considerable amount of water to enter the ground-water reservoir in the valleys. Much of this water returns to the streams, however, when their stage falls.

Recharge by Subsurface Movement

Although the principal sources of recharge in Cloud County are local precipitation and seepage from streams, considerable quantities of water are contributed to the ground-water reservoir by subsurface percolation into the county. The water-table contour map (Pl. 2) indicates that water moves into the county from the north and from the west. The quality of a part of the water moving into the county from the north is relatively good, but the quality of the water that moves into the county from the west and northwest is poor. Water that moves into the county from the north is discharged into the Republican River valley; the water that moves into the county from the west is discharged into Solomon River and Buffalo Creek.

Ground-Water Discharge

Ground water is discharged in Cloud County by transpiration and evaporation, by seepage into streams, by subsurface movement from the county, and by springs and wells. The rate of natural discharge depends greatly on the stage of the water table and the season of the year. Local differences of geology and topography cause more ground water to be discharged in some parts of the county than in others. More water is discharged from the ground-water reservoir by evaporation and transpiration adjacent to Republican and Solomon Rivers and other perennial streams than is discharged where the water table lies at greater depth. Before water was discharged by many wells in Cloud County, the quantity of perennial recharge to the ground-water reservoir and the quantity of perennial discharge were in a state of approximate equilibrium.

Discharge by Evaporation and Transpiration

Plants may draw water directly from the zone of saturation and discharge the water into the atmosphere by the process of transpiration. The rate at which water is withdrawn from the zone of saturation depends upon the type of plant, the depth of the water table, the climate, the season of the year, and the character of the soil.

Generally, the water table fluctuates in response to plant transpiration where the water table is near the land surface. The roots of some types of vegetation, especially alfalfa and some trees, are known to penetrate to great depths. In Cloud County the greatest amount of transpiration takes place in the valleys, where the water table is near the surface and where the soil is fertile and supports a vigorous vegetal growth. In the upland underlain by the Greenhorn Limestone and the Graneros Shale, most of the water that is transpired is soil moisture from the zone of aeration and little if any water is transpired from the zone of saturation. Farther east in the upland underlain by the Dakota Formation, some water probably is transpired from the zone of saturation where the water table is shallow.

Where the water table is extremely shallow, much water is evaporated from the zone of saturation after being drawn up into the zone of aeration by capillary forces. This type of discharge, like transpiration, takes place principally in the valleys.

Discharge by Seeps and Springs

A considerable quantity of water is discharged from the zone of saturation from seeps and springs, chiefly from the Dakota Formation, in the upland. A part of the water discharged by the seeps and springs is evaporated and a part runs off at the surface. Streams that are lower than the water table in surrounding deposits can contribute no water to the ground-water reservoir; instead, water is discharged into the streams from the ground-water reservoir. The water-table contours (Pl. 2) indicate that ground water moves toward the perennial streams and is discharging into them as effluent seepage. The water-table contours are based on measurements taken during the growing season. In the late fall after the first killing frost, when discharge by transpiration is at a minimum, considerably more water is available for discharge by seepage and springs, and probably the water table in the valleys rises slightly.

Discharge by Subsurface Movement

The water-table contours (Pl. 2) indicate that the water table slopes in general from west to east except along the edges of the principal valleys, where the direction of movement is toward the streams. Some water is discharged by subsurface movement into areas adjacent to the county, but much more water flows into the streams and leaves the county on the surface.

Discharge by Wells

The preceding discussion treats the natural discharge of ground water, which accounts for the greater part of ground-water discharge in Cloud County. The rest of the water is discharged by wells and is discussed under recovery of ground water. All the well water, of course, ultimately leaves the county by evapotranspiration or liquid outflow, adding to the quantities naturally discharged in those ways.

Recovery of Ground Water

Principles of Recovery

When water is standing in a well, static equilibrium exists between its head and the head of water in the aquifer outside the well. When water is withdrawn from the well, a difference in head is created between water inside the well and water outside the well. The water table in the vicinity of the well develops a cone of depression (Fig. 6), which is deepest at the wall of the well and extends some distance from the well. The greater the pumping rate in a well, the greater the drawdown. The specific capacity of a well is the rate of yield per unit of drawdown and is generally stated in gallons a minute per foot of drawdown.

The character of the water-bearing material controls the yield, drawdown, and specific capacity of a well. If the water-bearing material is coarse and well sorted, it will readily yield large quantities of water at a minimum drawdown. If the material is fine or poorly sorted, it will offer much resistance to the flow of water and decrease the yield and increase the drawdown. All other things being equal, the drawdown of a well varies inversely with the permeability of the water-bearing material.

Types of Wells

Several different types of wells are used for water supplies. The types of wells are generally differentiated by the method of construction. Selection of the type of well to be constructed generally de-

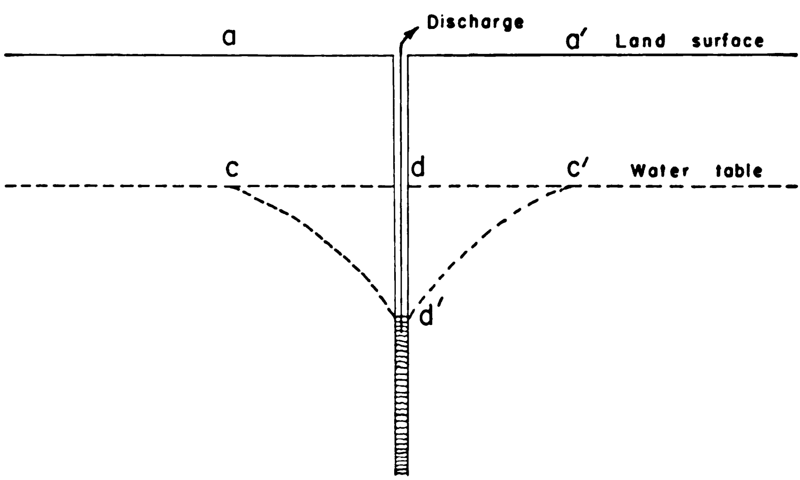

Fig. 6.—Diagrammatic section of a well being pumped, showing its drawdown, cone of depression, and radius of influence.

pends on the use for which the well is constructed, the geologic materials to be penetrated by the well, the depth to water, and the depth to which the well is to be dug or drilled.

Dug wells.—Dug wells are wells that have been excavated by hand, generally by use of pick and shovel. They are walled with stone, brick, wood, or concrete. Most dug wells are shallow. When

Cloud County was being settled many wells were dug, because no specialized equipment was needed to construct a dug well. In the upland, where only small yields can be expected from wells, dug wells are preferred because a large-diameter well acts as a storage reservoir to collect water for intermittent pumping. This advantage of a large-diameter well may be offset by the disadvantage that sealing such a well from surficial contamination is difficult.

Driven wells.—Most driven wells are 1¼ to 2½ inches in diameter and are constructed by driving a pipe having a well point or screen on the end until the point is below the water table. Water is recovered by a simple lift pump. Wells are driven only in areas of unconsolidated deposits in which the depth to water is less than about 25 feet. In Cloud County such areas are found only in the valleys.

Drilled wells.—At the present time most wells being constructed in Cloud County are drilled. Drilled wells are constructed with either a percussion or a rotary drilling machine. Nearly all are 4½ inches or more in diameter and some are more than 40 inches in diameter. The use for which the well is drilled generally determines the diameter. Most domestic and stock wells are small, 4½ to 8 inches, whereas municipal and irrigation wells are larger. The depth of drilled wells in Cloud County ranges from only a few feet to nearly 300 feet. Most wells in the upland obtain water from the Dakota Formation. In some wells the water in the upper part of the hole is cased off and only the lower part of the hole is left open to admit water. In others only the uppermost part of the hole is cased, the greater part of the hole being left uncased.

Many wells in the unconsolidated deposits in the valleys are drilled. These wells are drilled into the unconsolidated deposits, and a casing having a screen on the end is installed to prevent the sand and gravel from entering the well. In wells from which only small yields are expected, the length and type of screen are of minor importance, except that the screen openings should be of the correct size to keep out sand. In large-capacity wells, however, the size and length of screen are important. A municipal well or an irrigation well should be constructed with the maximum obtainable efficiency. It should be constructed and screened so that it will not admit sand after being developed properly. The maximum amount of water available from a well is determined by the materials in which it is constructed, and it is the problem of the driller to construct the well so that the maximum amount of water can be pumped with the least drawdown.

Utilization of Water

In Cloud County ground water is used chiefly for domestic and stock supplies and public supplies, although since 1953 considerable interest has been shown in the use of ground water for irrigation. A small amount of water is used for industrial purposes.

Domestic and Stock Supplies

Nearly all domestic and stock water supplies in rural areas and domestic supplies in towns having no public supply are obtained from wells. In the valleys these water supplies are obtained principally from driven and drilled wells; in the upland, from dug and drilled wells. In recent years much stock water has been obtained from ponds, to save the well water for domestic and auxiliary stock supplies.

Public Supplies

Aurora.—The Aurora water supply is obtained from two wells (7-2-15ba1 and 7-2-15ba2) in the southeastern part of the city. These wells were drilled in 1928 and are about 200 feet deep. They are 6 inches in diameter and are equipped with small rotary pumps. Water is obtained from the Dakota Formation. The water is pumped from the wells to an elevated steel tank having a capacity of 55,000 gallons. The maximum yield of the two wells is about 120,000 gallons per day, and the average daily use is about 10,000 gallons. The water, which is chlorinated at the wells, is metered to the customers. The chemical quality of the water from the Aurora wells is shown by an analysis in Table 3.

Concordia.—The Concordia water supply is obtained from 14 wells, 10 in the alluvium and terrace deposits of the Republican River valley at the northwest edge of the city and 4 within the city that obtain water from the Dakota Formation. Eight of the wells in the alluvium and terrace deposits are pumped by air lift and were drilled by the Air Made Well Co. in 1925-26. The depths of these wells range from 118 to 123 feet, although the wells penetrate only about 60 to 80 feet of alluvial material. They were drilled to a greater depth to obtain enough submergence so that the wells could be pumped by air. The other wells are equipped with turbine pumps. The wells in the valley are pumped at a rate of about 250 gpm each and those in the upland, about 60 gpm each. The city has two elevated steel tanks for storage, one having a capacity of 30,000 gallons and the other a capacity of 300,000 gallons. The maximum rated capacity of the water system is 3 million gallons per day and the average daily use is 1 million gallons. The water is chlorinated but receives no other treatment.

Clyde.—The Clyde water supply is obtained from two drilled wells (5-1-26ad1 and 5-1-26ad2) at the east edge of the city. These wells produce water from the Dakota Formation and are 158 feet deep. The wells are equipped with turbine pumps and each yields about 300 gpm. The water is pumped to a treatment plant, where it is softened by the lime-soda process and then chlorinated. A steel standpipe provides storage capacity of 380,000 gallons; average daily use is about 150,000 gallons. The analysis of raw water from one well (5-1-26ad2) is given in Table 3.

Glasco.—The Glasco water supply is obtained from two wells at the west edge of the town, which penetrate terrace deposits along Solomon River. Well 8-5-14bad1, 51 feet deep and 16 inches in diameter, gravel packed, was drilled by the Layne-Western Co. in 1931. The yield of this well is about 250 gpm. Well 8-5-14bad2 was dug in 1938 by W. P. A. labor and is 47 feet deep, 9 feet in diameter, and cased with concrete casing. It yields about 150 gpm. Both wells are equipped with turbine pumps. Water is chlorinated at the wells and delivered from a 50,000-gallon elevated steel tank to customers through meters. The maximum rated capacity of the wells is about 580,000 gallons per day and the average daily use is about 65,000 gallons.

Miltonvale.—The Miltonvale water supply is obtained from two wells within the city limits. These wells yield water from the Dakota Formation at a depth of 100 feet. Well 8-1-17dc1 yields about 250 gpm and well 8-1-17dc2 yields about 200 gpm. The maximum capacity of the wells is about 650,000 gallons per day, and the average daily use is about 60,000 gallons. The water is chlorinated and is pumped to a 50,000-gallon elevated steel tank. Analyses of the water from the Miltonvale wells are given in Table 3.

Jamestown.—The Jamestown water supply is obtained from three wells (5-5-22da) at the east edge of the city. The wells are drilled in terrace deposits along Buffalo Creek and are 140 feet deep. Two of the wells are equipped with cylinder pumps and the third with a turbine pump. The turbine-equipped well yields about 35 gpm. The water is chlorinated at the wells and pumped to an elevated steel tank of 50,000-gallon capacity. Maximum daily capacity of the supply is 110,000 gallons, and the average daily use is about 60,000 gallons.

Industrial Supplies

The quantity of water used for industrial supplies in Cloud County is comparatively small. Only four industrial wells were inventoried during the course of the investigation. These wells are used for cooling by the Natural Gas Pipeline Co. of America and are in the SE¼ sec. 7, T. 8 S., R. 4 W. The wells range in depth from 135 to 150 feet; they yield water from the Dakota Formation at rates ranging from 30 to 135 gpm per well.

Irrigation Supplies

Considerable interest in irrigation was shown in Cloud County in the period 1940-42, after the preceding years of severe drought. Several irrigation wells were drilled at that time, but during the next several years of adequate rainfall some of these wells were used only intermittently if at all. Since the dry years of 1952-55, interest in irrigation has revived. A few operators use water from streams for irrigation. W. A. Davidson pumps water from Solomon River in sec. 8, T. 8 S., R. 5 W., to irrigate chiefly corn and alfalfa. The amount pumped in 1953 was about 40 acre-feet. Elmo St. Pierre pumps water from Republican River in sec. 19, T. 5 S., R. 2 W., to irrigate corn and alfalfa also. C. H. Blosser pumps water from an old sand pit in sec 28, T. 5 S., R. 3 W., to irrigate alfalfa. Dan Mahon pumps from Republican River in sec. 29, T. 5 S., R. 2 W., to irrigate corn and alfalfa.

Eleven wells were in operation in the valleys of Republican and Solomon Rivers in 1954. These wells had an aggregate pumping capacity of about 9,000 gpm, or about 40 acre-feet per day, but were not pumped at full capacity.

The continued drought in 1955 intensified the interest in well irrigation in the county, and additional wells were drilled. By the end of October 1955, 37 wells were in operation or ready to operate. Their combined capacity was about 35,000 gpm, or 155 acre-feet per day. In the 1-year period the number of wells increased by 26 and the total capacity by about 26,000 gpm. The pumpage of water for irrigation in 1955 was probably about 3,500 acre-feet.

A map (Fig. 7) of the valleys of Republican River and Buffalo Creek was drawn to show the configuration of the pre-Pleistocene surface. A saturated-thickness map (Fig. 8) was then prepared by superimposing the water-table contour map (Pl. 2) over the bedrock map and connecting points of equal saturation. From this map the total volume of saturated material in the valleys was calculated for each township. By applying an estimated figure of 20 percent for specific yield, the volume of water in storage was calculated. The volume of water in storage in each township in the valleys is given in Table 2.

The volume of water in storage (Table 2) is equal to the volume of water that would be pumped in about 200 years at the 1955 rate of pumping from the valleys for irrigation and municipal supplies, considering no recharge to the valleys. The water-table contour map (Pl. 2) indicates that water moves into the valleys from the upland bordering the valleys, and although no estimate of the quantity thus contributed is made, it is considerable. Water also moves into the county in Republican River. Streamflow

TABLE 2.—*Volume of saturated material in Republican River and Buffalo Creek valleys in Cloud County, and total volume of water in storage theoretically available for pumping, based on a specific yield of 20 percent.*

TOWNSHIP	Volume of water-bearing materials, acre-feet	Volume of water, acre-feet (rounded)
T. 5 S., R. 1 W.	640,000	130,000
T. 5 S., R. 2 W.	520,000	100,000
T. 5 S., R. 3 W.	760,000	150,000
T. 5 S., R. 4 W.	1,200,000	240,000
T. 5 S., R. 5 W.	760,000	150,000
T. 6 S., R. 1 W.	200,000	40,000
Total	4,100,000	820,000

records at Concordia dating from 1946 indicate that the minimum flow in that period was 40 cubic feet per second in September 1952. This quantity of water is equal to about 80 acre-feet per day, or about half the quantity that could be pumped in one day from the 1955 installations. Recent completion of reservoirs on Republican River in Nebraska and Colorado has made it possible to maintain a flow in the river of at least 50 second-feet.

CHEMICAL CHARACTER OF WATER

The general chemical character of ground water in Cloud County is indicated by the analyses of 62 samples of water from wells and test holes distributed as uniformly as practicable within the area and among the principal water-bearing formations (Fig. 9, 10; Table 3).

In several test holes, samples of water were taken at different depths within the same hole in order to determine the relation

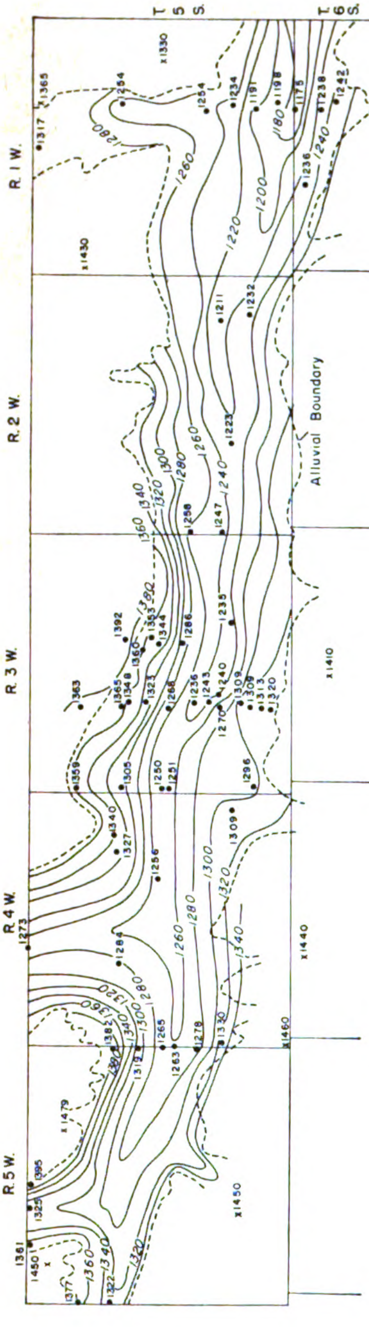

FIG. 7.—Map showing configuration of pre-Pleistocene surface in Republican River and Buffalo Creek valleys in Cloud County.

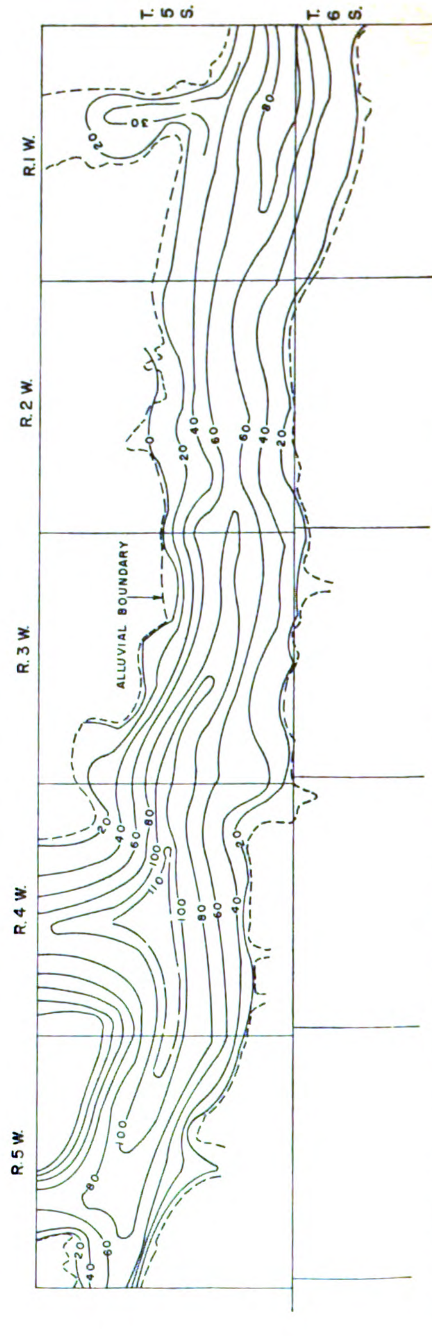

FIG. 8.—Map showing saturated thickness of Pleistocene deposits in Republican River and Buffalo Creek valleys in Cloud County.

between depth and quality of water. The numbers of these wells are repeated in Table 3 and the depth given is the depth at which the sample was taken. For all other wells the depth given is the depth of the well. Table 3 includes the analyses of 42 samples of water from the Dakota Formation, 15 samples of water from terrace deposits, and 5 samples of water from alluvial deposits. Analyses of public water supplies in the county are on file in the office of the Division of Sanitation of the Kansas State Board of Health. The samples of water were analyzed by Howard A. Stoltenberg, chemist, in the Water and Sewage Laboratory of the Kansas State Board of Health.

Chemical Constituents in Relation to Use

The following discussion of the chemical constituents of ground water has been adapted from publications of the U. S. Geological Survey.

Dissolved solids.—The residue left after a natural water has evaporated consists chiefly of rock materials but may include some organic material and some water of crystallization. Waters containing less than 500 parts per million of dissolved solids generally are satisfactory for domestic use, except for the difficulties resulting from their hardness and, in some areas, excessive iron content or corrosiveness. Waters having more than 1,000 ppm as a rule are not satisfactory, for they are likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in some other respect.

The waters in 27 of the 62 wells sampled in Cloud County contained less than 500 ppm of dissolved solids and are generally satisfactory for ordinary purposes. The water from 16 of the wells sampled in Cloud County contained 500 to 1,000 ppm of dissolved solids, and 18 contained more than 1,000 ppm of dissolved solids. Some very strong concentrations of dissolved solids were measured in samples from deep test holes in the Dakota Formation.

Hardness.—The hardness of water, which is the property that generally receives the most attention, is most commonly recognized by its effects when soap is used with water. Hard water is objectionable because it forms with soap a sticky insoluble curd difficult to remove from containers and fabrics, requires greater quantities of soap to produce lather, and forms scale in boilers and pipes, which reduces efficiency of heat transfer and may cause boiler failure. Calcium and magnesium cause virtually all the hardness

Table 3.—*Analyses of water from typical wells and test holes in Cloud County*

Analyzed by H. A. Stoltenberg. Dissolved constituents given in parts per million [a]

Well number	Depth, feet (b)	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	Carbonate	Noncarbonate
5-1-26ad2	158	Dakota Formation	8- 4-54	56	342	23	0.42	73	11	37	300	31	19	0.3	0.4	227	227	0
5-2-30bcc	38-40	Alluvium	6-12-54	57	1,110	31	...	38	11	365	351	118	368	.9	.9	140	140	0
5-2-30bcc	76-78	do	6-12-54	57	13,000	32	1.9	229	141	4,470	703	1,690	6,010	.9	5.3	1,150	576	575
5-3-15ab	340-341	Dakota Formation	10-18-55	56	32,000	...	...	412	353	11,300	870	3,510	16,000	...	...	2,750	714	1,770
5-3-18bbb	95-100	Terrace deposits	6-10-54	57	427	24	...	92	12	48	344	34	44	.2	3.3	279	279	0
5-3-19cb	62-67	do	6- 8-54	58	294	22	.86	47	12	38	200	57	17	.6	1.1	166	164	2
*5-3-22bc	78	Alluvium	4-15-43	...	4,590	...	...	107	59	1,650	415	468	2,150	.4	16	510	340	170
5-3-31bb	32-37	Terrace deposits	6- 3-54	56	659	35	...	107	21	104	459	82	80	.4	3.5	354	354	0
*5-3-32aa1	122	do	1- 2-45	...	589	...	...	110	17	78	381	91	72	.5	5.8	344	312	32
5-3-32aa2	122	do	...	...	728	8.6	.16	118	23	112	520	83	80	.4	5.3	389	389	0
5-3-32aa3	62	do	8- 4-54	...	596	31	.22	81	14	116	346	69	110	.4	1.1	260	260	0
5-5-4aab	78-80	Dakota Formation	11- 5-53	...	708	12	...	72	8.0	191	361	35	205	.4	7.1	212	212	0
5-5-4aab	158-160	do	11-17-53	...	33,200	20	...	206	392	11,900	1,210	3,660	16,400	1.6	19	2,120	994	1,130
5-5-4aab	400-402	do	11-17-53	...	36,000	19	...	210	431	12,900	1,280	3,960	17,800	1.6	17	2,300	1,050	1,250
5-5-4bb	49-53	Terrace deposits	10-30-53	...	19,200	28	...	285	242	6,670	858	2,250	9,310	1.5	28	1,710	704	1,000
5-5-7cc	53-55	do	5-18-54	57	2,940	23	...	107	40	944	508	416	1,150	.6	6.6	432	416	16
5-5-22da	140	do	7- 7-53	...	486	6.0	.06	116	11	49	364	72	43	.3	7.1	334	298	36
5-5-24dd	55-57	do	5-20-54	57	411	14	...	74	10	68	353	41	28	.4	1.3	226	226	0
6-1-3aa	36-41	Alluvium	6-15-54	57	392	25	.93	85	11	43	344	37	21	.3	.9	257	257	0
6-1-3aa	72-77	do	6-15-54	57	424	14	2.0	93	11	49	351	64	19	.3	.4	277	277	0
6-1-10cc	87	Dakota Formation	3- 4-54	54	293	11	.94	66	9.6	29	251	39	13	.2	1.7	204	204	0
6-1-24aa1	75	do	3- 4-54	54	1,190	11	2.3	221	48	53	105	17	203	.1	589	749	86	663
6-1-24aa1	75	do	6- 9-54	55	1,190	14	3.5	224	48	50	100	19	212	.1	571	752	82	670
6-1-24aa2	62	do	10-22-54	55	...	...	...	...	...	...	...	...	...	...	6.2	...	...	...
6-2-9dad	80	do	3- 4-54	55	413	14	4.3	82	13	53	283	45	64	.3	2.9	258	232	26
6-2-24cc	...	do	6- 9-54	56	304	12	...	29	7.2	73	156	41	62	.4	2.5	102	102	0
6-2-33dc	68-70	do	10- 6-54	58	286	15	...	48	13	39	210	25	40	1.1	1.5	174	172	2
6-2-33dc	138-140	do	10- 6-54	57	486	11	...	47	11	124	307	54	85	.6	2.3	162	162	0
6-2-33dc	233-235	do	10- 6-54	57	465	14	.69	53	13	105	305	52	75	.6	2.2	186	186	0
*6-3-4dc	...	do	3- 3-47	...	506	24	1.2	13.7	9.6	23	378	74	7.5	.2	42	382	310	72
*6-3-6dc	305	do	11- 3-42	58	938	...	5.7	7.8	2.8	371	677	93	70	9	4.1	31	31	0
6-4-5da	58	do	3- 3-54	54	703	22	.56	176	13	48	398	48	98	.1	102	492	326	166
6-4-12cd	90	do	3- 3-54	...	302	7.4	27	70	9.2	31	256	32	25	.4	.7	212	210	2
6-4-34cc	168-170	do	9-29-54	59	362	24	...	96	8.9	23	337	31	12	.3	.4	276	276	0

6-4-34cc	378-380	do	9-28-54	59	378	24	....	96	8.9	30	351	32	13	.3	.5	276	276	0
*6-4-36cb	308	do	11- 3-42	56	1,750	....	7.6	7.6	5.0	681	733	151	490	5.5	5.8	40	40	0
6-5-6cb	190	do	3- 3-54	54	953	7.4	3.1	20	13	341	501	74	247	2.6	1.1	104	104	0
6-5-26ab	....	do	3- 3-54	52	2,130	12	.80	171	42	529	661	565	370	.9	120	599	542	57
7-1-29aba	67	do	3- 4-54	54	259	9.0	.27	43	11	25	95	26	36	.2	62	152	78	74
ᶜ7-2-15ba1-2	200	do	7-20-54	....	424	20	1.5	109	15	30	376	73	9.0	.3	1.8	334	308	26
7-2-18ab	....	do	3- 4-54	54	474	2.0	2.7	104	24	41	405	86	17	.4	1.1	358	332	26
7-3-21ba	342	do	3- 4-54	54	741	5.6	8.4	60	22	193	522	153	48	1.4	1.5	240	240	0
7-3-35cb	75	do	3- 3-54	54	1,210	23	25	299	15	46	122	693	36	.8	42	908	100	708
7-4-22bb	183	do	3- 3-54	54	930	5.8	3.8	172	24	124	322	258	186	.3	1.7	528	264	264
7-5-8cc	148-150	do	9-17-54	59	15,700	6.5	....	123	332	5,320	1,450	2,470	6,710	2.0	1.8	1,670	1,200	476
7-5-8cc	258-260	do	9-17-54	59	19,800	7.0	....	180	438	6,650	1,590	3,210	8,560	1.6	1.8	2,250	1,300	945
7-5-8cc	378-380	do	9-16-54	59	18,900	6.0	....	182	413	6,340	1,580	3,040	8,130	1.7	1.3	2,150	1,300	853
7-5-13bad	240	do	3- 3-54	51	684	7.8	....	4.9	3.8	263	554	112	17	1.0	1.9	28	28	0
8-1-13ad	200	do	3- 5-54	53	176	9.2	2.9	34	5.6	24	159	16	8.0	.2	1.5	108	108	0
8-1-17dc1	100	do	6-11-52	....	315	9.4	.06	61	15	20	159	56	19	.3	49	214	130	84
8-1-17dc2	100	do	7-20-53	....	415	11	.18	76	18	34	170	54	49	.3	88	264	139	125
8-2-16dc	181	do	3- 4-54	54	257	21	.23	59	8.8	19	212	36	8.0	.3	1.3	183	174	9
8-2-36aa	69	do	3- 4-54	54	224	31	.44	32	9.2	28	154	31	12	.3	4.0	118	118	0
8-3-26cc	31	do	3- 3-54	54	711	23	1.6	98	18	99	212	54	40	.3	305	318	174	144
8-4-8ddc1	70	do	3- 3-54	54	383	21	.07	85	13	36	318	45	24	.2	1.7	266	261	5
8-4-8ddc2	50	do	3- 3-54	54	426	23	.08	2.4	1.6	163	373	28	19	.5	4.4	12	12	0
8-4-23cbd	128	do	3- 3-54	55	394	16	.68	88	12	42	353	44	16	.4	1.3	269	269	0
8-5-7cb	46-48	Terrace deposits	10-20-53	....	550	28	1.4	103	16	79	464	55	39	.1	2.1	323	323	0
8-5-14bad1	51	do	9-29-52	....	1,560	19	.07	218	35	254	488	144	423	.3	115	688	400	288
8-5-14bad2	47	do	1-29-54	....	1,190	24	.3	146	23	260	451	120	359	.3	27	458	370	88
8-5-17dca	22	do	3- 3-54	54	828	18	1.1	217	19	43	516	184	40	.2	53	620	423	197
8-5-25cc	50	do	3- 3-54	54	574	22	6.9	75	18	119	440	38	83	.4	1.5	261	261	0

a. 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.

b. Single figure denotes depth of well. Range of depth indicates depth from which sample was pumped.

c. Composite sample from city main.

* Taken from Kansas Geological Survey Bulletin 73 (Fishel, 1948).

of ordinary water. These constituents are also the active agents in the formation of the greater part of the scale in steam boilers and in other vessels in which water is heated or evaporated.

In addition to the total hardness the table of analyses shows the carbonate hardness and the noncarbonate hardness. The carbonate hardness is that due to the presence of calcium and magnesium bi-

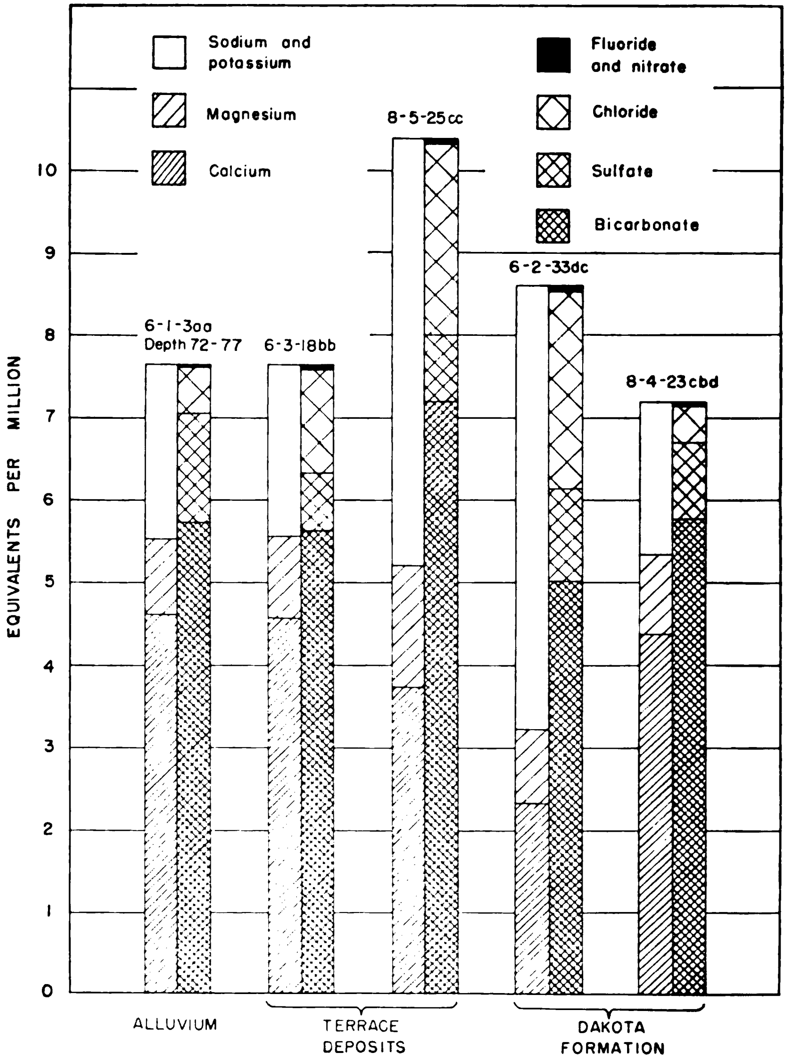

FIG. 9.—Graphic representation of analyses of water from principal water-bearing formations in Cloud County.

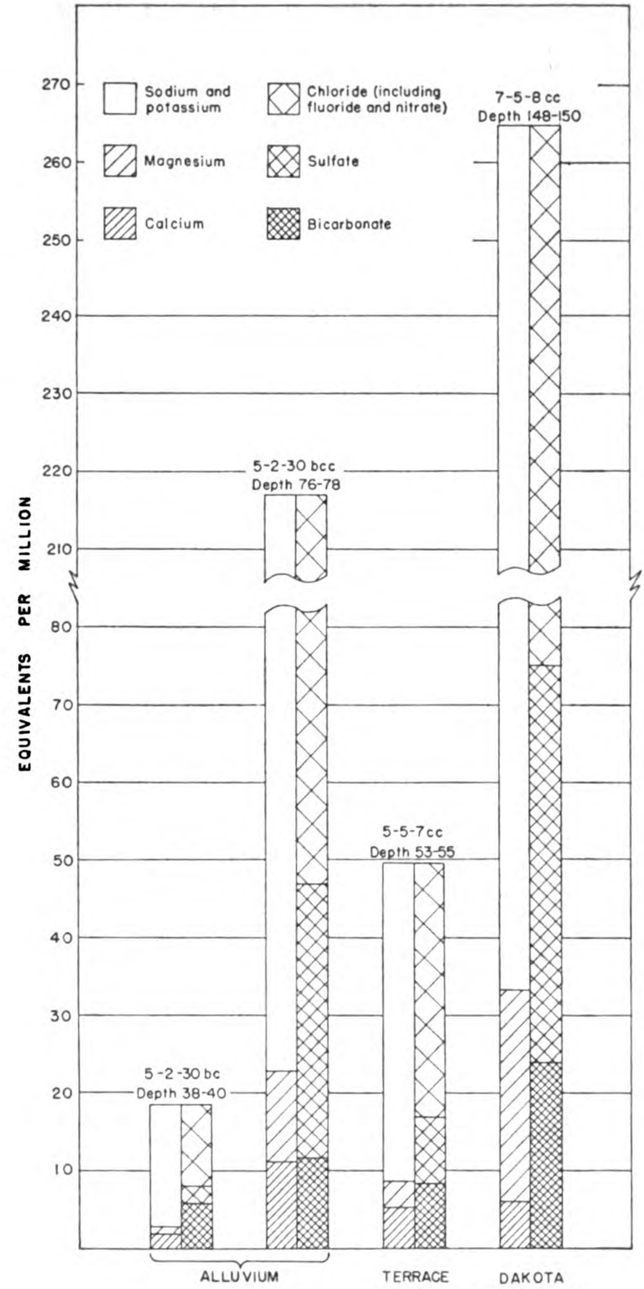

Fig. 10.—Graphic representation of analyses of mineralized water from principal water-bearing formations in Cloud County.

carbonates. It is almost completely removed by boiling; this type of hardness is called temporary hardness. The noncarbonate hardness is due to the presence of sulfates or chlorides of calcium and magnesium; it cannot be removed by boiling and hence has sometimes been called permanent hardness. With reference to use with soap there is no difference between the carbonate and noncarbonate hardness. In general the noncarbonate hardness forms harder scale in steam boilers.

Water having a hardness of less than 50 ppm is generally rated as soft, and under ordinary circumstances treatment to reduce hardness is not necessary. Hardness between 50 and 150 ppm does not interfere seriously with the use of water for most purposes, but it does increase somewhat the consumption of soap, and treatment by a softening process is profitable for laundries or other industries using large quantities of soap. Water in the upper part of this range of hardness will cause considerable scale in steam boilers. Hardness of more than 150 ppm can be noticed by anyone, and if the hardness is 200 or 300 ppm, it is common practice to soften water for household use or to install cisterns to collect soft rainwater. Where municipal water supplies are softened, hardness is generally reduced to about 80 ppm. The additional improvement from further softening of a public supply is not deemed worth the increase in cost.

Of the 61 samples of water from Cloud County that were analyzed for hardness, 9 had hardness of less than 150 ppm, 24 had hardness of 150 to 300 ppm, and 28 had hardness of 300 ppm or more.

Iron.—If water contains much more than 0.3 ppm of iron, the excess may precipitate and settle as a reddish sediment when exposed to the air. Iron, which may be present in sufficient quantity to give a disagreeable taste or to stain cooking utensils, may be removed from most water by aeration and filtration, but some waters require additional treatment.

Water samples from most of the test holes in Cloud County were pumped by the air-lift method. The resulting aeration of the water during pumping resulted in removal of much of the iron, so samples pumped by the air-lift method were not analyzed for iron. Of 40 samples of water from Cloud County, 5 contained less than 0.1 ppm of iron, 15 contained 0.1 to 1.0 ppm, 10 contained 1.0 to 3.0 ppm, and 10 contained 3.0 ppm or more.

Fluoride.—Although fluoride is usually present only in small quantities in ground water, the amount of fluoride present in water used by children should be known. Fluoride in water is associated with the dental defect known as mottled enamel, which may appear on the teeth of children who, during the formation of the permanent teeth, drink water containing too much fluoride. Dean (1936, p. 1,270) has described the effects of fluoride in drinking water on the teeth of children.

> From the continuous use of water containing 1 part per million, it is probable that the very mildest forms of mottled enamel may develop in about 10 per cent of the group. In waters containing 1.7 or 1.8 parts per million, the incidence may be expected to rise 40 or 50 per cent, although the percentage distribution of severity would be largely of the "very mild" and "mild" types. At 2.5 parts per million an incidence of about 75 to 80 per cent might be expected, with possibly 20 to 25 per cent of all cases falling into the "moderate" or severer type. A scattering few may show the "moderately severe" type.
>
> At 4 parts per million the incidence is, in general, in the neighborhood of 90 per cent, and as a rule, 35 per cent or more of the children are classified as "moderate" or worse. In concentrations of 6 parts per million or higher an incidence of 100 per cent is not unusual.

Recent studies (Dean and others, 1941) have indicated that, whereas fluoride in amounts exceeding 1.5 ppm may be detrimental because of mottling of the teeth of children, fluoride in quantities less than 1.5 ppm is beneficial in helping to prevent tooth decay.

The fluoride content of most of the water samples from Cloud County was low. Of 60 samples analyzed for fluoride, 48 contained less than 1.0 ppm, 3 contained 1.0 to 1.5 ppm, and 9 contained more than 1.5 ppm.

Chloride.—Chloride is widely distributed in nature; it is an abundant constituent of sea water and oil-field brines and is dissolved from most rock materials. Chloride has little effect on the suitability of water for ordinary use unless enough chloride salts are present to impart a salty taste or to cause the water to be corrosive. The removal of chloride from water is difficult and expensive.

Chloride salts in solution giving less than 250 ppm of chloride cannot be detected by taste, and waters of such purity are regarded as satisfactory for ordinary uses. Waters containing concentrations of chloride between 250 and 500 ppm may have a slight salty taste but can be used for drinking and household uses. Water having chloride concentrations between 500 and 750 ppm will have a disagreeable taste, but even such salty water may be consumed by human beings with no ill effects. Cattle have a fair tolerance for mineralized water. Although fresh water is preferable it is reported that cattle can drink water having a chloride content of 5,000 ppm.

Of the 61 samples of water that were analyzed for chloride, 46 contained less than 250 ppm, 5 contained 250 to 500 ppm, none of the samples contained 500 to 750 ppm, 2 samples contained 750 to 5,000 ppm, 4 contained 5,000 to 9,000 ppm, and 4 contained 9,000 ppm or more of chloride.

Nitrate.—The use of water containing an excessive amount of nitrate in the preparation of a baby's formula can cause cyanosis ("blue baby"), or oxygen starvation. Some authorities advocate that water containing more than 45 ppm of nitrate should not be used in preparation of formulas for infant feeding (Metzler and Stoltenberg, 1950). Water containing 90 ppm of nitrate generally is regarded as dangerous to infants, and water containing 150 ppm may cause severe cyanosis. Cyanosis is not produced in adults and older children by these concentrations of nitrate in drinking water. Boiling of water that contains excessive nitrate does not render it safe for use by infants; therefore, only water that is known to be low in nitrate should be used for this purpose. Several cases of severe cyanosis have been reported from Cloud County in recent years.

The nitrate content of the water from some wells is somewhat seasonal, being highest in the winter and lowest in the summer (Metzler and Stoltenberg, 1950). The water in well 6-1-24aa1 contained 589 ppm of nitrate on March 4, 1954, and 571 ppm on June 9, 1954. Therefore in October 1954 well 6-1-24aa2 was drilled to replace well 6-1-24aa1. Well 6-1-24aa2 is located about 250 feet west of well 6-1-24aa1. On October 22, 1954, the water in the new well contained only 6.2 ppm of nitrate. In general, water from wells that are most susceptible to surface contamination is likely to contain excessive nitrate.

Of 61 water samples from Cloud County, 51 contained less than 45 ppm of nitrate, 4 contained 45 to 90 ppm, 3 contained 90 to 150 ppm, and 3 contained 150 ppm or more.

Sulfate.—Sulfate in ground water is derived principally from the minerals gypsum or anhydrite (calcium sulfate) and from the oxidation of pyrite (iron disulfide). Magnesium sulfate (Epsom salts) and sodium sulfate (Glauber's salt), if present in sufficient quantity, will impart a bitter taste to the water, and the water may have laxative effect upon people who are not accustomed to drinking it.

Of 61 samples of water from Cloud County that were analyzed for sulfate, 23 contained less than 50 ppm, 25 contained 50 to 200 ppm, and 13 contained 200 ppm or more of sulfate.

Water for Irrigation

This discussion of the suitability of water for irrigation is adapted from Agriculture Handbook Number 60, U. S. Department of Agriculture (U. S. Salinity Laboratory Staff, 1954).

The development and maintenance of successful irrigation projects involve not only the supplying of irrigation water to the land but also the control of the salinity and alkalinity of the soil. The quality of irrigation water, irrigation practices, and drainage conditions are involved in salinity and alkali control. 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.

In areas of sufficient rainfall and ideal soil conditions the soluble salts originally present in the soil or added to the soil with water are carried downward by the water and ultimately reach the water table. This process of dissolving and transporting soluble salts by the downward movement of water through the soil is called leaching. If the amount of water applied to the soil does not exceed the amount needed by plants, water will not percolate down below the root zone, and mineral matter will accumulate in the root zone. Likewise, impermeable soil zones near the surface can retard the downward movement of water, resulting in waterlogging of the soil and deposition of salts. Unless drainage is adequate, attempts at leaching may not be successful, because leaching requires the free passage of water through and away from the root zone.

The characteristics of an irrigation water that seem to be most important in determining its quality are: (1) total concentration of soluble salts; (2) relative proportion of sodium to other cations (magnesium, calcium, and potassium); (3) concentration of boron or other elements that may be toxic; and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium.

For purposes of diagnosis and classification the total concentration of soluble salts in irrigation water can be adequately expressed in terms of electrical conductivity. Electrical conductivity is a measure of the ability of water having inorganic salts in solution to conduct an electrical current, and is usually expressed in terms of micromhos per centimeter. The electrical conductivity can be determined accurately in the laboratory, or an approximation of the electrical conductivity can be obtained by multiplying the total equivalents per million of anions by 100, or by dividing the total dissolved solids in parts per million by 0.64. Factors for converting parts per million to equivalents per million are given in Table 4. For example, to convert parts per million of calcium to equivalents per million, multiply the parts per million of calcium by 0.0499.

TABLE 4.—*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
		Cl^-	.0282
Na^+	.0435	NO_3^-	.0161
		F^-	.0526

In general, waters whose electrical conductivity does not exceed 750 micromhos per centimeter are satisfactory for irrigation insofar as salt content is concerned, although salt-sensitive crops such as strawberries, green beans, and red clover may be adversely affected by irrigation water having an electrical conductivity in the range of 250 to 750 micromhos per centimeter. Waters having an electrical conductivity in the range of 750 to 2,250 micromhos per centimeter are 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. Use of waters having a conductivity in excess of 2,250 micromhos per centimeter is the exception, and very few instances can be cited where such waters have been used successfully.

In the past the relative proportion of sodium to total principal cations in irrigation water (sodium, potassium, calcium, and magnesium) usually has been expressed simply as the "percent sodium". According to the U. S. Department of Agriculture, however, the sodium-adsorption ratio (SAR), used to express the relative activity of sodium ions in exchange reactions with soil, is a much better measure of the suitability of water for irrigation. The sodium-adsorption ratio 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 11. In using the nomogram to determine the sodium-adsorption ratio of a water, the concentration of sodium expressed in equivalents per million is plotted on the left scale (A), and the concentration of calcium plus magnesium expressed in equivalents per million is plotted on the right scale (B). The point at which a line connecting these two points intersects the sodium-adsorption-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 plotting these values on the diagram shown in Figure 12. Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Medium-sodium water (S2) will present an appreciable sodium hazard in certain fine-textured soils, especially under low-leaching conditions. This water may be safely used on coarse-textured or organic soils having moderate to high permeability. High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management such as good drainage, high 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. Moderately salt tolerant crops 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 having restricted drainage. Very high salinity water (C4) can be used only on certain crops and then only if special practices are followed.

Boron is essential to normal plant growth, but the quantity required is very small. Crops vary greatly in their boron tolerances, but in general it may be said that the ordinary field crops common to Kansas are not adversely affected by boron concentrations of less than 1 part per million.

Prolonged use, under adverse conditions, of water having a high concentration of bicarbonate could have an undesirable effect upon the soil texture and plant growth. When such water is concentrated

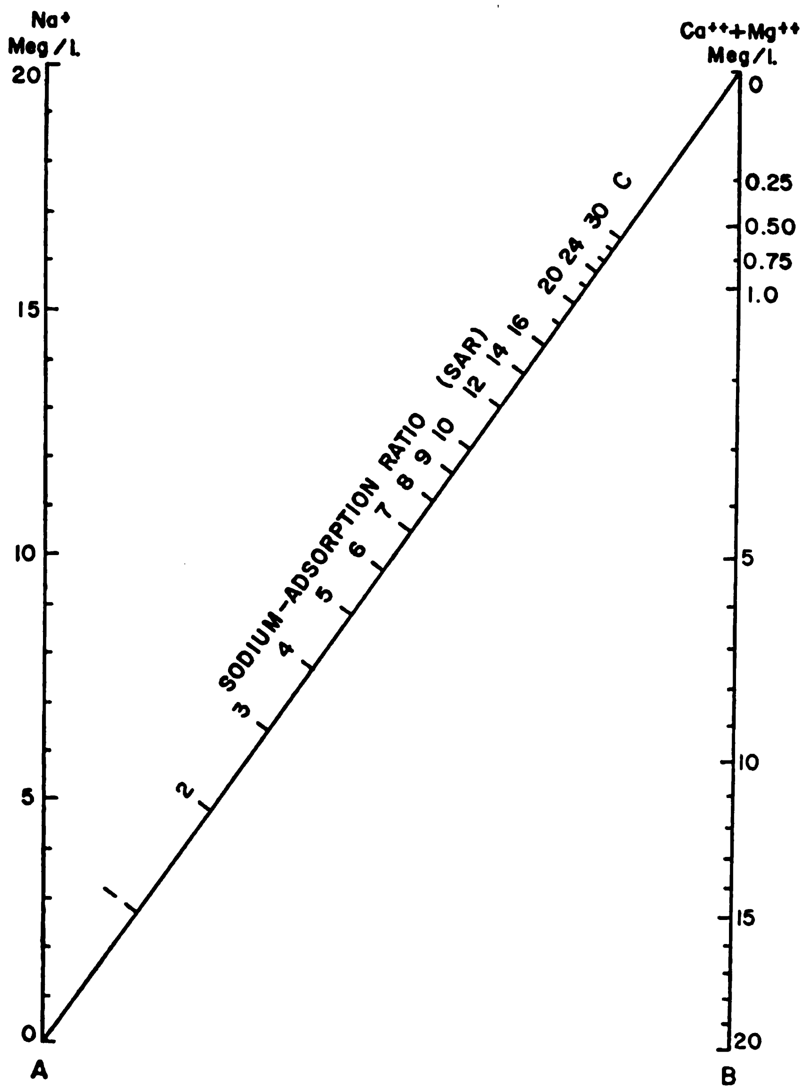

FIG. 11.—Nomogram for determining the sodium-adsorption ratio of irrigation water.

by evaporation, the calcium and magnesium precipitate out as carbonate. Thus the proportion of sodium in the water (percent sodium) increases, perhaps to an undesirable extent.

Figure 12 shows the classification of 20 representative samples of water from Cloud County with respect to suitability for irrigation. The well numbers for the symbols used in Figure 12 are given in Table 5.

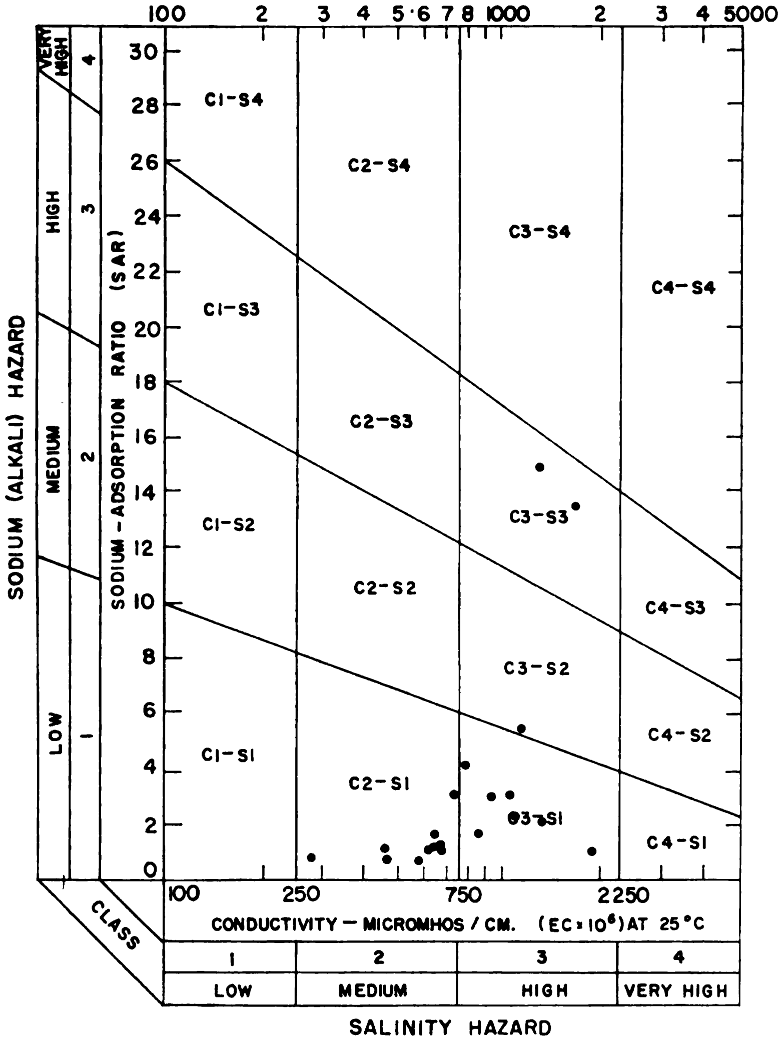

FIG. 12.—Diagram showing suitability of waters for irrigation.

All samples are of either medium or high salinity hazard, and proper irrigation or soil-management practices should be followed. One sample is of high salinity hazard and medium sodium hazard. Water of this class should be used only on very permeable soils, and under closely regulated conditions. Two samples are high both in salinity hazard and sodium hazard and can be regarded as generally unsatisfactory for irrigation use.

TABLE 5.—*Sodium-adsorption ratio (SAR), conductivity (C), class of irrigation water, and intervals sampled in wells shown in Figure 12.*

WELL NUMBER	Interval sampled (feet)	SAR	C	Class
5-2-30bcc	38-40	13.50	1,730	S3-C3
5-3-18bbb	95-100	1.25	670	S1-C2
5-3-19cb	62-67	1.15	460	S1-C2
5-3-31bb	32-37	2.40	1,030	S1-C3
5-3-32aa3	....	3.15	1,020	S1-C3
5-5-22da	....	1.15	650	S1-C2
5-5-24dd	55-57	1.90	640	S1-C2
6-1-3aa	72-77	1.25	660	S1-C2
6-2-33dc	138-140	4.25	760	S1-C3
6-2-33dc	233-235	3.20	730	S1-C2
6-4-12cd	....	.80	470	S1-C2
6-4-34cc	378-380	.75	590	S1-C2
6-5-6cb	....	14.80	1,490	S3-C3
7-3-21ba	....	5.50	1,160	S2-C3
7-3-35cb	....	1.05	1,900	S1-C3
7-4-22bb	....	2.35	1,450	S1-C3
8-1-13ad	....	.85	275	S1-C2
8-4-23cbd	....	1.10	620	S1-C2
8-5-7cb	46-48	1.90	860	S1-C3
8-5-25cc	....	3.20	910	S1-C3

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

PERMIAN SYSTEM (LEONARDIAN SERIES)

Sumner Group

Wellington Formation

The Wellington Formation underlies all of Cloud County but is not exposed at the surface anywhere in the county. The thickness of the Wellington Formation where the sequence is complete and the upper surface is not eroded is about 700 feet, but the maximum thickness in Cloud County is about 400 feet. This formation consists chiefly of gray shale but contains some red and green shale in the lower part. The most conspicuous of several thin limestone beds in the Wellington is the Hollenberg Limestone member, which lies about 40 feet above the base of the formation. It is somewhat dolomitic and locally cherty. Massive beds of gypsum are exposed in Saline, Dickinson, and Clay Counties and are buried in the subsurface of Cloud County. To the west and south of Cloud County thick beds of salt (Hutchinson Salt member) occur near the middle of the formation, but they are nowhere exposed at the surface.

The Wellington Formation is a very poor aquifer because of its low permeability and the large amount of mineral matter that can be taken into solution by ground water.

Cretaceous System (Gulfian Series)

Dakota Formation

Character and subdivisions.—The Dakota Formation includes the nonmarine material between the base of the marine Graneros Shale and the top of the marine Kiowa Shale. In areas where the Kiowa Shale is absent the base of the Dakota Formation is marked by a persistent cobble zone, as much as 3 feet thick, composed of polished pebbles and cobbles of quartzite, chert, and quartz embedded in sand and clay, which probably represents the time interval between the end of Permian deposition and the beginning of Cretaceous deposition. Where the Kiowa Shale is present, this cobble zone separates Permian rocks from the Kiowa Shale. The base of the Dakota Formation and the underlying beds are not exposed in Cloud County, but the Dakota Formation probably is underlain by the Kiowa Shale throughout much of the county. Because of the lithologic similarity of the Dakota Formation and the Kiowa Shale, the contact between the two formations was not recognized in test holes, and the entire sequence is logged as the Dakota Formation.

Because of the conspicuous outcrops formed by resistant beds or lenses of sandstone, it is popularly believed that the Dakota Formation is composed chiefly of sandstone. Test drilling has revealed, however, that it consists chiefly of clay of various colors interspersed with pyrite, limonite, and hematite and contains numerous thin beds of lignite.

The sandstone beds in the Dakota Formation are not continuous over large areas, and irregular beds or lenses of sandstone may be present in any part of the formation, but massive sandstone beds are most common in the upper half of the lower third and the lower half of the upper third of the formation. A quartzitic phase of the sandstone is common in the lower part of the formation. The quartzitic rock is not well exposed in Cloud County but has been extensively quarried in Lincoln County. Plummer and Romary (1947) divided the Dakota Formation into two members, the Terra Cotta Clay member, which comprises approximately the lower two-thirds of the formation, and the Janssen Clay member, which constitutes the upper part of the formation. A fairly persistent bed of lignite about 2 feet thick, lying about 12 feet below the top of the formation, has been mined in the area of the old community of Minersville, northeast of Concordia.

Distribution and thickness.—The Dakota Formation underlies all of Cloud County except possibly the most deeply scoured parts of the Republican River valley east of Clyde and of the Chapman Creek valley southeast of Miltonvale. The Dakota Formation is overlain by younger beds in much of the western part of the county. The thickness of the Dakota Formation in Cloud County ranges from a few feet, at most, beneath the deep valleys at the east side of the county to a known maximum thickness of about 400 feet in the northwestern part of the county.

Water supply.—The Dakota Formation is the only aquifer of major consequence in the uplands of Cloud County. In the outcrop area of the formation it yields an abundance of good water for domestic and stock use. In west-central Cloud County, where the formation is most deeply buried under younger formations, and in some other areas, where wells must be drilled to the lower part of the formation because there is no sandstone in the upper part, the water is somewhat mineralized.

In general, the area of greatest salt concentration lies west of the saddle or trough in the piezometric surface (Pl. 2) trending southwest from the west side of T. 6 S., R. 4 W. In this area, as elsewhere, the salinity increases with depth, but at a much higher rate than average. A water sample from test hole 5-3-15ab drilled into the Dakota Formation contained 32,000 ppm of dissolved solids, of which 16,000 ppm was chloride. It is believed that this mineralized water is moving southeast and is being discharged into the alluvial fill in the deepest part of the Republican River valley in the vicinity of Concordia.

Graneros Shale

Character.—The Graneros Shale consists of blue-black fissile noncalcareous clay shale that weathers olive drab. Selenite crystals may be present throughout the formation, and very thin rusty-colored lenses of sandstone are exposed in most weathered outcrops.

The Graneros Shale weathers to a heavy clay and forms a gentle slope from the base of the Greenhorn Limestone to the top of the Dakota Formation.

Distribution and thickness.—The Graneros Shale underlies most of the western half of Cloud County except along the valleys of Republican and Solomon Rivers and Buffalo Creek. The thickness of the Graneros Shale in Cloud County ranges from 20 to 40 feet.

Water supply.—No wells are known to yield water from the Graneros Shale in Cloud County. The shale is impermeable and yields little or no water.

Greenhorn Limestone

Character and subdivisions.—The Greenhorn Limestone is divided into four members. They are, in ascending order, the Lincoln Limestone member, Hartland Shale member, Jetmore Chalk member, and Pfeifer Shale member. The Lincoln Limestone member is composed chiefly of thin-bedded fossiliferous limestone, dark-gray to brown shale, and thin bentonite beds. The limestone beds of the Lincoln member are characterized by a strong petroliferous odor when freshly broken. The Hartland Shale member is composed of light-colored calcareous shale and beds of bentonite. The Jetmore Chalk member is composed of alternating beds of chalky limestone and calcareous shale and some thin bentonite beds. The top of the Jetmore Chalk member is marked by the very persistent "shell rock" bed. This bed is composed of a mass of invertebrate fossils in a matrix of chalky limestone. The Pfeifer Shale member, like the underlying Jetmore Chalk member, is composed of alternating beds of limestone and calcareous shale and some thin bentonite beds. The limestone beds of the Pfeifer Shale member are more massive and not as chalky as those of the Jetmore Chalk member. The top of the Pfeifer Shale member (top of the Greenhorn Limestone) is marked by the conspicuous Fencepost Limestone bed. This limestone bed is about 0.7 foot thick, contains *Inoceramus* shells, and has a persistent iron-stained layer in the middle. It is easily quarried into rectangular blocks about 6 feet long, and these blocks are used widely throughout central Kansas for fence posts.

Distribution and thickness.—The Greenhorn Limestone crops out on or underlies much of the western part of Cloud County. The areal distribution of the Greenhorn Limestone is shown on Plate 1. The average thickness of the formation in Cloud County is about 85 feet.

Water supply.—A few wells in Cloud County yield small quantities of water from the Greenhorn Limestone. Most of the water in the Greenhorn Limestone occurs in cracks above impervious layers, and dug wells of large diameter are constructed because of the greater infiltration area offered by this type of well. Most of the water from the Greenhorn Limestone is hard.

Carlile Shale

Character and subdivisions.—The Carlile Shale is the youngest Cretaceous formation in Cloud County. Because of its high topographic position and nonresistant nature, the Carlile Shale is poorly exposed in Cloud County. The formation is divided into the Fairport Shale member below and the Blue Hills Shale member above. Only the lower member, the Fairport, is present in Cloud County.

Distribution and thickness.—The Carlile Shale has been removed by erosion from all but the highest divides in west-central Cloud County, and nearly all outcrops are completely mantled by younger silt deposits. The maximum thickness of the formation in Cloud County probably does not exceed 30 feet.

Water supply.—The Carlile Shale does not yield water to wells in Cloud County.

Tertiary System (Pliocene Series)

Ogallala Formation

Character and subdivision.—The Ogallala Formation, which was deposited by streams flowing eastward from the Rocky Mountains, is the only Tertiary rock in Cloud County. The Ogallala Formation in Kansas is divided into three members, in ascending order the Valentine Member, Ash Hollow Member, and Kimball Member. The Kimball Member, the top of the Ogallala Formation, is commonly capped by the "Algal limestone". The "Algal limestone" is pink-white or gray-green concentrically layered sandy limestone and in Cloud County constitutes the entire Ogallala Formation.

Distribution and thickness.—The Ogallala Formation was recognized in only two places in Cloud County (Pl. 1). These localities are on high divides, and the Ogallala Formation is probably buried under younger silt deposits in similar topographic position throughout the western part of the county. The maximum observed thickness of the Ogallala Formation in Cloud County was about 1 foot.

Water supply.—The Ogallala Formation is above the water table in Cloud County and does not yield water to wells.

Quaternary System (Pleistocene Series)

Meade Group

Character and subdivisions.—Prior to February 1958 the State Geological Survey of Kansas classified the Holdrege and Fullerton as members of Nebraskan and Aftonian age, Meade Group, and the Grand Island and Sappa as members of Kansan and Yarmouthian age, Meade Group. Since February 1958 the Holdrege and Fullerton have been regarded as formations of Nebraskan and Aftonian age and the Grand Island and Sappa have been regarded as formations of Kansan and Yarmouthian age.

In the area studied for this report only deposits of Meade Group—Kansan age were recognized, and the Sappa and Grand Island Formations were not differentiated. In much of north-central Kansas the Meade Group consists of discontinuous terrace remnants along the major streams. These valley-fill deposits are composed principally of material transported from the west, but near the margin of glacial advance the deposits are composed of outwash materials. In eastern Kansas, south of the glacial outwash deposits, Kansan deposits consist principally of chert gravels and some pebbles of limestone and sandstone, nearly all locally derived. In other local areas in Kansas in which Meade deposits occur they are composed entirely of locally derived materials. In Cloud County, deposits that are in a high-terrace position and are associated with the Solomon River drainage system are thought to be Kansan in age. These deposits consist of a thin veneer of locally derived limestone gravel resting on a bedrock bench about 45 feet higher than the bedrock underlying the next lower terrace. Deposits near Kirwin, Phillips County, which lie in the deepest part of the Solomon River channel, underlying younger Illinoian deposits, have been identified as Kansan in age (Frye and Leonard, 1954). Kansan deposits near Kirwin occupy the lowest part of the valley, whereas the deposits in southwestern Cloud County that are believed to be Kansan occupy a high position, but these deposits probably are associated with a tributary stream rather than with the main stream. Deposits in the deepest parts of the valleys of Republican River and Buffalo Creek in northern Cloud County are classified in this report as being of Kansan age and as belonging to the Meade Group. These deposits underlie the younger Wisconsinan and Recent alluvium, and in some areas they probably are overlain by Illinoian deposits, but Kansan deposits could not be differentiated from Illinoian materials from test-drilling information.

The Kansan deposits consist chiefly of locally derived limestone and sandstone gravel in the lower part and silt and clay in the upper part. They are believed to be equivalent in age to the arkosic Kansan deposits in the ancestral Republican valley in Republic County, which probably were deposited prior to the capture or spilling over of the ancestral Republican River, but they differ lithologically because the source materials of the deposits in the two valleys differ.

Distribution and thickness.—The Kansan deposits associated with the Solomon drainage were observed at the surface in only one locality, about 3 miles north of Simpson, where they are about 15 feet thick. This small outcrop was not mapped.

The Kansan deposits in the Republican River valley occupy the deepest part of the valley and extend entirely through the county along both Republican River and Buffalo Creek, but do not crop out. Thickness ranges from a featheredge to as much as 60 feet.

Water supply.—The Kansan deposits along Solomon River are above the water table and do not yield water to wells. As previously mentioned, salt water is entering the basal alluvial fill (Kansan) of the Republican River valley in the vicinity of Concordia from the Dakota Formation. The fairly persistent silt and clay bed that forms the upper part of the Kansan deposits in this area acts as a seal to prevent the salty water from entering the overlying younger beds. In that part of the Republican River valley from a few miles west of Concordia to the east side of Range 2 West, wells should not be drilled through this clay layer, because salty water is likely to be encountered below it. East of the east side of Range 2 West, the clay layer at the top of the Kansan deposits is discontinuous or absent, and the salty water in the Kansan deposits is diluted by mixing with the fresh water in the overlying younger deposits, hence is not objectionably salty.

Sanborn Group

Nearly all the Pleistocene deposits of Cloud County, with the exception of the Kansan deposits, Recent alluvium, and dune sand, are part of the Sanborn Group. The Sanborn, as used by the Kansas Geological Survey, includes deposits of two glacial stages (Illinoian and Wisconsinan) and the several substages of the Wisconsinan; also it includes two unconformities and represents three distinct cycles of deposition. The Sanborn Group includes, in ascending order, the following formations: Crete, Loveland (containing the Sangamon buried soil in its upper part), unnamed early Wisconsinan alluvial deposits, Peoria (containing the Brady buried soil in its upper part), unnamed late Wisconsinan alluvial deposits; and Bignell. For the purpose of discussing the water-bearing characteristics, the eolian silt units of the Sanborn Group are considered together.

Crete Formation

The Crete Formation is present in two general areas of Cloud County, in a terrace position along Solomon River, and a unit identified as the Crete and Loveland Formations undifferentiated in a terrace position along Buffalo Creek and Republican River. Along Solomon River the top of the Crete is about 50 feet above the floodplain level. These deposits consist of both arkosic and locally derived gravel and minor amounts of interbedded silt and clay. In general, the sand and fine gravel of these deposits are arkosic, but the coarse gravel and cobbles are locally derived. In few places does the thickness of Crete deposits along Solomon River exceed 30 feet. The Crete Formation in the Solomon valley lies above the water table and does not yield water to wells. There are numerous gravel pits in Crete deposits, particularly along U. S. Highway 24 west of Glasco.

Deposits of the Crete and Loveland Formations adjacent to Republican River and Buffalo Creek are as a rule much thicker than those along Solomon River and are composed chiefly of silt and clay. A fairly persistent bed of almost entirely locally derived gravel was penetrated in test holes at the base of the Crete along Republican River and Buffalo Creek. There, the Crete-Loveland unit yields quantities of water suitable for domestic and stock uses, and locally the basal gravel may be thick enough to permit development of small irrigation supplies.

Loveland and Peoria Formations

Large parts of the upland as well as the Kansan and Crete terrace surfaces in Cloud County are blanketed with wind-deposited silt. The oldest of these eolian (loess) deposits, the Loveland Formation, of Illinoian age, was deposited immediately after or contemporaneous with the deposition of the Crete Formation. In unweathered exposures the Loveland consists of compact reddish-yellow silt and clay, but in many places in Cloud County almost its entire thickness is included within the Sangamon buried soil profile. The Sangamon soil formed during the period between the end of Loveland deposition and the beginning of Peoria deposition.

The Early Wisconsinan alluvial deposits, which are usually regarded as a part of the Sanborn Group in Kansas, were not recognized in Cloud County. The Peoria Formation (Wisconsinan age) is a massive calcareous buff to yellow silt and clay, locally containing many fossil snails. The upper surface of the Peoria, where it is overlain by the Bignell (late Wisconsinan) Formation, is marked in most places by the Brady buried soil. The Bignell Formation, which is the youngest formation of the Sanborn Group, was not recognized in Cloud County. No differentiation between the silts of the Sanborn Group was made in geologic mapping. They are above the water table in Cloud County and do not yield water to wells.

Wisconsinan Terrace Deposits

After the deposition of the Peoria Formation and prior to and in part contemporaneous with the deposition of the Bignell Formation, thick deposits of sand and gravel were laid down along the valleys of Solomon River, Republican River, Buffalo Creek, and other streams in the county. These deposits, now in a low-terrace position, are late Wisconsinan in age and are included in the Sanborn Group. To differentiate these deposits from the silts of the Sanborn Group, they have been mapped separately and are designated as Wisconsinan terrace deposits on Plate 1.

Wisconsinan terrace deposits in the valley of Buffalo Creek are about 40 feet thick and along Republican River are as much as 125 feet thick. Along Buffalo Creek the Wisconsinan terrace deposits are composed chiefly of silt and clay and contain only a minor amount of locally derived gravel. Yields of wells almost anywhere in the Wisconsinan terraces of Buffalo Creek are adequate for domestic and stock use, but generally are not large enough for irrigation. Owing to subsurface movement of mineralized water downstream from the salt marsh northwest of Jamestown and recharge of the terrace deposits from the Dakota Formation, the quality of water from the Wisconsinan terrace deposits of Buffalo Creek is not uniform. The ground water in both the Buffalo Creek and Salt Creek valleys is strongly mineralized where these two streams enter the county. The deepest part of the Buffalo Creek channel intersects sandstone beds in the Dakota Formation that yield salt water, and as the water in the Dakota is under a greater head than the water in the terrace deposits, the salty water moves upward into the terrace deposits. Shallower parts of the channel are receiving fresh water from the upper part of the Dakota Formation and from downward percolation of local precipitation. Depending on several very local geologic and recharge conditions, a well at a given location in Buffalo Creek valley terraces may yield fresh water whereas a nearby well may yield salt water.

The Wisconsinan terrace deposits along Republican River are composed of sand and silt in the upper part and almost entirely of sand and gravel in the lower part. The deposits supply water to many domestic and stock wells in the valley and yield abundant supplies to irrigation wells. The quality of water from the Wisconsinan terrace deposits of Republican River is generally good, but when a well is drilled care should be taken not to penetrate the silt and clay at the top of the underlying Kansan deposits where the Kansan deposits are known to contain salt water, as the water in the Kansan deposits is probably under a higher hydrostatic head than that in the overlying Wisconsinan and alluvial deposits, and salt water will flow upward into those deposits.

The thickness of the Wisconsinan terrace deposits along Solomon River and the minor streams in Cloud County does not exceed 50 feet. The terrace deposits along these streams are composed chiefly of silt and clay and contain only minor amounts of sand and gravel. Yields adequate for domestic and stock supplies are obtained from these deposits, and irrigation supplies may be developed in some areas from Wisconsinan terrace deposits along Solomon River.

Recent Deposits

Alluvium

The areas mapped as alluvium (Pl. 1) consist of the flood plains of streams. The alluvium consists of coarse sand and gravel intermixed with a small amount of silt and in places contains thin clay layers. Because of the similarity of material, alluvium cannot readily be distingushed from Wisconsinan terrace deposits, and there is no difference in their water-bearing characteristics. The present distribution of alluvium coincides in most places with the position of the deepest part of the channel, and as a result, wells drilled therein penetrate a greater thickness of permeable material, and hence have somewhat higher yields, than wells dug or drilled in Wisconsinan terrace deposits. Locally the alluvium of Republican River may be as much as 130 feet thick.

Dune Sand

At several places in Cloud County, the wind has piled up sand from the alluvium into dunes. These dunes are of Recent age, and some are semiactive, the sand being somewhat ineffectually held in place by a sparse cover of vegetation. The thickness of dune sand in Cloud County does not exceed 50 feet. The sand dunes are generally above the water table and yield only small supplies of water to wells, but are important areas of recharge because they absorb and transmit water so readily.

HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS

The quantity of water that a water-bearing formation will yield to wells depends upon the hydrologic properties of the material penetrated by the wells. The two hydrologic properties of greatest significance are the coefficients of transmissibility (T) and storage (S). These factors are used in making estimates of the quantity of water available in an aquifer and for predicting water-level decline resulting from continued pumping. Controlled aquifer tests in the field provide the data required to compute these coefficients.

The coefficient of transmissibility (T) may be defined as the number of gallons of water, at the prevailing temperature, that will move in 1 day through a vertical strip of the aquifer 1 foot wide, having a height equal to the full saturated thickness of the aquifer, under a hydraulic gradient of 100 per cent or 1 foot per foot.

The coefficient of storage (S) of an aquifer is the change in its stored volume of water per unit change in head per unit surface area of the aquifer. Under water-table conditions the coefficient of storage (S) is virtually the same as the specific yield of the aquifer.

The coefficient of permeability (P) of an aquifer is the discharge per unit of area per unit of hydraulic gradient. The field coefficient (P_f) may be measured in terms of the number of gallons of water a day, at the prevailing temperature, conducted laterally through each mile of aquifer under investigation (measured at right angles to the direction of flow) for each foot of thickness of the aquifer, and for each foot per mile of hydraulic gradient. The field coefficient of permeability multiplied by the thickness of the saturated water-bearing materials in feet, is equal to the coefficient of transmissibility.

Determinations of Transmissibility and Permeability

The coefficients of transmissibility and permeability of the alluvium and terrace deposits in the Republican River valley in Cloud County were determined by aquifer tests using three wells. Values for transmissibility were computed from the test data by the formulas developed by Theis, Thiem, and Cooper and Jacob.

Theis Recovery Method

The recovery method of determining the coefficient of transmissibility (Theis, 1935, p. 522) utilizes measurements of the water level in the pumped well during the recovery period. The Theis recovery formula is expressed as:

$$T = \frac{264Q \log_{10} t/t'}{s'}$$

in which T is the coefficient of transmissibility, in gallons per day per foot

Q is the pumping rate, in gallons a minute

t is the time since pumping began, in minutes

t' is the time since pumping stopped, in minutes

and s' is the residual drawdown in the pumped well, in feet, at time t'.

The residual drawdown (s') is computed by subtracting the static water-level measurement from the measurement at time t' after pumping ceases.

The ratio of $\log_{10} t/t'$ is determined graphically by plotting $\log_{10} t/t'$ against corresponding value of s'. This procedure is simplified by plotting t/t' on the logarithmic co-ordinate and s' on the arithmetic co-ordinate of semilogarithmic paper. If $\log_{10} t/t'$ is taken over 1 log cycle, it will become unity; s' will be the difference between drawdowns over 1 log cycle; and the equation becomes $T = \frac{264Q}{\Delta s'}$. In practice, water levels at time t' may be plotted and the residual drawdown need not be computed. Inasmuch as the value of T is related directly to the slope of the line formed by plotting water level against t/t', the selection of the proper points on the plot to determine Δs is very important. Theoretically the relation of s' to t/t' should plot as a straight line that passes through the point where residual drawdown is 0 and where t/t' is 1. In unconsolidated deposits this is not always true, as the plotted line is a curve that does not pass through the point of origin. The earliest points on the recovery curve may be erratic and may not fall in a straight line. This may be due in part to head losses in the well or to the surge of the column of water that falls back into the well after the pump is stopped. For this reason, the points where t/t' approaches 1 should be the most reliable and should be used in determining Δs, but the recovery data may not plot through the point where s' is 0 nor in a straight line in the later part of the test. It is then difficult to establish a line that determines Δs, and the latest data, where t/t' approaches 1, should not be used, but instead points earlier in the curve should be used. Where the data plot as an appreciable curve, almost any value can be obtained for Δs, and hence, the value of T can be considerably in error.

Thiem Method

The Thiem method of determining the coefficient of transmissibility of a water-bearing material consists of analyzing the decline in water level during the pumping period in several observation wells near the pumped well. After approximate equilibrium is established around a pumped well, approximately equal quantities of water move toward the pumped well per unit of time through a series of upright concentric cylindrical sections around the well. Because the areas of the large cylinders through which the water percolates are larger than the areas of the smaller cylinders, the velocity of the water percolating through the large cylinders is proportionately less than through the smaller cylinders and the hydraulic gradients are proportionately smaller. The Thiem formula is:

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

in which T is the coefficient of transmissibility, in gallons per day per foot

Q is the pumping rate, in gallons a minute

r_1 and r_2 are distances of observation wells from pumped well, in any unit

s_1 and s_2 are drawdowns of water level at distances r_1 and r_2 in feet.

When the values for drawdowns, s, are plotted on the arithmetic scale of semilogarithmic paper and the values for distances, r, are plotted on the logarithmic scale, the points fall on a straight line. For one log cycle, $\log_{10} \frac{r_2}{r_1}$ is equal to 1 and the Thiem formula becomes:

$$T = \frac{527.7Q}{\Delta s}$$

where Δs is the drawdown over one log cycle.

The Thiem method of determining the coefficient of transmissibility is based on the theory that the aquifer is homogeneous throughout, but because aquifers are not actually perfectly homogeneous a probable error in the value of T is introduced. In some aquifer tests the aquifer is so heterogeneous that the drawdown rate is slowed in one or more of the observation wells and perhaps accelerated in others, thus giving a false slope to the line used in determining a value for Δs. Therefore it is advisable to utilize more than two observation wells to evaluate the results of an aquifer test by the Thiem method. In thin aquifers a correction should be applied to the observed drawdown. This correction factor is $\frac{s^2}{2m}$ in which s is the observed drawdown and m is the saturated thickness of the aquifer. The observed drawdown is reduced by the amount of the correction.

Theis Nonequilibrium Method

The nonequilibrium formula introduced by Theis (1935) is:

$$T = \frac{114.6Q}{s} \int_u^\infty \frac{e^{-u}}{u} du \qquad (1)$$

$$\text{where } u = \frac{1.87\ r^2S}{Tt} \qquad (2)$$

or evaluating the integral

$$T = \frac{114.6Q}{s} \left(-0.5772 - \log e^u + w - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!} + \ldots\right) \qquad (3)$$

and
- s is the drawdown in an observation well, in feet
- r is the distance from pumped well to observation well, in feet
- Q is the discharge, in gallons per minute
- t is the time since pumping began, in days
- T is the coefficient of transmissibility, in gallons per day per foot
- S is the coefficient of storage.

The formula was developed on the basis of six theoretical assumptions: that the aquifer is infinite in extent, that it is homogeneous, that its transmissibility is constant at all places and in all directions, that it is confined between impermeable beds, that the coefficient of storage is constant, and that water is released instantaneously from storage with a decline in artesian head.

The exponential integral is often written symbolically as W(u), read as the "well function of u", and its substitution in the equation results in the expression $T = \frac{114.6Q\,W(u)}{s}$. The presence of two unknowns and the nature of the exponential integral in the nonequilibrium formula make an exact analytical solution impossible. Solution can be obtained by the use of a graphical method of superposition devised by Theis.

To determine values of s, the extrapolated graph of water levels before pumping began is compared with the graph of the water levels after pumping began. Under static or near-static conditions, however, the drawdown s in the well may be plotted directly. These values of s are plotted on logarithmic paper along the vertical axis, the values of t being plotted along the horizontal axis where r is the distance from the pumped well and t is the time in days since pumping began. These points describe the "field curve". Generally u is plotted against Wu to obtain a "type curve". In this report W(u) is plotted along the vertical axis against $\frac{1}{u}$ along the horizontal axis to yield a "type curve" of the same values except that it is reversed. This simplifies the plotting of the "field curve" because many calculations may be omitted by plotting s against t instead of s against r^2/t. Logarithmic paper of the same scale is used in plotting both the field curve and the type curve. If the basic assumptions are satisfied, the field curve will conform to a part of the type curve. A match of the two curves is obtained by superposing the field curve on the type curve, keeping the axes of the two parallel. With both curves in the matched position, a point on the type curve is selected and marked on the field curve. The co-ordinates of this common point, s, W(u), t, and $\frac{1}{u}$, are then used to solve the nonequilibrium formula for T and S. For convenience a match point may be selected at the intersection of the major axes of the type curve, for example where W(u) = 1.0 and u = 0.1.

Cooper-Jacob Generalized Methods

The Theis (1935) nonequilibrium formula requires the use of a "type curve" on which the test-data curve is superimposed to determine the coefficients of transmissibility and storage. Cooper and Jacob (1946) devised three generalized graphical methods utilizing straight-line graphs. The three types of graphs are referred to as the generalized distance-drawdown graph, the generalized time-drawdown graph, and the generalized composite drawdown graph.

In the distance-drawdown graph, drawdown is plotted on the arithmetic scale and distance of observation wells in feet from the pumped well is plotted on the logarithmic scale. The formulas for coefficients of transmissibility and storage are:

$$T = \frac{264Q}{\Delta s} \text{ and } S = \frac{0.3Tt}{r_0^2}$$

In the time-drawdown graph, drawdown is plotted on the arithmetic scale and time in days is plotted on the logarithmic scale. The formulas for coefficients of transmissibility and storage are:

$$T = \frac{264Q}{\Delta s} \text{ and } S = \frac{0.3Tt_0}{r^2}$$

In the composite drawdown graph, drawdown is plotted on the arithmetic scale and the value t/r^2 is plotted on the logarithmic scale. In this method the plots of all observation wells should fall on a straight line. The formulas for coefficients of transmissibility and storage are:

$$T = \frac{264Q}{\Delta s} \text{ and } S = \frac{0.3T}{(t/r^2)_0}$$

In the above formulas

- T is the coefficient of transmissibility, in gallons per day per foot
- S is the coefficient of storage
- Q is the rate of discharge of pumped well, in gallons per minute
- Δs is the drawdown over one log cycle
- t is the time since pumping started, in days
- r is the distance from pumped well, in feet
- t_0 is the value of t where drawdown $= 0$
- r_0 is the value of r where drawdown $= 0$
- $(t/r^2)_0$ is the value of t/r^2 where drawdown $= 0$

Aquifer Tests

Three aquifer tests were made by pumping irrigation wells in the Republican River valley between Concordia and Clyde. The test in which well 5-2-25cb (W. T. Wright No. 1) was used was made in 1942 (Fishel, 1948). The tests in which well 5-2-25cc (W. T. Wright No. 2) and 6-1-4bbc on the Franklin Day farm were used were made in the fall of 1955. Wells 5-2-25cb and 5-2-25cc are in a wide bend of Republican River where the Wisconsinan terrace deposits have been developed extensively for irrigation. Geologically this area is very favorable for obtaining a good irrigation well. Well 6-1-4bbc is near the edge of the Republican Valley and is not favorably located for yielding a large ground-water supply.

W. T. Wright Well 5-2-25cb

An aquifer test using well 5-2-25cb was made in 1942. Observation wells were not available, and therefore the Theis recovery formula was applied to determine the coefficient of transmissibility of the aquifer. The well was pumped at a rate of 730 gpm from 8:28 a. m. to 2:40 p. m.; water-level measurements made during the pumping and recovery period are given in Table 6.

The ratio t/t′ (time since pumping started, in minutes, divided by time since pumping stopped, in minutes) is plotted against the depth to water in Figure 13. From Figure 13 Δs, the change in water level over one log cycle, is 0.36. Hence,

$$T = \frac{(264)\,(730)}{0.36} = 540{,}000 \text{ gpd/ft.}$$

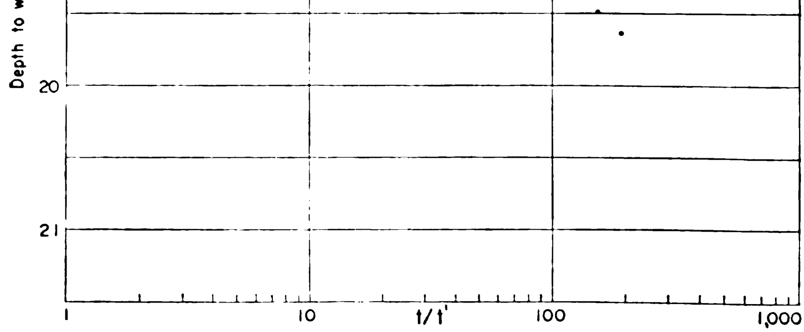

Fig. 13.—Depth to water in well 5-2-25cb plotted against t/t′, time since pumping started divided by time since pumping stopped.

TABLE 6.—*Water-level measurements made during pumping and recovery of Wright well 5-2-25cb and values for t, t', and t/t'.*

TIME	Time since pumping started, minutes t	Time since pumping stopped, minutes t'	t/t'	Depth to water, feet
8:20 a. m....	Static water level	....	....	18.43
8:28........	Pumping started	....	....	....
8:40........	12	....	....	30.32
9:10........	42	....	....	30.55
9:40........	72	....	....	30.59
10:45........	137	....	....	30.62
11:40........	192	....	....	30.55
1:00 p. m...	272	....	....	30.78
2:30........	362	....	....	30.70
2:40........	372 Pumping stopped	....	....	....
2:40:15.....	372.25	0.25	1,489	24.13
2:41........	373	1	373	20.51
2:42........	374	2	137	19.64
2:42:30.....	374.5	2.5	149.80	19.48
2:43........	375	3	125	19.38
2:43:30.....	375.5	3.5	107.29	19.32
2:44........	376	4	94	19.25
2:44:30.....	376.5	4.5	83.67	19.20
2:45........	377	5	75.40	19.16
2:45:30.....	377.5	5.5	68.64	19.13
2:46........	378	6	63	19.10
2:46:30.....	378.5	6.5	58.23	19.08
2:47........	379	7	54.14	19.06
2:48........	380	8	47.50	19.02
2:49........	381	9	42.33	18.99
2:50........	382	10	38.20	18.97
2:52........	384	12	32.00	18.92
2:54........	386	14	27.57	18.89
2:56........	388	16	24.25	18.86
2:58........	390	18	21.67	18.84
3:00........	392	20	19.60	18.82
3:05........	397	25	15.88	18.80
3:10........	402	30	13.40	18.77
3:15........	407	35	11.63	18.76
3:20........	412	40	10.30	18.75
3:30........	422	50	8.44	18.72
3:40........	432	60	7.20	18.68
4:00........	452	80	5.65	18.64
4:20........	472	100	4.72	18.62
4:40........	492	120	4.10	18.59
5:00........	512	140	3.66	18.59
5:30........	542	170	3.19	18.57

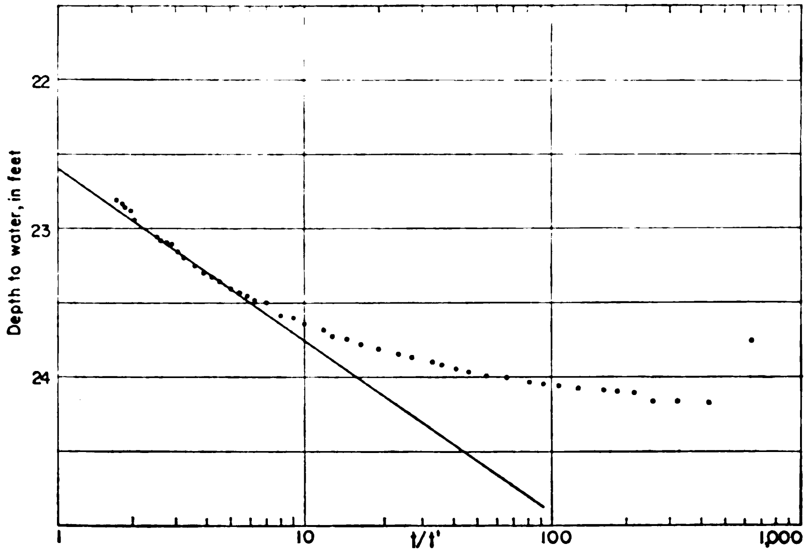

FIG. 14.—Depth to water in well 5-2-25cc plotted against t/t′, time since pumping started divided by time since pumping stopped.

The thickness, m, of the water-bearing material at the well is 47 feet, and from the relation $P = \frac{T}{m}$ the coefficient of permeability (P) is 11,500. Drawdown was 12.27 feet at a pumping rate of 730 gpm, giving a specific capacity of 59.5 gpm per foot of drawdown for the well.

W. T. Wright Well 5-2-25cc

An aquifer test using well 5-2-25cc was made in the fall of 1955. Four observation wells, a, b, c, and d, were drilled 20.4, 51, 100, and 150 feet, respectively, from the pumped well. Well 5-2-25cc was pumped for 320 minutes at a rate of 1,000 gpm. The water-level measurements made during the pumping and recovery periods and the values for t, t′, and t/t′ are given in Table 7.

The ratio t/t′ is plotted against depth to water on semilogarithmic paper in Figure 14. The points do not fall in a straight line, and the line drawn through the points does not go through the point of zero residual drawdown at the co-ordinate $t/t' = 1$. The points nearest $t/t' = 1$ give a value for T that is much lower than the value indicated by the observation wells; therefore, the line was arbitrarily drawn through the points where the values of t/t′ were between

TABLE 7.—*Water-level measurements made during pumping and recovery in Wright well 5-2-25cc and values for t, t′ and t/t′.*

TIME	Time since pumping started, minutes t	Time since pumping stopped, minutes t′	t/t′	Depth to water, feet
8:44 a. m.	Static water level	....	....	22.42
8:45	Pumping started	....	....	....
8:45:20	.33	....	....	31.20
8:46	1	....	....	31.72
8:46:30	1.5	....	....	31.90
8:47	2	....	....	31.94
8:47:30	2.5	....	....	31.97
8:48	3	....	....	32.01
8:49	4	....	....	32.03
8:50	5	....	....	32.10
8:51	6	....	....	32.17
8:52	7	....	....	32.22
8:53	8	....	....	32.26
8:54	9	....	....	32.30
8:55	10	....	....	32.31
8:58	13	....	....	32.31
9:00	15	....	....	32.31
9:05	20	....	....	32.32
9:10	25	....	....	32.34
9:15	30	....	....	32.38
9:20	35	....	....	32.39
9:30	45	....	....	32.47
9:40	55	....	....	32.50
9:45	60	....	....	32.57
10:00	75	....	....	32.62
10:10	85	....	....	32.66
10:30	105	....	....	32.71
10:45	120	....	....	32.78
11:04	139	....	....	32.86
11:20	155	....	....	32.90
11:35	170	....	....	32.90
11:50	185	....	....	32.91
12:05 p. m.	200	....	....	32.92
12:25	220	....	....	32.92
12:50	245	....	....	32.98
1:05	260	....	....	33.01
1:25	280	....	....	33.02
1:50	305	....	....	33.06
2:00	315	....	....	33.12
2:05	320 Pumping stopped	....	....	....
2:05:30	320.5	.5	641	23.75
2:05:45	320.75	.75	427.6	24.18
2:06	321	1.	321	24.17
2:06:15	321.25	1.25	257	24.17

TABLE 7.—*Water-level measurements made during pumping and recovery in Wright well 5-2-25cc and values for t, t' and t/t'.—Concluded*

TIME	Time since pumping started, minutes t	Time since pumping stopped, minutes t'	t/t'	Depth to water, feet
2:06:30 p. m.	321.5	1.5	214	24.11
2:06:45.....	321.75	1.75	183	24.10
2:07........	322	2	161	24.09
2:07:30.....	322.5	2.5	129	24.08
2:08........	323	3	107	24.07
2:08:30.....	323.5	3.5	92	24.05
2:09........	324	4	81	24.04
2:10........	325	5	65	24.01
2:11........	326	6	54	23.99
2:12........	327	7	46	23.97
2:13........	328	8	41	23.95
2:14........	329	9	36	23.92
2:15........	330	10	33	23.90
2:17........	332	12	27	23.87
2:19........	334	14	24	23.85
2:22........	337	17	20	23.82
2:25........	340	20	17	23.78
2:28........	343	23	15	23.75
2:31........	346	26	13	23.73
2:34........	349	29	12	23.69
2:39........	354	34	10	23.65
2:44........	359	39	9	23.61
2:49........	364	44	8	23.59
3:00........	375	55	7	23.51
3:05........	380	60	6.3	23.49
3:10........	385	65	5.9	23.47
3:15........	390	70	5.5	23.44
3:25........	400	80	5.0	23.41
3:35........	410	90	4.5	23.36
3:45........	420	100	4.20	23.33
3:55........	430	110	3.90	23.32
4:10........	445	125	3.56	23.26
4:25........	460	140	3.28	23.21
4:40........	475	155	3.06	23.16
4:55........	490	170	2.88	23.12
5:10........	505	185	2.73	23.09
5:25........	520	200	2.60	23.08
5:30........	525	205	2.55	23.06
7:10........	625	305	2.04	22.95
7:40........	655	335	1.95	22.89
8:10........	685	365	1.87	22.87
8:40........	715	395	1.81	22.84
9:25........	760	440	1.72	22.81

2 and 5. The line so drawn indicates a value of 1.15 for Δs. Applying the Theis recovery formula:

$$T = \frac{(264)\ (1{,}000)}{1.15} = 230{,}000 \text{ gpd/ft.}$$

The thickness m is 47.6 feet, and from the relation $P = \frac{T}{m}$, P = 4,800 gpd/square foot. The drawdown at the end of the pumping period was 10.7 feet at 1,000 gpm, and thus the specific capacity was 93 gpm per foot of drawdown.

Depth-to-water measurements made in observation wells a, b, c, and d during the pumping period on well 5-2-25cc are given in Tables 8, 9, 10, and 11 respectively. Measurements made during the recovery period in observation well b are also given in Table 9.

Drawdown measurements in observation wells a, b, c, and d are plotted against t/r^2 in the composite straight-line graph shown in Figure 15. A line drawn using the later data from each of the ob-

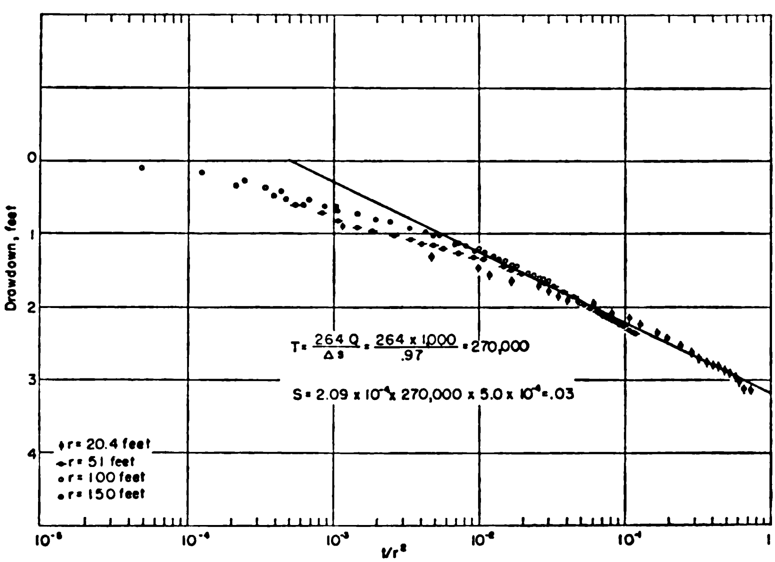

FIG. 15.—Drawdown in observation wells a, b, c, and d, plotted against t/r^2, in aquifer test using well 5-2-25cc.

servation wells gives a value of 0.97 for Δs. Applying the Cooper-Jacob composite generalized formula:

$$T = \frac{(264)\ (1{,}000)}{0.97} = 270{,}000 \text{ gpd/ft.}$$

and

$$S = (2.09 \times 10^{-4})\ (270{,}000)\ (5.0 \times 10^{-4}) = 0.03$$

In Figure 16 the depth-to-water measurements made during the recovery period in observation well b are plotted against the time since pumping stopped. A line through the late points in the recovery period gives a value of 1.0 for Δs; applying the Cooper-Jacob generalized time-drawdown formula:

$$T = \frac{(264)(1{,}000)}{1.0} = 260{,}000 \text{ gpd/ft.}$$

The corrected drawdowns in observation wells a, b, c, and d at 305 minutes after pumping began are plotted in Figure 17 against

TABLE 8.—*Water-level measurements in observation well a, 20.4 feet from pumped well 5-2-25cc.*

TIME	Time since pumping started, minutes t	t/r^2	Depth to water, feet	Drawdown, feet
8:44 a. m.	Static water level	....	24.87	....
8:45	Pumping started	....	....	....
8:45:30	.5	1.2×10^{-3}	25.79	.92
8:47	2	4.8×10^{-3}	26.20	1.33
8:49	4	9.6×10^{-3}	26.35	1.48
8:50	5	1.2×10^{-2}	26.45	1.58
8:52	7	1.7×10^{-2}	26.53	1.66
8:56	11	2.6×10^{-2}	26.59	1.72
8:58	13	3.1×10^{-2}	26.66	1.79
9:00	15	3.6×10^{-2}	26.74	1.87
9:02	17	4.1×10^{-2}	26.78	1.91
9:05	20	4.8×10^{-2}	26.80	1.93
9:10	25	6.0×10^{-2}	26.86	1.99
9:20	35	8.4×10^{-2}	26.97	2.10
9:30	45	1.1×10^{-1}	27.03	2.16
9:40	55	1.3×10^{-1}	27.13	2.26
9:55	70	1.7×10^{-1}	27.26	2.39
10:05	80	1.9×10^{-1}	27.31	2.44
10:25	100	2.4×10^{-1}	27.42	2.55
10:45	120	2.9×10^{-1}	27.51	2.64
11:05	140	3.3×10^{-1}	27.60	2.73
11:20	155	3.7×10^{-1}	27.64	2.77
11:35	170	4.1×10^{-1}	27.69	2.82
11:50	185	4.4×10^{-1}	27.71	2.84
12:05 p. m.	200	4.8×10^{-1}	27.77	2.90
12:25	220	5.3×10^{-1}	27.80	2.93
12:45	240	5.8×10^{-1}	27.86	2.99
1:05	260	6.2×10^{-1}	27.91	3.04
1:25	280	6.7×10^{-1}	28.00	3.13
1:50	305	7.3×10^{-1}	28.02	3.15
2:05	Pumping stopped	....	....	....

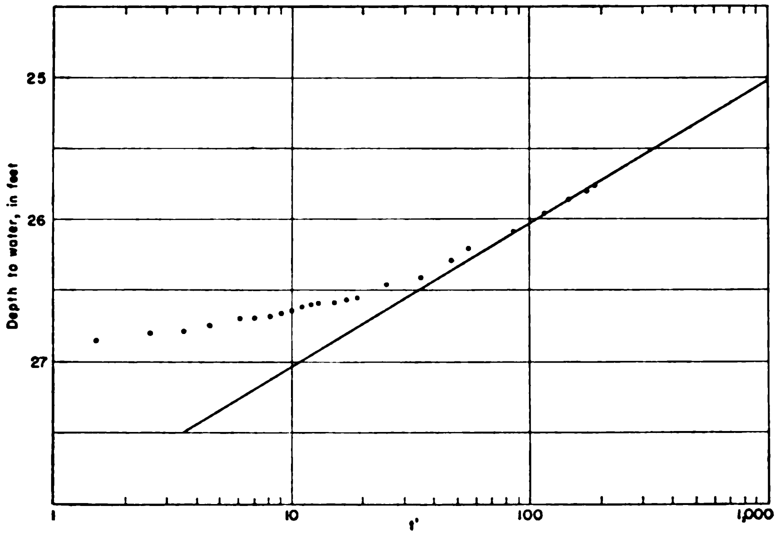

FIG. 16.—Depth to water in observation well b plotted against time since pumping started (t) or stopped (t') in well 5-2-25cc.

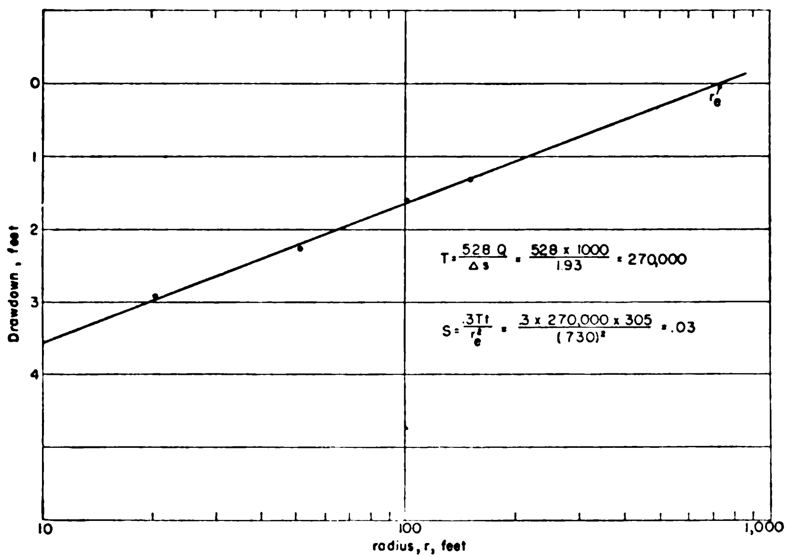

FIG. 17.—Drawdowns in observation wells a, b, c, and d at 305 minutes after pumping started plotted against distance (r) of observation wells from pumped well 5-2-25cc.

Table 9.—*Water-level measurements in observation well b, 51 feet from pumped well 5-2-25cc.*

Time	Time since pumping started, minutes t	Time since pumping stopped, minutes t′	t/r^2	Depth to water, feet	Draw-down, feet
8:44 a. m.	Static water level	....	....	25.04	....
8:45.....	Pumping started	....	....	....	....
8:45:30...	.5	....	1.9x10^{-4}	25.44	....
8:46:30...	1.5	....	5.7x10^{-4}	25.66	.62
8:47:15...	2.25	....	8.6x10^{-4}	25.77	.73
8:48.....	3	....	1.1x10^{-3}	26.88	.84
8:49.....	4	....	1.5x10^{-3}	25.95	.91
8:50.....	5	....	1.9x10^{-3}	26.02	.98
8:51.....	6	....	2.3x10^{-3}	26.04	1.00
8:52.....	7	....	2.7x10^{-3}	26.07	1.03
8:53.....	8	....	3.1x10^{-3}	26.11	1.07
8:54.....	9	....	3.5x10^{-3}	26.13	1.09
8:55.....	10	....	3.8x10^{-3}	26.15	1.11
8:56.....	11	....	4.2x10^{-3}	26.18	1.14
8:57.....	12	....	4.6x10^{-3}	26.20	1.16
8:58.....	13	....	5.0x10^{-3}	26.22	1.18
8:59.....	14	....	5.4x10^{-3}	26.23	1.19
9:00.....	15	....	5.8x10^{-3}	26.25	1.21
9:02.....	17	....	6.5x10^{-3}	26.26	1.22
9:05.....	20	....	7.6x10^{-3}	26.32	1.28
9:08.....	23	....	8.8x10^{-3}	26.35	1.31
9:10.....	25	....	9.6x10^{-3}	26.36	1.32
9:15.....	30	....	1.1x10^{-2}	26.40	1.36
9:20.....	35	....	1.2x10^{-2}	26.47	1.43
9:25.....	40	....	1.5x10^{-2}	26.50	1.46
9:30.....	45	....	1.7x10^{-2}	26.54	1.50
9:38.....	53	....	2.0x10^{-2}	26.61	1.57
9:45.....	60	....	2.3x10^{-2}	26.64	1.60
9:55.....	70	....	2.7x10^{-2}	26.72	1.68
10:00.....	75	....	2.9x10^{-2}	26.74	1.70
10:10.....	85	....	3.3x10^{-2}	26.78	1.74
10:15.....	90	....	3.5x10^{-2}	26.81	1.77
10:25.....	100	....	3.8x10^{-2}	26.85	1.81
10:45.....	120	....	4.6x10^{-7}	26.94	1.90
11:05.....	140	....	5.4x10^{-2}	27.03	1.99
11:20.....	155	....	5.9x10^{-2}	27.07	2.03
11:35.....	170	....	6.5x10^{-2}	27.12	2.08
11:50.....	185	....	7.1x10^{-2}	27.16	2.12
12:05 p. m.	200	....	7.7x10^{-2}	27.20	2.16
12:25.....	220	....	8.4x10^{-2}	27.24	2.20

TABLE 9.—*Water-level measurements in observation well b, 51 feet from pumped well 5-2-25cc.—Concluded*

TIME	Time since pumping started, minutes t	Time since pumping stopped, minutes t′	t/r^2	Depth to water, feet	Draw-down, feet
12:45 p. m.	240	....	9.2×10^{-2}	27.29	2.25
1:05.....	260	....	1.0×10^{-1}	27.33	2.29
1:25.....	280	....	1.1×10^{-1}	27.38	2.34
1:50.....	305	....	1.2×10^{-1}	27.43	2.39
2:05.....	Pumping stopped	....	....	....	....
2:05:30...	305.5	.5	....	26.86	....
2:07:30...	307.5	2.5	....	26.81	....
2:08:30...	308.5	3.5	....	26.78	....
2:09:30...	309.5	4.5	....	26.75	....
2:11.....	311	6	....	26.70	....
2:12.....	312	7	....	26.69	....
2:13.....	313	8	....	26.68	....
2:14.....	314	9	....	26.66	....
2:15.....	315	10	....	26.63	....
2:16.....	316	11	....	26.61	....
2:17.....	317	12	....	26.60	....
2:18.....	318	13	....	26.59	....
2:20.....	320	15	....	26.58	....
2:22.....	322	17	....	26.56	....
2:24.....	324	19	....	26.55	....
2:30.....	330	25	....	26.46	....
2:40.....	340	35	....	26.36	....
2:52.....	352	47	....	26.28	....
3:00.....	360	55	....	26.22	....
3:30.....	390	85	....	26.09	....
4:00.....	420	115	....	25.96	....
4:30.....	450	145	....	25.87	....
5:00.....	480	175	....	25.80	....
5:13.....	493	188	....	25.77	....

distance of the observation wells from the pumped well 5-2-25cc. A line through these points gives a value of 2.12 for Δs; applying the Thiem formula:

$$T = \frac{(528)\ (1{,}000)}{2.12} = 270{,}000$$

and

$$S = \frac{(0.3)\ (270{,}000)\ (305)}{(730)^2} = 0.03$$

Summary of Wright Aquifer Tests

The value of the coefficient of transmissibility (T) obtained from the test on well 5-2-25cb was 540,000 gpd per foot. From the test using well 5-2-25cc, values for T were obtained by the Theis re-

TABLE 10.—*Water-level measurements in observation well c, 100 feet from pumped well 5-2-25cc.*

TIME	Time since pumping started, minutes t	t/r^2	Depth to water, feet	Drawdown, feet
8:44 a. m.	Static water level	....	22.45	....
8:45	Pumping started	....	....	....
8:45:30	.5	$5.0x10^{-5}$	22.55	.10
8:46:30	1.5	....	....	....
8:47:30	2.5	$2.5x10^{-4}$	22.73	.28
8:48:30	3.5	$3.5x10^{-4}$	22.85	.40
8:49:30	4.5	$4.5x10^{-4}$	22.88	.43
8:50:30	5.5	$5.5x10^{-4}$	22.97	.52
8:52	7	$7.0x10^{-4}$	23.02	.57
8:53	8	$8.0x10^{-4}$	23.06	.61
8:54	9	$9.0x10^{-4}$	23.09	.64
8:56	11	$1.1x10^{-3}$	23.13	.68
8:58	13	$1.3x10^{-3}$	23.17	.72
9:00	15	$1.5x10^{-3}$	23.20	.75
9:03	18	$1.8x10^{-3}$	23.24	.79
9:05	20	$2.0x10^{-3}$	23.27	.82
9:10	25	$2.5x10^{-3}$	23.31	.86
9:15	30	$3.0x10^{-3}$	23.35	.90
9:25	40	$4.0x10^{-3}$	23.42	.97
9:35	50	$5.0x10^{-3}$	23.48	1.03
9:45	60	$6.0x10^{-3}$	23.50	1.05
9:55	70	$7.0x10^{-3}$	23.59	1.14
10:05	80	$8.0x10^{-3}$	23.63	1.18
10:15	90	$9.0x10^{-3}$	23.63	1.18
10:25	100	$1.0x10^{-2}$	23.68	1.23
10:45	120	$1.2x10^{-2}$	23.77	1.32
11:05	140	$1.4x10^{-2}$	23.82	1.37
11:20	155	$1.5x10^{-2}$	23.85	1.40
11:35	170	$1.7x10^{-2}$	23.90	1.45
11:50	185	$1.8x10^{-2}$	23.93	1.48
12:05 p. m.	200	$2.0x10^{-2}$	23.97	1.52
12:25	220	$2.2x10^{-2}$	24.02	1.57
12:45	240	$2.4x10^{-2}$	24.05	1.60
1:05	260	$2.6x10^{-2}$	24.09	1.64
1:25	280	$2.8x10^{-2}$	24.11	1.66
1:50	305	$3.1x10^{-2}$	24.12	1.67

covery method, the Thiem method, and the Cooper-Jacob generalized composite method. These values ranged from 230,000 gpd per foot in the pumped well, as computed by the Theis recovery method, to 270,000 gpd per foot by the Thiem method. The value for T obtained by the Theis recovery method is probably in error because the points in Figure 14 do not fall in a straight line. The value for T obtained from well 5-2-25cb seems to be too high, as the geologic conditions at wells 5-2-25cb and 5-2-25cc are very

TABLE 11.—*Water-level measurements in observation well d, 150 feet from pumped well 5-2-25cc.*

Time	Time since pumping started, minutes t	t/r^2	Depth to water, feet	Drawdown, feet
8:44 a. m.	Static water level	....	23.95	....
8:45	Pumping started	....	....	....
8:48	3	1.3×10^{-4}	24.13	.18
8:50	5	2.2×10^{-4}	24.29	.34
8:52	7	3.1×10^{-4}	24.36	.41
8:54	9	4.0×10^{-4}	24.43	.48
8:56	11	4.9×10^{-4}	24.50	.55
8:58	13	5.8×10^{-4}	24.50	.55
9:00	15	6.6×10^{-4}	24.57	.62
9:03	18	8.0×10^{-4}	24.59	.64
9:05	20	8.8×10^{-4}	24.57	.62
9:10	25	1.1×10^{-3}	24.60	.65
9:15	30	1.3×10^{-3}	24.60	.65
9:25	40	1.7×10^{-3}	24.73	.78
9:35	50	2.2×10^{-3}	24.80	.85
9:45	60	2.7×10^{-3}	24.81	.86
9:55	70	3.1×10^{-3}	24.85	.90
10:05	80	3.5×10^{-3}	24.88	.93
10:15	90	4.0×10^{-3}	24.90	.95
10:25	100	4.4×10^{-3}	24.95	1.00
10:45	120	5.3×10^{-3}	24.98	1.03
11:05	140	6.2×10^{-3}	25.04	1.09
11:20	155	6.9×10^{-3}	25.06	1.11
11:35	170	7.5×10^{-3}	25.09	1.14
11:50	185	8.2×10^{-3}	25.13	1.18
12:05 p. m.	200	8.8×10^{-3}	25.15	1.20
12:25	220	9.8×10^{-3}	25.18	1.23
12:45	240	1.1×10^{-2}	25.23	1.28
1:05	260	1.2×10^{-2}	25.25	1.30
1:25	280	1.3×10^{-2}	25.28	1.33
1:50	305	1.4×10^{-2}	25.32	1.37
2:05	Pumping stopped	....	....	....

similar and would not indicate as great a difference. The values of T obtained by the Cooper-Jacob generalized composite method, the Thiem method, and the modified nonequilibrium method on well 5-2-25cc are all in fair agreement and probably are near the true value for T in this area. The values obtained for the coefficient of storage (S) indicate water-table conditions in the vicinity of the well. The values of S probably are much less than the true value of the storage coefficient. In a longer test the value of S would continue to increase until a nearly true value could be obtained.

Franklin Day Well 6-1-4bbc

An aquifer test was made by pumping well 6-1-4bbc in the fall of 1955. The well was pumped for a period of 245 minutes at a rate of 540 gpm. Three observation wells, a, b, and c, were drilled at distances of 48 feet, 100 feet, and 147 feet, respectively, from the pumped well, and drawdown measurements were made during the period of pumping. The water-level measurements made in well 6-1-4bbc during the drawdown and recovery periods, and values for t, t′, and t/t′, are given in Table 12.

The ratio t/t′ is plotted against depth to water (s′) on semilogarithmic paper in Figure 18. The later points, as plotted, seem to fall on a straight line that approaches the zero-drawdown point

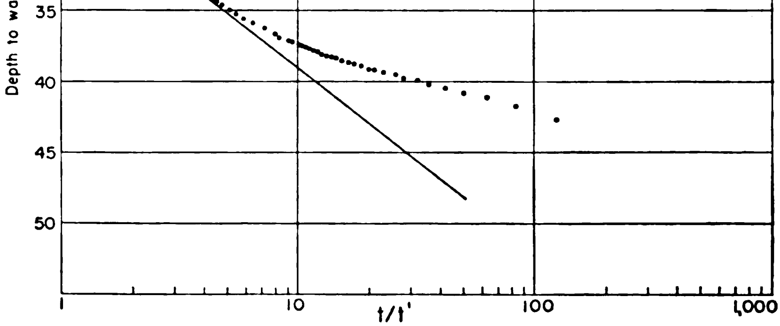

FIG. 18.—Depth to water in well 6-1-4bbc plotted against t/t′, time since pumping started divided by time since pumping stopped.

TABLE 12.—*Water-level measurements made during pumping and recovery in Day well 6-1-4bbc and values for t, t′ and t/t′.*

Time	Time since pumping started, minutes t	Time since pumping stopped, minutes t′	t/t′	Depth to water, feet
12:25 p. m.	Static water level	....	....	26.05
12:30	Pumping started	....	....	....
12:30:20	.3	....	....	37.80
12:30:45	.75	....	....	40.80
12:31	1	....	....	42.55
12:32	2	....	....	45.00
12:32:30	2.5	....	....	46.50
12:33	3	....	....	47.60
12:34	4	....	....	48.30
12:35	5	....	....	51.30
12:36	6	....	....	52.40
12:37	7	....	....	53.48
12:38	8	....	....	54.80
12:39	9	....	....	55.52
12:40	10	....	....	56.09
12:45	15	....	....	58.44
12:50	20	....	....	60.51
12:55	25	....	....	62.75
1:00	30	....	....	64.45
1:10	40	....	....	65.14
1:21	51	....	....	66.05
1:30	60	....	....	66.06
4:35	245	Pumping stopped	....	....
4:37	247	2	123	42.71
4:38	248	3	83	41.72
4:39	249	4	62	41.18
4:40	250	5	50	40.81
4:41	251	6	42	40.50
4:42	252	7	36	40.22
4:43	253	8	32	39.98
4:44	254	9	28	39.74
4:45	255	10	26	39.55
4:46	256	11	23	39.41
4:47	257	12	21	39.26
4:48	258	13	20	39.11
4:49	259	14	18.5	38.97
4:50	260	15	17.3	38.83
4:51	261	16	16.3	38.70
4:52	262	17	15.4	38.56
4:53	263	18	14.6	38.44

TABLE 12.—*Water-level measurements made during pumping and recovery in Day well 6-1-4bbc and values for t, t' and t/t'.—Concluded*

TIME	Time since pumping started, minutes t	Time since pumping stopped, minutes t'	t/t'	Depth to water, feet
4:54 p. m...	264	19	13.9	38.33
4:55........	265	20	13.2	38.22
4:56........	266	21	12.7	38.10
4:57........	267	22	12.1	37.99
4:58........	268	23	11.7	37.86
4:59........	269	24	11.2	37.77
5:00........	270	25	10.8	37.66
5:01........	271	26	10.4	37.55
5:02........	272	27	10.1	37.45
5:03........	273	28	9.7	37.34
5:04........	274	29	9.4	37.23
5:05........	275	30	9.18	37.13
5:07........	277	32	8.15	36.93
5:10........	280	35	8.00	36.67
5:15........	285	40	7.12	36.25
5:20........	290	45	6.45	35.86
5:25........	295	50	5.90	35.53
5:30........	300	55	5.46	35.22
5:35........	305	60	5.08	34.93
5:40........	310	65	4.77	34.66
5:45........	315	70	4.50	34.40
5:50........	320	75	4.27	34.14
5:56........	326	81	4.02	33.88
6:00........	330	85	3.88	33.68
6:06........	336	91	3.70	33.45
6:15........	345	100	3.45	33.11
6:25........	355	110	3.23	32.80
6:35........	365	120	3.04	32.50
7:53........	443	198	2.24	30.83
8:25........	475	230	2.07	30.35
9:30........	540	295	1.83	29.65
8:50 a. m....	1,220	975	1.25	27.26

where $t/t' = 1$. This line gives a value for Δs of 13.0. Applying the Theis recovery formula $\left(T = \dfrac{264Q}{\Delta s'}\right)$, $T = 11{,}000$ gpd/ft.; but the data from the observation wells indicate that this value is too low, probably because of entrapped air, which could be heard escaping for a considerable period after pumping stopped. Presumably the water level did not recover as rapidly as it would have if air had not been entrapped, and the plotted line based on observed water levels therefore is displaced somewhat from its expectable position. Hence, T as calculated may be in error. An arbitrary line can be drawn through the values of t/t' from about 3.5 to 6, which will give 13,000, a value for T that more nearly equals the value obtained from the observation-well data. The thickness of saturated material (m) at the well is 43 feet; hence, from the relation $P = \frac{T}{m}$ the permeability is computed to be 300 gpd per square foot. The specific capacity is 13.5 gpm per foot of drawdown.

Drawdown measurements made in observation well a during the pumping period are given in Table 13. Observation well a was 48 feet from pumped well 6-1-4bbc. The data in Table 13 are plotted on logarithmic paper in Figure 19, the time since pumping started (t) being plotted along the horizontal axis and the drawdown (s) along the vertical axis. The match point on the type curves gives s = 8.3 and t = 17.8 minutes. Using the Theis nonequilibrium formulas where

$$T = \frac{208.5Q}{s} \text{ and } S = \frac{3.71 \times 10^{-6}\,(Tt)}{r^2}, \; T = 13{,}500 \text{ gpd/foot and}$$

S = 0.003. The value for S = 0.003 indicates a semiartesian or a slow-draining condition.

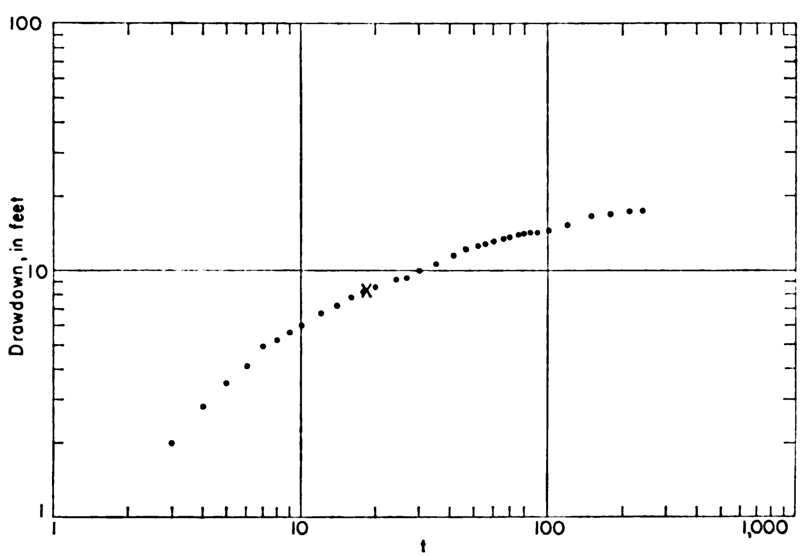

FIG. 19.—Drawdown of water level in observation well a plotted against time since pumping started (t) in well 6-1-4bbc.

TABLE 13.—*Water-level measurements in observation well a, 48 feet from pumped well 6-1-4bbc.*

TIME	Time since pumping started, minutes t	Depth to water, feet
12:26 p. m.	Static water level	26.66
12:30	Pumping started	....
12:31	1	27.05
12:32	2	27.52
12:33	3	28.69
12:34	4	29.49
12:35	5	30.22
12:36	6	30.82
12:37	7	31.66
12:38	8	31.95
12:39	9	32.34
12:40	10	32.70
12:42	12	33.31
12:44	14	33.89
12:46	16	34.44
12:48	18	34.86
12:50	20	35.27
12:54	24	36.00
12:57	27	36.43
1:00	30	36.86
1:05	35	37.49
1:11	41	38.11
1:16	46	38.69
1:21	51	39.13
1:25	55	39.40
1:30	60	39.70
1:35	65	39.96
1:40	70	40.19
1:45	75	40.44
1:50	80	40.72
1:55	85	40.90
2:00	90	41.10
2:11	101	41.38
2:20	110	41.63
2:30	120	41.84
2:40	130	42.05
2:52	142	42.25
3:00	150	42.42
3:15	165	42.61
3:30	180	42.79
3:45	195	42.94
4:00	210	43.04
4:15	225	43.15
4:30	240	43.20
4:35	Pumping stopped	....

Table 14.—*Water-level measurements in observation well b, 100 feet from pumped well 6-1-4bbc.*

Time	Time since pumping started, minutes t	Depth to water, feet
12:26 p. m.	Static water level	25.88
12:30	Pumping started	....
12:31	1	25.89
12:32	2	25.92
12:33	3	26.20
12:34	4	26.49
12:35	5	26.86
12:36	6	27.23
12:37	7	27.76
12:38	8	28.23
12:40	10	28.84
12:41	11	29.28
12:42	12	29.93
12:44	14	30.36
12:48	18	31.41
12:50	20	31.82
12:52	22	32.39
12:54	24	32.71
12:56	26	33.18
12:58	28	33.47
1:02	32	33.98
1:04	34	34.22
1:06	36	34.53
1:10	40	34.93
1:15	45	35.45
1:21	51	35.75
1:26	56	36.45
1:31	61	36.78
1:36	66	37.10
1:41	71	37.35
1:46	76	37.62
1:52	82	37.87
1:57	87	38.08
2:01	91	38.24
2:11	101	38.58
2:21	111	38.85
2:30	120	39.11
2:40	130	39.40
2:50	140	39.60
3:00	150	39.82

TABLE 14.—*Water-level measurements in observation well b, 100 feet from pumped well 6-1-4bbc.*—CONCLUDED.

TIME	Time since pumping started, minutes t	Depth to water, feet
3:15 p. m.	165	40.05
3:30	180	40.27
3:45	195	40.45
4:00	210	40.60
4:15	225	40.74
4:30	240	40.82
4:35	245 Pumping stopped	....

Drawdown measurements made in observation well b during the pumping period in well 6-1-4bbc are given in Table 14. Observation well b was 100 feet from the pumped well. The drawdown data are plotted on logarithmic paper in Figure 20, the time in minutes along the horizontal axis and the drawdown along the vertical axis. The match point on the type curve gives s = 9.0 and t = 43 minutes. Using the Theis nonequilibrium formulas applied in the preceding paragraph, T = 12,500 gpd/ft. and S = 0.001.

Drawdown data for observation well c obtained during the pump-

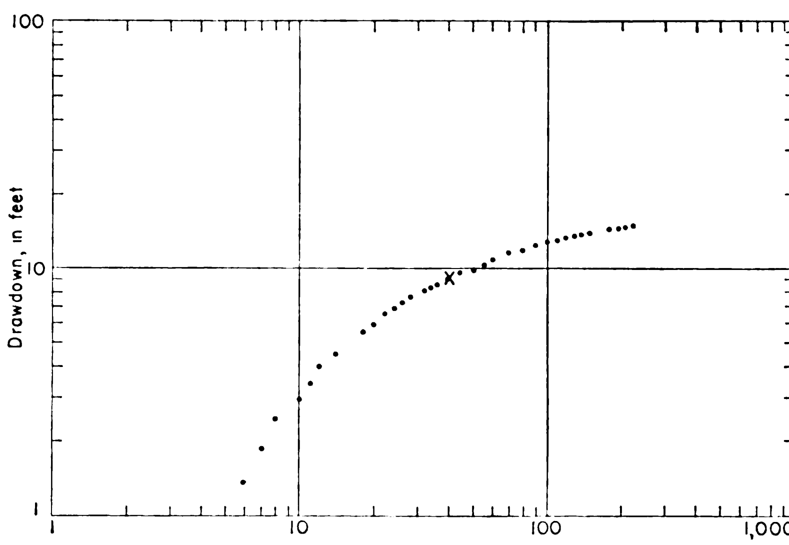

FIG. 20.—Drawdown of water level in observation well b plotted against time since pumping started (t) in well 6-1-4bbc.

ing period of well 6-1-4bbc are given in Table 15 and plotted on logarithmic paper, the time (t) being plotted along the horizontal axis and the drawdown (s) along the vertical axis (Fig. 21). The match point on the type curve gives $s = 8.6$ and $t = 28$ minutes. Using the Theis nonequilibrium formulas applied for wells a and b, $T = 13{,}000$ gpd/ft. and $S = 0.006$.

TABLE 15.—*Water-level measurements in observation well c, 147 feet from pumped well 6-1-4bbc.*

TIME	Time since pumping started, minutes t	Depth to water, feet
12:23 p. m.	Static water level	26.82
12:30	Pumping started	....
12:31	1	26.82
12:40	10	26.89
12:45	15	27.16
12:50	20	27.38
12:55	25	27.60
1:00	30	27.86
1:05	35	28.13
1:10	40	28.40
1:15	45	28.90
1:21	51	28.97
1:25	55	29.18
1:30	60	29.40
1:35	65	29.64
1:40	70	29.70
1:45	75	30.08
1:50	80	30.33
1:55	85	30.52
2:00	90	30.69
2:10	100	31.06
2:20	110	31.42
2:30	120	31.69
2:40	130	32.00
2:50	140	32.32
3:00	150	32.58
3:15	165	32.93
3:30	180	33.29
3:45	195	33.63
4:00	210	33.89
4:15	225	34.16
4:30	240	34.85
4:35	Pumping stopped	....

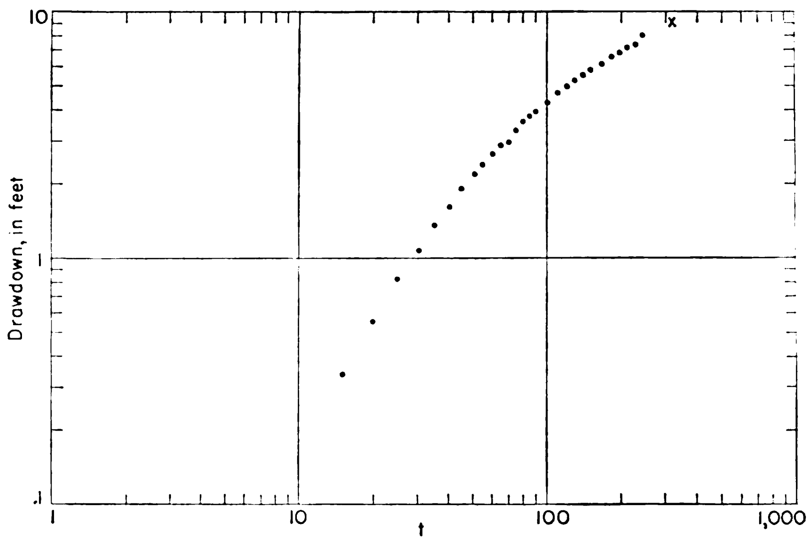

FIG. 21.—Drawdown of water level in observation well c plotted against time since pumping started (t) in well 6-1-4bbc.

Summary of Day Aquifer Test

The results from the Day aquifer test using three observation wells are in fair agreement, and the values for T and S are accurate within practical limits. Calculations based on the data obtained during the test indicate that the pumping rate during the test was excessive and pumping could not continue very long at this rate. The well probably could be pumped at a rate of 400 gpm for a period of about 10 days before the yield would decline appreciably. Inasmuch as the well is used for short periods of continuous pumping and is then allowed to recover for several days, a discharge rate of about 400 gpm, though it could not be safely exceeded, probably could be maintained.

SUMMARY OF GROUND-WATER CONDITIONS IN CLOUD COUNTY

Cloud County may be divided into two general categories, the upland area and the valley area. In the upland area, ground water is obtained from consolidated Cretaceous rocks. The Dakota Formation is the chief aquifer, although a few shallow wells obtain meager supplies of water from the Greenhorn Limestone. The Dakota Formation generally yields water of good quality in adequate quantity for stock and domestic use, but in a region in north-central and northwestern Cloud County salt water may be encountered. Over most of the region in which the water is salty, the upper part of the Dakota Formation yields water of good quality in quantity sufficient for domestic use, but the salinity increases with depth. South of Buffalo Creek, in western Cloud County, in an area several square miles in extent, the water in the entire Dakota Formation is salty. In this area shallow wells in the Greenhorn Limestone yield small supplies of water to wells.

The valley area in Cloud County contains deposits of two general classes, the alluvium and low terrace deposits (Wisconsinan and Recent) and the high terrace deposits (Illinoian). The alluvium and low terrace deposits although not covering the largest area in the county, are the most important aquifer. All irrigation wells obtain water from these deposits, and yields may be as much as 1,500 gpm. Much water for future development of irrigation is in storage in these beds, but overdevelopment probably would result in a lowering of the water table in the area and would diminish to some extent the flow of the river. Lowering the water table to any great extent would upset the hydrologic balance in the valley, which at present tends to hold back a part of the salt water that enters the valley where water in the Dakota Formation is salty. Upsetting this balance by overpumping might result in a serious salt-water problem in the valley area.

The second, or high-terrace, area includes the Illinoian terraces along the valley walls of Buffalo Creek and Republican River. These deposits are composed principally of silt, but some sand is interbedded and a few feet of sand and gravel lies near the base. These high-terrace deposits yield enough water for domestic or stock use but not enough for irrigation. Illinoian deposits bordering the valley of Solomon River contain sand and gravel composed of transported arkosic material and also pebbles of limestone and sandstone of local origin, but they lie principally above the water table and are not important as an aquifer.

RECORDS OF WELLS, TEST HOLES, AND SPRINGS

Statistics for 170 wells, 186 test holes, and 1 spring are given in Table 16. Information classed as reported was obtained from the owner, tenant, or driller. Measured depths of wells are given to the nearest tenth of a foot below measuring point, and measured depths to water are given to the nearest hundredth of a foot. The well-numbering system used in this table is described on page 12.

TABLE 16.—*Records of wells, test holes, and spring in Cloud County, Kansas.*

WELL NUMBER	Location	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, inches	Type of casing (3)	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. 4 S., R. 4 W.															
4-4-33dc	SW SE sec. 33	Bureau of Reclamation	Th	130	4		Sand, gravel	Terrace deposits			Land surface					In Republic Co.
	T. 5 S., R. 1 W.															
5-1-1da	NE SE sec. 1	A. F. Danielson	Dr	56.2	6	GI	Sandstone	Dakota Formation	Cy,W,H	S	Base of pump	0.3	1386.8	35.10	9-31-54	
5-1-2ba	NE NW sec. 2		A	39.0	4		Sand	Terrace deposits			Land surface		1342.5	27.30	6-15-54	On public road.
5-1-3ba	NE NW sec. 3		A	20.0	4		do	do			do		1324.8	15.00	6-15-54	do
5-1-4aaa	NE NE sec. 4		A	50.0	4		do	do			do		1364.7	40.00	6-15-54	do
5-1-4aa	NE NE sec. 4	H. G. Moore	Du	53.9	36	R	do	do	Cy, H	S	Top of 1-inch pipe at west side of pump	1.5	1367.1	38.65	8-31-54	
5-1-7bba	NW NW sec. 7	W. J. Cottam	Dr	63.4	6	GI	Sandstone	Dakota Formation	Cy, H	S	Base of pump	0.2	1430.2	52.75	8- 3-54	
5-1-10dd	SE SE sec. 10		A	85.0	4		Sand	Terrace deposits			Land surface		1339.1	38.00	6-10-54	On public road.
5-1-11bbd	NW NW sec. 11	H. Funk	Dr, Th	185	4		Sand, gravel	do			do		1348.1	40.00	9-21-55	Test hole for irrigation use.
5-1-11cc	SW SW sec. 11	U. S. Geol. Survey	Th	86	4		do	do			do		1334.0	35.60	6-25-54	
5-1-13cc	SW SW sec. 13	Anna Resco	Dr	71.4	6	GI	Sandstone	Dakota Formation	Cy, W	S	Base of pump	0.8	1335.9	42.52	8-31-54	
5-1-14ab	NW NE sec. 14		A	45.0	4		Sand	Terrace deposits			Land surface		1331.8	36.80	6-14-54	On public road.
5-1-14ccc	SW SW sec. 14		A	25	4		do	do			do		1303.7	18.30	6-17-54	do
5-1-15ab	NW NE sec. 15		A	24.0	4		Sand, gravel	do			do		1312.9	21.60	4-15-54	do
5-1-15ba	NE NW sec. 15		A	35.0	4		do	do			do		1319.2	23.30	4-15-54	do
5-1-18dad	NE SE sec. 18	F. J. Feight	Dr	39.8	6	GI	do	do	Cy, W	S	Base of pump	0.2	1340.1	27.21	8-31-54	
5-1-19cca	SW SW sec. 19	F. Martin	Dr	25.7	18	GI	do	Alluvium	Ce, G	I	Top of casing	0.3	1285.5	8.00	10-26-55	
5-1-19cc	SW SW sec. 19	do	Dr	38.5	18	S	do	do	Ce, G	I	do	0.5	1289.7	11.10	10-26-55	
5-1-20dda	SE SE sec. 20		A	19.0	4		do	do			Land surface		1294.5	15.80	4-14-54	On public road.
5-1-20ddd	SE SE sec. 20		A	19.0	4		do	do			do		1293.9	16.80	4-14-54	do
5-1-22dd	SE SE sec. 22	U. S. Geol. Survey	Th	83.0	4		do	Terrace deposits			do		1312.4	35.80	6-10-54	do
5-1-25ddd	SE SE sec. 25		A	29.0	4		do	do			do		1286.0	23.00	4-15-54	do
5-1-26ad1	SE NE sec. 26	City of Clyde	Dr	158	12	S	Sandstone	Dakota Formation	T, E	P			1294.4			South well.
*5-1-26ad2	SE NE sec. 26	do	Dr	158	12	S	do	do	T, E	P						North well.
5-1-26cb	NW SW sec. 26	U. S. Geol. Survey	Th	60	4		Gravel	Terrace deposits			Land surface		1279.4			

5-1-30aac	NE NE sec. 30	Bennet	Dr	50.0	18	GI	Sand, gravel	Alluvium	Ce, T	I	Top of casing	0.6	1285.5	9.00	10-26-55	
5-1-30dcb	SW SE sec. 30	H. St. Pierre	Dr	70.6	18	GI	do	do	T, B	I	Hole in pump base	0.7	1287.3	11.20	10-26-55	Est. yield 1200.
5-1-31bd	SE NW sec. 31	Harley Gram	Dr	78	18	GI	do	Terrace deposits	T, T	I	do	1.0	1302.2	22.60	10-26-55	Est. yield 800.
5-1-32cc	SW SW sec. 32	L. Goering	Dr	98.0	18	GI	do	do	T, T	I	do	1.0	1307.6	27.70	9-21-55	
5-1-33cb	NW SW sec. 33		A	24.0	4		do	do			Land surface		1296.4	19.40	4-13-54	On public road.
5-1-34aa	NE NE sec. 34	U. S. Geol. Survey	Th	100	4		do	Alluvium			do		1286.0			
5-1-35bc	SW NW sec. 35	do	Th	100	4		do	do			do		1281.0			
5-1-36ad	SE NE sec. 36		A	14.0	4		do	Terrace deposits			do		1275.4	13.30	4-15-54	On public road.
5-1-36ddd	SE SE sec. 36		A	14.0	4		do	do			do		1276.3	13.30	4-15-54	do
	T. 5 S., R. 2 W.															
5-2-5aab	NE NE sec. 5		A	19.0	4		do	do			do		1324.4	9.10	4-14-54	do
5-2-5abb	NW NE sec. 5		A	24.0	4		do	do			do		1337.6	15.30	4-14-54	do
5-2-5bbb	NW NW sec. 5		A	34.0	4		do	do			do		1329.4	15.70	4-14-54	do
5-2-6ab	NW NE sec. 6		A	40.0	4		Silt	do (?)			do		1340.9	20.40	4-14-54	do
5-2-7dd	SE SE sec. 7	J. A. Janson	Dr	103.0	6	GI	Sandstone	Dakota Formation	Cy, W	S	Base of pump	1.0	1433.1	95.75	8-31-54	
5-2-10bba	NW NW sec. 10	L. B. Ekstrom	Dr	41.0	6	GI	do	do	Cy, W	S	do	0.1	1357.1	29.20	8-31-54	
5-2-13ccc	SW SW sec. 13		A	34.0	4		Sand, gravel	Terrace deposits			Land surface		1318.4	27.60	4-14-54	On public road.
5-2-15cbc	NW SW sec. 15	J. W. Decker	Du	58.5	48	R	Sandstone	Dakota Formation	Cy, W	S	Base of pump	0.3	1359.1	52.23	8-31-54	
5-2-15cd	SE SW sec. 15		A	24.0	4		Sand, gravel	Terrace deposits			Land surface		1317.9	19.50	4-14-54	On public road.
5-2-15ddc	SE SE sec. 15		A	24.0	4		do	do			do		1313.4	17.60	4-14-54	do
5-2-16dcc	SW SE sec. 16		A	19.0	4		do	do			do		1320.3	18.70	4-14-54	do
5-2-17ccc	SW SW sec. 17		A	49.0	4		Sandstone	Dakota Formation			do		1355.8	34.70	4-14-54	do
5-2-17dcc	SW SE sec. 17		A	34.0	4		Sand	Terrace deposits			do		1338.7	32.70	4-14-54	do
5-2-17ddd	SE SE sec. 17		A	24.0	4		do	do			do		1325.8	17.90	4-14-54	do
5-2-19cb	NW SW sec. 19	U. S. Geol. Survey	Th	75	4		Sand, gravel	Alluvium			do					
5-2-20cca	SW SW sec. 20	D. Morgan	Dr	45.2	18	GI	do	do	T, T	I	Hole in base of pump	1.0	1317.5	7.40	9-21-55	
5-2-21bb	NW NW sec. 21	W. E. Johnson	Dr	35.2	18	GI	do	Terrace deposits	N	I	Top of casing	1.2	1325.2	20.30	10-26-55	New well, pump not installed.
5-2-21da	NE SE sec. 21		A	14.0	4		Sand	Alluvium			Land surface		1306.6	9.80	4-14-54	On public road.
5-2-22bdc	SE NW sec. 22		A	14.0	4		do	do			do		1307.6	11.20	4-14-54	do
5-2-22ca	NE SW sec. 22	Pierce	Dr	55.4	18	GI	Sand, gravel	do	Ce, T	I	do	1.5	1306.4	10.91	10-26-55	Est. yield 600.
5-2-25bb	NW NW sec. 25		A	14.0	4		Sand	do			do		1294.3	8.20	4-13-54	On public road.
5-2-25bca	SW NW sec. 25	D. Garlow	Dr	85	18	GI	Sand, gravel	Terrace deposits	T, T	I	Hole in base of pump	0.4	1304.6	22.15	10-26-55	Est. yield 1200.
5-2-25bc	SW NW sec. 25		A	24.0	4		Sand	do			Land surface		1307.1	20.80	4-13-54	On public road.
5-2-25cb	NW SE sec. 25	W. T. Wright	Dr	65.0	18	GI	Sand, gravel	do	T, E	I	Base of pump	0.6	1305.5	21.50	10-27-54	Aquifer test made in 1942.
5-2-25cbc	NW SW sec. 25		A	24.0	4		Sand	do			Land surface		1305.5	18.80	4-13-54	On public road.
5-2-25cc	SW SW sec. 25	W. T. Wright	Dr	72.0	18	GI	Sand, gravel	do	T, B	I	Hole in pump base	0.2	1304.8	22.42	10-11-55	Aquifer test made 10-11-55
5-2-25dad	NE SE sec. 25	Nailleaux	Dr	68.4	16	S	do	do	T, T	I	Base of pump	2.0	1304.2	27.65	10-27-54	
5-2-26aad	NE NE sec. 26	Marvin Cleveland	Dr	75.0	18	GI	do	do	T, T	I	Land surface		1306.4	21.30	10-26-55	
5-2-26aad	NE NE sec. 26	U. S. Geol. Survey	Th	110	4		do	Alluvium			do					

TABLE 16.—*Records of wells, test holes, and spring in Cloud County, Kansas.*—*Continued*

Well number	Location	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, inches	Type of casing (3)	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. 5 S., R. 2 W.															
5-2-26ad	SE NE sec. 26	Marvin Cleveland	Dr	80.4	18	GI	Sand, gravel	Terrace deposits	T, T	I	Base of pump	0.6	1306.9	21.85	10-27-54	Owner reports drawdown of 6 after continuous pumping at 1100.
5-2-28aad	NE NE sec. 28		A	14.0	4		do	Alluvium			Land surface		1304.9	8.00	4-14-54	On public road.
5-2-28cb	NW SW sec. 28	U. S. Geol. Survey	Th	106	4		do	do			do					
5-2-30bb	NW NW sec. 30		A	14.0	4		Sand	do			do		1326.3	7.50	4-9-54	On public road.
*5-2-30bcc	SW NW sec. 30	U. S. Geol. Survey	Th	96.0	4		Sand, gravel	do	A	Th	do		1326.7	8.00	6-12-54	
5-2-30bcd	SW NW sec. 30	Charbonneau	Dr	39.5	14	S	do	do	Ce, B	I	Top of casing	0.0	1326.8	9.15	10-26-55	Est. yield 800.
5-2-30cb	NW SW sec. 30		A	12.0	4		do	do			Land surface		1324.6	10.60	4-9-54	On public road.
5-2-31bb	NW NW sec. 31		A	20.0	4		do	do			do		1330.9	12.50	4-9-54	do
5-2-31bc	SW NW sec. 31		A	29.0	4		Sand	Terrace deposits			do		1341.5	22.60	4-9-54	do
5-2-32ada	SE NE sec. 32		A	29.0	4		do	do			do		1330.5	23.60	4-13-54	do
5-2-32cb	NW SW sec. 32	Walter Doyen	Dr	50.0	18	GI	Sand, gravel	do	T, B	I	Hole in pump base	1.0	1338.0	29.00	10-26-55	Est. yield 750.
5-2-32da	NE SE sec. 32		A	29.0	4		Sand	do			Land surface		1333.1	25.20	4-13-54	On public road.
5-2-32db	NW SE sec. 32	Tom McDaniels	Dr	54	18	GI	Sand and gravel	do	T, B	I	Hole in pump base	1.0	1334.7	25.00	10-26-55	Est. yield 1000.
5-2-32ddd	SE SE sec. 32		A	39.0	4		Sand	do			Land surface		1344.3	38.30	4-13-54	On public road.
5-2-34aab	NE NE sec. 34	F. Wentz	Dr	80.8	18	GI	Sand and gravel	do	T, B	I	Hole in pump base	1.5	1312.8	22.92	10-26-55	Estimated yield 1500.
5-2-35aa	NE NE sec. 35		A	24.0	4		Silt	do			Land surface		1303.6	17.30	4-13-54	On public road.
5-2-36bc1	SW NW sec. 36		A	29.0	4		Sand	do			do		1309.9	22.20	4-13-54	do
5-2-36bc2	SW NW sec. 36	B. Garlow	Dr	39.8	18	S	Sand and gravel	do	T, T	I	Hole in pump base	1.5	1305.8	23.20	10-26-55	Est. yield 330.
	T. 5 S., R. 3 W.															
5-3-6cc	SW SW sec. 6	U. S. Geol. Survey	Th	60	4		do	do			Land surface		1407.4	43.50	6-14-54	
5-3-8aa	NE NE sec. 8	do	Th	70	4		do	do			do		1423.4			
5-3-10bcb	SW NW sec. 10	W. E. Morgan	Dr	127.8	6	GI	Sandstone	Dakota Formation	Cy, H	S	Base of pump	0.2	1434.8	62.65	8-31-54	

5-3-14dd	SE SE sec. 14	School District	Dr	66.8	5	GI	do	do	Cy, H	D	do	0.4	1384.7	53.11	8-31-54	
5-3-15ab	NW NE sec. 15	U. S. Geol. Survey	Th	384.0	4	N	do	do	N	N	Land surface		1428.6			
5-3-15bdd	SE SE NW sec. 15		Dr, Th	72							do		1413.3			
5-3-15cd	SE SW sec. 15		Dr, Th	36							do		1372.3			
5-3-15dbd	SE NW sec. 15		Dr, Th	40							do		1387.9			
5-3-16bb	NW NW sec. 16	U. S. Geol. Survey	Th	70	4						do		1411.3			
5-3-16cb	NW SW sec. 16	do	Th	65	4						do		1382.2			
5-3-17aa	NE NE sec. 17	do	Th	70	4		Sandstone	Dakota Formation			do		1410.9	53.70	6-14-54	
5-3-17bbb	NW NW sec. 17		A	65.0	4		Sand, gravel	Terrace deposits			do		1395.2	49.00	4- 8-54	On public road.
5-3-17cbb	NW SW sec. 17		A	39.0	4		do	do			do		1376.8	25.10	4- 8-54	do
5-3-18bab	NE NW sec. 18		A	49.0	4		do	do			do		1391.1	45.00	4- 9-54	do
•5-3-18bbb	NW NW sec. 18	U. S. Geol. Survey	Th	110.0	4		do	do	A	Th	do		1406.6	51.10	6-14-54	
5-3-18cc	SW SW sec. 18	do	Th	140	4		do	do		Th	do		1372.8	20.20	6- 8-54	
5-3-19bb	NW NW sec. 19	do	J	38.6	¾	GI	do	do		O	Top of pipe	2.0	1375.0	22.96	9- 1-54	
•5-3-19cb	NW SW sec. 19	do	Th	85.0	4		do	do	A	Th	Land surface		1361.9	10.30	6- 9-54	
5-3-19dd	SE SE sec. 19	do	Th	90	4		do	Alluvium			do					
5-3-20aa	NE NE sec. 20	do	Th	110	4		do	Terrace deposits			do		1368.1			
5-3-20bbb	NW NW sec. 20		A	29.0	4		do	do			do		1368.9	23.40	4- 8-54	On public road.
5-3-20bc	SW NW sec. 20		A	9.0	4		Sand	Alluvium			do		1352.4	7.80	4- 8-54	do
5-3-20bcc	SW SW NW sec. 20	U. S. Geol. Survey	Th	120	4						do					Drilled in 1943.
5-3-20cb	NW SW sec. 20		A	9.0	4		do	do			do		1353.0	8.00	4- 8-54	do
5-3-20dd	SE SE sec. 20	U. S. Geol. Survey	J	15.0	¾	GI	Sand, gravel	do		O	Top of pipe	1.0	1351.0	11.50	4- 8-54	
5-3-21bbc	SW NW NW sec. 21	do	Th	100	4		Sandstone	Dakota Formation			Land surface		1355.1			
5-3-21cb	NW SW sec. 21	U. S. Geol. Survey	Th	120	4		do	do			do		1352.0			
5-3-21cc	SW SW sec. 21	do	Th	110	4		do	do			do		1348.8			
5-3-22bc	SW NW sec. 22	War Prison Camp	Dr	78.0	18	C	Sand, gravel	Alluvium	N	N	Top of pipe					Too salty to use.
5-3-22bda	NE SE SW sec. 22	U. S. Geol. Survey	Th	78	4						Land surface		1359.6			
5-3-23cb	NW SW sec. 23	do	J	20.8	¾	GI	do	do		O	Top of pipe	1.5	1340.0	8.97	9- 1-54	
5-3-23dad	NE SE sec. 23		A	29.0	4		Sand	Terrace deposits			Land surface		1340.5	19.80	4- 9-54	On public road.
5-3-23dd	SE SE sec. 23		A	9.0	4		Sand, gravel	Alluvium			do		1325.4	5.50	4- 9-54	do
5-3-24ad	SE NE sec. 24		A	34.0	4		do	Terrace deposits			do		1324.7	34.00	4- 9-54	do
5-3-24cb	NW SW sec. 24		A	9.0	4		do	Alluvium			do		1325.9	4.20	4- 9-54	do
5-3-27da	NE SE sec. 27	U. S. Geol. Survey	Th	105	4		do	do			do		1332.	4.10		
5-3-27dda	SE SE sec. 27		A	14.0	4		do	do			do		1337.5	9.00	4-12-54	On public road.
5-3-28bac	SW NE NW sec. 28	U. S. Geol. Survey	Th	105	4		do	do			do		1346.0			
5-3-28bbd	SE NW NW sec. 28	do	Th	110	4		do	do			do		1347.5			
5-3-28bc	SW NW sec. 28	do	Th	90	4		do	do			do		1349.8			
5-3-28cbc	SW NW SW sec. 28	do	Th	50	4		do	do			do		1349.9			
5-3-29adc	NE SE NE sec. 29	do	Th	100	4		do	do			do		1349.3			
5-3-29dd1	SE SE sec. 29	do	J	20.4	¾	GI	do	do		O	Top of pipe	1.1	1351.0	19.20	8-31-54	
5-3-29dd2	SE SE sec. 29	do	Th	50	4		do	do			Land surface		1349.8			
5-3-30aaa	NE NE sec. 30		A	9.0	4		do	do			do		1351.6	8.40	4- 8-54	On public road.
5-3-30ada	SE NE sec. 30		A	14.0	4		do	do			do		1353.3	11.00	4- 8-54	do
•5-3-31bb	NW NW sec. 31	U. S. Geol. Survey	Th	69.0	4½		do	Terrace deposits	A	Th	do		1364.9	15.70	6- 2-54	
5-3-31bc	SW NW sec. 31	Roy Ward	Du, Dr	54.0	48-8	S	do	do	Cy, G	I	Top of wood cover	0.2	1372.7	21.65	8-20-42	Dug 28 ft. Drilled to 54 ft.

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TABLE 16.—*Records of wells, test holes, and spring in Cloud County, Kansas.*—*Continued*

WELL NUMBER	Location	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, inches	Type of casing (3)	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. 5 S., R. 3 W.															
5-3-31cab	NE SW sec. 31		A	24.0	4		Sand	Terrace deposits			Land surface		1374.0	20.70	4-8-54	On public road.
*5-3-32aa1	NE NE sec. 32	City of Concordia	Dr	122	18	C	Sand and gravel.	do	A, E	P						Concordia well No. 4.
*5-3-32aa2	NE NE sec. 32	do	Dr	122	18	C	do	do	A, E	P						Concordia well No. 6.
*5-3-32aa3	NE NE sec. 32	do	Dr	122	18	C	do	do	A, E	P						Concordia well No. 1.
5-3-32aa4	NE NE sec. 32	do	Dr	122	18	C	do	do	A, E	P						Concordia well No. 3.
5-3-32ab1	NW NE sec. 32	do	Dr	122	18	C	do	do	A, E	P						Concordia well No. 5.
5-3-32ab2	NW NE sec. 32	do	Dr	122	18	C	do	do	A, E	P						Concordia well No. 2.
5-3-32ada	NE SE NE sec. 32	do	Dr, Th	58			do	do			Land surface		1368.0			
5-3-32ad	SE NE sec. 32	do	Dr, Th	58			do	do			do		1375.0			
5-3-34aaa	NE NE sec. 34		A	9.0	4		do	Alluvium			do		1337.8	7.70	4-12-54	On public road.
5-3-34aad	NE NE sec. 34		A	14.0	4		do	do			do		1337.9	12.80	4-12-54	do
5-3-34add	SE NE sec. 34		A	29.0	4		do	Terrace deposits			do		1349.5	19.00	4-12-54	do
5-3-34da	NE SE sec. 34		A	27.0	4		do	do			do		1350.4	25.50	4-12-54	do
5-3-35abc	NW NE sec. 35	Tolliver	Dr	64.8	18	GI	do	Alluvium	N	I	Top of casing	0.4	1342.8	16.70	10-26-55	New well, pump not installed.
5-3-36ab	NW NE sec. 36	G. Fredrickson	Dr	85	18	GI	do	do	T, B	I	Hole in pump base	2.0	1338.4	17.20	10-26-55	
5-3-36da	NE SE sec. 36		A	39.0	4		Sand	Terrace deposits			Land surface		1345.9	19.60	4-12-54	On public road.
	T. 5 S., R. 4 W.															
5-4-2abb	NW NE sec. 2	Lora McCullough	Dr	42.3	6	S	do	do	Cy, G	S	Top of casing	0.5	1414.2	12.90	8-31-54	
5-4-4aac	NE NE sec. 4	Karen Ross	Dr	64.2	18	GI	Sand and gravel.	do	T, G	I	Base of pump	0.4	1378.4	13.00	8-31-54	Reported yield about 1400.
5-4-7da	NE SE sec. 7		A	34.0	4		Sand	do			Land surface		1397.7	20.50	4-7-54	On public road.
5-4-8ca	NE SW sec. 8		A	19.0	4		do	do			do		1390.2	13.90	4-7-54	do

5-4-8cb	NW SW sec. 8		A	14.0	4		do	do			do		1386.1	8.40	4- 7-54	do
5-4-8da	NE SE sec. 8		A	19.0	4		do	do			do		1390.2	13.90	4- 7-54	On public road.
5-4-8dad	NE SE sec. 8	Bob Collins	Dr	60.0	18	GI	Sand and gravel.	do	T, G	I	Hole in pump base	0.8	1395.9	20.00	10-27-55	Est. yield 1000.
5-4-8dda	SE SE sec. 8	do	Dr	60.0	18	GI	do	do	T, G	I	do	1.0	1392.3	16.20	10-27-55	Est. yield 1000.
5-4-8dd	SE SE sec. 8	U. S. Geol. Survey	J	41.4	¾	GI	do	do		O	Top of pipe	2.5	1391.0	18.00	9- 1-54	
5-4-9aab	NE NE sec. 9	do	J	20.5	¾	GI	do	Alluvium		O	do	1.5	1370.5	6.30	9- 1-54	
5-4-9cca	SW SW sec. 9	Kiaser	Dr	75.0	18	GI	do	Terrace deposits	T, G	I	Hole in pump base	0.2	1396.0	23.48	10-26-55	Est. yield 1200.
5-4-11dc	SW SE sec. 11		A	24.0	4		do	do			Land surface		1382.8	17.30	4- 9-54	On public road.
5-4-11dcc	SW SW SE sec. 11	U. S. Geol. Survey	Th	60	4		do	do			do					
5-4-11dd	SE SE sec. 11	do	J	39.5	¾	GI	do	do		O	Top of pipe	2.0	1385.0	22.70	4- 9-54	
5-4-11ddd	SE SE SE sec. 11	do	Th	56	4		do	do			Land surface		1381.3			
5-4-12cd	SE SW sec. 12		A	34.0	4		Sand	do			do		1384.4	22.70	4- 9-54	On public road.
5-4-12dc	SW SE sec. 12		A	44.0	4		do	do			do		1396.2	35.70	4- 9-54	do
5-4-14aba	NW NE sec. 14		A	24.0	4		do	do			do		1371.8	17.70	4- 9-54	do
5-4-14bc	SW NW sec. 14	U. S. Geol. Survey	J	21.0	¾	GI	do	Alluvium		O	Top of pipe	1.5	1373.0	9.60	9- 1-54	
5-4-15aaa	NE NE sec. 15		A	14.0	4		do	do			Land surface		1375.6	11.70	4- 8-54	On public road.
5-4-15aba	NW NE sec. 15	H. J. Carr	Dr	69.4	18	GI	do	do	T, T	I	Base of pump	1.3	1373.0	13.12	10-23-53	
5-4-15bba	NW NW sec. 15		A	9.0	4		do	do			Land surface		1375.7	8.30	4- 8-54	On public road.
5-4-15dd	SE SE sec. 15	U. S. Geol. Survey	Th	120	4		do	do			do					
5-4-16ab	NW NE sec. 16		A	14.0	4		do	do			do		1374.0	5.80	4- 7-54	On public road.
5-4-16ba	NE NW sec. 16		A	14.0	4		do	Terrace deposits			do		1385.3	11.70	4- 7-54	do
5-4-16bd	SE NW sec. 16	Ida Hanson	Dr	82.6	18	GI	do	do	T, T	I	Base of pump	0.0	1385.4	17.80	10-23-53	
5-4-16ca	NE SW sec. 16	do	Dr	80	18	GI	Sand and gravel.	do	T, T	I			1385.8			Water became salty 1955.
5-4-16cc	SW SW sec. 16	T. Kiaser	Dr		18	GI	do	do	T, T	I	Hole in pump base		1382.3	14.20		Water became salty 1955.
5-4-16dd	SE SE sec. 16	M. L. Paulsen	Dr	60.0	18	GI	do	do	T, G	I	Base of pump	1.0	1382.0	18.00	10-27-55	Est. yield 600.
5-4-17aa	NE NE sec. 17	U. S. Geol. Survey	Th	95	4		do	do			Land surface		1377.3			
5-4-17cd	SE SW sec. 17	A. C. Anderson	Dr	184.5	6	GI	Sand	do	Cy, W	S	Top of casing	0.5	1381.0	9.85	10-23-54	
5-4-21ba	NE NW sec. 21	Peterson	Dr	59.0	18	Ci	do	do	T, G	I	Base of pump	1.0	1384.2	16.00	9- 1-54	Reported draw-down 10 after continuous pumping at 800.
5-4-21bd	SE NW sec. 21	do	Dr	59.0	18	Ci	Sand, gravel	do	N	I	Top of casing	0.6	1382.4	17.30	10-27-55	
5-4-22aaa	NE NE sec. 22		A	24.0	4		Sand	do			Land surface		1381.0	18.30	4- 8-54	On public road.
5-4-22ad	SE NE sec. 22		A	14.0	4		do	do			do		1372.5	10.60	4- 8-54	do
5-4-24cb	NW SW sec. 24	Hansen	Dr	80.6	18	S	Sand, gravel	Alluvium	T, T	I	Hole in pump base	0.5	1367.0	12.42	10-27-54	Est. yield 1000.
5-4-25bd	SE NW sec. 25	U. S. Geol. Survey	Th	66	4		do	do			Land surface		1358.7			
5-4-26cb	NW SW sec. 26		A	24.0	4		Sand	Terrace deposits			Hole in pump base		1380.9	16.50	4- 8-54	On public road.
5-4-27ad	SE NE sec. 27		A	19.0	4		Sand, gravel	do			Land surface		1376.6	15.70	4- 8-54	do
5-4-30bcc	SW SW NW sec. 30	U. S. Geol. Survey	Th	70	4		do	do			do		1389.6	5.50	6- 3-54	
5-4-31cc	SW SW sec. 31	L. L. Amspacker	Dr	55.2	6	GI	Sandstone	Dakota Formation	Cy, H	N	Top of casing	0.3	1463.0	43.65	10-23-53	
5-4-36ccd	SW SW sec. 36		A	29.0	4		Sand	Terrace deposits			Land surface		1389.2	17.00	4- 8-54	On public road.
5-4-36cd	SE SW sec. 36		A	19.0	4		do	do			do		1383.8	12.00	4- 8-54	do

TABLE 16.—*Records of wells, test holes, and spring in Cloud County, Kansas.*—*Continued*

WELL NUMBER	Location	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, inches	Type of casing (3)	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. 5 S., R. 5 W.															
5-5-2cc	SW SW sec. 2	S. A. Hanson	Dr	89.5	6	GI	Sandstone	Dakota Formation	Cy, W	S	Hole in casing	0.4	1477.0	52.10	10-22-54	
5-5-3bc	SW NW sec. 3		A	28.0	4		do	do			Land surface		1421.1	27.60	4- 7-54	On public road.
5-5-3ccc	SW SW sec. 3		A	24.0	4		Gravel	Terrace deposits			do		1413.1	22.00	4- 1-54	do
*5-5-4aab	NW NE NE sec. 4	U. S. Geol. Survey	Th	428	4		Sandstone	Dakota Formation	A	Th	do		1424.6	24.00	11- 3-53	do
5-5-4ab	NW NE sec. 4	do	Th	60	4		Gravel	Terrace deposits		Th	do		1400.6			
*5-5-4bb	NW NW sec. 4	do	Th	75.0	4		do	do	A	Th	do		1393.7	8.00	10-30-53	
5-5-5ba	NE NW sec. 5	U. S. Geol. Survey	Th	50	4		do	do		Th	do		1398.4			
5-5-6ad	SE NE sec. 6	M. M. Madison	Dr	100.5	6	GI	Sandstone	Dakota Formation	N	N	Top of casing	0.2	1454.7	34.22	10-22-53	
5-5-7bb	NW NW sec. 7		A	34.0	4		Sand	Terrace deposits			Land surface		1435.1	32.50	4- 7-54	On public road.
5-5-7bbb	NW NW NW sec. 7	U. S. Geol. Survey	Th	59	4						do		1435.7			
5-5-7cb	NW SW sec. 7		A	24.0	4		Sand	Terrace deposits			do		1409.2	13.90	4- 7-54	On public road.
*5-5-7cc	SW SW sec. 7	U. S. Geol. Survey	Th	96.0	4		Sand, gravel	do	A	Th	do		1435.7			
5-5-8bbb	NW NW sec. 8		A	34.0	4		do	do			do		1426.8	25.00	4- 6-54	On public road.
5-5-10cb	NW SW sec. 10		A	14.0	4		Silt	do			do		1396.4	10.30	4- 7-54	do
5-5-10cc	SW SW sec. 10		A	14.0	4		do	do			do		1393.0	9.50	4- 7-54	do
5-5-12dd	SE SE sec. 12	U. S. Geol. Survey	Th	42	4		Sand, gravel	do			do		1419.4	28.30	6- 3-54	
5-5-13add	SE SE NE sec. 13	do	Th	89	4		Sand	do			do		1402.7	20.80	6- 3-54	
5-5-13dad	SE NE SE sec. 13	do	Th	100	4		Silt	do			do		1388.7	7.60	6- 3-54	
5-5-15aa	NE NE sec. 15	Harry Heaton	Dr, Th	130	4		Gravel	do	N	N	do		1404.0	19.00	10-23-53	Test hole for irrigation well.
5-5-15ac	SW NE sec. 15	do	Dr, Th	107	4		do	do	N	N	do		1386.0	10.20	10-22-53	do
5-5-15cb	NW SW sec. 15		A	19.0	4		Clay	do			do		1392.9	10.50	4- 6-54	On public road.
5-5-15cc	SW SW sec. 15		A	14.0	4		do	do			do		1392.8	8.00	4- 6-54	do
5-5-16aa	NE NE sec. 16		A	15.0	4		do	do			do		1391.0	13.50	4- 6-54	do
5-5-18bb	NW NW sec. 18		A	14.0	4		do	do			do		1410.1	9.20	4- 7-54	do
5-5-19ac	SW NE sec. 19	M. Marcy	Dr	158.2	6	GI	Sandstone	Dakota Formation	Cy, H	N	Top of casing	0.2	1491.9	76.20	10-21-53	
5-5-21aa	NE NE sec. 21	W. H. Wall	Du	52.7	36	R	Sand	Terrace deposits	Cy, H	N	Base of pump	0.2	1426.7	33.00	10-22-53	
5-5-22ccd	SW SW sec. 22		Dr	88.0	12	S	Gravel	do	T, T	I	Land surface		1406.5	14.00		Well penetrated 10 ft. of limestone gravel at base.

*5-5-22da	NE SE sec. 22	City of Jamestown	Dr	140	8	S	do	do	Cy,T,E	P	do		1412.6			Three identical wells.
5-5-22dab	NE SE sec. 22	Jamestown Bank	Dr	113	5	GI	do.	do	N	N	do			25.		To be used for air conditioning.
5-5-24aa	NE NE sec. 24	U. S. Geol. Survey	Th	120	4		do	do			do		1382.6	5.00	6- 3-54	
5-5-24ad	SE NE sec. 24	do	Th	126	4		do	do			do		1381.2	5.90	6- 3-54	
*5-5-24dd	SE SE sec. 24	do	Th	113 0	4		do	do	A	Th	do		1384.4	5.40	6- 3-54	
5-5-28dc	SW SE sec. 28		A	29.0	4		Sand	do			do		1411 5	13.90	4- 6-54	On public road.
5-5-31dd	SE SE sec. 31	J. A. Powell	Dr	32.2	6	GI	Limestone	Greenhorn Limestone	Cy, W	S	Top of casing	0.3	1460.7	20.00	10-21-53	
5-5-32aa	NE NE sec. 32		A	24.0	4		Sand, gravel	Terrace deposits			Land surface		1419.0	18.35	4- 6-54	On public road.
5-5-32cd	SE SW sec. 32	Octavius Nixon	Dr	68 0	6	GI	Sandstone	Dakota Formation	Cy,W,H	S	Top of casing	0.6	1453.0	27.10	10-21-53	
5-5-33aa	NE NE sec. 33	M. M. Nelson	Dr	101.0	6	GI	Limestone	Greenhorn Limestone	Cy, W	S	Base of pump	1.2	1492.3	62.30	10-22-53	
5-5-34ba	NE NW sec. 34		A	39.0	4		Sand, gravel	Terrace deposits			Land surface		1450.0	35.70	4- 6-54	On public road.
	T. 6 S., R. 1 W.															
6-1-1ad	SE NE sec. 1		A	19.0	4		Sand, gravel	Alluvium			Land surface		1270 5	14.30	4-15-54	On public road.
6-1-1cc	SW SW sec. 1	Elmo St. Pierre	Dr		18	GI	do	Terrace deposits	T, B	I	Hole in pump base	0.2	1290.6	20.		Estimated yield 600.
6-1-2aa	NE NE sec. 2	E. A. Christinn	Dr	56.7	18	GI	do	Alluvium	N	I	Top of casing	1.0	1275.9	9.20	10-25-55	New well, pump not installed.
*6-1-3aa	NE NE sec. 3	U. S. Geol. Survey	Th	110.0	4		do	do	A	Th			1278.1	6.05	6-25-54	
6-1-3da	NE SE sec. 3	do	Th	70	4		do	Terrace deposits		Th	Land surface		1292.8	17.50	6-25-54	
6-1-3dd	SE SE sec. 3		A	50.0	4		do	do			do		1325.9	38.60	6-15-54	On public road.
6-1-4bbc	NW NW sec. 4	Franklin Day	Dr	69.3	18	GI	do	do	T, B	I	Hole in pump base	1.3	1305.0	23.00	10-27-54	Aquifer test made 10-12-55.
6-1-5aaa	NE NE sec. 5		A	29.0	4		do	do			Land surface		1301.6	23.50	4-13-54	On public road.
6-1-5aad	NE NE sec. 5		A	29 0	4		do	do			do		1302.5	23.20	4-13-54	do
6-1-10add	SE NE sec. 10		A	59 0	4		Sand	do			do		1331.1	40.80	6-16-54	do
*6-1-10cc	SW SW sec. 10	P. Bachand	Dr	87	6	S	Sandstone	Dakota Formation	Cy, E	D, S	do		1357.4	63.		
6-1-11bba	NE NW NW sec. 11	U. S. Geol. Survey	Th	110	4		Silt	Terrace deposits			do		1334.7	48.60	6-25-54	
6-1-17dad	NE SE sec. 17	Lydia Fuller	Du	40.8	48	R	Sandstone	Dakota Formation	Cy, H	S	Base of pump	1.0	1352.7	17.90	8-26-54	
6-1-22bba	NW NW sec. 22		A	50.0	4		Sand	Terrace deposits			Land surface		1352 5	28.00	6-16-54	On public road.
6-1-23bbb	NW NW sec. 23		A	40.0	4		do	do			do		1346.7	33.40	6-16-54	do
*6-1-24aa1	NE NE sec. 24	A. L. Dreasseau	Dr	75	6	GI	Sandstone	Dakota Formation	Cy, E	D	do		1374.7	60.		
*6-1-24aa2	NE NE sec. 24	do	Dr	62.0	6	S	do	do	Cy, E	D	Base of pump	0.6	1376.0	56.00	10-20-54	New well to replace 6-1-24aa1
6-1-26dc	SW SE sec. 26	L. Mollier	Dr	96.5	6	GI	do	do	Cy, W	S	do	1.1	1394.2	72.45	8-27-54	
6-1-32aa	NE NE sec. 32	School District	Dr	91.4	6	GI	do	do	Cy, W	D	do	0.9	1394.2	32.00	8-27-54	
	T. 6 S., R. 2 W.															
6-2-1cc	SW SW sec. 1	School District	Dr	79.5	6	GI	do	do	Cy, H	D	do	0.3	1365.5	40.32	8-26-54	
*6-2-9dad	NE SE sec. 9	Raymond Lewis	Dr	80 0	6	S	do	do	Cy, W	S	Top of casing	0.9	1404.7	53.00	3- 4-54	
*6-2-24cc	SW SW sec. 24	School District	Dr		6	GI	do	do	Cy, H	D						
6-2-30dad	NE SE sec. 30	I. H. Gardner	Dr	170 1	6	GI	do	do	Cy, E	D, S	Base of pump	0.1	1477.5	116.00	8-26-54	
*6-2-33dc	SW SE sec. 33	U. S. Geol. Survey	Th	270	4		do	do	A	Th	Land surface		1412.9	29.00	10-20-54	

TABLE 16.—*Records of wells, test holes, and spring in Cloud County, Kansas.*—*Continued*

Well number	Location	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, inches	Type of casing (3)	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. 6 S., R. 3 W.															
6-3-4bb	NW NW sec. 4	City of Concordia	Dr	250.0	10	S	Sandstone	Dakota Formation	T, E	P						At city water tower.
*6-3-4dc	SW SE sec. 4	do	Dr		8	S	do	do	T, E	P			1418.3			
*6-3-6dc	SW SE sec. 6	B. E. Thurston	Dr	305.0	8	S	do	do	Cy, W	D, S	Top of casing	1.3		127.	8-20-42	
6-3-12dc	SW SE sec. 12	A. B. Mahien	Dr	82.6	6	S	do	do	Cy,W,H	S	Base of pump	1.0	1437.5	65.60	8-24-54	
6-3-16cb	NW SW sec. 16	D. Rody	Dr	154.8	6	GI	do	do	Cy, W	S	Top of casing	0.5	1515.1	143.00	8-24-54	
6-3-27ccb	SW SW sec. 27	J. S. Whelan	Dr	140.1	6	GI	do	do	N	N	do	0.0	1483.3	41.85	8-24-54	
	T. 6 S., R. 4 W.															
*6-4-5da	NE SE sec. 5	F. McCowen	Dr	58.5	6	GI	do	do	Cy, H	D, S	Base of pump	1.0	1443.4	46.40	3- 3-54	
*6-4-12cd	SE SW sec. 12	C. R. Larson	Dr	90	8	S	do	do	Cy, W	D, S			1443.8	60.		
6-4-19bb	NW NW sec. 19	W. M. Dotson	Dr	162.0	6	GI	do	do	Cy,W,H	N	Top of casing	0.6	1539.3	131.40	10-23-53	
6-4-21aad	NE NE sec. 21	E. H. Johnson	Dr	196.5	6	GI	do	do	Cy, W	S	do	0.3	1525.7	112.70	8-24-54	
6-4-29dd	SE SE sec. 29	School District	Dr	125.0	6	GI	do	do	Cy, E	D, S	do	0.3	1547.3	99.31	8-24-54	
*6-4-34cc	SW SW sec. 34	U. S. Geol. Survey	Th	390.0	4		do	do	A	Th	Land surface		1472.0	23.00	9-29-54	
6-4-35ba	NE NW sec. 35	School District	Dr	58.0	6	GI		do	Cy, H	D	Base of pump	0.3	1436.8	19.00	8-24-54	
*6-4-36cb	NW SW sec. 36	M. V. B. Van De Mark	Dr	308.0	5	S	do	do	Cy, W	S				90.	6- 5-42	
	T. 6 S., R. 5 W.															
6-5-3cb	NW SW sec. 3	School District	Dr	105.0	6	GI	do	do	Cy, H	D	Base of pump	0.2	1530.0	99.50	10-22-53	
*6-5-6cb	NW SW sec. 6	R. Flinn	Dr	190	6	GI	do	do	Cy, E	D, S			1533.3			
6-5-20ab	NW NE sec. 20	W. H. Goodreau	Dr	96.1	6	GI	do	do	N	N	Top of casing	0.2	1544.5	92.50	10-21-54	
6-5-20cc	SW SW sec. 20	W. G. Culp	Du	26	40	R	Limestone	Greenhorn Limestone	N	N	Top of platform	0.5	1569.8	11.90	10-21-54	
6-5-22aa	NE NE sec. 22	Julia Herbin	Dr	125.0	6	GI	Sandstone	Dakota Formation	Cy, W	S	Base of pump	1.0	1500.1	50.20	10-22-54	
*6-5-26ab	NW NE sec. 26	A. A. Odette	Dr				do	do					1551.1			
6-5-26ca	NE SW sec. 26	E. Coyer	Dr	168.0	4	GI	do	do	Cy, W	N	Base of pump	0.6	1552.0	34.80	10-22-53	

	T. 7 S., R. 1 W.													
7-1-7aa	NE NE sec. 7	School District	Dr	59.6	3	GI	do	do	Cy, H	D	do	0.4	1414.9	32.70	8-26-54
7-1-9ccb	SW SW sec. 9	P. Labarge	Du	19.4	36	R	do	do	Cy, H	S	do	0.2	1389.3	14.67	8-26-54
7-1-10ad	SE NE sec. 10	E. Harnois	Du	30.2	44	R	do	do	Cy, W	S	do	1.2	1398.2	26.12	8-27-54
7-1-25cc	SW SW sec. 25	Flora Lindsay	Du	85.2	36	R	do	do	Cy, W	S	do	1.0	1455.6	75.82	8-27-54
•7-1-29aba	NW NE sec. 29	J. A. Gunter	Dr	67	6	GI	do	do	Cy, W	D, S	Land surface	.....	1420.0	32.	.....
	T. 7 S., R. 2 W.													
7-2-2aab	NW NE NE sec. 2	U. S. Geol. Survey	Th	26	4	.....	.....	.....	.....	.....	do	.....	1408.1	.....	.....
7-2-2bb	NW NW sec. 2	C. M. Bottger	Dr	99.0	5	GI	Sandstone	Dakota Formation	Cy,W,H	S	Base of pump	0.4	1440.2	88.10	8-26-54
7-2-5aab	NE NE sec. 5	School District	Dr	155	6	GI	do	do	Cy, E	D	.....	.....	1469.0	.....	.....
•7-2-15ba1	NE NW sec. 15	City of Aurora	Dr	200	6	S	do	do	T, E	P	.....	.....	1481.3	.....	.....
•7-2-15ba2	NE NW sec. 15	do	Dr	200	6	S	do	do	Cy, E	P	.....	.....	1481.3	.....	.....
•7-2-18ab	NW NE sec. 18	Wm. Goyette	Dr	.....	6	GI	do	do	Cy, W	D, S	.....	.....	1486.0	.....	.....
7-2-23aa	NE NE sec. 23	School District	Dr	112.8	5	GI	do	do	Cy, H	D, S	Base of pump	0.3	1450.7	84.00	8-26-54
7-2-28cc	SW SW sec. 28	do	Dr	78.8	5	GI	do	do	Cy, H	D	Top of platform	0.3	1603.5	50.50	8-24-54
7-2-35ddc	SE SE sec. 35	.....	Sp	.....	.....	.....	do	do	.....	S	Land surface	.....	1544.5	.....	.....
	T. 7 S., R. 3 W.													
7-3-2aa	NE NE sec. 2	O. Kindell	Du	47.2	48	R	do	do	Cy,W,H	S	Base of pump	0.5	1535.0	44.68	8-24-54
•7-3-21ba	NE NW sec. 21	KFRM Radio Transmitter	Dr	342	8	S	do	do	Cy, E	D	Land surface	.....	1619.0	159.	.....
7-3-24bb	NW NW sec. 24	School District	Dr	51.8	6	GI	Limestone	Greenhorn Limestone	Cy, H	D	Base of pump	0.6	1638.9	36.40	8-24-54
•7-3-35cb	NW SW sec. 35	M. Flynn	Dr	75.5	6	GI	Sandstone	Dakota Formation	Cy,W,H	S	do	0.8	1512.1	38.00	3- 3-54
	T. 7 S., R. 4 W.													
7-4-2cd	SE SW sec. 2	G. W. Doak	Dr	155.2	6	GI	do	do	Cy, W	S	Land surface	.....	1510.4	80.	.....
7-4-8dc	SW SE sec. 8	E. W. Bray	Dr	133.8	6	GI	do	do	Cy, W	S	Base of pump	1.2	1580.0	129.30	10-29-53
•7-4-22bb	NW NW sec. 22	School District	Dr	182.6	6	GI	do	do	Cy, H	D	do	0.7	1599.0	138.20	3- 3-54
7-4-22dcd	SW SE sec. 22	W. B. Edwards	Dr	102.0	6	GI	do	do	Cy, W	S	Top of casing	0.5	1549.0	72.90	8-24-54
7-4-25cd	SE SW sec. 25	L. A. Willars	Dr	161.5	6	GI	do	do	Cy,W,H	D, S	Base of pump	0.6	1618.0	137.50	8-24-54
7-4-29aa	NE NE sec. 29	C. Fletcher	Du	43.0	36	R	Limestone	Greenhorn Limestone	N	N	Top of stone over well	1.3	1589.0	26.60	10-29-53
	T. 7 S., R. 5 W.													
7-5-1aa	NE NE sec. 1	J. E. Burton	Dr	215	8	GI	Sandstone	Dakota Formation	Cy, W	D, S	Base of pump	0.4	1562.9	163.35	10-23-53
7-5-1dd	SE SE sec. 1	Bertha Marlatt	Dr	84.5	6	GI	Limestone	Greenhorn Limestone.	Cy, H	N	Hole in pump	1.3	1588.4	48.30	10-23-53
7-5-3dd	SE SE sec. 3	B. S. Williams	Dr	200	6	GI	Sandstone	Dakota Formation	Cy, W	D, S	Base of pump	0.1	1558.7	178.20	10-21-53
•7-5-8cc	SW SW sec. 8	U. S. Geol. Survey	Th	390.0	4	.....	do	do	A	Th	Land surface	.....	1470.0	48.	.....
•7-5-13bad	NE NW sec. 13	Ross Teasley	Dr	240	6	GI	do	do	Cy, E	D, S	do	.....	1569.0	140.	.....
7-5-17ad	SE NE sec. 17	B. Lee	Dr	82.0	6	GI	Sandstone(?)	Dakota (?) Formation	N	N	Top of casing	0.2	1554.8	76.30	10-21-53
7-5-20cb	NW SW sec. 20	J. Robertson	Dr	149.0	6	GI	do	do	Cy, W	S	Top of curb	0.8	1452.0	90.04	10-21-53
7-5-23da	NE SE sec. 23	S. E. Teasley	Dr	130.5	6	GI	do	do	Cy, W	S	Base of pump	0.7	1567.9	93.50	10-22-53
7-5-30bba	NE NW NW sec. 30	U. S. Geol. Survey	Th	20	4	.....	.....	.....	.....	.....	Land surface	.....	1425.0	.....	.....

TABLE 16.—*Records of wells, test holes, and spring in Cloud County, Kansas.*—*Concluded*

Well number	Location	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, inches	Type of casing (3)	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. 7 S., R. 5 W.															
7-5-30cc	SW SW sec. 30	U. S. Geol. Survey	Th	30	4	......	Sand, gravel	Terrace deposits	......	......	Land surface	......	1378.0	23.25	10-28-53	
7-5-31bcb	NW SW NW sec. 31	do	Th	38	4	......	Sand	do	......	......	do	......	1351.0	13.12	10-28-53	
7-5-31cbc	SW NW SW sec. 31	do	Th	35	4	......	do	do	......	......	do	......	1341.0	9.20	10-29-53	
7-5-36ad	SE NE sec. 36	E. Ott	Dr	......	6	GI	Sandstone	Dakota Formation	Cy, W	S	Base of pump	0.5	1431.9	95.60	10-22-53	
7-5-36dc	SW SE sec. 36	......	A	25.0	4	......	Sand	Terrace deposits	......	......	Land surface	......	1404.2	13.00	4- 5-54	
	T. 8 S., R. 1 W.															
8-1-5ad	SE NE sec. 5	P. D. Chartier	Dr	31.0	6	GI	Sandstone	Dakota Formation	Cy, H	D, S	Base of pump	0.2	1475.3	18.70	8-26-54	
*8-1-13ad	SE NE sec. 13	R. Austin	Dr	200	16	C	do	do	F	N	Top of casing	1.7	1328.4	Flow	3- 5-54	Flowing well. Drilled for coal prospect hole.
*8-1-17dc1	SW SE sec. 17	City of Miltonvale	Dr	100	20	C	do	do	T, E	P	Land surface	......	1373.2	65.	......	
*8-1-17dc2	SW SE sec. 17	do	Dr	100	20	C	do	do	T, E	P	do	......	1374.7	......	......	
8-1-24bc	SW NW sec. 24	F. M. Brown	Dr	55.3	6	GI	do	do	Cy, W	S	Base of pump	0.8	1388.1	47.40	8-27-53	
8-1-29aba	NW NE sec. 29	Coleman	Dr	108.6	6	GI	do	do	Cy, W	S	do	0.3	1428.4	75.85	8-26-54	
8-1-36da	NE SE sec. 36	B. Trowbridge	Dr	53.6	6	GI	do	do	Cy,W,H	S	do	0.9	1359.4	40.51	8-27-54	
	T. 8 S., R. 2 W.															
8-2-1aba	NW NE sec. 1	A. Adam	Dr	135	6	GI	do	do	Cy, W	S	Top of casing	1.2	1492.5	43.10	8-26-54	
8-2-11cc	SW SW sec. 11	A. Cyr	Dr	179.6	5	GI	do	do	N	N	do	0.3	1544.7	131.90	8-26-54	
*8-2-16dc	SW SE sec. 16	W. F. Smith	Dr	181	6	GI	do	do	Cy, W	D, S	Land surface	......	1623.1	171.	......	Blowing well.
8-2-25cc	SW SW sec. 25	Clara Rhodes	Du	49.5	36	R	do	do	Cy, H	N	Base of pump	0.3	1481.6	34.10	8-26-54	
8-2-32aa	NE NE sec. 32	School District	Dr	116.5	6	GI	do	do	Cy, H	D	do	0.3	1540.0	22.05	8-26-54	
*8-2-36aa	NE NE sec. 36	Vern Coleman	Dr	69	6	GI	do	do	Cy, J, W, E	D, S	Land surface	......	1419.4	65.	......	
8-2-36bbc	NW NW sec. 36	Lawrence Held	Dr	174.4	6	GI	do	do	Cy, W	D, S	Base of pump	1.0	1518.6	164.50	3- 4-54	
	T. 8 S., R. 3 W.															
8-3-12da	NE SE sec. 12	J. W. Frybargar	Dr	167	6	GI	do	do	N	N	Top of casing	0.4	1644.4	57.10	8-24-54	
8-3-16bcb	SW NW sec. 16	Quality Oil Service	Dr	193.0	6	GI	do	do	Cy, E	D	do	0.1	1477.5	115.00	8-24-54	
8-3-25ab	NW NE sec. 25	School District	Dr	110.6	6	GI	do	do	Cy, H	D	Base of pump	0.2	1603.0	93.63	8-26-54	
*8-3-26cc	SW SW sec. 26	C. E. Cotton	Du	31.0	48	R	do	do	Cy, W	S	do	0.2	1512.3	23.10	3- 3-54	

	T. 8 S., R. 4 W.															
8-4-7dd	SE SE sec. 7	Natural Gas Pipe-line Co. of America	Dr	150	6	S	do	do	T, E	Ind.	Land surface		1379.3	80.		Four almost identical wells located in small area.
*8-4-8ddc1	SE SE sec. 8	Roy Lavy	Dr	70	6	GI	do	do	J, E	S	do		1402.2	40.		
*8-4-8ddc2	SE SE sec. 8	do		50			do	do	J, E					40.		
8-4-9cc	SW SW sec. 9	School	Dr	56.2	6	GI	do	do	Cy, G	D	Base of pump	0.1	1398.0	39.50	10-29-53	
8-4-12cc	SW SW sec. 12	do	Dr	72.9	6	GI	do	do	Cy, H	D	do	0.9	1488.3	68.00	8-24-54	
8-4-18dd	SE SE sec. 18	H. N. Sheets	Dr	69.7	6	GI	do	do	Cy, W	N	do	0.8	1363.0	51.05	10-29-53	
8-4-20bb	NW NW sec. 20		A	70.0	4		do	do			Land surface		1365.8	52.00	4- 2-54	
8-4-22bc	SW NW sec. 22	L. Laman	Dr	73.4	6	GI	do	do	Cy, W	D, S	Base of pump	0.4	1386.0	35.15	10-29-53	
*8-4-23cbd	NW SW sec. 23	J. Hare	Dr	128	6	GI	do	do	Cy, W	D, S	Land surface		1472.5	109.		
8-4-31bb	NW NW sec. 31	R. E. Pitner	Dr	53.0	12½	S	Gravel	Terrace deposits	T, E	I	Top of casing	2.1	1312.0	31.53	10-29-53	Reported yield 500.
8-4-33ab	NW NE sec. 33	W. E. Betts	Du	22.1	36	R	do	do	Cy, W	D, S	Base of pump	1.0	1335.0	19.18	10-29-53	
8-4-34bb	NW NW sec. 34	C. E. Patrick	Du	32.1	36	R	Sandstone	Dakota Formation	Cy, W	N	do	0.4	1370.0	28.90	10-29-53	
8-4-36dda	SE SE sec. 36	L. A. Willars	Dr	79.5	6	GI	do	do	Cy, W	S	do	0.3	1371.9	37.30	8-24-54	
	T. 8 S., R. 5 W.															
8-5-1ad	SE NE sec. 1	Pamila Rogers	Du	32.0	30	R	Gravel	Terrace deposits	N	N	Top of platform	0.3	1385.3	20.60	10-22-53	
8-5-4da	NE SE sec. 4	A. J. Franks	Du	42.0	42	R	do	do	Cy, W	N	do	1.5	1368.3	36.85	10-22-53	
8-5-6cb	NW SW sec. 6	U. S. Geol. Survey	Th	60	4		do	do			Land surface		1332.2	17.00	10-29-53	
8-5-6cc	SW SW sec. 6	do	Th	58	4		do	do			do		1330.0	19.50	10-28-53	
*8-5-7cb	NW SW sec. 7	do	Th	52	4		do	do	A	Th	do		1333.0	26.85	10-29-53	
8-5-7cc	SW SW sec. 7	do	Th	45	4		do	do			do		1338.0	31.46	10-28-53	
8-5-9dd	SE SE sec. 9	E. Smith	Dr	23.7	6	GI	do	do	Cy, H	S	Base of pump	1.2	1323.1	21.90	10-22-53	
8-5-11db	NW SE sec. 11	T. B. Downey	Dr	45.2	6	GI	do	do	N	D, S	Land surface		1332.4	21.80	10-29-53	New well. To be used for domestic and stock.
*8-5-14bad1	NE NW sec. 14	City of Glasco	Dr	51	16	S	do	do	T, E	P	do		1317.2	22.		East well.
*8-5-14bad2	NE NW sec. 14	do	Du	47	108	C	do	do	T, E	P	do		1312.9	22		West well.
*8-5-17dca	SW SE sec. 17	H. Pinkall	Du	22.0	36	R	do	do	Cy, G	S	Top of platform	1.2	1323.0	12.00	10-21-53	
8-5-18bcb	NW SW NW sec. 18	U. S. Geol. Survey	Th	50	4		do	do			Land surface		1344.0	32.42	10-28-53	
8-5-19bbc	SW NW NW sec. 19	do	Th	32	4		do	do			do		1376.0			
8-5-19cb	NW SW sec. 19	do	Th	30	4		do	do			do		1374.0	22.35	10-27-53	
8-5-21dd	SE SE sec. 21	G. Davidson	Du	41.5	36	R	Sandstone	Dakota Formation	Cy, W	N	Base of pump	1.0	1351.4	33.30	10-21-53	
*8-5-25cc	SW SW sec. 25	Ward Butler	Dr	50	6	GI	Gravel	Terrace deposits	J, E	D	Land surface		1313.0	20.00		
8-5-28cc	SW SW sec. 28	H. W. Dalrymple	Dr	82.5	6	GI	Sandstone	Dakota Formation	Cy, W, H	S	Top of casing	1.0	1420.5	48.30	10-21-54	

* Indicates that chemical analysis is given.

1. A, auger hole; Dr, drilled; Du, dug; J, jetted; Sp, spring; Th, test hole.
2. Reported depths given in feet; measured depths given in feet and tenths.
3. C, concrete; Ci, cast iron; GI, galvanized iron; R, rock; S, steel.
4. Type of pump: A, air; Ce, centrifugal; Cy, cylinder; F, flowing well; J, jet; N, none; T, turbine.
   Type of power: B, butane; E, electricity; G, gasoline; H, hand; N, none; T, tractor; W, wind.
5. D, domestic; I, irrigation; Ind, industrial; N, none; O, observation; P, public supply; S, stock; Th, test hole.
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

The logs of 76 test holes drilled or jetted in Cloud County by the Federal and State Geological Surveys are given on the following pages. Of these, 44 logs were prepared by the authors from field study of the cuttings in 1954; 24 were prepared by V. C. Fishel from field and laboratory study in 1943; and 8 were prepared by the driller jetting the test holes in 1950. Also included are logs of 5 test holes drilled by the Air Made Well Company, 2 drilled by Layne-Western Company, and 1 drilled by the Bureau of Reclamation in 1941.

4-4-33dc.—*Sample log of test hole in SW¼ SE¼ sec. 33, T. 4 S., R. 4 W., 0.3 mile west of section line and 7 feet north of center of road. Surface altitude, 1,397.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, soft, yellow gray and black; contains some sand,	3	3
Clay, compact, dark and light gray; contains some sand	7	10
Sand, coarse to fine; contains some fine gravel	5	15
Gravel, medium to fine; contains some coarse to fine sand and caliche nodules	5	20
Gravel, arkosic; contains some fine sand	44	64
Kansan Stage		
Silt, clayey, buff; contains some caliche	6	70
Silt, clayey, buff; contains much caliche	30	100
Silt, soft, gray green; contains fine sand	10	110
Silt, soft, carbonaceous, gray brown; contains fine sand	5	115
Gravel, limestone pebbles, coarse to fine	9	124
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, gray, pink, and yellow; contains fine sand and some pyrite and lignite	6	130

5-1-11bbd.—*Drillers log of test hole in SE¼ NW¼ NW¼ sec. 11, T. 5 S., R. 1 W. Drilled September 1955 by H. Thoman. Surface altitude, 1,348.1 feet; depth to water, 40.00 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt and clay	52	52
Sand and gravel	15	67
CRETACEOUS—Gulfian		
Dakota Formation		
Clay	4	71
Sandstone	12	83
Shale, clayey	10	93
Shale and sandstone interbedded	92	185

5-1-11cc.—*Sample log of test hole in SW cor. sec. 11, T. 5 S., R. 1 W., on north edge of road about 50 feet east of road intersection. Drilled June 17, 1954. Surface altitude, 1,334.0 feet; depth to water, 35.60 feet, June 25, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, black	2	2
Clay, sandy, tan to gray	3	5
Clay, sandy, red brown	10	15
Clay, sandy and silty, tan to brown	15	30
Gravel, chiefly limestone and sandstone, fine to medium; contains some clay	4	34
Clay, sandy, tan to brown	6	40
Clay, very sandy, red brown, interbedded with fine to medium sand, and some ironstone gravel	16	56
Clay, sandy, light gray to white; contains a few thin sand stringers	24	80
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, tan and blue gray	6	86

5-1-22dd.—*Sample log of test hole in SE¼ SE¼ sec. 22, T. 5 S., R. 1 W., on north edge of road, 375 feet west of road intersection. Drilled June 16, 1954. Surface altitude, 1,334.0 feet; depth to water, 35.80 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Peoria Formation		
Clay and silt, black	2	2
Clay and silt, greenish tan	3.5	5.5
Clay and silt, greenish tan, mottled with brown	7.5	13
Illinoian Stage—Crete and Loveland Formations		
Silt, blocky, dark brown to black, (Sangamon soil)	2	15
Silt, clayey, sandy, red tan	7	22
Sand, fine; contains some clay	1	23
Silt and clay, sandy, red tan	15	38
Sand, fine, and red-tan clay	3	41
Clay, blue gray; contains many shell fragments	20	61
Sand, fine; contains many shell fragments	16	77
Sand, fine to medium, tan	3	80
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, tan to gray	3	83

5-1-26cb.—*Sample log of test hole in NW cor. SW¼ sec. 26, T. 5 S., R. 1 W., 100 feet east of Kansas Highway 9, on south side of first street north of Republican River bridge in Clyde. Drilled June 16, 1954. Surface altitude, 1,279.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	2	2
Sand, fine	9	11
Sand, medium to coarse, and fine to medium arkosic gravel	9	20

	Thickness, feet	Depth, feet
Gravel, fine to medium, and coarse arkosic sand	8	28
Illinoian Stage—Crete and Loveland Formations		
Clay, tan and gray	17	45
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, sandy, blue gray; contains some lignite and brown sandstone	15	60

5-1-34aa.—*Sample log of test hole in NE¼ NE¼ sec. 34, T. 5 S., R. 1 W., 2 feet south of center of road and 12 feet west of stop sign. Surface altitude, 1,286.0 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, soft, gray; contains much sand and many caliche nodules	4	7
Gravel, fine, and coarse to fine sand	3	10
Gravel, medium to fine, and coarse to fine sand	13	23
Clay, blue gray; contains fine sand	.5	23.5
Gravel and sand, coarse to fine, green	6.5	30
Gravel, medium to fine, and coarse to fine sand	10	40
Gravel, coarse to fine, and coarse to medium sand	10	50
Gravel (arkosic), fine, and coarse sand	13	63
Kansan Stage		
Silt, soft, buff; grading downward to gray, sandy	7	70
Silt, soft, buff; contains pebbles of limestone and sandstone	20	90
Silt, clayey, dark gray	5	95
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, soft, white; contains some pyrite	5	100

5-1-35bc.—*Sample log of test hole in SW¼ NW¼ sec. 35, T. 5 S., R. 1 W., 0.45 mile south of section line and 9 feet east of center of road. Surface altitude, 1,281.0 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, soft, light yellow gray; contains sand	6	8
Gravel and sand, coarse to fine, green	22	30
Gravel, medium to fine, and coarse to fine sand	10	40
Gravel, fine, and coarse to fine sand	10	50
Gravel and sand, coarse to fine, brown and green	10	60
Gravel, arkosic, fine, and coarse to fine brown sand	6	66
Kansan Stage		
Silt, soft, buff; contains some sand	2	68

	Thickness, feet	Depth, feet
Silt, clayey, gray; contains some sand	10	78
Gravel, limestone and sandstone pebbles, medium to fine	2.5	80.5
Silt, clayey, gray	2.5	83
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, soft, white; contains pyrite	17	100

5-2-19cb.—*Sample log of test hole in NW¼ SW¼ sec. 19, T. 5 S., R. 2 W., 0.6 mile south of section line and 30 feet south of curve in road to gravel pit.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, dark and light gray; contains fine sand	6	7
Gravel, medium to fine, and coarse to medium sand	3	10
Gravel, medium to fine, and coarse to fine silty sand	20	30
Gravel, fine, and coarse to fine brown sand	10	40
Gravel, medium to fine, and coarse to fine brown sand,	31	71
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, sandy, gray, yellow, and pink	4	75

5-2-26aad.—*Sample log of test hole in SE¼ NE¼ NE¼ sec. 26, T. 5 S., R. 2 W., 0.25 mile south of section line and 33 feet west of center of road.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Soil, gray black; contains fine sand	3	3
Silt, yellow gray; contains fine sand	3.5	6.5
Silt, sandy, gray black	.5	7
Silt, soft, yellow gray, and fine to medium sand	9.5	16.5
Gravel, fine, and coarse to fine sand	8.5	25
Gravel, medium to fine, coarse to fine sand, and soft gray silt	15	40
Gravel and sand, coarse to fine	10	50
Gravel, medium to fine, and coarse to fine sand	10	60
Gravel, medium to fine, coarse to fine sand, and soft gray silt	10	70
Gravel, medium to fine, and coarse to fine sand	9	79
Silt, soft, buff	4	83
Silt, soft, gray and black; contains fine sand	3	86
Gravel, limestone pebbles, coarse to fine, and coarse to medium sand	11.5	97.5
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, light gray; contains some sand and sandstone	12.5	110

5-2-28cb.—*Sample log of test hole in NW¼ SW¼ sec. 28, T. 5 S., R. 2 W., 0.55 mile south of section line and 9 feet east of center of road.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Soil, silty, dark gray; contains some sand	3	3
Silt, clayey, yellow gray; contains some sand	2	5
Sand, coarse to fine; contains some fine gravel	5	10
Gravel, medium to fine, and coarse to fine sand	10	20
Gravel and sand, coarse to fine	10	30
Gravel, medium to fine, and coarse to fine sand	10	40
Gravel and sand, coarse to fine	10	50
Gravel, medium to fine, and coarse to fine sand	6.5	56.5
Silt, soft, light green; contains some fine sand	.5	57
Gravel, arkosic, and coarse to fine sand	8	65
Kansan Stage		
Silt, soft, buff and green	3	68
Gravel, limestone and sandstone pebbles, coarse to fine	4	72
Silt, soft, buff; contains very fine sand	3	75
Gravel, limestone and sandstone pebbles, coarse to fine	4	79
Silt, soft, buff and blue gray; contains fine sand	10	89
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, gray and gray white; contains sand and soft light-gray sandstone	17	106

5-2-30bcc.—*Sample log of test hole in SW cor. NW¼ sec. 30, T. 5 S., R. 2 W., 15 feet east of center of road, 100 feet north of railroad track. Drilled June 11, 1954. Surface altitude, 1,326.7 feet; depth to water, 8.00 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, sandy, brown	8	8
Sand, medium to fine; contains some coarse gravel	8	16
Sand, coarse to fine; contains some coarse gravel	8	24
Sand, fine to coarse, arkosic	6	30
Gravel, fine to medium, and fine to coarse sand	18	48
Sand, medium to coarse, arkosic	6	54
Sand, coarse, and fine to medium arkosic gravel	6	60
Kansan Stage		
Gravel, limestone and sandstone pebbles, fine to medium	6	66
Gravel, limestone and sandstone pebbles, fine to medium; contains some light-gray clay	9	75
Clay, light blue gray	5	80
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone and ironstone, hard, brown	16	96

5-3-6cc.—*Sample log of test hole in SW cor. sec. 6, T. 5 S., R. 3 W., on east side of road, 50 feet north of road intersection. Drilled June 10, 1954. Surface altitude, 1,407.4 feet; depth to water, 43.50 feet June 14, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, black	2	2
Silt and clay, tan	3	5
Silt, tan	6	11
Silt and clay, blocky, greenish gray	8	19
Silt and clay, blocky, greenish gray; contains some ironstone gravel	9	28
Silt, sandy, tan	10	38
Silt, very sandy, red brown	6	44
Gravel, chiefly ironstone, fine; contains some sand and clay	4	48
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone and light-tan clay	12	60

5-3-8aa.—*Sample log of test hole near NE cor. sec. 8, T. 5 S., R. 3 W., on north edge of school yard 20 feet north of NW corner of school house. Drilled June 10, 1954. Surface altitude, 1,423.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Peoria Formation		
Silt, black	2	2
Silt, greenish tan; contains some caliche	7	9
Illinoian Stage—Crete and Loveland Formations		
Silt, black; drilled harder (Sangamon soil)	2	11
Silt, sandy, tan to buff	46	57
Gravel, sandstone and ironstone pebbles, fine to medium	3	60
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, bright yellow	2	62
Clay, blue gray	6	68
Sandstone, tan to brown	2	70

5-3-15ab.—*Sample log of test hole in NW¼ NE¼ sec. 15, T. 5 S., R. 3 W., 600 feet south of NW corner of NE¼. Drilled September 27, 1955. Surface altitude, 1,428.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, sandy, gray	3	3
Silt, light brown	11	14
Clay, brown	4	18
Silt, sandy, buff	19	37
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, fine; contains limonite streaks	57	94

	Thickness, feet	Depth, feet
Clay, gray to yellow	2	96
Sandstone, yellow and gray; contains some clay streaks	29	125
Clay, dark gray	3	128
Sandstone, iron-cemented, yellow	4	132
Clay, red and gray; contains several thin streaks of lignite and sandstone	58	190
Sandstone, limy, white	10	200
Clay, pink and gray; contains a lignite streak at 246½ feet	94	294
Sandstone; contains pyrite	16	310
Clay, gray; contains thin sandstone streaks	20	330
Sandstone, gray; contains some clay; drilled hard	40	370
PERMIAN—Leonardian		
Wellington Formation		
Shale, hard, blue gray	12	382
Limestone, very hard, white	2	384

5-3-15bdd.—*Drillers log of test hole in SE¼ SE¼ NW¼ sec. 15, T. 5 S., R. 3 W., 2,880 feet north and 2,140 feet east of SW cor. of section. Drilled by Air Made Well Company. Surface altitude, 1,413.3 feet.*

	Thickness, feet	Depth, feet
Clay, yellow	11	11
Clay, brown	8.5	19.5
Clay, dark blue	9.5	29
Clay, yellow; contains white streaks of "soapstone"	23.5	52.5
Sand, very fine	0.5	53
Clay, hard, blue	3	56
Sand, fine, tight	13	69
Shale, blue	3	72

5-3-15cd.—*Drillers log of test hole in SE¼ SW¼ sec. 15, T. 5 S., R. 3 W., 200 feet north and 2,140 feet east of SW cor. of section. Drilled by Air Made Well Company. Surface altitude, 1,372.3 feet.*

	Thickness, feet	Depth, feet
Clay, sandy, yellow	9	9
Clay, light	5	14
Sand, fine	3	17
Clay, hard, light	1	18
Sand, very fine	10	28
Clay, hard, light	0.5	28.5
Sand rock	7.3	35.8

5-3-15dbd.—*Drillers log of test hole in SE¼ NW¼ SE¼ sec. 15, T. 5 S., R. 3 W., 1,350 feet north and 3,560 feet east of SW cor. of section. Drilled by Air Made Well Company. Surface altitude, 1,387.9 feet.*

	Thickness, feet	Depth, feet
Soil	35	35
Rock	5	40

5-3-16bb.—*Sample log of test hole in NW¼ NW¼ sec. 16, T. 5 S., R. 3 W., 0.15 mile south of crossroad. Surface altitude, 1,411.3 feet.*

	Thickness, feet	Depth, feet
Road fill	.5	.5
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Soil, silty, brown	.5	1
Silt, tan and gray	62	63
CRETACEOUS—Gulfian		
Dakota Formation		
Clay and fragments of yellow-buff siltstone	4	67
Clay, light gray; contains some limonite	3	70

5-3-16cb.—*Sample log of test hole in NW¼ SW¼ sec. 16, T. 5 S., R. 3 W., 0.35 mile north of SW cor. of section. Surface altitude, 1,382.2 feet.*

	Thickness, feet	Depth, feet
Road fill	.5	.5
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Soil, silty	4.5	5
Silt, tan and brown	25	30
Clay, sandy; contains some gravel	13	43
Gravel, medium, and coarse brown sand	16	59
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, mottled red, gray, and yellow	6	65

5-3-17aa.—*Sample log of test hole near NE cor. sec. 17, T. 5 S., R. 3 W., on south side of road, 300 feet west of section corner. Drilled June 10, 1954. Surface altitude, 1,410.9 feet; depth to water, 53.70 feet June 14, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Peoria Formation		
Silt, black	2	2
Silt, greenish gray	6	8
Illinoian Stage—Crete and Loveland Formations		
Silt, blocky, black (Sangamon soil)	2	10
Silt and clay, red brown	10	20
Silt and clay, buff to tan	26	46
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, red and tan	14	60
Clay, light gray; contains some sandstone in lower part	10	70

5-3-18bbb.—*Sample log of test hole in NW cor. sec. 18, T. 5 S., R. 3 W., on south side of road about 150 feet east of section corner. Drilled June 9, 1954. Surface altitude, 1,406.6 feet; depth to water, 51.10 feet June 14, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Soil, dark brown	1	1
Clay, silty, yellow to gray	2	3
Clay, yellow to gray	5	8
Clay, silty; contains some fine sand	9	17
Clay, light tan	8	25
Clay, tan; contains some very fine sand	13	38
Sand, very fine, tan	3	41
Sand, fine to coarse, and fine to medium gravel	6	47
Sand, medium to coarse, and fine to coarse gravel	11	58
Clay, light brown, slightly sandy at base	11.5	69.5
Gravel, limestone pebbles, fine to coarse	7.5	77
Clay, silty, light tan	18	95
Clay, gray; contains some very fine sand	3	98
Gravel, limestone and sandstone pebbles, fine to coarse	4	102
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, fine grained, very hard; contains a few thin stringers of red clay	8	110

5-3-18cc.—*Sample log of test hole in SW cor. sec. 18, T. 5 S., R. 3 W., in center of triangle at road intersection. Drilled June 4, 1954. Surface altitude, 1,372.8 feet; depth to water, 20.20 feet June 8, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt and very fine sand	6	6
Clay, silty, tan	5	11
Silt, clayey, soft, tan to gray	8	19
Sand, very fine to medium	8	27
Sand, fine to coarse, and fine to medium arkosic gravel	63	90
Kansan Stage		
Sand and gravel, fine to coarse; contains some limestone and sandstone pebbles	6	96
Clay, sandy, blue gray	11	107
Sand, fine to coarse, and fine to medium gravel; contains many limestone and sandstone pebbles	16	123
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, fine grained, white; contains much pyrite,	17	140

5-3-19bb.—*Drillers log of jetted test hole in NW¼ NW¼ sec. 19, T. 5 S., R. 3 W. Surface altitude, 1,375.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Top soil	2	2
Clay, silty	19	21
Sand, medium to coarse, silty	18	39

5-3-19cb.—*Sample log of test hole near NW cor. SW¼ sec. 19, T. 5 S., R. 3 W., on east side of road where road ends, 15 feet south of gate into field. Drilled June 7, 1954. Surface altitude, 1,361.9 feet; depth to water, 10.30 feet June 9, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, very sandy, light tan	2.5	2.5
Sand, fine to very fine	7.5	10
Sand, fine to coarse, and fine to medium arkosic gravel	30	40
Sand, medium to coarse, and fine to medium arkosic gravel	10	50
Sand, medium to coarse, and fine arkosic gravel	28	78
Sand, medium to coarse; contains some arkosic gravel and clay	2	80
Kansan Stage		
Clay, sandy, soft	5	85

5-3-19dd.—*Sample log of test hole in SE cor. sec. 19, T. 5 S., R. 3 W., 5 feet north and 30 feet west of center of T road intersection.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, soft, gray white; contains fine sand and caliche	5	7
Gravel, medium to fine, coarse to fine sand, and greenish-gray silt	10	17
Clay, silty, greenish gray	.5	17.5
Gravel and sand, coarse to fine; contains some greenish-gray silt	12.5	30
Gravel and sand, coarse to fine	13	43
Silt, soft, gray white; contains much coarse to medium sand	3	46
Gravel and sand, coarse to fine	4	50
Gravel, fine to medium, and coarse sand	12	62
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, medium, soft, yellow brown	6	68
Clay, gray	2	70
Clay, silty, light gray; contains some fine sand	8	78
Coal, lignitic, and dark-gray sandy clay	2	80
Clay, dark gray, medium to fine sand, and sandstone,	10	90

5-3-20aa.—*Sample log of test hole in NE cor. sec. 20, T. 5 S., R. 3 W., 78 feet south and 7 feet west of crossroad. Surface altitude, 1,368.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Soil, silty, black and brown	2	2
Silt, tan and brown	20	22
Sand, medium; contains some brown gravel	8	30
Gravel, fine, and coarse brown sand	10	40
Gravel, medium, and coarse brown sand	10	50
Sand, coarse, and fine brown gravel	40	90
Kansan Stage		
Sand, coarse, and fine gravel; contains some yellow-brown clay	3	93
Gravel, limestone and sandstone pebbles, medium, coarse sand, and yellow clay	7	100
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, very fine, sandy, yellow	10	110

5-3-20bcc.—*Sample log of test hole in SW cor. NW¼ sec. 20, T. 5 S., R. 3 W.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Soil, sandy, gray black	3	3
Silt, clayey, gray	4	7
Silt, soft, gray and blue gray; contains much sand and gravel	3	10
Gravel and sand, coarse to fine; contains some compact greenish-gray silt	10	20
Gravel and sand, coarse to fine	10	30
Gravel, medium to fine, and coarse to medium sand	10	40
Gravel, coarse to fine, and fine to medium sand	20	60
Gravel, coarse to medium, and coarse to fine brown sand; contains some clayey tan silt	12	72
Kansan Stage		
Silt, soft, tan and blue gray; contains some medium to fine sand	3	75
Gravel, limestone and sandstone pebbles, fine to coarse	2.5	77.5
Silt, clayey, dark gray; contains some medium to fine sand	10.5	88
Clay, silty, gray; contains some medium to fine sand	14	102
Gravel, medium to fine	4	106
CRETACEOUS—Gulfian		
Dakota Formation		
Silt, clayey, gray white and pink; contains some medium to fine sand and some coal	14	120

5-3-20dd.—*Drillers log of jetted test hole in SE¼ SE¼ sec. 20, T. 5 S., R. 3 W. Surface altitude, 1,351.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Top soil, silty	4	4
Sand, fine	6	10
Sand, medium to fine	5	15

5-3-21bbc.—*Sample log of test hole in SW¼ NW¼ NW¼ sec. 21, T. 5 S., R. 3 W., 0.15 mile south of intersection and 6 feet east of center of road. Surface altitude, 1,355.1 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Soil, silty, brown and black	2	5
Clay, silty, gray	5	10
Sand, silty, fine, and fine brown gravel	10	20
Gravel, medium, and coarse gray-green sand	20	40
Gravel, arkosic, medium, and coarse sand	40	80
Kansan Stage		
Gravel, limestone and sandstone pebbles; contains much clay	12	92
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, gray; contains lignite	8	100

5-3-21cb.—*Sample log of test hole in NW cor. SW¼ sec. 21, T. 5 S., R. 3 W., 100 feet south of east-west road and 15 feet east of center of north-south road. Surface altitude, 1,352.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Soil	3	3
Sand, coarse to fine; contains some medium to fine brown gravel	12	15
Gravel, fine, and coarse to fine sand	5	20
Gravel, very coarse to fine; contains some coarse to medium sand	10	30
Gravel, coarse to fine; contains some medium to fine sand	10	40
Gravel, coarse to fine, and coarse sand	10	50
Gravel, fine to medium, and coarse sand	10	60
Sand, coarse to fine, and soft gray silt	10	70
Gravel, fine, coarse sand, and soft gray silt	10.5	80.5
Kansan Stage		
Silt, clayey, gray	28.5	109
Gravel, limestone and sandstone pebbles, medium to fine, and coarse sand	7	116
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, compact, pink and white	4	120

5-3-21cc.—*Sample log of test hole in SW¼ SW¼ sec. 21, T. 5 S., R. 3 W., 108 feet south of south end of bridge and 12 feet east of center of road. Surface altitude, 1,348.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Soil, silty, brown and black	2	2
Gravel, medium, and coarse to medium sand	18	20
Gravel, coarse to medium, and coarse gray sand	50	70
Sand, medium to coarse, and medium gravel, brown and gray	8	78
Kansan Stage		
Clay, very fine sandy, gray to brown; contains some gravel	22	100
Gravel, limestone and sandstone pebbles, medium to coarse; contains some yellow-buff clay	6	106
CRETACEOUS—Gulfian		
Dakota Formation		
Shale, clayey, red and white mottled	4	110

5-3-22bda.—*Drillers log of test hole in NE¼ SE¼ NW¼ sec. 22, T. 5 S., R. 3 W., 1,600 feet south and 2,140 feet east of NW cor. of section. Drilled by Air Made Well Company. Surface altitude, 1,359.6 feet.*

	Thickness, feet	Depth, feet
Soil, black	3	3
Clay, hard, yellow	13	16
Mud, fine sandy	19	35
Sand, medium fine	16	51
Sand, medium coarse	14	65
Sand, coarse	13	78

5-3-23cb.—*Drillers log of jetted test hole in NW¼ SW¼ sec. 23, T. 5 S., R. 3 W. Surface altitude, 1,340.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Top soil	4	4
Clay, silty	2	6
Sand, medium to coarse	7	13
Gravel, medium to fine	8	21

5-3-27da.—*Sample log of test hole in NE¼ SE¼ sec. 27, T. 5 S., R. 3 W., 0.45 mile north of sec. line. Surface altitude, 1,332 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, gray black; contains much sand	2	2
Sand, coarse to fine; contains some fine gravel	8	10
Gravel, fine to medium; contains much medium sand,	12.5	22.5
Silt, soft, blue gray	.5	23
Sand, coarse to fine; contains some medium gravel	7	30
Gravel, medium to fine, and coarse to fine sand	20	50
Gravel, fine, and coarse to fine sand	25	75

	Thickness, feet	Depth, feet
Kansan Stage		
Silt, soft, buff and gray, interbedded with gravel and sand	7.5	82.5
Gravel, limestone and sandstone pebbles, and coarse to fine sand	3.5	86
Silt, soft, tan; contains much fine sand	5	91
Gravel, limestone and sandstone pebbles, coarse to fine	6.5	97.5
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, dark gray; contains fine sand, pyrite, and hard black coal	7.5	105

5-3-28bac.—*Sample log of test hole in SW¼ NE¼ NW¼ sec. 28, T. 5 S., R. 3 W., 1,086 feet south and 1,334 feet east of NW corner of section. Surface altitude, 1,346.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Sand, medium to fine, and gray silt	5	5
Silt, gray black; contains some medium to fine sand and some pebbles	6	11
Gravel, medium to fine, and coarse to fine sand	12	23
Silt, clayey, gray green	2.5	25.5
Gravel, coarse to medium, and coarse to fine sand	4.5	30
Gravel and sand, coarse to fine	30	60
Gravel, fine, and coarse sand	3	63
Kansan Stage		
Clay, silty, light gray green; contains some coarse to fine sand	2	65
Gravel, limestone and sandstone pebbles, fine to coarse, and coarse sand	10	75
Silt, soft, clayey, buff; contains fine sand	5	80
Silt, soft, sandy, clayey, gray and greenish blue gray,	10	90
Silt, gray and greenish gray; contains fine sand	11	101
Gravel, limestone pebbles, coarse to medium	2	103
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, red, white, and yellow	2	105

5-3-28bbd.—*Sample log of test hole in SE¼ NW¼ NW¼ sec. 28, T. 5 S., R. 3 W., 1,071 feet south and 1,148 feet east of NW corner of section. Surface altitude, 1,347.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Sand, medium to fine, and soft black silt	2.5	2.5
Sand, coarse to medium; contains some fine brown gravel	9.5	12
Sand, coarse to medium, medium to fine gray gravel, and greenish-gray silt	18	30
Gravel, medium to fine; contains some coarse sand	20	50

	Thickness, feet	Depth, feet
Gravel, coarse to fine, and coarse to medium sand	5.5	55.5
Silt, soft, buff, gray, and brown; contains much fine sand	7.5	63
Gravel, fine to coarse; contains some coarse to fine sand	13	76
Kansan Stage		
Clay, silty, buff and gray	4	80
Clay, silty, gray and black	10	90
Clay, silty, gray black and gray green	11	101
Gravel, limestone pebbles, medium to fine	6	107
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, red and white	3	110

5-3-28bc.—*Sample log of test hole in SW¼ NW¼ sec. 28, T. 5 S., R. 3 W., 115 feet north of T road to east and 5 feet east of center of road. Surface altitude, 1,349.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, clayey, black	3	3
Clay, very fine sandy, gray	4	7
Sand, medium, and fine brown gravel	3	10
Sand, medium to coarse, brown	10	20
Gravel, medium to coarse, and coarse sand	10	30
Gravel, medium to coarse, and medium to coarse gray-green sand	24	54
Gravel, coarse to very coarse, and pink-tan clay	6	60
Kansan Stage		
Clay, gray; contains some limestone gravel	10	70
Gravel, limestone and sandstone pebbles, coarse, yellow brown	16	86
CRETACEOUS—Gulfian		
Dakota Formation		
Shale, clayey, red and white	4	90

5-3-28cbc.—*Sample log of test hole in SW¼ NW¼ SW¼ sec. 28, T. 5 S., R. 3 W., 0.25 mile north of SW cor. of section and 9 feet east of center of road. Surface altitude, 1,349.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan and Recent Stages—Alluvium and terrace deposits		
Soil, silty, brown and black	4	4
Gravel, fine, coarse sand, and brown and gray clay	4	8
Gravel, medium, and coarse gray-green sand	26	34
Gravel, coarse, and some coarse sand; contains sandstone and ironstone fragments	7	41
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, yellow, buff, and gray	6	47
Clay, yellow, red, and gray	3	50

5-3-29ada.—*Sample log of test hole in NE¼ SE¼ NE¼ sec. 29, T. 5 S., R. 3 W., 30 feet south of T road to east and 50 feet north of river. Surface altitude, 1,349.3 feet.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Soil, silty, brown	7.5	8.5
Sand, medium; contains some brown gravel	4.5	13
Gravel, medium, and coarse gray-green sand	19	32
Clay	2	34
Gravel, medium, and coarse gray-green sand	18	52
Clay, silty, yellow buff	8	60
Sand, fine, and gray clay; contains some gravel	10	70
Kansan Stage		
Gravel, limestone and sandstone pebbles, medium	21	91
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, light gray, mottled, to red	9	100

5-3-29dd1.—*Drillers log of test hole jetted by Federal and State Geological Surveys in SE¼ SE¼ sec. 29, T. 5 S., R. 3 W. Surface altitude, 1,351.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Top soil	2	2
Silt and fine sand	6	8
Sand, medium to fine	7	15
Sand, coarse, and fine gravel	3	18
Gravel, medium to coarse	3	21

5-3-29dd2.—*Sample log of test hole in SE¼ SE¼ sec. 29, T. 5 S., R. 3 W., 300 feet north of NE municipal well at Concordia and 9 feet west of center of road. Surface altitude, 1,349.8 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Wisconsinan and Recent Stages—Alluvium and terrace deposits		
Sand, very fine, and brown silt	7	9
Gravel, fine to coarse, and coarse brown sand	13	22
Gravel, fine to coarse, and coarse gray-green sand	19	41
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, slightly sandy, yellow buff and gray	9	50

5-3-31bb.—*Sample log of test hole near NW cor. sec. 31, T. 5 S., R. 3 W., on west side of road, west of center of long corncrib. Drilled June 2, 1954. Surface altitude, 1,364.9 feet; depth to water, 15.70 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, very sandy, tan	2	2
Sand, fine	3	5
Clay, sandy, tabular, dark tan	11	16
Sand, fine to coarse, and fine arkosic gravel	12	28
Clay, sandy, blue gray	2	30
Sand, fine to coarse, and fine arkosic gravel; contains many snail shells	9	39
Kansan Stage		
Clay, sandy, light gray	12	51
Clay, silty to sandy, buff	15	66
Gravel, fine to medium, and fine to coarse sand; composed entirely of sandstone and limestone fragments	3	69
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, crystalline, very hard and glassy, light gray	.5	69.5

5-3-32ada.—*Drillers log of test hole in NE¼ SE¼ NE¼ sec. 32, T. 5 S., R. 3 W. Drilled by Layne-Western Company. Surface altitude, 1,368.0 feet.*

	Thickness, feet	Depth, feet
Soil	5	5
Clay	15	20
Sand	5	25
Sand and gravel	17	42
Sand, fine	6	48
Sand, fine, packed	4	52
Clay	3	55
Sand, fine, packed (Dakota? Formation)	3	58

5-3-32ad.—*Drillers log of test hole in SE¼ NE¼ sec. 32, T. 5 S., R. 3 W. Drilled by Layne-Western Company. Surface altitude, 1,375.0 feet.*

	Thickness, feet	Depth, feet
Soil	5	5
Clay	25	30
Sand, fine	5	35
Sand and gravel	15	50
Sand, fine, packed	5	55
Clay	1	56
"Soapstone" (Dakota? Formation)	2	58

5-4-8dd.—*Drillers log of jetted test hole in SE¼ SE¼ sec. 8, T. 5 S., R. 4 W. Surface altitude, 1,390.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Top soil	2	2
Clay	16	18
Sand, medium	6	24
Sand, coarse, and fine gravel	15	39

5-4-9aab.—*Drillers log of jetted test hole in NW¼ NE¼ NE¼ sec. 9, T. 5 S., R. 4 W. Surface altitude, 1,381.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Top soil	3	3
Sand, medium to coarse	10	13
Gravel, medium	4	17
Sand, medium	4	21

5-4-11dcc.—*Sample log of test hole in SW cor. SE¼ sec. 11, T. 5 S., R. 4 W., 150 feet east of half-section line and 150 feet north of center of road.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Soil, gray black, and yellow-gray sandy silt	5	5
Silt, compact, clayey, gray brown; contains fine sand,	2	7
Silt, soft, yellow gray, and very fine sand; contains some caliche nodules	13	20
Silt, soft, gray, and fine sand	7	27
Gravel, medium to fine, and coarse to fine brown sand,	23	50
Gravel, coarse to fine, and yellow-brown silt	6	56
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, silty, cream and pink; contains some yellow-brown sandstone	4	60

5-4-11dd.—*Drillers log of jetted test hole in SE¼ SE¼ sec. 11, T. 5 S., R. 4 W. Surface altitude, 1,385.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Top soil, sandy	4	4
Clay, sandy, silty, fine	16	20
Sand, medium	20	40
CRETACEOUS—Gulfian		
Dakota Formation		
Shale		40

5-4-11ddd.—*Sample log of test hole in SE cor. sec. 11, T. 5 S., R. 4 W., 45 feet north and 9 feet west of right angle road off curve. Surface altitude, 1,381.3 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, clayey, brown gray	7	10

	Thickness, feet	Depth, feet
Silt, clayey, yellow gray	9	19
Silt, soft, buff; contains some gravel and sand	4	23
Gravel, fine, and coarse to fine sand	7	30
Gravel, medium to fine, and coarse to fine brown sand,	11	41
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, gray, and fine yellow-brown sandstone	6	47
Clay, carbonaceous, dark gray; contains some soft medium-grained brown and white sandstone	6	53
Clay, gray white; contains fine sand	3	56

5-4-14bc.—*Drillers log of jetted test hole in SW¼ NW¼ sec. 14, T. 5 S., R. 4 W. Surface altitude, 1,373.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Top soil, silty	5	5
Sand, medium	7	12
Sand, blue; contains weathered shale	4	16
Gravel, medium	2	18
Gravel, coarse to medium	3	21

5-4-15dd.—*Sample log of test hole in SE cor. sec. 15, T. 5 S., R. 4 W., 221 feet east and 6 feet north of center of intersection.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, soft, yellow gray; contains much sand	8	8
Sand and gravel, coarse to fine	12	20
Gravel and coarse to fine sand; contains some clayey blue-gray silt	6	26
Silt, soft; contains some sand and gravel	14	40
Gravel and sand, coarse to fine	10	50
Gravel, medium to fine, and coarse to fine sand	20	70
Gravel, coarse to fine, and some fine sand	10	80
Gravel, medium to fine, dark brown; contains some coarse sand	5	85
Kansan Stage		
Silt, sandy, soft, buff and gray	5	90
Silt, clayey, gray	18	108
Gravel, limestone pebbles, medium to fine; contains some coarse sand	9.5	117.5
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, gray, reddish brown, and gray white; contains some sandstone	2.5	120

5-4-17aa.—*Sample log of test hole in NE cor. sec. 17, T. 5 S., R. 4 W. Drilled by Bureau of Reclamation, 1941. Surface altitude, 1,377.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Soil	3	3
Clay, yellow	15	18
Sand, fine, yellow	7	25

	Thickness, feet	Depth, feet
Sand and gravel	40	65
Sand, fine, white	10	75
Sand and gravel	18.5	93.5
CRETACEOUS—Gulfian		
Dakota Formation		
Shale, brown	1.5	95

5-4-25bd.—*Sample log of test hole near SE cor. NW¼ sec. 25, T. 5 S., R. 4 W., on high point of land on west edge of trail, about 0.6 mile north of Hannan elevator. Drilled June 3, 1954. Surface altitude, 1,358.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, black	2	2
Silt, sandy, tan	6	8
Sand, arkosic, fine to medium; contains a few snail shells	12	20
Sand, fine to coarse, and fine to medium arkosic gravel,	10	30
Clay, tan to gray	10	40
Clay, sandy, yellow	10	50
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, sandy, firm, gray	6	56
Clay, mottled red and gray	10	66

5-4-30bcc.—*Sample log of test hole in SW cor. NW¼ sec. 30, T. 5 S., R. 4 W., on the north edge of old section of highway, 20 feet east of T intersection. Drilled June 1, 1954. Surface altitude, 1,389.6 feet; depth to water, 5.50 feet June 3, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Clay and silt, black	2	2
Clay, silty, gray to tan	8	10
Clay, silty, greenish gray	6	16
Clay, silty, light tan to buff	11	27
Clay, light tan to buff; contains some sand and gravel,	20	47
Kansan Stage		
Gravel, fine to medium, very angular; composed of weathered sandstone and limestone	3	50
Sand, medium to coarse, and fine to medium gravel; composed of sandstone and limestone	10	60
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, sandy, hard, red and light gray	10	70

5-5-4aab.—*Sample log of test hole in NW¼ NE¼ NE¼ sec. 4, T. 5 S., R. 5 W., on south side of road about 700 feet west of road intersection. Drilled November 3, 1953. Surface altitude, 1,424.6 feet; depth to water, 24.00 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt and clay, dark brown	4	4
Clay, brown	13	17

	Thickness, feet	Depth, feet
Clay, silty, brown	7	24
Gravel, limestone pebbles, fine to medium	3	27
Clay, gray and yellow	2	29
Gravel, limestone pebbles, fine to medium	1	30
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, blue to blue gray	17	47
Sandstone, tan to gray	1	48
Clay, gray; contains lignite	12	60
Sandstone, tan	2	62
Clay, gray to yellow	7	69
Sandstone, yellow	1	70
Clay, dark gray	8	78
Sandstone, tan	3	81
Clay, gray	33	114
Lignite	1	115
Clay, light gray	17	132
Sandstone, gray	4	136
Clay, gray and brown; contains some red streaks	42	178
Sandstone; contains some pyrite	8	186
Clay, gray	22	208
Sandstone, fine grained, gray	32	240
Clay, gray; contains a few thin red streaks	78	318
Sandstone, tan	3	321
Clay, sandy, dark gray	8	329
Sandstone, very fine grained; contains some clay in lower part	51	380
Clay, dark gray	7	387
Sandstone	4	391
Clay, sandy, blue gray	13	404
Sandstone, fine	23	427
PERMIAN—Leonardian		
Wellington Formation		
Shale, blue gray	1	428

5-5-4ab.—*Sample log of test hole in NW¼ NE¼ sec. 4, T. 5 S., R. 5 W., on south side of road, 300 feet west of drive to north. Drilled October 29, 1953. Surface altitude, 1,400.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	4	4
Clay, silty, calcareous, brown	4	8
Clay, tan; contains some limestone gravel	8	16
Clay, dark gray; contains caliche nodules	7	23
Clay, calcareous, green to brown	15	38
Gravel, fine to coarse, very silty; consists chiefly of limestone, contains some shell fragments	8	46
Kansan Stage		
Clay, very calcareous, blue gray	6	52
Clay, gray	2	54
Clay, light gray; contains some limestone gravel	6	60

5-5-4bb.—*Sample log of test hole in NW¼ NW¼ sec. 4, T. 5 S., R. 5 W., on south side of road at curve to northwest, about 250 feet east of edge of salt marsh. Drilled October 29, 1953. Surface altitude, 1,393.7 feet; depth to water, 8.00 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	4	4
Clay, silty, dark gray	3	7
Silt and clay, gray	7	14
Clay, sandy, blue	5	19
Clay, calcareous, green to gray	4.5	23.5
Silt, gray	9.5	33
Clay, blue	3	36
Gravel, limestone pebbles, fine to coarse	3	39
Kansan Stage		
Clay, gray; contains some limestone gravel	7	46
Gravel, limestone pebbles, coarse	7	53
Clay, gray	4	57
Sand, fine clayey	3	60
Clay, very silty, gray	9	69
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, brown; contains some lignite	6	75

5-5-5ba.—*Sample log of test hole in NE¼ NW¼ sec. 5, T. 5 S., R. 5 W. Drilled October 29, 1953. Surface altitude, 1,398.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	2	2
Silt, dark gray	7	9
Clay, silty	4	13
Gravel, limestone pebbles, fine to medium, tan	5	18
Clay, tan; contains some fine limestone gravel	15	33
Clay, blue gray; contains some fine limestone gravel	4	37
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, black	13	50

5-5-7bbb.—*Sample log of test hole in NW¼ NW¼ sec. 7, T. 5 S., R. 5 W. Drilled May 18, 1954. Surface altitude, 1,435.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, black	3	3
Silt and clay, brown to tan	2	5
Clay, light tan	5	10
Clay, silty, dark brown	4	14
Clay, silty, brown to light tan	5	19
Clay, silty and sandy, light brown; contains a trace of gravel	11	30
Clay, silty to slightly sandy, light brown	10	40
Clay, silty, mottled gray and brown	9	49

	Thickness, feet	Depth, feet
Silt, dark brown	6	55
Kansan Stage		
Clay, silty; contains considerable fine angular limestone gravel	3.5	58.5
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, sandy, light gray	.5	59

5-5-7cc.—*Sample log of test hole near SW cor. sec. 7, T. 5 S., R. 5 W., on east side of road, midway between two bridges, across road from fence gap into field. Drilled May 18, 1954. Surface altitude, 1,407.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt and clay, black	5	5
Clay, tan to dark gray	5	10
Clay, sandy, tan to gray	7	17
Illinoian Stage—Crete and Loveland Formations		
Clay, sandy, blue gray; contains many snail shells	10	27
Clay, slightly sandy, dark gray	3	30
Clay, greenish gray	6	36
Clay, dark gray; contains much very fine sand	8	44
Kansan Stage		
Gravel, fine to coarse, and medium to coarse sand; composed entirely of limestone and sandstone	13	57
Sand, fine to coarse, and fine to medium gravel	3	60
Gravel, fine to coarse, and medium to coarse sand	5	65
Clay; contains much sand and gravel	18	83
Gravel, limestone and sandstone pebbles, medium to coarse; contains some clay	3	86
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, very sandy, light gray to white	9	95

5-5-12dd.—*Sample log of test hole in SE cor. sec. 12, T. 5 S., R. 5 W. Drilled May 19, 1954. Surface altitude, 1,419.4 feet; depth to water, 28.30 feet June 3, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, black	2	2
Clay, silty, tan	6	8
Clay, silty, brown	3	11
Clay, silty, brown to buff	9	20
Clay, very silty, red brown; contains some fine sand	16	36
Gravel, chiefly limestone and sandstone, fine to medium; contains some clay	1	37
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, fine, friable, light tan	4	41
Clay, very sandy, light gray and red	1	42

5-5-13add.—*Sample log of test hole in SE¼ SE¼ NE¼ sec. 13, T. 5 S., R. 5 W., on west side of road, midway between two farm houses on east side of road. Drilled May 19, 1954. Surface altitude, 1,402.7 feet; depth to water, 20.80 feet June 3, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, black	3	3
Clay, dark gray to black	4	7
Clay, slightly silty, tan	4	11
Clay, red tan; contains some very fine sand	13	24
Clay, light tan	16	40
Clay, very silty, light tan	4	44
Kansan Stage		
Clay and fine sand; contains a few snail shells and a trace of sandstone gravel	6	50
Clay, dark gray to blue gray; contains fine to medium sand and snail shells	4	54
Clay, slightly sandy, greenish tan	10	64
Clay, slightly sandy, tan to brown; contains a trace of limestone gravel	9	73
Clay, tan; contains considerable weathered sandstone and ironstone gravel	11	84
CRETACEOUS—Gulfian		
Dakota Formation		
Clay shale, sandy, light gray	5	89

5-5-13dad.—*Sample log of test hole in SE cor. NE¼ SE¼ sec. 13, T. 5 S., R. 5 W. Drilled May 19, 1954. Surface altitude, 1,388.7 feet; depth to water, 7.60 feet June 3, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	3	3
Clay and silt, dark gray	2	5
Clay, tan to brown	7	12
Clay, sandy, greenish tan	8	20
Clay, sandy, buff	6	26
Silt, black; contains numerous shells	3	29
Clay, green	12	41
Kansan Stage		
Sand, fine to medium; contains some green clay and shell fragments	8	49
Clay, sandy, green	4	53
Clay, tan; contains some sand and gravel	4	57
Clay, tan, and sand	4	61
Sand, medium to coarse, and fine limestone and sandstone gravel	7	68
Gravel, limestone and sandstone pebbles, fine to coarse; contains some tan clay	3	71
Clay, tan; contains some gravel	6	77
Clay, black; contains shells	3	80

	Thickness, feet	Depth, feet
Clay, dark gray	5	85
Clay, tan; contains some gravel	3	88
CRETACEOUS—Gulfian		
Dakota Formation		
Clay shale, micaceous, dark gray; contains some sandstone and pyrite in lower 2 feet	12	100

5-5-24aa.—*Sample log of test hole in NE cor. sec. 24, T. 5 S., R. 5 W. Drilled May 20, 1954. Surface altitude, 1,382.6 feet; depth to water, 5.00 feet June 3, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	3	3
Clay, silty, tan	8	11
Clay, black to dark gray; contains snail shells	10	21
Clay, green; contains snail shells	4	25
Clay and fine sand, green; contains shells	7	32
Clay, sandy, greenish gray	4	36
Kansan Stage		
Sand, fine to coarse, and fine to medium gravel	8	44
Clay, sandy, gray	4	48
Clay, sandy, light gray	4	52
Sand, fine to medium	6	58
Clay, sandy, gray	5	63
Gravel, limestone pebbles, fine to medium, and fine to coarse limestone sand	7	70
Clay, very silty, tan to brown	20	90
Clay, silty, black; contains many snail shells	13	103
Gravel, limestone pebbles, fine to coarse	7	110
Sand, quartz, fine to medium	8	118
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone; contains some pyrite and lignite	2	120

5-5-24ad.—*Sample log of test hole in SE¼ NE¼ sec. 24, T. 5 S., R. 5 W., on west side of road about 450 feet south of bridge. Drilled May 20, 1954. Surface altitude, 1,381.2 feet; depth to water, 5.90 feet June 3, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	3	3
Clay, silty, tan to brown	14	17
Clay, silty, blue gray	4	21
Clay, dark gray to black	7	28
Clay, green	9	37
Kansan Stage		
Sand, fine to coarse; contains some fine gravel and snail shells	10	47
Clay, sandy to silty, greenish gray	6	53

	Thickness, feet	Depth, feet
Sand, quartz and limestone grains, fine; contains some fine gravel and clay	8	61
Clay, tan; contains much fine sand	9	70
Sand, mostly limestone grains, fine to medium; contains some clay and fine gravel	10	80
Clay, gray tan	6	86
Clay, sandy, gray tan	27	113
Sand, fine to coarse, and fine limestone gravel	5	118
CRETACEOUS—Gulfian		
Dakota Formation		
Clay shale, sandy, gray; contains pyrite	8	126

5-5-24dd.—*Sample log of test hole in SE¼ SE¼ sec. 24, T. 5 S., R. 5 W., on west side of road, midway between railroad and section corner. Drilled May 20, 1954. Surface altitude, 1,384.4 feet; depth to water, 5.40 feet June 3, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	2	2
Silt, clayey, tan brown	2	4
Clay, silty, gray to tan	9	13
Silt, clayey, black	4	17
Clay, green	7	24
Clay, silty, gray	8	32
Kansan Stage		
Sand, fine to coarse, and fine gravel; composed chiefly of limestone but contains some arkosic material	10	42
Clay, sandy, gray	2	44
Gravel, limestone granules, fine, angular; contains some clay	2	46
Sand, fine to coarse, and fine limestone gravel	9	55
Clay, blue gray	8	63
Clay, tan, and fine to coarse sand	7	70
Sand, fine to coarse, and fine limestone gravel	12	82
Gravel, fine to medium, and medium to coarse sand	4	86
Sand, fine to medium, interbedded with gray clay	15	101
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, white to light gray; contains some pyrite	12	113

6-1-3aa.—*Sample log of test hole in NE cor. sec. 3, T. 6 S., R. 1 W., on west side of road, 40 feet south of road intersection. Drilled June 15, 1954. Surface altitude, 1,278.1 feet; depth to water, 6.05 feet June 25, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Recent Stage—Alluvium		
Silt, black	2.5	2.5
Sand, fine to coarse, and fine to medium gravel	60.5	63
Kansan Stage		
Clay, blue gray	9	72

	Thickness, feet	Depth, feet
Sand, fine to medium; contains considerable weathered sandstone	10	82
Sand, fine	21	103
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, contains some standstone and lignite	7	110

6-1-3da.—*Sample log of test hole in NE cor. SE¼ sec. 3, T. 6 S., R. 1 W., on west side of road, 200 feet south of half-mile line. Drilled June 15, 1954. Surface altitude, 1,292.8 feet; depth to water, 17.50 feet June 25, 1954.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Clay, black	4	6
Clay, gray to tan	14	20
Clay, black	6	26
Sand, fine to medium, and fine arkosic gravel	5	31
Gravel, fine to coarse, arkosic, and medium to coarse sand	12	43
Illinoian Stage—Crete and Loveland Formations		
Clay, sandy, red tan	8	51
Sand, fine, reddish tan	4	55
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, light gray	9	64
Sandstone, fine, light tan	6	70

6-1-11bba.—*Sample log of test hole in NE¼ NW¼ NW¼ sec. 11, T. 6 S., R. 1 W., on south side of road about 800 feet east of section corner. Drilled June 16, 1954. Surface altitude, 1,334.7 feet; depth to water, 48.60 feet June 25, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Peoria Formation		
Silt, black	2	2
Silt, soft, tan (loess)	12	14
Illinoian Stage—Crete and Loveland Formations		
Silt, blocky, black (Sangamon soil)	3	17
Silt and clay, reddish tan	6	23
Silt, sandy, tan	20	43
Silt, sandy, tan to gray	22	65
Silt, and clay, very sandy; contains some sand and limestone gravel	9	74
Silt and clay, blocky, dark gray (soil?)	2	76
Clay; contains some weathered sandstone gravel	5	81
Sand, fine; contains some ironstone gravel	12	93
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, red and light tan; contains some clay	17	110

6-2-33dc.—*Sample log of test hole in SW¼ SE¼ sec. 33, T. 6 S., R. 2 W., 0.4 mile west of section corner, 40 feet north of center line of road. Drilled September 30, 1954. Surface altitude, 1,412.9 feet; depth to water, 29.00 feet October 20, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, and clay, dark gray to black	1	1
Clay, silty, blocky, dark tan; contains some sand	23	24
Silt, sandy, gray to brown	3	27
Clay, sandy, buff and brown	5	32
Gravel, sandstone and limestone pebbles, coarse	3.5	35.5
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, white to light gray	6.5	42
Sandstone, fine to medium	4.5	46.5
Clay, blue gray	6.5	53
Clay, gray to white	9.5	62.5
Sandstone, fine, white	2	64.5
Clay, blue gray to brown	11.5	76
Clay, blue gray to brown; contains some thin sandstone streaks	6	82
Lignite	2	84
Lignite and pyrite	2	86
Clay, sandy, light gray	3	89
Clay shale, gray	11	100
Shale, gray	7	107
Shale and sandstone; contains pyrite	1	108
Shale, gray	8	116
Shale, gray; contains sandstone streaks and some lignite	6	122
Sandstone, fine; contains a few thin shale streaks	18	140
Sandstone, fine	18	158
Shale, compact, dark gray; contains sandstone streaks,	12	170
Shale, compact, gray	10	180
Clay shale, gray to dark gray; contains sand in upper part	10	190
Clay shale, very sandy, gray	20	210
Shale, sandy, dark gray; contains some pyrite	5.5	215.5
Clay shale, sandy, gray	8.5	224
Clay shale, sandy, gray streaked with yellow	8	232
Sandstone, fine grained, interbedded with clay	3	235
Clay shale, white to yellow	15	250
Shale, very sandy, gray green	18	268
PERMIAN—Leonardian		
Wellington Formation		
Shale and dolomitic limestone, gray to white	2	270

6-4-34cc.—*Sample log of test hole in SW cor. sec. 34, T. 6 S., R. 4 W., about 80 feet east and 30 feet north of center of road intersection. Drilled September 21, 1954. Surface altitude, 1,472.0 feet; depth to water, 23.00 feet September 24, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	3	3
Silt, blocky, dark gray	4	7
Silt, gray brown	4	11
Silt, clayey, buff	5	16
Clay, buff, and limestone gravel	6	22
Clay, gray	7	29
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, fine	3	32
Clay, gray	2.5	34.5
Lignite	2	36.5
Clay, light gray	2.5	39
Clay, gray	5	44
Lignite	1.5	45.5
Clay, sandy, gray, and lignite	3.5	49
Shale, sandy, gray, and sandstone	18	67
Clay shale, sandy, light gray	19	86
Clay shale, dark gray	3	89
Clay shale, light gray	10	99
Shale, sandy, hard, gray	2	101
Clay shale, gray; contains sandy lenses and pyrite nodules	26	127
Sandstone, fine to very fine; contains a few thin clay stringers	43	170
Sandstone, medium grained	7	177
Clay shale, sandy, gray	4	181
Sandstone; contains some clay and pyrite	9	190
Shale, light gray to gray; contains some sandstone	5.5	195.5
Sandstone, fine	2	197.5
Clay shale, sandy, gray	6.5	204
Sandstone and sandy shale; contains some lignite	6	210
Shale, sandy, gray and brown	34	244
Sandstone; contains some dark-gray shale	2	246
Clay shale, sandy, light gray	9	255
Clay shale, sandy, gray to blue gray	41	296
Sandstone, fine to medium, hard; contains some pyrite and lignite	24	320
Shale, gray to dark gray; contains some pyrite and sandstone	30	350
Clay shale, sandy, gray to blue gray	15	365
Sandstone, fine	2	367
Clay shale, gray to light gray, interbedded with thin sandstone beds	8	375

	Thickness, feet	Depth, feet
Sandstone, fine; contains some clay	7	382
Clay shale, gray	3.5	385.5
PERMIAN—Leonardian		
Wellington Formation		
Limestone, hard, gray	1	386.5
Shale, gray	3.5	390

7-2-2aab.—*Sample log of test hole in NW¼ NE¼ NE¼ sec. 2, T. 7 S., R. 2 W., about 0.15 mile west of section corner. Drilled September 30, 1954. Surface altitude, 1,408.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Loveland Formation		
Clay, dark gray to brown	4	4
Clay, sandy, buff to tan	14	18
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, light gray to brown	8	26

7-5-8cc.—*Sample log of test hole in SW cor. sec. 8, T. 7 S., R. 5 W., on east side of road, 75 feet north of section corner. Drilled September 10, 1954. Surface altitude, 1,470.0 feet; depth to water, 48.00 feet September 16, 1954.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	2	2
Silt, tan	4	6
Clay, dark gray	2	8
Clay, buff; contains some limestone gravel	3	11
Clay, buff to yellow; contains much limestone and ironstone gravel	8	19
CRETACEOUS—Gulfian		
Dakota Formation		
Clay shale, blue gray; contains much pyrite	36.5	55.5
Clay shale, light gray	2	57.5
Clay shale, blocky, blue gray	1	58.5
Lignite	1	59.5
Clay shale, light gray; contains pyrite	4.5	64
Clay shale, gray; contains thin lenses of light-gray sandstone	10	74
Clay shale, blue gray	2.5	76.5
Shale, sandy, dark gray	8.5	85
Lignite	0.5	85.5
Shale, brownish gray; contains much very fine sand and some pyrite	5.5	91
Lignite	1	92
Shale, sandy, light gray to blue gray	7	99
Clay shale, light gray	41	140
Clay shale, gray; contains some sand	30	170
Clay, blue gray to gray	15	185
Pyrite	0.5	185.5

	Thickness, feet	Depth, feet
Sandstone, fine to medium, cemented, white	14.5	200
Clay shale, red and gray; contains a few thin sandstone stringers	20	220
Clay shale, dark gray to black	10	230
Clay shale, gray	30	260
Sandstone, fine to medium	46	306
Sandstone, cemented, red and white	4	310
Clay shale, sandy, gray	20	330
Clay shale, red	10	340
Clay shale, sandy, red and gray	10	350
Sandstone, fine	20	370
PERMIAN—Leonardian		
Wellington Formation		
Shale, light gray; contains very thin beds of limestone or calcareous shale	20	390

7-5-30bba.—*Sample log of test hole in NE¼ NW¼ NW¼ sec. 30, T. 7 S., R. 5 W., on shoulder of road approximately 800 feet east of NW corner. Drilled October 1953. Surface altitude, 1,425.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, yellow	7	7
Sand, coarse	2	9
Gravel, limestone pebbles, coarse	4	13
Clay, gray	5	18
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, yellow and red	2	20

7-5-30cc.—*Sample log of test hole in SW cor. sec. 30, T. 7 S., R. 5 W., 120 feet north and 20 feet east of center of road crossing. Drilled October 28, 1953. Surface altitude, 1,378.0 feet; depth to water, 23.25 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Illinoian Stage—Crete and Loveland Formations		
Silt, dark gray	2	2
Silt, brown	3	5
Silt, tan	8	13
Sand, quartz, fine, and coarse limestone gravel	9	22
Clay, light gray	2	24
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, red	1	25
Clay, yellow	3	28
Clay, blue	2	30

7-5-31bcb.—*Sample log of test hole in NW¼ SW¼ NW¼ sec. 31, T. 7 S., R. 5 W. Drilled October 28, 1953. Surface altitude, 1,351.0 feet; depth to water, 13.12 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	3	3
Clay, brown	3	6
Silt, sandy	3	9
Clay, brown	2	11
Clay, calcareous, light tan	11	22
Sand, quartz, fine to medium	8	30
Sand, fine to medium; contains some fine limestone gravel	2	32
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, blue gray	6	38

7-5-31cbc.—*Sample log of test hole in SW¼ NW¼ SW¼ sec. 31, T. 7 S., R. 5 W., on east side of road, 25 feet north of a concrete culvert. Drilled October 29, 1953. Surface altitude, 1,341.0 feet; depth to water, 9.20 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	4	4
Clay, dark gray	2	6
Clay, light gray	2	8
Clay, brown	3	11
Clay, dark brown	2	13
Clay, silty, tan	4	17
Clay, yellow to gray	5	22
Sand, quartz, fine to medium	6	28
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, red and yellow	3	31
Clay, gray	3	34
Clay, red and gray	1	35

8-5-6cb.—*Sample log of test hole in NW¼ SW¼ sec. 6, T. 8 S., R. 5 W. In town of Simpson, in NW corner of triangle formed by railroad and old highway. Drilled October 29, 1953. Surface altitude, 1,332.2 feet; depth to water, 17.00 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt and clay, brown	12	12
Clay, silty, brown	13	25
Clay, gray green	6	31
Sand, coarse, and fine to medium quartz and limestone gravel	7	38
Sand, quartz and limestone grains, coarse, iron stained,	5	43
Gravel, fine; contains some limestone pebbles	3	46

	Thickness, feet	Depth, feet
Sand, quartz, fine, yellow	6	52
CRETACEOUS—Gulfian		
Dakota Formation		
Sandstone, hard, light gray	8	60

8-5-6cc.—*Sample log of test hole in SW¼ SW¼ sec. 6, T. 8 S., R. 5 W., on north side of road, about 45 feet east of road intersection. Drilled October 28, 1953. Surface altitude, 1,330.0 feet; depth to water, 19.50 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	3	3
Silt and clay, brown	2	5
Clay and silt, gray and brown	22	27
Clay, black	9	36
Sand, fine to medium	6	42
Gravel, quartz and limestone pebbles, medium	3	45
Sand, quartz, fine	9.5	54.5
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, blue gray	3.5	58

8-5-7cb.—*Sample log of test hole in NW¼ SW¼ sec. 7, T. 8 S., R. 5 W., on east side of road, 40 feet south of half-section line. Drilled October 28, 1953. Surface altitude, 1,333.0 feet; depth to water, 26.85 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, gray	6	6
Clay, dark gray	9	15
Clay, sandy, light gray	12	27
Silt, light brown; contains some fine limestone gravel,	5	32
Sand, quartz, fine to medium	6	38
Gravel, quartz and limestone pebbles, fine to coarse	10	48
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, pink and gray	4	52

8-5-7cc.—*Sample log of test hole in SW cor. sec. 7, T. 8 S., R. 5 W. Drilled October 28, 1953. Surface altitude, 1,338.0 feet; depth to water, 31.46 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt and clay, black	4	4
Silt and clay, dark brown	2	6
Clay, silty, brown	2	8
Silt and clay, dark brown	3	11
Clay, sandy, brown	10	21
Sand and gray clay	17	38
Gravel, limestone and quartz pebbles, fine to medium,	2	40
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, sandy, red and gray	2	42
Clay, blue gray	3	45

8-5-18bcb.—*Sample log of test hole in NW¼ SW¼ NW¼ sec. 18, T. 8 S., R. 5 W., on east side of road about 20 feet south of culvert into field. Drilled October 28, 1953. Surface altitude, 1,344.0 feet; depth to water, 32.42 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, clayey, black	7	7
Clay, silty, dark gray	4	11
Clay, gray	5	16
Clay, light gray	11	27
Clay, tan to gray	10	37
Sand, fine	5	42
Gravel, limestone pebbles, fine to coarse	3	45
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, red	5	50

8-5-19bbc.—*Sample log of test hole in SW¼ NW¼ NW¼ sec. 19, T. 8 S., R. 5. W., on east side of road, 70 feet west of red tin barn. Drilled October 27, 1953. Surface altitude, 1,376.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	5	5
Clay, silty, gray	3	8
Clay, silty, dark brown	8	16
Clay, silty, light brown	5	21
Gravel, limestone pebbles, fine to medium	7	28
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, gray	4	32

8-5-19cb.—*Sample log of test hole in NW¼ SW¼ sec. 19, T. 8 S., R. 5 W., on east side of road, 54 feet south of culvert across drive to house east of road. Drilled October 27, 1953. Surface altitude, 1,374.0 feet; depth to water, 22.35 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Wisconsinan Stage—Terrace deposits		
Silt, black	4	4
Clay, silty, brown	9	13
Clay, brown	5	18
Gravel, limestone pebbles, fine to coarse, angular	7	25
CRETACEOUS—Gulfian		
Dakota Formation		
Clay, dark gray	5	30

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AREAL GEOLOGY OF CLOUD COUNTY, KANSAS

State Geological Survey of Kansas

by Charles K. Bayne and Kenneth L. Walters

1954

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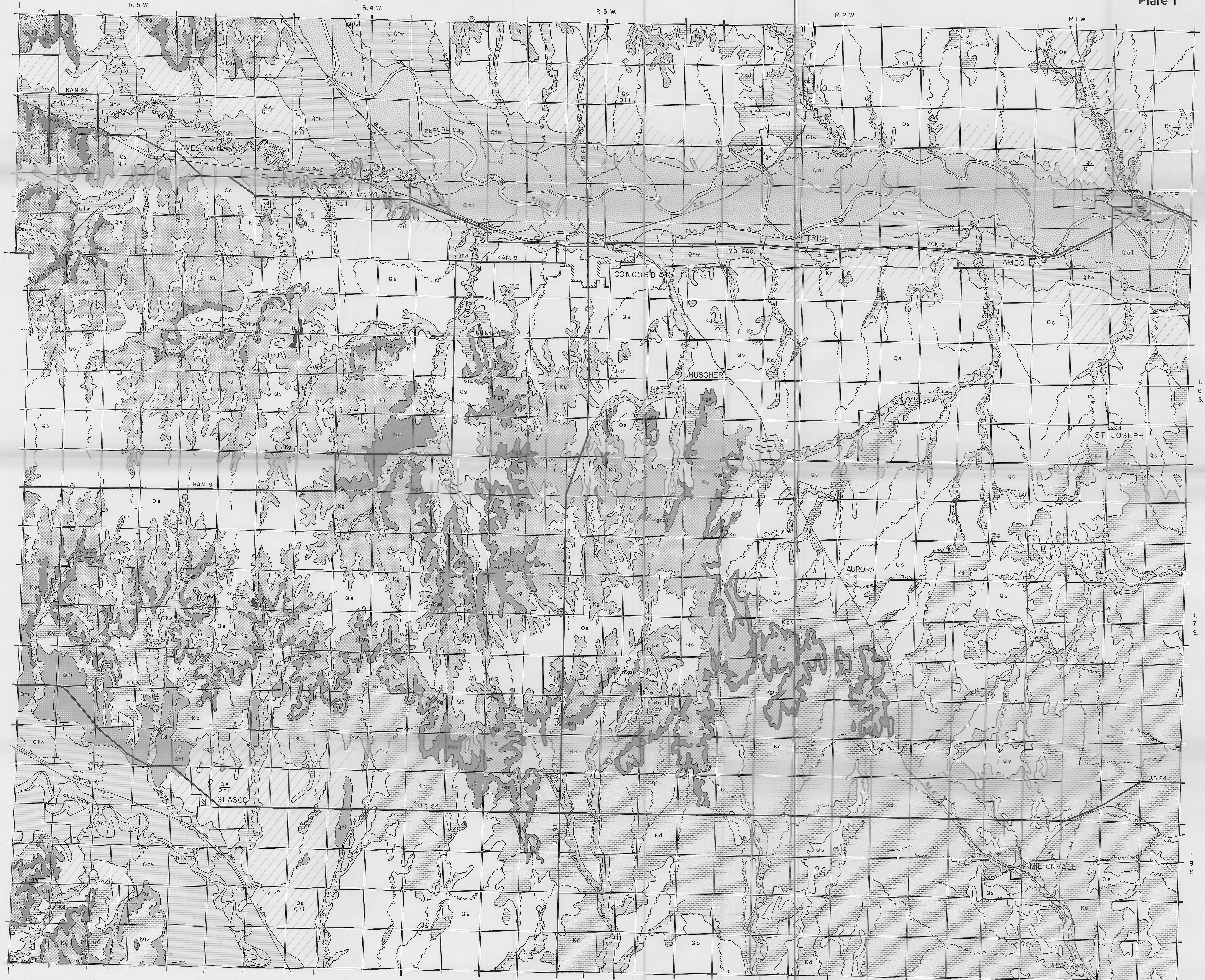
Plate 1



EXPLANATION

QUATERNARY

PLEISTOCENE

Recent

Qds — **Dune sand**
Medium and fine sand and silt. Yields small supplies of water to a few wells.

Qal — **Alluvium**
Sand, gravel, and silt. Yields large supplies of water of good quality along major streams.

Sanborn Group

Wisconsinan

Qtw — **Terrace deposits**
Sand, gravel, and silt. Yields large supplies of water of good quality along major streams.

Qs — **Eolian silts**
Fine wind-deposited silt. Lies above water table and yields no water to wells.

Qs/Qti — **Eolian silts overlying Illinoian terrace deposits**
Wind-deposited silts over water-laid silt, sand, and gravel. Yields small to moderate supplies of water to wells.

Illinoian

Qti — **Loveland and Crete Formations**
Sand and gravel and locally silt. Yields moderate supplies of water to wells locally but is generally above water table.

TERTIARY

PLIOCENE

Tc — **Ogallala Formation**
Thin caliche or pisolitic limestone containing scattered sand grains. Lies above water table and yields no water to wells.

CRETACEOUS

GULFIAN

Kc — **Carlile Shale**
Calcareous shale. Lies above water table and yields no water to wells.

Kg — **Greenhorn Limestone**
Thin interbedded limestones and shales. Yields small quantities of hard water to wells.

Kgs — **Graneros Shale**
Dark fissile shale. Yields no water to wells.

Kd — **Dakota Formation**
Clay, sandstone, lignite, and siltstone. Yields moderate to large quantities of water to wells.

0 1 2 3 4 5
SCALE IN MILES

MAP OF CLOUD COUNTY, KANSAS

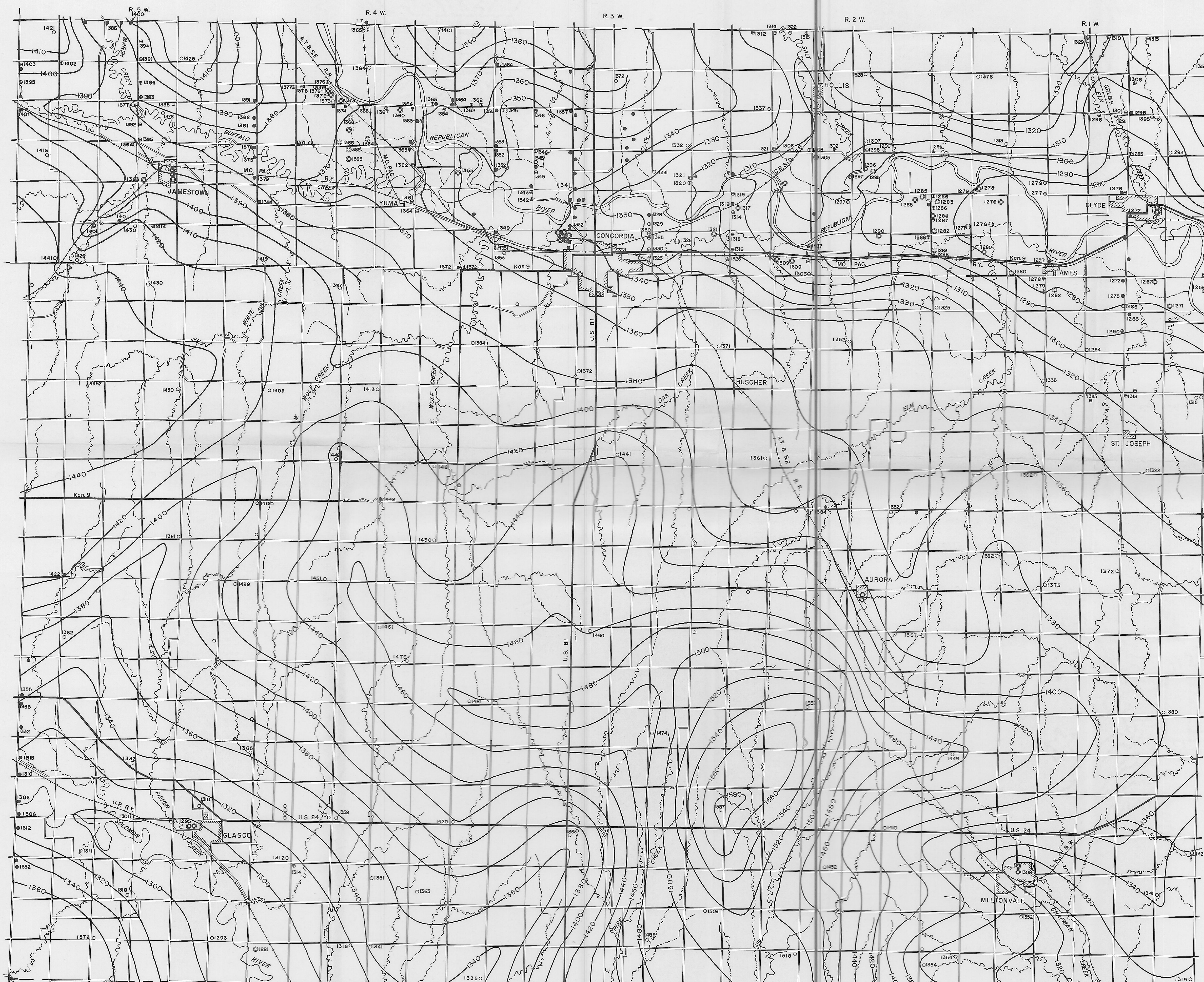
showing water-table contours and wells, test holes, and auger holes for which records are given

by Charles K. Bayne and Kenneth L. Walters

1954

State Geological Survey of Kansas

Bulletin 139
Plate 2



Base compiled from map prepared by the Soil Conservation Service

Drainage from map prepared by U. S. Dept. of Agriculture

EXPLANATION

- Domestic and stock well
- Auger hole
- Test hole
- Irrigation well
- Public supply well

1400

Contours based on instrumental levels. Contour interval 10 feet in valley area and 20 feet in upland area.

1361

Number refers to altitude of water level.

0 1 2 3 4 5

SCALE IN MILES