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BULLETIN 154

GEOLOGY AND GROUND-WATER RESOURCES OF OTTAWA COUNTY, KANSAS

By

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Prepared by the United States Geological Survey and the State Geological Survey of Kansas 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.

Printed by authority of the State of Kansas
Distributed from Lawrence

January, 1962

PRINTED BY
JEAN M. NEIBARGER, STATE PRINTER
TOPEKA, KANSAS
1962

28-8447

* Intermittent employment only.

† Deceased.

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By

LESLIE E. MACK

ABSTRACT

Ottawa County includes approximately 723 square miles in north-central Kansas and is geologically within the Salina Basin. The exposed rocks are sedimentary, strike generally north-northeastward, dip westward less than a degree, and range in age from Permian to Recent. Most of the county is underlain by the Dakota Formation of Cretaceous age.

The Dakota Formation and the Pleistocene terrace deposits are the major aquifers. The Dakota Formation is composed of lenticular beds of clay, silt, and sandstone having a wide range in permeability, hence the aquifers may be either artesian or water table. The Dakota is connected hydraulically with the graded terrace deposits. Changes in river level cause changes in altitudes of piezometric surfaces in adjoining aquifers. Cross sections of the Solomon River valley and a map of the piezometric surface were made from records of more than 300 wells and test holes. Two aquifer tests in Illinoisan terrace deposits indicate transmissibilities of 50,000 and 60,000 gpd (gallons per day) per foot. Another aquifer test in a sandstone of the Dakota Formation near a lake indicates a transmissibility of 15,000 gpd per foot.

About 90 percent of the precipitation returns to the atmosphere by evaporation and transpiration. Almost all the rest leaves the county as runoff, part of which is supplied by ground water. About 4 percent of the natural recharge is pumped from wells. Characteristics of discharge in Solomon and Saline Rivers are shown by graphs of annual flow and by curves of daily-flow duration, low-flow frequency, base recession, and momentary peak discharge.

Analyses of 101 samples of ground water show that its chemical character differs throughout the county. Variations in concentrations of calcium, magnesium, bicarbonate, and sulfate are contoured on outline maps. Mineralization of ground water generally is attributed to solution of minerals in the Dakota Formation. The concentration of dissolved solids in Solomon and Saline Rivers decreases with increased flow because of dilution by surface water.

The Kansas Water Appropriation Act of 1945 and amendments of 1957 provide an adequate framework for resolving conflicts in equity by law with physical principles of water behavior.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

This report is the result of an investigation, by the U. S. Geological Survey and the State Geological Survey of Kansas in co-operation with the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture, made to evaluate the ground-water resources of Ottawa County in relation to geology, hydrology, and water quality. Since 1937, reports on

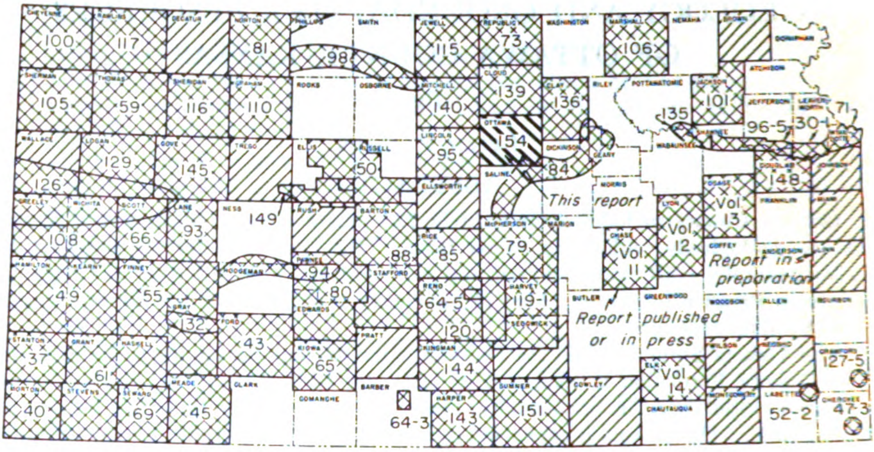

Fig. 1.—Index map of Kansas showing area discussed in this report and other areas for which ground-water reports have been published or are in preparation.

more than half the counties in Kansas have been published or are in preparation (Fig. 1).

The increasing importance of water makes imperative the collection, analysis, and presentation of data that may be utilized for water-supply development. Adequate data are essential for the proper use of water resources. Agriculture, municipalities, and industry all depend on vast quantities of water for their operations.

Location and Extent of Area

Ottawa County, in north-central Kansas, is bounded by Cloud County on the north, Mitchell and Lincoln Counties on the west, Saline County on the south, and Dickinson and Clay Counties on the east (Fig. 1). It contains 20 townships, T. 9 to 12 S., R. 1 to 5 W., which constitute approximately 723 square miles.

Previous Investigations

No publication to date specifically describes the geology or ground-water resources of Ottawa County. Plummer and Romary (1942, 1947) measured geologic sections and collected samples of clay. Two samples of clay from the Dakota Formation had been examined to determine their chemical, petrographic, and ceramic properties (Plummer and others, 1954). A statistical analysis of cross-stratified sandstone in the Dakota Formation was made by Franks and others (1959). Schoewe (1937) described "Rock City" near Minneapolis. Pleistocene volcanic ash was reported by Swineford and Frye (1946) and by Carey and others (1952).

Several reports provide geological and water-resource data from adjoining counties, which include Lincoln County (Berry, 1952), Mitchell County (Hodson, 1959), Cloud County (Bayne and Walters, 1959), Clay County (Walters and Bayne, 1959), and part of Saline County (Latta, 1949). Lee (1956) discussed the Salina Basin, which includes Ottawa County. The Dakota Formation in Kansas and Nebraska has been the subject of much paleontologic and lithologic study. The Dakota flora was treated by Lesquereux (1874). Logan (1897) made generalized stratigraphic distinctions; Twenhofel (1920, 1924) and Stanton (1922) made more detailed studies. Tester (1931) compared the type section of the Dakota Formation with more extensive sections in Kansas and Nebraska.

Methods of Investigation

Data were collected at intervals between June 1957 and October 1958. A total of 199 private and municipal wells were inventoried, and 111 test holes were augered or drilled. Auger and drill cuttings were examined microscopically. Water samples from 101 wells were analyzed for concentration of dissolved solids. The altitude of each well was determined by alidade, the geology was mapped, and numerous geologic sections were measured. Aerial photos were used as an aid in locating stratigraphic contacts. Three pumping tests were made to determine aquifer characteristics. Runoff records were obtained from the Surface Water Branch of the Geological Survey. Weather data were obtained from published records of the U. S. Weather Bureau. The base map was drafted from a county map prepared by the Kansas State Highway Commission.

Well-Numbering System

The well and test-hole numbers used in this report give location according to General Land Office surveys in the following sequence: township, range, section, 160-acre tract within that section, 40-acre tract within that quarter section, and 10-acre tract within that quarter-quarter section. The 160-acre, 40-acre, and 10-acre tracts each are designated a, b, c, and d in a counter-clockwise direction beginning in the northeast quarter. If two or more wells or test holes are within a 10-acre tract, the wells are numbered serially beginning with the first well measured. Below are two examples illustrating the well-numbering system:

Well number	General Land Office description
10-2-15abc	SW¼ NW¼ NE¼ sec. 15, T. 10 S., R. 2 W.
11-5-31dbb	NW¼ NW¼ SE¼ sec. 31, T. 11 S., R. 5 W.

Acknowledgments

The writer is grateful to the many residents of Ottawa County who permitted inventory of wells and who supplied much of the geologic and ground-water information. Several people in Minneapolis were especially helpful. They are George Davis (Soil Conservation Service), Louis Cooper and Norman Schlesener (Ottawa County Agents), Kermit Peterson (Park Superintendent, Kansas Forestry, Fish, and Game Commission), Rollind Olson (City Engineer), and Lionel Robins (Contractor). O. S. Fent (Hydraulic Drilling Company, Salina), J. G. Lassey (driller, Miltonvale), and George Cox (driller, Clifton) supplied logs of test holes and wells in Ottawa County.

Chemical analyses of water samples were made by Howard Stoltenberg and staff of the Sanitary Engineering Laboratory, State Board of Health. E. R. Leeson, Surface Water Branch of the U. S. Geological Survey, and R. L. Smith and W. E. Steps, Kansas Water Resources Board, supplied data on and an analysis of streamflow. Norman Plummer and Paul Franks contributed information and suggestions based on their experience in Ottawa County. Paul Franks also supplied x-ray, petrographic, and mechanical-analysis data. E. L. Reavis, Carrie Reavis, William Gellinger, and C. V. Fishel assisted in collecting a large part of the basic hydrologic data. The report was typed by Lottie Rodenhaus and Margaret Broeker, and the illustrations were drafted by Nancy Roofe Chamney.

GEOGRAPHY

Physiography

Ottawa County lies within the Interior Plains physiographic unit (Fenneman, 1931). The physiographic subdivisions coincide with areas of outcrop of some of the major stratigraphic units. The Permian rocks in the southeast corner of the county are assigned to the Osage Plains of the Central Lowland. The Permian portion of the Osage Plains was further assigned by Schoewe (1949) to the Flint Hills Upland subdivision. The rest of the county lies within the Plains Border of the Great Plains province and is composed of rocks of Cretaceous age. The Plains Border was further subdivided by Schoewe and that part of it in Ottawa County assigned to the Dissected High Plains, which is composed of the Smoky Hills and the Blue Hills.

The Smoky Hills are the psysiographic expression of Kiowa Shale and Dakota Formation in most of the county. The Blue Hills in the northwest corner of the county are composed of rocks of Cretaceous age that are younger than the Dakota Formation. The Graneros Shale is less resistant than the overlying Greenhorn Limestone, which caps a westwarddipping cuesta, the Blue Hills, bounded on the east by a bold escarpment. Gently inclined Permian rocks, though poorly exposed, form a dissected plain. Sharp differences in relief are minimized by eolian deposits on most of the bedrock.

Rocks of Cretaceous age, especially the Dakota Formation, generally have a much bolder topographic expression than rocks of Permian age, although the Kiowa Shale is physiographically inconspicuous in Ottawa County. Thin sand zones in the Dakota Formation, generally less than 2 feet thick and firmly cemented by iron oxides, form resistant caps on many hills, resulting in a rugged, dissected, eastward-facing series of escarpments having relief as much as 300 feet, especially in the northeastern, south-central, and western parts of the county. The uppermost and lowermost parts of the Dakota Formation contain most of the sand; the middle part contains mostly silt and clay, hence produces a gently rolling land surface along the strike from the north-central part of the county toward the southwest.

Drainage

Solomon River enters the county about 6 miles east of the northwest corner, trends to the south and east, and leaves the county about 5 miles west of the southeast corner. Solomon River flows perennially, but it is joined by several intermittent tributaries within the county. Largest of these is Salt Creek, which flows eastward from Mitchell and Lincoln Counties and joins Solomon River about 3 miles south of Minneapolis. Pipe and Lindsey Creeks flow southward from the north-central part of the county and are confluent with Solomon River north and south of Minneapolis respectively. Limestone Creek drains from hills in the northwestern part of the county southeastward to Solomon River. Sand and Coal Creeks are the only other major tributaries of Solomon River; both flow southward into the southeastern part of the county.

In the northeastern part of the county, Chapman and West Chapman Creeks flow southeastward into Clay County. South of the divide in the southwestern part of the county, all drainage is to Saline River, the only other stream in Ottawa County that flows perennially.

Climate

Ottawa County is in a subhumid belt that varies from semiarid to humid. Much of the following climatic discussion is adapted from Robb (1941) and Flora (1948). Temperature extremes at Minneapolis have ranged from -29°F in February 1899 to 119°F in August 1936. The average January temperature is 29°F, and the average July temperature is 80°F. The annual mean temperature is 56.4°F. The average date of the first killing frost is October 15 and that of the last is April 22. The growing season averages 176 days, and average warm-season (April to September, inclusive) precipitation is about 20 inches. The annual mean precipitation at Minneapolis is 26.62 inches. During the period of record from 1893 to 1945, precipitation was 0.01 inch or more for an average of 80 days annually, 0.25 inch or more for 30 days, and 1.00 inch or more for 6 days. Precipitation is discussed further in the section on hydrology.

Population

After the organization of Ottawa County in 1866, the population increased greatly and then declined gradually for many years. Available records, beginning in 1878, show a large increase in population for 12 years when settlers were moving west after the Civil War (Fig. 2). The

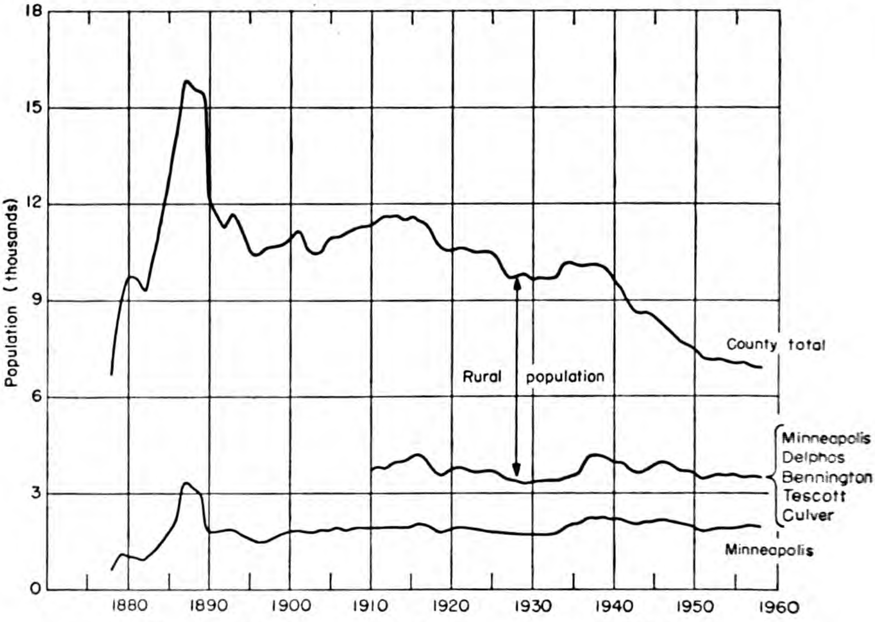

Fig. 2.—Population trends in Ottawa County, 1878-1958.

population decreased more than 20 percent in 1890 because of a nearly complete crop failure, the last of a series of failures starting in 1887 (Kansas State Board of Agriculture, 1893). Population increased slowly from 1896 until 1901, when another drought caused farmers to leave the county. This decline in population was minor compared to that of the previous decade. Rural population increased generally after 1901 until World War I. The major industrial expansion in other states after World

War I caused the population in Ottawa County to decline until the early thirties, when the economic depression reduced the opportunity for industrial employment. The population remained relatively constant until World War II, but thereafter until 1958 the rural population declined almost continuously but at a decreasing rate. The population of Ottawa County in 1958 was at its lowest point since 1878. The rate of decline indicates a slow decrease in rural population in the future.

The city of Minneapolis has had a relatively stable population. The trends suggest fluctuation of rural population only. Both urban and rural population increased during the depression, and the rate of decrease since that time has been much greater in rural areas.

Agriculture

Farming is the most important segment of Ottawa County's economy and includes both stock raising and cash crops. In 1958 the county had 27,600 cattle of all types. Although the number of farms decreased almost steadily from 1,465 farms in 1941 to 945 farms in 1958, the number of farm acres has increased from 385,063 to 404,420 during the same period. Acreage of crops planted for harvest in 1958 is shown in Table 1.

Table 1.—*Acreage of crops planted in Ottawa County in 1958*

Crop	Acres
Winter wheat	108,074
Oats	9,309
Corn	7,095
Winter barley	6,520
Rye	5,396

In 1957, an area of only 98 acres was irrigated from wells and 508 acres from streams. During that year, available facilities would have permitted irrigation of 1,397 acres from wells and streams.

Mineral Resources

Sand and gravel for local use have been quarried from the higher terraces of Pleistocene age. Most of these terrace materials are poorly sorted and contain a large percentage of fine sand and silt. The deposits are small and are not suitable for large-scale commercial quarries. A report by Plummer and Romary (1947) on the clays in the Dakota Formation discusses locations, stratigraphic sections, and firing properties of clays in Ottawa County. Extensive deposits of kaolinitic refractory clays in the county are not produced commercially. Oil and gas are not produced in Ottawa County. Twenty wildcat wells in the county have been reported to the State Geological Survey. Surface mapping and geophysical exploration indicate structural highs, but wildcat wells have not produced oil. Shale suitable for making lightweight aggregate is present in usable quantities in the Kiowa and Graneros Shales (Plummer and Hladik, 1951), and clay suitable for making lightweight refractories is present in the Dakota Formation. The shale and clay have not been utilized commercially in the county.

GENERAL GEOLOGY*

Geologic History

A study of the geologic history of north-central Kansas aids in understanding the geology of Ottawa County. The sequence of sedimentation and structural events in north-central Kansas is adapted, in part, from Lee (1956).

An uneven surface of Precambrian granite, gneiss, and schist underlies Paleozoic rocks in the county. During Late Cambrian and Early Ordovician time, a large syncline, in which the Arbuckle Group was deposited, extended northwestward across central Kansas. The Southeast Nebraska Arch, which extended into north-central and northeastern Kansas, formed the northern flank of the syncline. From Middle Ordovician until Mississippian time, the Southeast Nebraska Arch subsided, forming the North Kansas Basin, and the southwest flank of the syncline arched upward, accentuating the Central Kansas Uplift. St. Peter Sandstone, Platteville Formation, Viola Limestone, Maquoketa Shale (all of Ordovician age), Silurian dolomite, and Chattanooga Shale (Devonian and Mississippian) were deposited during this time. The Central Kansas Uplift attained its maximum development near the end of the Mississippian Period; uplift had ceased when the Wellington Formation (Permian) was deposited. Near the end of the Mississippian Period the Nemaha Anticline began to arch upward, splitting the North Kansas Basin into the Forest City Basin on the east and the Salina Basin on the west. Most of the uplift occurred during the Pennsylvanian Period, however.

Rocks of Mississippian and Pennsylvanian ages in Ottawa County include (older to younger): Upper Sedalia Dolomite, Gilmore City Limestone, Burlington Limestone, Keokuk Limestone, Warsaw Limestone, and Salem Limestone (Mississippian) and Cherokee, Marmaton, Pleasanton, Lansing, Kansas City, Douglas, Shawnee, and Wabaunsee Groups (Pennsylvanian). The abundance of Mississippian limestone indicates that an epicontinental sea prevailed during this time, whereas Pennsylvanian shale, limestone, and sandstone indicate deposition in various environments.

Permian deposits include the Wolfcampian Series (Admire, Council

* The stratigraphic nomenclature used in this report is that of the State Geological Survey of Kansas and does not necessarily follow that of the U. S. Geological Survey.

Grove, and Chase Groups), and the Leonardian Series (Sumner Group). Rocks of the Wolfcampian Series are principally shale, limestone, and sandstone. In general, each group is more saliferous than the older underlying group. Rocks of the Leonardian Series include thick beds of varicolored shale, redbeds, massive salt beds, gypsum beds, and thin beds of limestone. The withdrawal of Permian seas, aided by a gentle tilting of the area toward the Hugoton Embayment, was followed by a long period of erosion. Triassic and Jurassic strata are absent in north-central Kansas, although the Morrison Formation (Jurassic) is in the subsurface of western Kansas.

In most places, a cobble zone lies on the eroded surface of Permian rocks at the contact of Permian and Cretaceous rocks. This cobble zone underlies Cheyenne Sandstone, Kiowa Shale, or Dakota Formation, depending on which formation is in contact with Permian rocks (Plummer and Romary, 1942). Perhaps these cobbles are the only remnant of Triassic and Jurassic erosion. The Permian surface has relief as much as 100 feet (Green, 1909).

The advance of a Cretaceous sea began a phase of earth history that strongly affected the physiography and mineral resources of Ottawa County, for most of the rocks that crop out in the county are of Cretaceous age. The depositional environments of these Cretaceous rocks have been the object of speculation for many years. Twenhofel (1920) stated that the sea encroached from the south. Cheyenne Sandstone was a continental deposit along the margin of the sea southwest of Ottawa County and was overlain by marine Kiowa Shale as far north as Salina. During deposition of Dakota sediments, the sea advanced and retreated several times between south-central Kansas and the area near Salina, including at least one advance to southern South Dakota. Twenhofel believed the Dakota Formation to be part marine and part continental and that the Cretaceous sea retreated as far south as Texas; then it advanced and deposited the post-Dakota chalky limestones and shales of the Colorado Group. After additional study, Twenhofel (1924) suggested the possibility of a disconformity between the Kiowa and Dakota because of channel fillings that cut through the "Mentor" beds of Kiowa age, but he preferred the concept that the Kiowa and Dakota intertongue and are contemporaneous—the Dakota being the terrestrial equivalent of the Kiowa. Stanton (1922) agreed with Twenhofel that the Cheyenne and Kiowa were deposited in one transgression but thought that the Dakota represented a halt in advance of the sea rather than a retreat of the sea to Texas. He pointed out that the Kiowa and Dakota or the Dakota and the overlying Graneros Shale are not separated by distinct boundaries.

Depositional environment of the Dakota received additional explanation by Rubey and Bass (1925, p. 62) who stated,

> . . . variegated and carbonaceous mudstones . . . might be interpreted as silts and fine sands deposited in the back waters of wide flood plains, the various colors possibly being due to different degrees of oxidation. . . . The evenly bedded sandstone unit at the top of the Dakota may have been deposited as beach sands, the immediately ensuing marine Graneros Shale and the general aggradation of the stream valley suggesting an encroachment of the sea.

Plummer and Romary (1942) compared the environment of Dakota time with the Mississippi delta of the present. They stated also that the sandstones have no stratigraphic significance and may be at any position in the section. Most of these theories on depositional environments during Cretaceous time seem to be satisfactory, but a more comprehensive explanation is warranted.

The Cretaceous sea advanced slowly from the south, sorting and reworking the continentally derived Cheyenne Sandstone on an uneven surface eroded in rocks of Permian age. The marine Kiowa Shale, which overlies the Cheyenne Sandstone conformably but extends farther northward and eastward, was deposited farther off shore during the advance of the sea (Fig. 3). The Cheyenne Sandstone is not present in Ottawa County, but it is in Russell County about 40 miles farther west, (Rubey

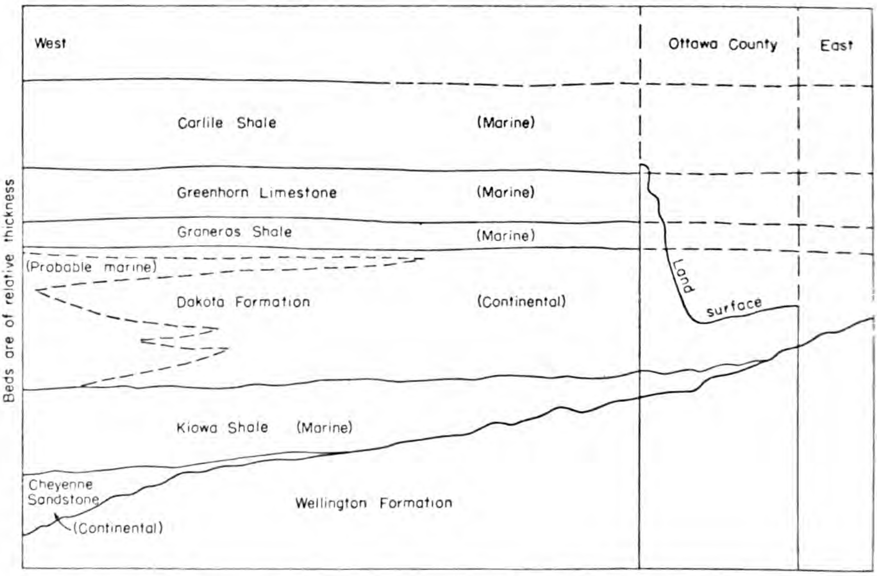

Fig. 3.—Diagrammatic cross section showing Cretaceous sedimentation in north-central Kansas through central Ottawa County. Not to scale.

and Bass, 1925), where it thins from 62 feet in the western part to 0 feet in the eastern part.

The Kiowa Shale overlies strata of Permian age unconformably and was deposited in a shallow sea at least as far east as Ottawa County but probably not much farther north on the eastern boundary of the basin. Portions of the Kiowa directly overlying Permian strata are composed of siltstone, but higher in the section the siltstone grades into fissile shale. Near the end of Kiowa time, subsidence ceased and erosion of Kiowa Shale began along its eastern border of deposition leaving several ero-

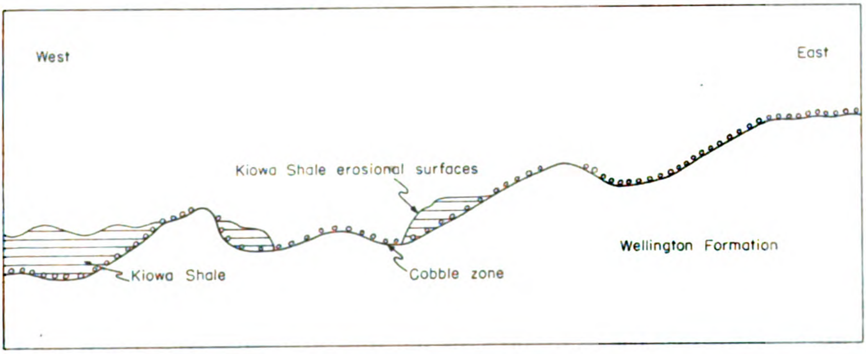

Fig. 4.—Generalized section across southeastern Ottawa County showing the post-Kiowa pre-Dakota erosional surface.

sional remnants in Ottawa County (Fig. 4). Deposition of sand, silt, and clay of the Dakota Formation began after the erosional surface on the Kiowa was formed. Erosional channels in the Kiowa were filled with sandstone of Dakota age; a channel in sec. 14, T. 10 S., R. 1 W., is 20 to

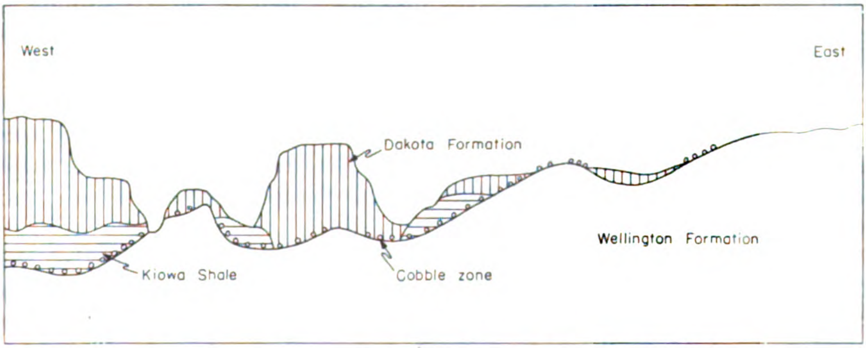

Fig. 5.—Generalized section across southeastern Ottawa County showing typical stratigraphic relations.

25 feet deep. Erosion since Dakota time reveals irregular Permian-Kiowa-Dakota interrelations (Fig. 5).

An environment under which each of the Dakota lithologies was deposited must be considered. Well-sorted, crossbedded channel and bar-finger sandstones cut through other sediments throughout the Dakota section, and well-sorted, massive sandstones, indicating delta-front sheet or delta-margin island sands (Fisk, 1955) also are abundant. Thin-bedded to massive siltstones indicate long periods of constant settling velocity typical of estuaries or deltas. Thin to massive beds of claystone and clay are indicative of a very low settling velocity and may have been deposited in lagoons, lakes, swamps, stagnant streams, or deltas. The clay has been colored variously by chemical action since the time of deposition. Lignite and other carbonaceous matter is disseminated throughout many beds of clay. Pyrite is common in much of the section, and imperfect selenite crystals are common locally. The Dakota Formation contains numerous local unconformities.

Both continental and marine fossils have been found in the Dakota. An *Ankylosaurus*, resembling a heavily armored giant armadillo, estimated to have been 8 to 10 feet long, was collected in 1955 by members of the staff of the Museum of Natural History, University of Kansas. This dinosaur was found in the SW¼ sec. 8, T. 10 S., R. 1 W., which would place it stratigraphically about 100 feet above the base of the Dakota. Leaves of *Sassafras, Laurus, Magnolias, Platanus, Populus, Salix,* and *Menispermites* have been found at various horizons in nearby counties (Lesquereux, 1874). Marine invertebrates were reported by Stanton (1922) near the top of the formation in adjoining counties to the west.

The Dakota Formation probably was deposited in a marshy coastal area of low relief. Meandering streams built overlapping flood plains and deltas. Dicotyledonous leaves indicate a temperate and subhumid to humid climate. The degree of sorting in the channel sands and silts indicates perennial streamflow. Dip of crossbeds, although locally variable, indicates that streamflow generally was from the northeast. The Cretaceous sea basin was filled slowly and crustal movement was slight. This accounts for the similarity of Dakota sediments over a wide area and yet allows for a distinct faunal change between Kiowa and Graneros times.

The Dakota environment may have been comparable to that of the Texas Gulf Coast today. The Gulf Coast includes a wide area of low land extending toward and filling the Gulf of Mexico. Parts of the coast between New Jersey and Georgia also illustrate similar characteristics, such as sand bars, lagoons, estuaries, wide flood plains, extensive swamps

(Dismal Swamp), and a variety of vegetation. Lesquereux (1874) described the Dakota of central Kansas and compared its deposition with deposition along the shore of the North Sea in Holland and Belgium.

In western Kansas, some of the Dakota exhibits a marine aspect; glauconite is common in well cuttings. Figure 3 illustrates the marine characteristics of the Dakota basinward.

The Dakota in Ottawa County has a distinct lithologic pattern. The lower section contains large quantities of sand intermixed with silt and clay. The middle section is composed chiefly of silt and clay containing scattered lenticular beds of sandstone. The upper section has large amounts of sand intermixed with silt and clay and is similar to the lower section. Sandstone in the upper and lower parts of the Dakota is expressed as rugged topography, and the middle Dakota is expressed as gently rolling hills. All beds are lenticular and traceable for only a few miles. The uppermost sediments of the Dakota in Ottawa County show more distinct bedding than those in the middle. Although Janssen Clay and Terra Cotta Clay members might be mappable elsewhere, subdivision of the Dakota Formation was not practicable for this study.

Transgression of the sea began, ending Dakota time. Transgression continued slowly while the Graneros Shale, a noncalcareous fissile black shale, was being deposited conformably on the Dakota until conditions became favorable for the deposition of chalky Greenhorn Limestone and Carlile Shale (Fig. 3). Perhaps the climate changed in addition to subsidence.

Post-Dakota deformation tilted the rocks northward and could have induced the Cretaceous sea to recede in this direction. Stratigraphic evidence of the sea's recession from Ottawa County has been removed by extensive erosion since the Cretaceous Period. Presumably, in north-central Kansas the Tertiary Period was a time of extensive erosion. The Ogallala Formation, of Pliocene age, composed of material derived from the Rocky Mountains, was spread over the western half of Kansas, but the only remnant of Tertiary deposits in Ottawa County is a 3- to 4-inch bed of "Algal" limestone, which is regarded as the uppermost bed of the Ogallala Formation.

Events of early Pleistocene time (Nebraskan and Kansan Stages) are indicated only vaguely. High, locally derived terrace deposits are perched 100 feet above the present floodplain and relatively near the confluence of some minor tributaries with the major drainage. These terrace deposits, lying far below the Ogallala, probably are of the Nebraskan Stage. One high terrace deposit in sec. 8, T. 10 S., R. 5 W., lies adjacent to a tributary stream 3½ miles north of Salt Creek, an eastward-flowing stream that is entrenching itself southward. A bed of Pearlette Ash of Kansan age, identified by Swineford and Frye (1946), crops out only 1 mile north of Salt Creek, in sec. 29, T. 10 S., R. 5 W., near the tributary adjacent to the high terrace deposit. The terrace deposit is at an altitude of about 1,380 feet and about 40 feet above the tributary, but the ash is at 1,290 feet and about 5 feet above the tributary, which is about 10 feet above Salt Creek; hence, the terrace deposit is much older than the ash and probably is of Nebraskan age. Fossils were not found.

If the above hypothesis is correct, only those few terrace deposits remain that were protected from stream action subsequent to their deposition. The valleys were widened and deepened extensively during the Kansan Stage, but subsequent erosion has removed Kansan terrace deposits. The only identifiable Kansan bed remaining is the Pearlette Ash. This theory is in accord with conclusions of regional Pleistocene studies in Kansas (Frye and Leonard, 1952) except that the writer believes that drainage flowed eastward through the Flint Hills throughout Pleistocene time. Frye and Leonard (1952) stated that Solomon and Saline Rivers flowed southward into the McPherson Valley until captured by the ancestral Kansas River during late Kansan or early Yarmouthian time.

Pearlette Ash was found in three localities in Ottawa County. The deposit in sec. 29, T. 10 S., R. 5 W., is approximately 6 feet thick and is lenticular. A small pocket of ash occurs in the hills of northeast Ottawa County in sec. 3, T. 9 S., R. 2 W., at an altitude of about 1,390 feet. A 1-foot auger sample collected in sec. 2, T. 10 S., R. 4 W., outside of the river terraces in Solomon River valley was identified as Pearlette Ash by Swineford (personal communication). The measured altitude of this lenticular bed is 1,276 feet, which is 32 feet below land surface.

After the Pearlette Ash was deposited as a thin layer over the land surface during the Kansan Stage, it could not have remained in place long. The ash probably collected in depressions or protected places and remains as an indicator of Kansan Stage topography. Later redeposition is unlikely, as the ash is not contaminated with other materials. On these assumptions, the three Pearlette Ash deposits indicate that post-Kansan erosion has not removed much material from the uplands but has deepened the major drainage.

Erosion during the Illinoisan and Wisconsinan Stages extended and enlarged the effects of erosion started in earlier Pleistocene time. Most of the earlier terrace deposits were removed and new ones created during the Illinoisan Stage. Illinoisan terraces flank the major streams, and scattered deposits remain along the major tributaries. In many places the Illinoisan terrace deposits are as thick as the Wisconsinan terrace deposits.

Erosion early in the Wisconsinan Stage did not appreciably widen the valleys as it did during the Illinoisan Stage, but it did cut a large channel through the Illinoisan terrace deposits and in most places deepened the valleys slightly. A major factor in deepening and widening the valleys is increased water velocity, which may be caused by increased gradients or by increased stream discharge. Under the fluctuating climatic conditions of the Pleistocene Epoch, increased quantity of flow is a more logical explanation than crustal movement or headward advance of a knickpoint. Alluviation late in the Wisconsinan Stage filled the channels thus cut. The normal sequence of sediments consists of gravel at the base grading upward to silt and clay. As the particle size of suspended sediment is dependent on water velocity, it is apparent that the average velocity of streamflow has decreased considerably during and since late Wisconsinan time; aggradation continues to the present day.

A mantle of eolian silt and colluvium, which probably has been accumulating since Illinoisan time, overlies the terrace borders and adjoining bedrock. The deposits are confined mainly to the east side of Solomon River and the north side of Salt Creek.

In summary, the geologic history of Ottawa County has been varied but not complex. Paleozoic sediments were deposited in epicontinental seas or near their borders. During the Mesozoic, a long period of erosion preceded transgression of the Cretaceous sea. Dakota time marked a halt in advance of the sea while continental sediments filled the Cretaceous sea toward the center of the basin. Renewed transgression provided the depositional environment of post-Dakota rocks of the Colorado Group. Erosion was extensive during Tertiary time except for minor deposition of the Ogallala. The land surface today is a product of repeated attacks by Pleistocene water power, the impact of which has been partly disguised by alluviation.

Summary of Stratigraphy

The oldest rocks that crop out in Ottawa County are in the Wellington Formation, of the Permian System, exposed only in the southeastern part of the county. The Kiowa Shale, of the Cretaceous System, overlies the Wellington unconformably. The Kiowa pinches out on the surface in the east but attains a subsurface thickness exceeding 80 feet in the west. The Dakota Formation (Cretaceous) unconformably overlies the Wellington Formation and Kiowa Shale in the eastern part of the county, where the upper part of the Dakota is eroded, and thickens to about 350 feet in the western part, where the entire thickness remains.

The Graneros Shale (Cretaceous) conformably overlies the Dakota and is about 38 feet thick. The Greenhorn Limestone (Cretaceous), about 75 feet thick, is conformable below with the Graneros Shale and above with the Carlile Shale (Cretaceous), which has been so eroded that the thickness in Ottawa County is not more than 15 feet.

Nebraskan terrace deposits, of Early Pleistocene age, are not more than 15 feet thick, but Illinoisan and Wisconsinan terrace deposits, of Late Pleistocene age, which fill the valleys, may be as thick as 70 feet. Loess and colluvial deposits have a considerable range in thickness; the maximum observed was 70 feet.

A tabular summary of the stratigraphy is given in Table 2. The surface relations of the rocks are shown on the geologic map (Pl. 1).

Structure

Regionally, Ottawa County lies near the axis of the Salina Basin, and rocks of Mississippian age and older are depressed to form the basin. Rocks of Pennsylvanian age and younger dip more gently and tend to fill the Salina Basin. Three deep test holes in the northwestern part of Ottawa County indicate that the top of the Dakota dips S 80° W about 20 feet per mile.

Some local structures are present within the county. Vine Creek Dome (Folger, 1948) lies approximately 6 miles west of Lindsborg Anticline and has its apex in sec. 27, T. 10 S., R. 1 W. The dome extends generally north-south for 8 miles and has about 40 feet of closure. Wildcat wells on and near Vine Creek Dome have proved unproductive.

A high-angle normal fault extends approximately 5 miles from sec. 10, T. 12 S., R. 3 W., to sec. 19, T. 12 S., R. 2 W. The north side of the

Plate 2.—Fore-set beds in Dakota Formation.

TABLE 2.—*Geologic formations of Ottawa County and their water-bearing properties* *

System	Series	Stratigraphic unit	Thickness, feet	Character	Water-bearing properties
Neogene	Pleistocene	Alluvium	0–40	Unconsolidated sand, silt, and clay deposited in river channels of major valleys.	Where saturated, yields moderate quantities of good water to wells.
		Upper Pleistocene rocks, undifferentiated	0–70	Unconsolidated sand, silt, and clay; loess, colluvium, and buried soils.	Where saturated, yield small quantities of hard water to wells.
		Wisconsinan (Stage) terrace deposits	0–70	Unconsolidated sand, gravel, silt, and clay; graded, feldspathic.	Where saturated, yield moderate to large quantities of good to hard water to wells.
		Illinoisan (Stage) terrace deposits	0–70	Unconsolidated sand, gravel, silt, and clay; graded, feldspathic.	Where saturated, yield moderate to large quantities of good to hard water to wells. Locally, water has high iron content.
		Nebraskan and Kansan (Stage) terrace deposits	0–15	Locally derived sand and gravel, silt, clay, and volcanic ash.	Not known to yield water to wells in Ottawa County.
Cretaceous	Upper Cretaceous	Carlile Shale	0–15	Gray calcareous shale, thin chalky limestone, thin bentonite beds.	Not known to yield water to wells in Ottawa County.
		Greenhorn Limestone	0–75	Chalky light-gray limestone; crystalline limestone, thin bentonite beds near base, fossiliferous.	Not known to yield water to wells in Ottawa County.
		Graneros Shale	0–38	Dark-gray, noncalcareous shale; thin bentonite beds, fossiliferous.	Not known to yield water to wells in Ottawa County.
	Lower(?) Cretaceous	Dakota Formation	0–350	Lenticular fine to medium sand, consolidated and unconsolidated, iron oxide and carbonate cement, light-brown to yellow silt; red, yellow, gray, brown, red-gray mottled clay, lignite, pyrite, gypsum.	Where saturated, yields small to moderate quantities of good to hard water to wells. Locally, water has high iron content.
	Lower Cretaceous	Kiowa Shale	0–80	Gray siltstone, gray fissile shale; cone-in-cone, fine sandstone lenses, gypsum, pyrite.	Not known to yield water to wells in Ottawa County.
Permian	Middle Permian	Wellington Formation	50+	Bright red and green shale, thin fine-grained crystalline limestone.	Not known to yield water to wells in Ottawa County.

* Stratigraphic nomenclature of the State Geological Survey of Kansas.

fault has dropped about 20 feet. Although the fault may be observed only in a few places, local geology indicates that the fault may extend several miles farther northwest, parallel to Solomon River. Thus, the course of the river may have been affected by the fault.

Minor flexures are common throughout the county, but their distribution has no pattern. They, and minor faults, seem to be caused by local adjustment. Depositional features (Pl. 2) may seem to be the result of structural movement but close examination shows them to be fore-set beds.

Geomorphology

The course of Solomon River and its tributaries is a direct result of the regional and local structure and the lithology of the stratigraphic units. Although much of the drainage history of Solomon River is not known, some geologic factors in the county have affected its course. Where the Solomon enters the northwestern part of the county, its course changes from southeastward to southward. Test holes across the valley near Delphos indicate that a buried Illinoisan channel lies about a mile east of the present channel. General topographic expression indicates a down-dip (westward) entrenchment. From the Salt Creek-Solomon River confluence to the southeastern part of the county, the Solomon borders the southern valley wall along the downthrown side of the fault in T. 12 S., R. 2 and 3 W. A southern extension of Vine Creek Dome (or Lindsborg Arch) causes the river to veer southward where it leaves the county. Salt Creek, though relatively small in drainage area, is a mature stream with paired, inverted terrace development, but it lacks Kansan terraces. Pearlette Ash is present, however. High terraces (Nebraskan or Kansan) border the Solomon Valley west of Glasco but not in Ottawa County.

Tributaries of Solomon River in the county are controlled by variations in Dakota lithology. Indurated clay or case-hardened zones in sandstone cemented with iron oxide generally form local drainage divides. Consequently, the tributaries tend to follow unconsolidated channel or bar sandstones or silt lenses. Present stream drainage aids in understanding the Dakota environment.

GEOLOGIC FORMATIONS IN RELATION TO GROUND WATER

Permian System—Sumner Group

Wellington Formation

The Wellington Formation crops out only in the southeastern part of the county but underlies younger rocks in the subsurface in the rest of the county. No test holes were drilled through the Wellington into the Chase Group, but lithologic characteristics indicate that the exposed section includes the lower part of the Wellington, and its thickness exceeds 50 feet.

The pre-Dakota erosional surface of the Wellington is irregular but exposures are few. In sec. 1, T. 12 S., R. 1 W., the surface is estimated to be 60 to 75 feet higher than nearby outcropping Dakota. The lower part of the Wellington consists mainly of bright-red and greenish-gray shale containing thin-bedded crystalline or wavy-bedded impure limestone. The following section is typical of exposures of the Wellington Formation.

Section of Wellington Formation on west creek bank in NE¼ SE¼ sec. 21, T. 12 S., R. 1 W., measured July 18, 1957.

	Thickness, feet
Permian—Leonardian	
Wellington Formation	
Limestone, thin bedded, laminated; iron oxide stain	0.2
Shale, red and greenish gray, mottled	8.3
Limestone, thin bedded, light brown	0.2
Shale, red and green, mottled, platy	2.8
Shale, grayish green; thin, wavy-bedded light-brown limestone	1.2
Shale, dull red and grayish green, mottled, blocky to platy	3.6
Shale, black, blocky	0.2
Shale, light and dark gray, silty	1.0
Shale, black and dark brown, blocky, silty	1.0
Total thickness measured	18.5

Water supply.—No wells are known to derive water from the Wellington Formation. Its permeability is so low that it serves as a nearly impermeable boundary below water-bearing formations. Water in the upper part is strongly mineralized. Two wells that tap an overlying aquifer but penetrate or come in contact with the Wellington are in the NE¼ NE¼ NE¼ sec. 18, T. 11 S., R. 1 W., and the SE¼ NE¼ SE¼ sec. 10, T. 12 S., R. 3 W. Both yield water that is hard and contains much sulfate; water from the second well also contains much chloride.

Cretaceous System

Kiowa Shale

The Kiowa Shale crops out only in isolated patches in southeastern and eastern Ottawa County. It is in the subsurface in the rest of the county except in the northeastern part, where it pinches out and the Dakota lies directly on the Permian, and in the southeastern part where Permian rocks are at the surface. Test holes in the northwest part of the county penetrated 80 feet of Kiowa without reaching the Wellington. An additional 20 to 40 feet might be expected.

The Kiowa is predominantly a gray fissile marine shale containing thick zones of gray siltstone along the eastern boundary. The predominant clay mineral in the shale is illite. Thin zones of fine sand are in the subsurface to the west. Gypsum and pyrite are common. Pelecypods (*Cardium, Corbula, Exogyra, Gryphaea, Mactra, Ostrea, Pecten, Trigonia*) in nearby counties have been reported by Twenhofel (1924). Gastropods are represented by *Turritella.* Cephalopods, brachiopods, coelenterates, and annelids have also been reported by Twenhofel.

The following measured sections of Kiowa illustrate basic similarities, even though there are some differences.

Section of Kiowa Shale on south bank of Solomon River in NE¼ NE¼ NW¼ sec. 19, T. 12 S., R. 2 W., measured August 7, 1958.

	Thickness, feet
Cretaceous	
Dakota Formation	
Sandstone, light brown, friable, tabular, crossbedded in part; fine to medium quartzose sand, some solution holes, linear iron oxide stain	15.0
Sandstone, reddish brown; fine to coarse quartzose sand, thin lignitic zones, pyrite, coarse conglomerate on uneven base	5.0
Disconformity	
Kiowa Shale	
Shale, black, fissile, weathers with white coating, not present continuously; abundant euhedral gypsum crystals; cone-in-cone near center	3.9
Siltstone, medium gray, blocky; much clay toward top, pyrite, iron oxide stain	7.0
Siltstone, medium to light gray, blocky, resistant near top; fine black laminations; pyrite	4.5
Siltstone, medium to light gray, resistant; surficial iron oxide stain	0.7
Siltstone, medium gray; localized pyrite	2.9
Siltstone, light gray, resistant; surficial iron oxide stain	0.9
Siltstone, medium gray, blocky	4.8
Siltstone, light gray, blocky	5.3
Siltstone, medium gray; locally contains fine black laminations and some small lenses of very fine sand, iron oxide stain	11.7
Total thickness measured	61.7

Section of Kiowa Shale exposed in ravine at cen. W. line, sec. 10, T. 11 S., R. 1 W., measured July 16, 1957.

	Thickness, feet
CRETACEOUS	
Kiowa Shale	
Siltstone, light brown, variegated; iron oxide stain	2.4
Shale, medium gray, fissile to blocky	4.0
Shale, black, fissile	1.0
Siltstone, white; fine laminations	0.3
Shale, clayey, black	1.8
Clay; contains concretions cemented with iron oxide	0.6
Shale, black, fissile	1.5
Shale, clayey, gray	0.5
Siltstone, light brown, mottled with dark brown	0.3
Shale, black, fissile	0.6
Shale, medium brown, blocky	1.8
Shale, black, fissile	4.8
Siltstone, light gray, weathers white; gypsum crystals	0.2
Shale, black, fissile; contains iron oxide at base	0.6
Shale, black, fissile	0.8
Shale, gray, blocky	0.4
Shale, black, fissile; gypsum crystals	1.1
Shale, clayey, medium gray	0.6
Shale, black, blocky	1.5
Shale, gray, fissile; contains iron stain along fissure planes, gypsum crystals	5.4
Total thickness measured	30.2

Section of Kiowa Shale exposed on south side of ravine southeast of hill in SW¼ NW¼ SE¼ sec. 11, T. 10 S., R. 1 W., measured August 10, 1958.

	Thickness, feet
CRETACEOUS	
Dakota Formation	
Clay, light gray, blocky; red and yellow stain, irregular gypsum crystals,	8.0
Clay, dark to medium brown, streaked yellow, indurated; lignite and plant fossil fragments	1.5
Clay, light gray and brown, mottled; iron oxide stain spotted throughout, lignite near top	2.3
Sandstone, light brown, medium grained, quartzose, well sorted, friable; iron oxide stain, faint crossbedding near top	5.5
Siltstone, clayey, medium to light gray; grades to fine sandstone near top	3.0
Disconformity	
Kiowa Shale	
Shale, black, fissile, nonfossiliferous, carbonaceous; cone-in-cone at base,	0.3
Shale, medium gray, fissile; iron-stain streaks	7.8
Shale, medium gray, blocky grading to fissile, iron stained along joints; medium-gray, finely crystalline limestone 0.2 foot thick at top	3.8
Shale, medium gray, fissile to blocky, iron stained along joints; medium-gray, finely crystalline limestone 0.2 foot thick at top	2.0
Total thickness measured	34.2

Water supply.—The Kiowa Shale is not known to yield water to wells in Ottawa County, but some strongly mineralized water containing much calcium and sulfate may come from thin sandstone layers in wells in the SE¼ NW¼ NE¼ sec. 9, and in the SE¼ SE¼ SW¼ sec. 11, T. 12 S., R. 4 W.

Dakota Formation

The Dakota Formation is exposed in much of Ottawa County and thereby forms the basis for the topography. The Dakota unconformably overlies either Wellington Formation or Kiowa Shale in the southeastern part of the county, and it is conformably overlain by Graneros Shale in the northwest, where test holes show that the Dakota is as much as 350 feet thick. The thickness is not uniform, however, because of the basal unconformity.

In Ottawa County, the Dakota Formation consists of three intergrading units. The upper and lower hundred feet are chiefly massive lenticular sandstone interbedded with lenticular silt and clay. The middle 100 to 150 feet is lenticular silt and clay interbedded with lenticular sand. Deep test holes, numerous outcrops, and general topography provide evidence for this interpretation. Lenticularity of all beds prevents correlation of any bed for a distance greater than a few miles. Local disconformities are numerous throughout the section.

Clays of the Dakota are kaolinitic. They may be red, yellow, blue, gray, black, or white. Red and gray mottled clay is restricted to and very abundant throughout the lower two-thirds of the section. Most soft light-brown siltstone near the base and top of the section is bedded; where it is not bedded, it may grade into clay.

The Dakota is best known for its sandstone, which constitutes only 25 to 40 percent of the formation. Quartz sandstone case hardened by iron oxide cement forms a resistant cap on small mesas. Generally, the sandstones are composed of well-sorted, poorly consolidated, fine and medium quartzose sand. Crossbeds are abundant and dip in an average direction of S 57° W (Franks and others, 1959).

Several sandstone samples were analyzed mechanically and statistically by Paul Franks and George Coleman. The results are summarized in Table 3.

The lithology, depositional environment, and water-bearing properties of sandstone in the Dakota Formation were studied from sections of several representative samples.

A photomicrograph of a thin section of typical iron oxide cemented cap rock that covers the mesas is shown in Plate 3A. The sample is from the SE¼ SE¼ SE¼ sec. 11, T. 9 S., R. 1 W. Paul Franks, who made

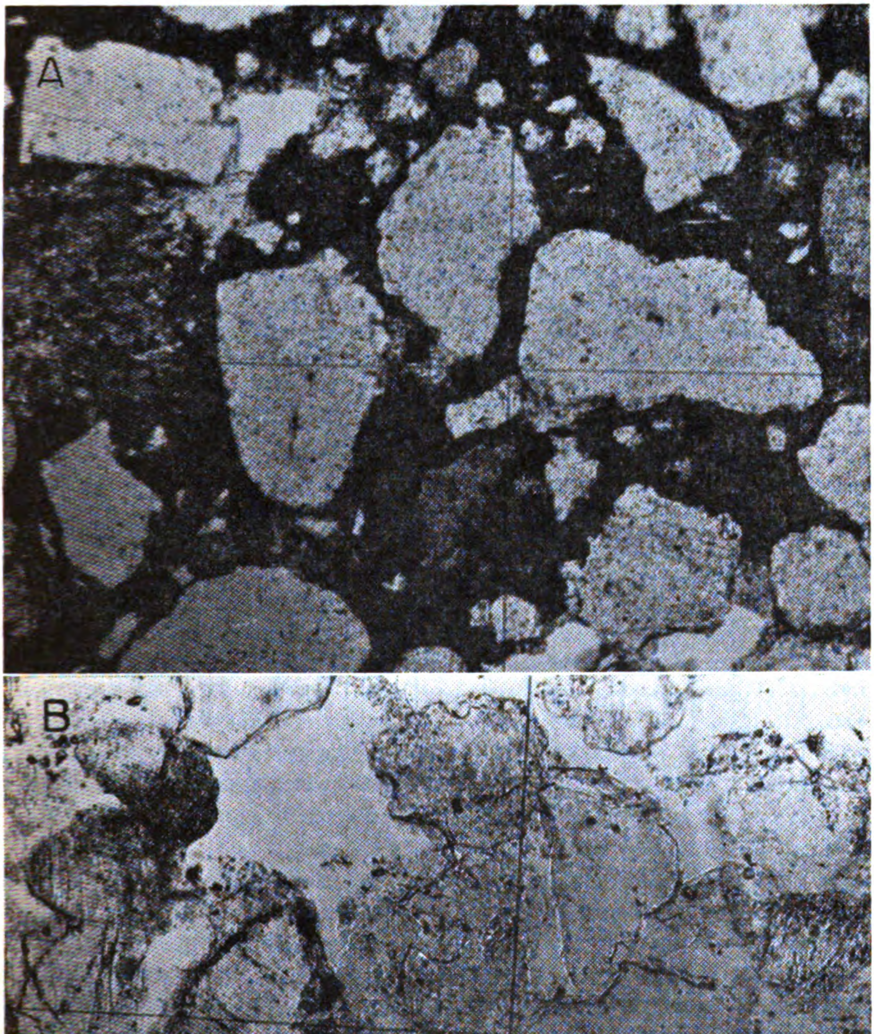

PLATE 3.—Photomicrographs of thin sections of samples of typical sandstone in Dakota Formation in Ottawa County, plane-polarized light, × 100. A, iron oxide-cemented cap rock from SE¼ SE¼ SE¼ sec. 11, T. 9 S., R. 1 W. Black areas are opaque "limonite". B, Massive channel sandstone from SW¼ NW¼ NW¼ sec. 1, T. 9 S., R. 1 W. Black areas are clay matrix, some of which is entrapped in silica overgrowths on quartz grains.

petrographic examinations of the sandstone samples, provided the following statements:

The rock is a light-brown to grayish-brown (5 YR 5/6 to 5 YR 3/2) and grayish red-purple (5 RP 4/2), medium-grained, iron oxide enriched sandstone that has "limonite"-walled tubular cavities measuring as much as 6 mm in diameter. The "limonite" walls of the cavities are as much as 1.5 mm thick.

In thin section, angular to well-rounded quartz grains, which constitute about 80 percent of the rock, are embedded in a matrix of "limonite" that contains birefringent goethite(?). The sections contain less than 1 percent feldspar and mica and only traces of tourmaline and staurolite in detrital grains. Most of the angular detrital grains have sutured margins; quartz overgrowths are uncommon.

TABLE 3.—*Summary of mechanical and statistical analyses of grab samples of sandstone in Dakota Formation, Ottawa County*

Analyzed by Paul Franks and George Coleman

SAMPLE	NE¼ sec. 14, T. 11 S., R. 2 W.		NW¼ sec. 26, T. 9 S., R. 5 W.		NE¼ sec. 19, T. 12 S., R. 2 W.		SE¼ sec. 20, T. 10 S., R. 4 W.		Sec. 34, T. 9 S., R. 2 W.	
Size* (mm)	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent
2.000	....	....	....	....	....	....	....	....	....	....
1.000	....	....	....	....	0.05	0.05	....	....	2.42	2.42
0.840	....	....	....	....	0.11	0.16	0.01	0.01	3.02	5.44
0.710	....	....	....	....	0.52	0.68	0.03	0.04	6.30	11.74
0.589	....	....	....	....	1.62	2.30	0.21	0.25	6.84	18.58
0.500	0.02	0.02	0.01	0.01	4.42	6.72	0.29	0.54	11.57	30.15
0.417	0.01	0.03	0.01	0.02	5.49	12.21	0.37	0.91	12.86	43.01
0.350	0.03	0.06	0.01	0.03	13.08	25.29	0.66	1.57	24.20	67.21
0.295	0.25	0.31	0.04	0.07	32.19	57.48	1.03	2.60	17.34	84.55
0.250	8.48	8.79	0.12	0.19	28.11	85.59	1.69	4.29	4.07	88.62
0.210	29.62	38.41	0.24	0.43	4.73	90.32	1.69	5.98	0.36	88.98
0.175	41.08	79.49	1.80	2.23	4.26	94.58	3.80	9.78	1.28	90.26
0.149	14.69	94.18	16.63	18.86	1.97	96.55	23.59	33.37	0.99	91.25
0.125	1.86	96.04	22.64	41.50	0.80	97.35	23.22	56.59	0.68	91.93
0.105	1.09	97.13	24.04	65.54	0.66	98.01	21.08	77.67	0.94	92.87
0.088	0.50	97.63	12.52	78.06	0.28	98.29	7.62	85.29	0.60	93.47
0.074	0.63	98.26	10.93	88.99	0.34	98.63	6.33	91.61	1.18	94.65
0.062	0.30	98.56	3.74	92.73	0.18	98.81	1.63	93.24	0.69	95.34
pan	1.43	99.99	7.27	100.00	1.19	100.00	6.75	99.99	4.66	100.00
Median diameter (mm)	....	0.201	....	0.118	....	0.31	....	0.157	....	0.405
Quartile diameter (mm)	....	0.024	....	0.024	....	0.046	....	0.030	....	0.047
Percentile 10/90 diameter (mm)	....	0.060	....	0.045	....	0.117	....	0.051	....	0.280

Averages for all samples: Median diameter—0.23 mm; quartile diameter—0.04 mm; percentile 10/90 diameter—0.11 mm.

* Retained on screen of this mesh opening.

Plate 3B is a photomicrograph of thin-section cut normal to the bedding of a typical massive channel sandstone body in the SW¼ NW¼ NW¼ sec. 1, T. 9 S., R. 1 W.

The rock is a light grayish-orange (10 YR 8/4), fine- to medium-fine-grained sandstone that shows only faint indication of bedding or lamination. Minute light-gray argillaceous specks may be weathered feldspar.

In thin section, the rock is seen to be composed mainly of detrital quartz grains embedded in a clay matrix that is stained by iron oxide. Bedding is indicated by slight tendency for subparallel alignment of long axes of detrital grains. The quartz grains constitute more than 90 percent of the rock, are slightly rounded, and many have overgrowths, but the overgrowths commonly do not surround the grains completely. Long diameters of the quartz grains range from 0.04 to 0.84 mm. The

TABLE 3.—*Continued*

Sec. 31, T. 11 S., R. 2 W.		Sec. 33, T. 11 S., R. 3 W.		Sec. 2 and 11, T. 11 S., R. 1 W.		Sec. 8 and 9, T. 12 S., R. 5 W.		Sec. 28, T. 12 S., R. 5 W.		Sec. 19, T. 12 S., R. 5 W.	
Percent of whole	Cumulative percent	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent	Percent of whole	Cumulative percent
1.86	1.856	....	....	....	....	....	....	....	....	....	....
6.32	8.18	0.01	0.01	....	....	....	....	....	....	....	....
4.23	12.41	0.01	0.02	....	....	0.01	0.01	....	....	....	....
8.23	20.64	0.13	0.15	0.01	0.01	0.01	0.02	....	....	0.01	0.01
10.64	31.28	0.23	0.38	0.01	0.02	0.02	0.04	0.01	0.01	0.02	0.03
25.82	57.10	0.44	0.82	0.02	0.04	0.05	0.09	0.02	0.03	0.04	0.07
22.83	79.93	0.37	1.19	0.02	0.06	0.03	0.12	0.02	0.05	0.02	0.09
9.16	89.09	1.35	2.54	0.06	0.12	0.09	0.21	0.05	0.10	0.14	0.23
1.01	90.10	3.42	5.96	0.12	0.24	0.35	0.56	0.15	0.25	1.02	1.25
0.55	90.65	11.79	17.75	0.67	0.91	6.23	6.79	1.52	1.77	10.91	12.16
0.08	90.73	15.21	32.96	6.70	7.61	21.55	28.34	4.16	5.93	23.64	35.80
0.55	91.28	22.82	55.78	42.73	50.34	40.01	68.35	11.44	17.37	42.65	78.45
0.46	91.84	22.02	77.80	33.88	84.22	19.40	87.75	24.67	42.04	15.65	94.10
0.23	92.07	11.19	88.99	8.14	92.36	4.54	92.29	24.93	66.97	1.95	96.05
0.43	92.50	5.19	94.18	2.68	95.04	2.80	95.09	16.62	83.59	1.00	97.05
0.35	92.85	1.17	95.35	1.21	96.25	1.02	96.11	6.74	90.33	0.45	97.50
0.88	93.74	1.46	96.81	1.30	97.55	0.86	96.97	4.82	95.15	0.60	98.10
0.61	94.34	0.25	97.06	0.35	97.90	0.58	97.55	1.07	96.22	0.19	98.29
5.66	100.00	2.94	100.00	2.10	100.00	2.45	100.00	3.78	100.00	1.71	100.00
....	0.54	....	0.183	....	0.179	....	0.190	....	0.140	....	0.200
....	0.100	....	0.067	....	0.021	....	0.032	....	0.027	....	0.023
....	0.29	....	0.078	....	0.035	....	0.057	....	0.053	....	0.050

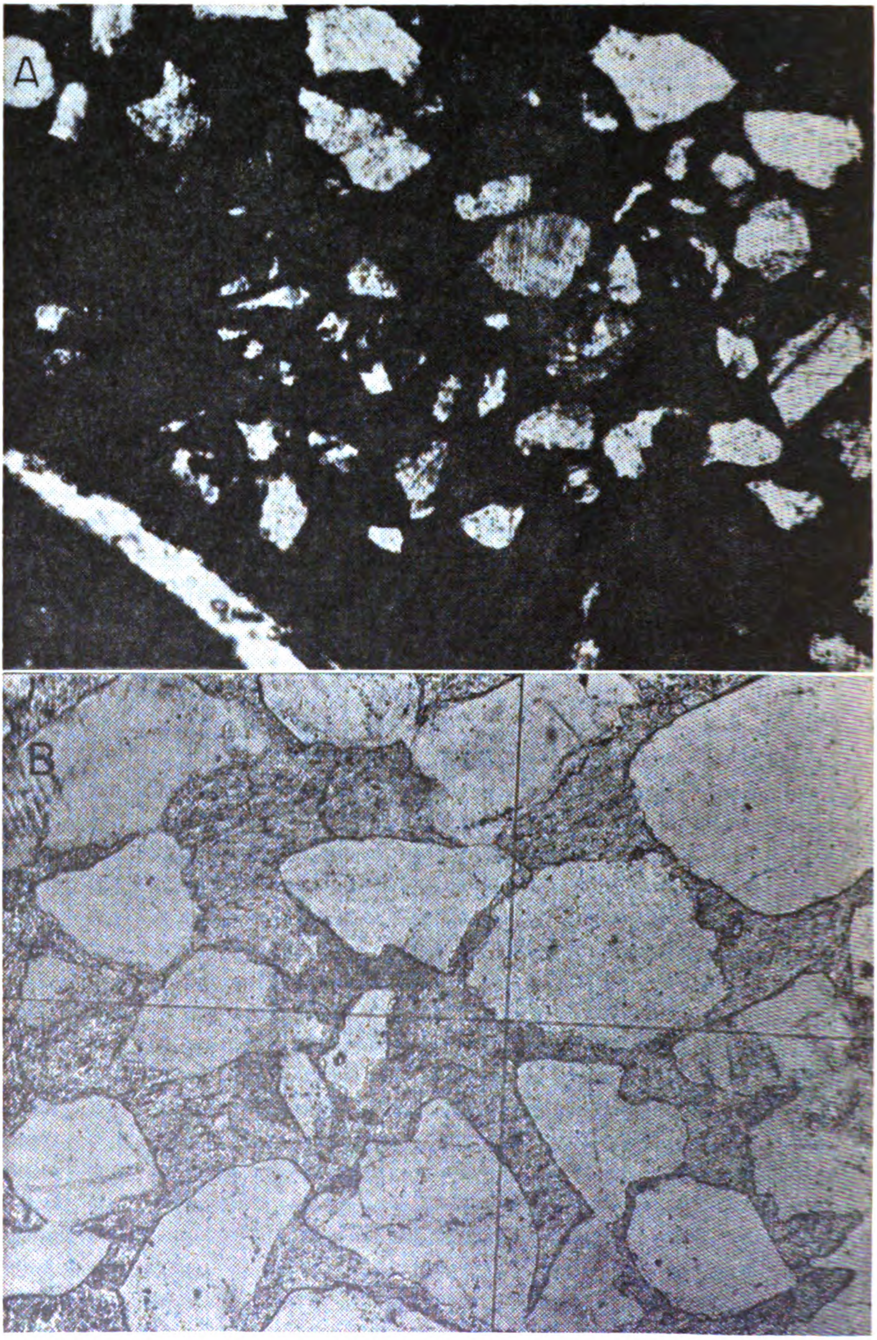

PLATE 4.—Photomicrographs of thin sections of typical sandstone in Dakota Formation, plane-polarized light, × 100. **A,** cellular iron oxide-enriched sandstone in NW¼ SW¼ NW¼ sec. 25, T. 11 S., R. 4 W. Black areas are mainly "limonite" and hematite. **B,** Calcite-cemented sandstone concretion in NW¼ SW¼ NW¼ sec. 30, T. 12 S., R. 5 W.

quartz grains locally are coated with leucoxene. In addition to quartz, the detrital grains include 1 or 2 percent feldspar, some of which is fresh; traces of muscovite as shredded books; 1 percent detrital chert and schist fragments; and traces of tourmaline, staurolite, and leucoxene. The clay matrix constitutes less than 5 percent of the rock but surrounds each detrital grain as a thin film; it fills pore spaces only locally.

The cellular sandstone (Pl. 4A), which is from a rock similar in appearance to scoria in the NW¼ SW¼ NW¼ sec. 25, T. 11 S., R. 4 W., consists of silty clay pellets surrounded by iron oxide cemented sand. The clay near the surface is removed by weathering, which causes the rock to appear scoriaceous.

The rock is cellular, iron oxide enriched sandstone in which the pits measure as much as 8 mm in long diameter, are roughly ovoid, and on fresh fractures are filled with silty ferruginous clay. Color on weathered surface is reddish purple (5 RP 4/2); on fresh surface, light brown to moderate-reddish brown (5 YR 6/4 to 10 R 4/6).

In thin section, the rock is seen to be similar to the type described by Swineford (1947). Large ovoid pockets (0.5 to 8 mm in long diameter) are separated by a "limonite" and hematite matrix that includes numerous quartz grains and may contain birefringent goethite. The matrix constitutes approximately 40 percent of the rock. The included quartz grains, constituting about 40 percent of the matrix, range in long diameter from 0.02 to 0.7 mm; some are well rounded, but most have sutured margins. The matrix contains less than 1 percent detrital feldspar grains and muscovite shreds. The ovoids are filled with illitic(?) clay that is stained brown by iron oxide and with silt-size quartz grains (0.01 to 0.12 mm in long diameter). Quartz constitutes approximately 20 percent of the ovoids, which probably are clay pellets.

An examination of a thin section of a sample from a concretion (Pl. 4B) in the NW¼ SW¼ NW¼ sec. 30, T. 12 S., R. 5 W., and similar to those in "Rock City", near Lamar, and other places in Ottawa County indicates that most of the quartz grains are separated by calcite cement. Formation of the concretions was described by Schoewe (1937). Mineralized water, flowing through well-sorted sand, supplied calcium and bicarbonate ions that precipitated as calcium carbonate (calcite) around a core, either organic or inorganic, that was compatible for its precipitation. Once the precipitation had started, it continued concentrically in the homogeneous sand as long as calcium and bicarbonate ions were available in sufficient concentration. Subsequent to their formation, the concretions have been exposed by the removal of the material around them in "Rock City" and Lamar (Pl. 5). Other concretions in the county are partly or wholly covered. According to Franks:

The rock from the NW¼ SW¼ NW¼ sec. 30, T. 12 S., R. 5 W., is a light brownish-gray (5 YR 7/1) sandstone that has dark-gray (N 3) stain on fracture or bedding surfaces. It is very fine to fine grained and cemented with calcite. The calcite seemingly is in large crystalline grains as much as 1 cm in diameter. The rock breaks along the calcite cleavage directions.

In thin section, the rock is similar to those described by Swineford (1947) and is composed mainly of detrital quartz grains set in calcite cement. Bedding is indicated by subparallel alignment of the long axes of the detrital grains, which approximate 55 percent of the rock and include, in addition to quartz, chert (1 percent), feldspar (1 percent), sphene (trace), and zircon (trace). The quartz grains are much sutured and embayed by the calcite cement, show no overgrowths, and measure 0.08 to 0.60 mm along their long diameters. The calcite cement occurs as optically continuous patches that are sieved by the detrital grains, measure as much as 1 cm in diameter, and approximate 45 percent of the rock.

The following measured sections give almost a complete section of the Dakota Formation in the general area along U. S. Highway 81 south of Solomon River from sec. 14 to sec. 36, T. 12 S., R. 3 W.

Section of Dakota Formation exposed on east side of U. S. Highway 81 at base of radio tower in NW¼ sec. 36, T. 12 S., R. 3 W. Altitude about 1,400 feet.

	Thickness, feet
CRETACEOUS	
Dakota Formation	
Sandstone, dark brown, hard; medium to coarse well-rounded quartzose grains, iron oxide cement; rests on disconformity—a channel sandstone	2-3.5
Clay, silty, medium gray, more silty at top, weathers light gray; no apparent bedding	8.0+

Section of Dakota Formation exposed on west side U. S. Highway 81 at large road cut in SE¼ NE¼ SE¼ sec. 26, T. 12 S., R. 3 W. Altitude about 1,390 feet.

	Thickness, feet
Shale, dark red, clayey, blocky; contains light-brown clay zones	3.0
Silt, sandy, light brown, limonitic, hard	0.5
Clay, medium gray, not bedded; streaked iron oxide stains	4.8
Silt, clayey, yellow brown	1.1
Clay, dark brown; small fragments of plant fossils	2.0
Clay, medium to dark gray, blocky; iron oxide stains	5.8
Clay, dark red	1.8
Clay, medium to light gray; dark red and brown stains	2.6
Siltstone, light brown, poorly bedded, resistant	1.8
Clay, light to dark gray, silty; slight iron oxide stain	4.8
Clay, greenish gray, dark red, and brown, mottled	6.8
Clay, light gray; light-brown mottling, abundant selenite crystals	5.5
Siltstone, light brown, resistant; iron oxide cement	0.5

Section of Dakota Formation on east side of U. S. Highway 81 at small road cut in cen. W. line sec. 25, T. 12 S., R. 3 W. Altitude about 1,350 feet.

	Thickness, feet
Clay, medium gray, silty; contains dark-red, brown, and gray clay	5.0
Sand, light brown, fine to medium grained; iron oxide stain	1.5
Clay, medium gray, silty, laminated	2.3
Siltstone, medium gray; contains iron-stained zones of clay; plant fragments near center	2.3

Plate 5.—Sandstone concretions in Dakota Formation. **A**, "Rock City" in the SE¼ SE¼ SW¼ sec. 14, T. 11 S., R. 4 W. **B**, "Rock City" concretions showing crossbedding.

	Thickness, feet
Clay, dark grayish brown, silty; contains numerous lignite fragments, sparser toward top	4.3
Clay, medium gray, blocky	2.5

Section of Dakota Formation on west side of U. S. Highway 81 at small road cut in SE¼ SE¼ NE¼ sec. 26, T. 12 S., R. 3 W. Altitude about 1,330 feet.

Sandstone, light brown, tabular, resistant	1.0
Sandstone, very light brown, well sorted; some iron oxide stain; partly covered	5.0
Sandstone, light brown; hard hematite zones near top; mostly covered,	5.0
Sandstone, light brown, fine grained, poorly consolidated, massive; crossbeds at top and bottom, liesegang rings at top; variable iron oxide stain	13.0

Section of Dakota Formation on west side of U. S. Highway 81 at small road cut in SE¼ NE¼ SE¼ sec. 23, T. 12 S., R. 3 W. Altitude about 1,300 feet.

	Thickness, feet
Sandstone, yellowish brown, well sorted, very fine to fine grained, angular, quartzose; iron oxide stain; channel sand overlain by hard, fine conglomerate. Laterally grades into light-brownish-gray silty clay containing fragments of plant fossils (where above channel sand is absent)	1.5
Sandstone, variegated, massive, angular, medium grained, quartzose	5.0
Sandstone, medium yellowish brown, massive, very fine to fine grained, subhedral to anhedral, quartzose	6.0 +

Section of Dakota Formation on west side of U. S. Highway 81 at road cut in NE¼ SE¼ NE¼ sec. 14, T. 12 S., R. 3 W. Altitude about 1,230 feet.

	Thickness, feet
Clay, silty, light gray and yellow brown; some fine sand	6.0 +
Silt, medium yellowish brown, platy bedding; some fine sand	0.8
Shale, clayey, medium gray, silty; sharp bedding planes	5.0
Sandstone, variegated, red, yellow, gray, brown, white, poorly consolidated to friable; 1- to 4-foot beds	25.0
Total thickness measured	220.0

About 20 feet of basal Dakota is not exposed, and about 90 feet of uppermost Dakota has been eroded from the top of this section.

Section of Dakota Formation along creek in SE¼ SW¼ sec. 14, T. 9 S., R. 5 W.

	Thickness, feet
CRETACEOUS	
Graneros Shale	
Shale, dark gray, laminated	1.0
Dakota Formation	
Clay, medium gray and yellow; mostly covered	24.6
Shale, clayey, medium gray, fissile, soft, weathers light gray	8.0
Sandstone, white, unconsolidated, fine to medium grained; capped with 0.2 foot of sandstone cemented by iron oxide	2.0

	Thickness, feet
Covered	3.5
Siltstone, light yellow; gray sandy clay	0.7
Siltstone, light brown, laminated; iron oxide cement	0.7
Clay, light and dark gray, streaked yellow; mostly covered	10.5
Sandstone, light gray; hard iron oxide cap that is 0.2 foot thick	0.8
Clay, gray, stained yellow; mostly covered	4.7
Sandstone, light brown, medium to fine grained, poorly consolidated; iron concretions near base, crossbeds near top	7.0 +
Total thickness measured	56.5

There are numerous small outcrops of Dakota in Ottawa County, but most of them are sandstone that is similar to that described and do not have any stratigraphic significance.

Water supply.—All wells in Ottawa County that do not obtain water from Pleistocene deposits are finished in the Dakota Formation. Stock wells yield 1 to 5 gpm (gallons per minute), but one industrial well, in sec. 34, T. 11 S., R. 5 W., yields 145 gpm. The dissolved solids range from about 100 to 2,000 ppm. The water in most places is hard and contains enough iron to stain laundry and plumbing. The amount of dissolved sulfate differs considerably, but chloride content of most samples is small.

Several wells are dug, but most are drilled. The deepest known drilled water well in the county is 177 feet deep. Successful wells can be drilled most places in the Dakota Formation. In some places no sand is encountered, but this situation is rare. The hydrologic properties of the Dakota Formation are discussed on page 60.

Graneros Shale

Except for two small localities in southwestern Ottawa County, the Graneros Shale is confined to the northwest, where a cover of Greenhorn Limestone protects it from rapid erosion. Colluvial cover makes natural outcrops uncommon. The Graneros Shale is about 38 feet thick and is conformable, below and above, with the Dakota Formation and the Greenhorn Limestone, respectively. Its distinctive lithology, relatively uniform thickness, and wide distribution make the Graneros Shale a good marker bed for drillers.

The Graneros Shale is composed chiefly of black fissile shale, noncalcareous except somewhat calcareous near the top. Thin limestone beds, scattered through the section, are more abundant near the base. Thin beds of bentonite are common throughout the section.

The following exposed section was measured within a quarter of a mile from a test hole drilled for surface-subsurface correlation.

Section of Graneros Shale along steep stream bed on east side of road in sec. 14, T. 9 S., R. 5 W., measured July 11, 1958.

	Thickness, feet
Cretaceous	
Greenhorn Limestone	
Limestone, gray, dense to fine grained, fossiliferous	0.3
Graneros Shale	
Shale, black to dark gray, calcareous; 0.2-foot yellow-stained bentonite bed near top	3.0
Shale, black, fissile; 0.2-foot bentonite beds at top and bottom	1.0
Shale, black, fissile, slightly calcareous; two 0.2-foot gray crystalline limestone beds near top; pelecypods abundant	5.2
Shale, black, fissile; two 0.1-foot bentonite beds 0.2 foot apart near top,	3.0
Shale, black, fissile, noncalcareous; 0.3-foot bentonite bed at top	1.2
Shale, black, fissile; 0.2-foot bentonite bed at top	1.2
Shale, limy, and shaly limestone, dark brown, soft	1.2
Shale, black, fissile, weathers light gray	1.4
Shale, limy, dark brown, soft, carbonaceous; 0.4-foot yellow-stained white bentonite near top	3.0
Limestone, platy, medium grained crystalline	1.2
Shale, black, fissile; partly covered	11.2
Limestone, platy, medium grained crystalline	0.8
Shale, dark gray and brown, laminated, fissile	2.8
Limestone, platy, medium brown, medium grained crystalline	0.7
Bentonite, yellowish white	0.5
Shale, dark gray, laminated	1.0
Dakota Formation	
Clay, gray and yellow; streaks of iron stain	21.6
Total thickness measured	60.2

Water supply.—The Graneros Shale is not known to yield water to wells in Ottawa County. A small amount of mineralized water seeping down from the Graneros through fissures and joints into the Dakota Formation probably affects the quality of the underlying Dakota water.

Greenhorn Limestone

The Greenhorn Limestone has almost the same distribution as the Graneros Shale—two small areas in the southwestern part of the county and the hilly area in the northwest. The Greenhorn Limestone is conformable with the Graneros Shale below and with the Carlile Shale above. The Greenhorn is about 75 feet thick where it is overlain by the Carlile Shale.

The Greenhorn Limestone is chalky except for some crystalline limestone and some bentonite beds. The chalky limestone and chalky "shale" are reported to have the same percentage of CaO (Norman Plummer, personal communication). Some of the limestone beds are composed almost entirely of fossils—mostly oysters, such as *Inoceramus labiatus*, and foraminifera, such as *Globigerina* (Stanton, 1922). The "Fencepost" Limestone bed, which is about half a foot thick and easily identified by an iron-stained zone in the middle, does not crop out commonly in Ottawa County.

The following measured section was made above the section of Graneros Shale given on page 38.

Section of Greenhorn Limestone on east side of road in sec. 14, T. 9 S., R. 5 W., measured July 11, 1958.

	Thickness, feet
CRETACEOUS	
Greenhorn Limestone	
Limestone, light grayish brown, medium grained, wavy bedded; pelecypods	0.3
Limestone, shaly, light brown, chalky, papery	1.0
Limestone, light brown, coarse grained; fossiliferous	0.2
Limestone, shaly, light grayish brown, chalky, platy to tabular	1.7
Limestone, grayish brown, coarse grained, hard, fossiliferous	1.1
Limestone, shaly, light grayish brown, chalky, laminated, platy	1.1
Limestone, light grayish brown, laminated	0.2
Limestone, shaly, light brownish gray, chalky; contains crystalline limestone zones	1.4
Limestone, light grayish brown, hard; pelecypods	0.4
Limestone, shaly, light brownish white, chalky; oyster bed	1.0
Limestone, light grayish brown, hard; oysters on base	0.4
Limestone, shaly, light grayish brown, chalky, very fossiliferous	0.8
Limestone, light brown, hard, even bedded; contains iron oxide streak in center, abundant fossils	0.5
Limestone, shaly, light grayish brown, chalky, very fossiliferous	0.5
Limestone, light gray, chalky, fossiliferous	0.4
Limestone, light grayish tan, chalky, very fossiliferous	0.7
Limestone, light gray, chalky	0.3
Limestone, shaly, very light gray, chalky, finely laminated	0.6
Limestone, very light brownish gray, powdery, fossiliferous	0.4
Limestone, shaly, light gray, papery, chalky	1.6
Limestone, very light gray, dense to powdery, weathers light brown	0.6
Limestone, shaly, light gray; iron oxide stain	1.4
Limestone, shaly, light grayish brown, finely laminated; 0.2-foot chalky limestone at top	1.0
Limestone, shaly, light grayish brown; finely laminated 0.7-foot bed of light-gray, dense to chalky limestone at top	1.4
Limestone, light gray, chalky	0.3
Limestone, shaly, light gray, papery	0.4
Limestone, light gray, dense to chalky; iron oxide stain	0.3
Shale, medium gray, calcareous, papery, stained yellow, thin lenses of fissile black shale	2.3
Shale, light gray, calcareous, platy	3.4
Shale, black, fissile, carbonaceous	0.5
Shale, grayish brown, calcareous, papery	0.5
Bentonite; yellowish stain	0.2
Limestone, shaly, light gray, platy	3.0
Limestone, medium gray, fine grained, dense, fossiliferous	0.3
Graneros Shale	
Total thickness measured	30.2

Water supply.—No wells in Ottawa County are known to obtain water from the Greenhorn Limestone. Although there is some jointing, no known water supplies are obtained from the joint system. Wells drilled in this area extend to the Dakota Formation for dependable yield.

Carlile Shale

The Carlile Shale is present only in the northwest part of the county where it is near the top of the highest hills. The Carlile is easily eroded and is mantled by loess or soil, and hence no exposures were observed. It is about 15 feet thick and is generally overlain by a thin layer of limestone not more than 0.2 foot thick, which may be the "Algal" limestone of the Ogallala Formation, of Pliocene age.

The only Carlile rocks studied are samples from a test hole in the SE¼ SE¼ sec. 7, T. 9 S., R. 5 W. These included a thin, yellowish-brown limestone, a bed of greenish-gray shale several feet thick containing thin beds of bentonite, and a thin white chalky limestone.

The Carlile Shale is not known to yield water to wells in Ottawa County.

Neogene System—Pleistocene Series

Nebraskan and Kansan Stages

High terrace and volcanic ash deposits are the only known Lower Pleistocene deposits in Ottawa County. The volcanic ash is the Pearlette Ash of late Kansan age (Swineford and Frye, 1946). The high terrace deposits are classified as Nebraskan age. They are present only along Salt Creek, West Chapman Creek, and Coal Creek (Pl. 6A). No deposit exceeds 15 feet in thickness.

The high terrace deposits are composed of locally derived materials—mostly sand and iron nodules of the Dakota Formation, but the terrace deposit north of Ada is derived predominantly from Greenhorn Limestone. The sorting generally is very poor. No fossils were found in any terrace deposit. The Pearlette Ash is composed of slightly weathered volcanic ash, having a predominance of silt-size glass shards.

The high terrace and ash deposits lie above the water table and do not yield water to wells.

Illinoisan Stage Terrace Deposits

Illinoisan terraces flank major stream valleys, and remnants flank some of the major tributaries. Depending on the size of the drainage area, Illinoisan terrace deposits may range in height from a few feet to 20 feet above the Wisconsinan terrace deposits. The thickest terrace deposit observed was 68 feet thick.

PLATE 6.—**A,** High terrace deposit of Nebraskan age south of Salt Creek composed of locally derived material. **B,** Typical loess deposit in the SE¼ SE¼ SW¼ sec. 25, T. 10 S., R. 4 W.

Sand and gravel are at the base of the Illinoisan terrace deposits. The sediments grade upward to silt and clay sizes. The test hole in the NW¼ NW¼ NE¼ sec. 15, T. 9 S., R. 4 W., penetrated 44 feet of sand and gravel, of which 38 feet was water saturated. Ordinarily, only 5 to 15 feet of sand and gravel may be expected. The sand and gravel are derived from the Ogallala Formation, which in turn was derived from the Rocky Mountains, and are composed mainly of quartz but contain abundant feldspar and smaller amounts of magnetite, tourmaline, sphene, amphiboles, and pyroxenes.

Water supply.—Where saturated, Illinoisan terrace deposits yield large quantities of water to wells. The water may be hard and may contain much bicarbonate and iron locally, but it is potable and may be used for irrigation. The towns of Delphos and Tescott and irrigation wells in sec. 3, T. 9 S., R. 4 W.; sec. 18, T. 9 S., R. 4 W.; and sec. 21, T. 11 S., R. 3 W., derive water from Illinoisan terrace deposits.

Wisconsinan Stage Terrace Deposits

Wisconsinan Stage terrace deposits, in this report, include all the terrace deposits that are younger than Illinoisan and older than material (alluvium) covered by the average annual flood. All deposits along intermittent tributaries are mapped as Wisconsinan terrace deposits because the alluvium is too insignificant to be mapped separately. The terrace deposit, including a thin strip of alluvium, is more than 2 miles wide in places along Solomon River but is not more than 70 feet thick. Along major tributaries the thickness of the terrace deposits near the confluence with Solomon River is equal to that of the Solomon, but along smaller tributaries the thickness at the confluence is less than in the Solomon Valley.

Wisconsinan terrace deposits are similar to Illinoisan terrace deposits in lithology and grading but differ in topographic position. Sand and gravel of the Wisconsinan terraces, like those of the Illinoisan, are composed chiefly of quartz, although feldspars are common, but unlike those in the Illinoisan terraces, they contain only small quantities of heavy minerals. Wisconsinan terraces are topographically lower than Illinoisan terraces except in a few places where natural levees of Wisconsinan age rise above the Illinoisan terraces.

Water supply.—Moderate quantities of water having a wide range in quality are obtained from several wells in the Wisconsinan terrace deposits. Generally the quality is good, but in the southeast, where the terrace deposits come in contact with rocks of the Wellington Formation or Kiowa Shale, wells yield mineralized water. Also, in the broad floodplain area at the confluence of Solomon River and Salt Creek, the aquifer is very silty and its water contains a greater concentration of dissolved solids. No irrigation wells obtain water from the Wisconsinan terrace deposits.

Undifferentiated Deposits

Loess, colluvium, buried soils, sheet wash, and thin alluvial deposits overlie Upper Pleistocene terraces where they adjoin bedrock. They attain their greatest thickness along the north and east side of Solomon River and the north side of Salt Creek. These deposits do not exceed 70 feet in thickness. Although most of these deposits are Late Pleistocene in age, Pearlette Ash and 20 feet of material of Early Pleistocene age below it were present in one locality.

These undifferentiated deposits represent several types of sedimentation. At some places, the basal part contains a few feet of well-sorted sand, which may be saturated. Commonly the rest of the deposit is composed of silt-size particles, which may be in the form of loess, clayey ancient soils showing structure, or colluvium, or any combination of the three. A typical loess deposit is shown in Plate 6B.

Water supply.—Several wells obtain small amounts of water from the coarse basal fractions of these deposits where they overlie relatively impermeable bedrock, such as the Wellington Formation and Kiowa Shale or clay of the Dakota Formation. The quality of water is likely to be very poor if the deposits are in contact with the Wellington Formation or Kiowa Shale.

Alluvium

In this report, alluvium includes that material that is covered by the river at the stage of its average flood. Rare major floods that cover the entire valley may deposit some sediment on Wisconsinan terraces, hence the terrace deposits may be concealed. Alluvium was mapped along perennial streams only. Its thickness ranges from about 20 to 40 feet.

The alluvium is composed of unconsolidated sand, gravel, silt, and clay and commonly contains organic residue.

No wells were observed in the alluvium as defined above, but moderately large yields may be expected.

GROUND WATER

Role of Ground Water in the Water Cycle

Ground water is defined by Meinzer (1923) as that part of the subsurface water that is in the zone of saturation. The subsurface water above the zone of saturation—that is, water in the zone of aeration—is called suspended subsurface water or vadose water. Ground water takes a small but very important part in the water cycle.

Basically, ground water is derived from precipitation in the form of rain or snow. Part of the precipitation runs off directly into 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 the zone of saturation. This is the zone saturated with water under hydrostatic pressure.

Ground water percolates slowly through the rocks in directions determined by the geology, topography, and geologic structure until it is discharged eventually into surface-water bodies through springs and seeps, by withdrawal from wells, or by evaporation and transpiration in areas where the water table is shallow.

Movement of Ground Water

In Ottawa County, ground water moves toward the major streams; and, once it reaches the terrace deposits, it flows toward the streams but with a down-valley component. Thus, part of the ground water discharges into the river and becomes surface water. Ground water moves through the Dakota Formation into the north-central part of the county from Cloud County, and some enters the southwestern corner of the county from Saline and Lincoln Counties; otherwise, most ground-water movement is away from Ottawa County. Large amounts of ground water move through the terrace deposits into the county in the Solomon and Saline River valleys. A smaller amount enters in Salt Creek valley.

More than 200 wells were inventoried for the preparation of a map showing the configuration of the piezometric surface (Pl. 7). This is the surface of the water table or the height to which water, under hydrostatic pressure, will rise in a well. This surface, roughly parallel to the topography, in Ottawa County, fluctuates as ground water is discharged or recharged. All points on each contour line on Plate 7 are at an equal altitude above sea level. A line crossing perpendicular to the contour lines indicates the direction of ground-water movement as it passes from a higher to a lower altitude. Because of the lack of water in the Wellington Formation, piezometric contours are not given in areas of outcrop of this formation.

Many of the inventoried wells are in the Dakota Formation, which contains water under hydrostatic and atmospheric pressure (artesian) and water under atmospheric pressure only (nonartesian). The conditions under which the Dakota was deposited were such as to cause lenticularity

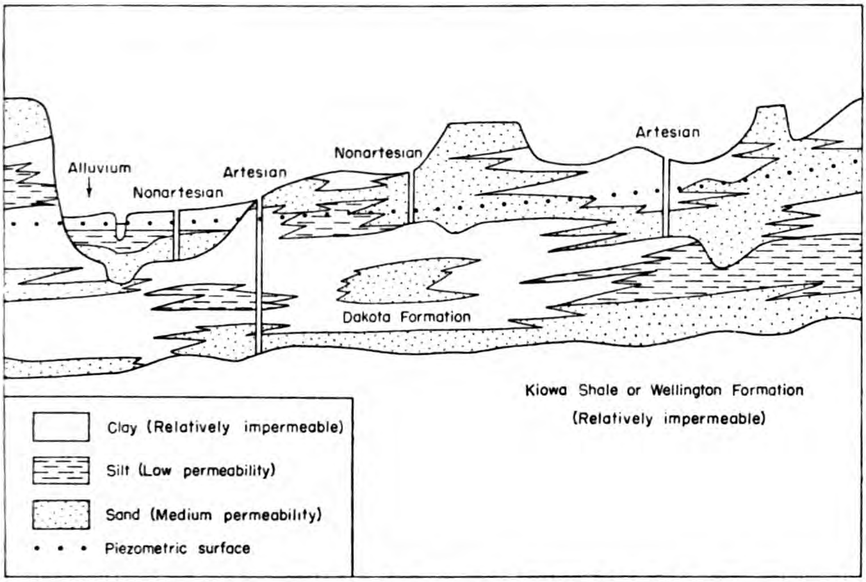

FIG. 6.—Diagrammatic cross section of Dakota Formation and river terraces in Ottawa County showing intertonguing lenticular beds of different permeability, typical artesian and nonartesian wells, and hydraulic gradient.

of all beds. Thus, the Dakota Formation is composed of intertonguing lenses of permeable sand, less permeable silt, and relatively impermeable clay (Fig. 6).

Water-level records, chemical analysis of water, and geologic studies indicate an interconnected hydraulic system within the Dakota Formation. Some wells in the Dakota Formation obtain perched water from zones that lie above the piezometric surface. A few wells obtain water from a deep zone in the Dakota Formation in which the static water level is below the piezometric surface in nearby wells. The hydraulic connection between the zones is very poor or does not exist. Only 12 out of more than 300 test holes and inventoried wells obtained water from perched or deep zones.

Upper Pleistocene terrace deposits, although stratigraphically separated from the Dakota Formation, are hydraulically connected with it (Pl. 8). Terrace deposits are composed of stratified sediments that grade upward from coarse to fine material. Numerous test-hole samples show that, in many places, saturated sandstone of the Dakota Formation directly underlies basal sand and gravel in the terrace deposits. In addition, numerous massive sandstones of the Dakota adjoin the terrace borders. Static water-level measurements show that the piezometric surface passes smoothly from the Dakota into the terrace deposits (Pl. 7). Water-quality data do not distinguish between a Dakota or terrace-deposit source, except for local anomalies. Base flow discharge of Solomon River at Niles is about twice the discharge at Beloit in Mitchell County. Records of discharge at these stations are published in the annual series of Water-Supply Papers by the U. S. Geological Survey. Hence, data prove hydraulic interconnection between the Dakota and the terrace deposits and discharge of ground water from the Dakota into the terrace deposits.

Ground-Water Recharge

Precipitation accounts for most of the ground-water recharge in Ottawa County. If the average annual precipitation in the county is assumed to be 26.6 inches, the average in Minneapolis, then Ottawa County receives an average of 1.0 million acre-feet of precipitation per year. Only a small fraction of the precipitation becomes ground water. Most is either returned to the atmosphere by evapotranspiration or discharged by direct runoff. The average rate of evapotranspiration in Ottawa County is 24 inches per year (Foley, Smrha, and Metzler, 1955). Slightly more than half this amount is transpired (1.03 feet) and slightly less than half is evaporated (0.97 foot). If the average precipitation is 26.6 inches and the average evapotranspiration is 24 inches, then 2.6 inches becomes runoff, which is equivalent to about 100,000 acre-feet. Thus, the runoff of about 100,000 acre-feet represents water that flows directly from the surface into the rivers and water that recharges the ground-water reservoir and then seeps into the rivers as ground-water discharge. Streamflow analyses indicate that about half the total runoff is ground-water discharge. Hence, an average of about 50,000 acre-feet of water each year recharges the ground-water reservoir, moves down a hydraulic gradient, and discharges into streams.

Some ground water moves into Ottawa County from Cloud County. A smaller amount moves into the southwestern corner of the county from Saline and Lincoln Counties.

In 1957 the amount of ground-water recharge due to irrigation from surface water was negligible. All irrigated areas are near a river or stream. As ground water normally discharges into the river or stream, any recharge to ground water would soon be routed back to the surface water. No shallow aquifers in Ottawa County are recharged by irrigation water obtained from a deeper aquifer.

Ground-Water Discharge

Ground water discharges into bodies of surface water, primarily rivers, and to a lesser degree lakes and ponds, even during periods of drought; Solomon River continued to flow during the prolonged 1952-57 drought. Ground water discharging, without the agency of man, upon the land or into a body of surface water, is known as a spring or seep. Owing to the abundance of saturated sandstone that crops out in Ottawa County, springs and seeps are common. If there were less vegetation to absorb ground water near zones of discharge, springs would be more obvious. Vegetation uses ground water whenever plant roots reach the zone of saturation or the capillary fringe just above the water table. If ground water or the capillary fringe is sufficiently near the surface, evaporation will take place. The last two types of ground-water discharge are known jointly as evapotranspiration. Surface water and vadose water supply most water for evapotranspiration. A considerable amount of ground water moves in the subsurface from Ottawa County to all adjacent counties. The only ground water not discharged by natural causes is that pumped from wells. All the municipalities and most of the farms obtain their water from wells. Most farm and stock wells yield only a few gallons per minute, but municipal and irrigation wells yield 100 to 600 gpm.

The total amount of water pumped from wells in Ottawa County during 1957, itemized in Table 4, was about 1,280 acre-feet.

Table 4.—*Use and amount of ground water pumped during 1957.*

Use	Gallons per day	Acre-feet per year
Public supply	359,000	400
Rural domestic supply	168,000	190
Stock	450,000 (est.)	500
Industry	144,000 (est.)	160
Irrigation	27,000 (est.)	30
Total		1,280

Although the population of Minneapolis has declined only slightly since the beginning of World War II, there has been a marked increase in the quantity of water used (Fig. 7). Throughout World War II, the consumption varied only slightly and ranged between 30 and 35 million gallons per year, or approximately 43 gallons per capita per day. Since World War II, with the exception of the 1951 flood year, the consumptive demand has increased greatly. In 1956, the quantity used was approximately 100 gallons per capita per day. Two main reasons account for this greater water consumption. There continues to be a large increase in appliances that require water; air conditioners, garbage-disposal units, lawn and garden sprinkling systems, and automatic washers are a few

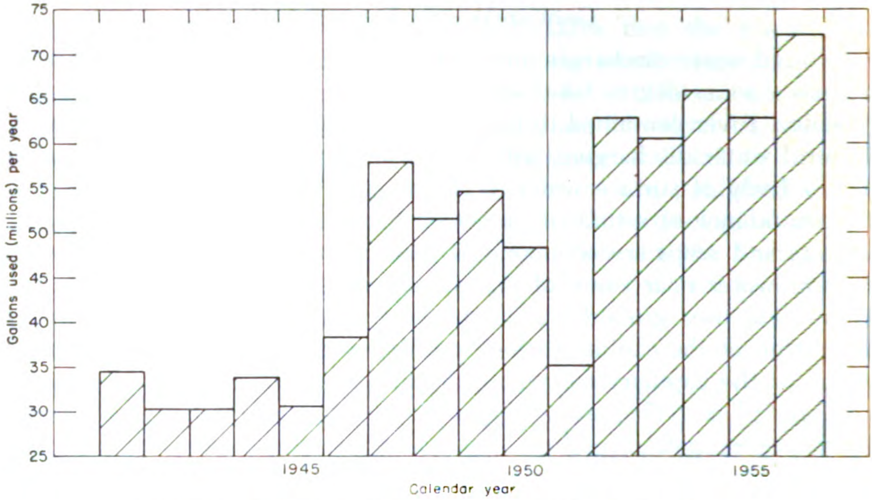

Fig. 7.—Annual use of water at Minneapolis, 1941-1956.

examples. In addition, many new houhehold plumbing systems have been installed and old ones expanded. The other reason for increased water consumption was the drought from the fall of 1951 until the spring of 1957. Large quantities of water were used for gardens and lawns, and water was hauled from the city to rural areas.

Interrelations of Surface and Ground Waters

Normally, ground water is discharged into the rivers in Ottawa County. At times, however, the rivers lose water to the ground-water reservoir. Figure 8 shows a cross section of a river and adjoining water-table aqui-

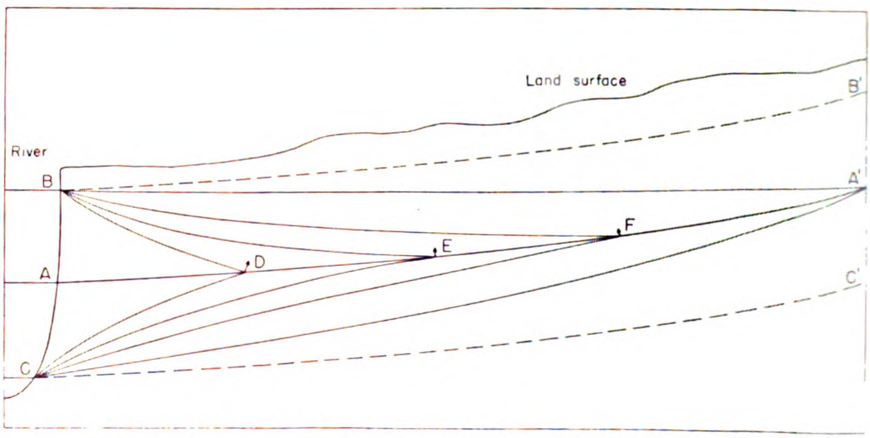

Fig. 8.—Effects of changes in stream level on adjacent water table.

fer. It is assumed that the aquifer is homogeneous and isotropic (water flows with equal facility in any direction) and that there is no surface of seepage at the river bank. Under conditions of normal flow, water moves in dynamic equilibrium from source A′ to the river level, A, in the direction of the hydraulic gradient A′A; ground water is being discharged into the river. If the river level should rise suddenly to B, then readjustment of the hydraulic gradient would commence immediately and pass consecutively through lines BDA′, BEA′, and BFA′ until equilibrium was again regained along the hydraulic gradient A′B. A′ has a slightly greater head than B, so the direction of flow would be toward the river again. During the readjustment of the hydraulic gradient there are simultaneously two slopes, BA and A′A, and hence, two directions of flow. When the river rises from A to B, the river recharges the ground-water reservoir, for example, along BD. But at this moment, water from the aquifer is still moving along A′D toward the river. At point D, the vector of flow is the resultant of BD and A′D vectors. In other words, at point D, the water level rises upward and slightly away from the river. When the hydraulic gradient is BEA′, the curvilinear triangle BDE has become saturated by recharge from the river, and the vector at point E is almost vertical. By the time curvilinear triangle BEF is saturated, the vector at point F is upward and slightly toward the river. Water from the river is still recharging the ground-water reservoir but at a decreasing rate. Eventually the direction of flow will, at all points, be toward the river when equilibrium is regained between a pressure head at A′ and a slightly lower point at B. The same principles are applied in reverse if the river is suddenly lowered from A to C. Steady-state conditions will be regained along A′C only after successive dewatering of curvilinear triangles CAD, CAE, CAF, and finally CAA′.

In essence, a constant quantity of water flows in equilibrium along a constant gradient, according to Darcy's law, if the permeability, cross-sectional area, and difference in head are constant. But, if the head changes, along either a source or a drain, then two gradients form, which are connected by a point of flexure (or intermediate head) moving from the source or drain that was changed to the source or drain that remained unchanged until equilibrium is regained. The motion of the flexure point is the resultant vector of the gradient vectors.

River recharge to ground water in Ottawa County generally does not follow the above explanation except in areas where relatively homogeneous sandstone of the Dakota Formation is in contact with the river. Most of the valley fill is heterogeneous and includes several feet of silt and clay at the top. The piezometric surface in the valley fill is above the sand and gravel in many places. Numerous test holes show that it passes through silt and clay and that much of the ground water in the valleys is under slight artesian pressure. Under artesian conditions a rapid rise in the river level will not cause appreciable movement of water from the river toward the aquifer; but, instead, it will cause a rise in the piezometric surface. Because the piezometric surface outside the valley is higher than the top of the river bank, as shown by line AA′ (Fig. 9), the water does not move into the aquifer. Theoretically, the rise of the

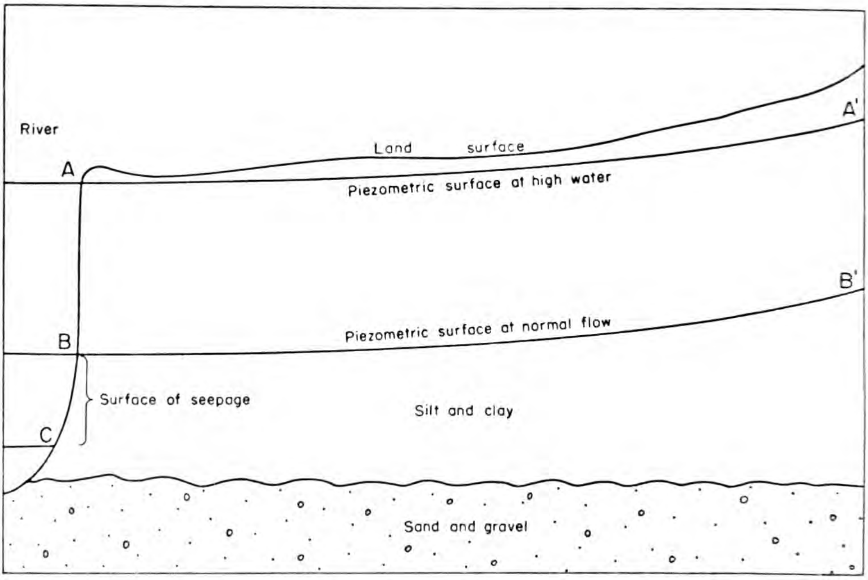

FIG. 9.—Diagrammatic cross section of typical river valley under artesian conditions. Relations between river stages and piezometric surface are shown.

piezometric surface should be instantaneous with a rise in the river level, but generally there is a time lag, increasing with distance away from the river because of elasticity of the valley fill and very slight compression of the water.

Along a gaining stream the piezometric surface is either level with or above the river stage if the aquifer and the river are connected hydraulically. Figure 9 shows, for example, the piezometric surface at BB′ while the river stage could be either at B or at C. If the river stage is at C and the piezometric surface intersects the river bank at B, the distance between B and C is known as the surface of seepage. Commonly, it is the interface between flow in a porous medium and flow in an open channel. The surface of seepage occurs if water in the river can discharge at a rate greater than ground water can recharge it. Thus, by eliminating the surface of seepage, the rate of ground-water discharge to a stream can be determined if river discharge is controlled and measured (at a dam) so that the level of the river is equal in altitude to the piezometric surface. River discharge will equal increase in streamflow from ground-water discharge. This assumes, of course, that there is no evaporation or additional surface-water inflow. Ground-water discharge to the river may differ in amount from place to place, but the total quantity can be measured. If the total quantity of discharge is known, then the average permeability of the artesian aquifer can be determined by assuming a constant hydraulic gradient and area.

Ground-water discharge along the reach of a stream is generally assumed to equal the amount by which base flow increases through that reach. Base flow is the discharge of a stream without additional surface-water inflow. A surface of seepage, which may be as much as 10 feet wide in places along Solomon River, provides an ideal situation for evaporation. The potential rate of evaporation may exceed ground-water seepage, and the surface of seepage may seem dry. Because the piezometric surface is close to the land surface near the stream, the opportunity for transpiration by plants is great. Base flow, then, is equal to ground-water discharge minus an unknown but large amount of evaporation from the surface of seepage and transpiration by plants, under ordinary circumstances. If the rate of evaporation and transpiration exceeds the rate of ground-water discharge, the river will cease to flow.

Although the surface of seepage from an artesian aquifer is illustrated in the above example of determining ground-water discharge to a river, artesian conditions are not necessary. The surface of seepage is found wherever discharge from a drain (usually an open channel) exceeds recharge from a source having different flow rate or permeability (usually saturated material). It may be present under artesian or nonartesian conditions and in a two-dimensional (riverbank, dam) or a three-dimensional (well) hydraulic system.

Recharge of a Well by Surface Water

To understand the process by which a well is recharged by surface water, it is first necessary to understand the behavior of each hydraulic system. The last section discussed surface-water and ground-water systems, which were treated essentially as two-dimensional systems, the third dimension being regarded as infinite. The flow of water toward a well is radial, but lowering the water level (drawdown) by pumping creates a third dimension. Therefore, recharge to a well from a body of surface water is the addition of two-dimensional flow from surface water to the existing three-dimensional flow around a well.

When a well in a water-table aquifer is pumped, the water level in the well is lowered, and water surrounding the well flows into it by the force of gravity. The surface of the water moving toward a well is that of a curvilinear cone having its vertex downward and is called the cone of depression. Its slope is controlled by the rate of discharge of the well, the permeability of the saturated material, and the thickness of the saturated material. Also, if the aquifer is not completely penetrated, the slope is affected. The cone of depression may be symmetrical or asymmetrical.

Ground water is in motion wherever there is a hydraulic gradient, as there is in nearly all natural ground-water reservoirs. When a well is pumped at a steady rate of discharge, an asymmetrical cone of depression will develop in the vicinity of the well (Fig. 10). When discharge ceases,

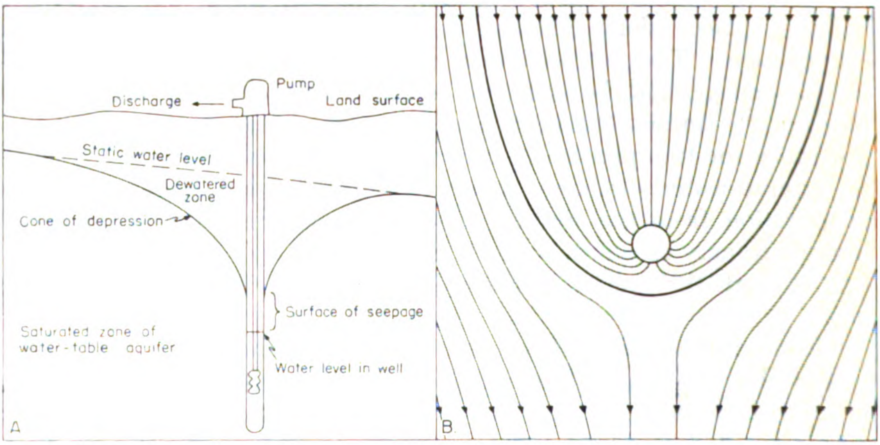

FIG. 10.—A, Diagrammatic cone of depression developed in nonartesian aquifer by pumping well. B, Plan view of flow lines in vicinity of pumping well.

the cone will disappear, and the water will approach the original static level. The process of filling the cone of depression takes exactly as long as forming it, assuming the hydraulic gradient to be the same. If the total discharge of all wells within a given ground-water reservoir is less than the recharge that maintains the hydraulic gradient, the ground-water reservoir will never be depleted. If the converse is true, then water is being mined, and the reservoir will be depleted. Recharge to ground water in Ottawa County far exceeds present discharge from wells.

The slope of the cone of depression formed by pumping a well is of the same nature as the slope of the surface of water draining from a body

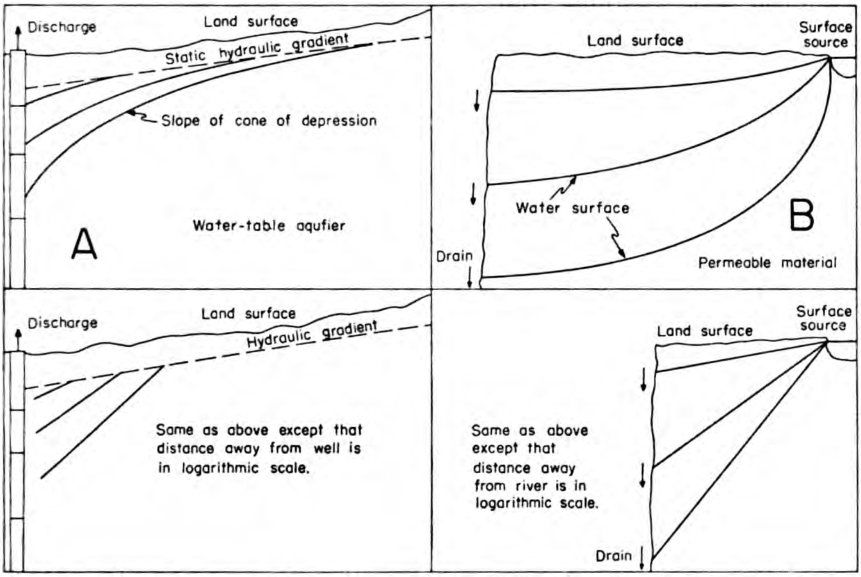

FIG. 11.—**A,** Cross sections showing half cones of depression around well discharging water from nonartesian aquifer. **B,** River recharging dewatered permeable material. Each drawing shows three stages of equilibrium.

of surface water (river) into permeable material (Fig. 11). The lower two drawings in Figure 11 are plotted on a logarithmic scale horizontally for ease in visualization. In basic form,

$$Q = PIA$$

where Q is discharge, P is the coefficient of permeability, I is the slope or change in head per unit length, and A is the cross-sectional area.

Thus, if water is being discharged from a well or draining into the ground-water reservoir from a river at the same rate (Q) in equilibrium, through porous material of identical permeability (P), and the area (A) along the river is chosen to equal the area around the well, the slopes (I) would be identical whether the river and well were hydraulically connected or completely separated. The flow capability through porous material is the same. Only the flow pattern toward a well or away from a river differs.

AQUIFER TESTS

Haddock Test

An aquifer test was made October 14, 1958, using an irrigation well owned by R. A. Haddock in the SE¼ SE¼ NW¼ sec. 21, T. 11 S., R. 3 W. The well has a diameter of 18 inches and a depth of 56.0 feet and is equipped with a turbine pump driven by a propane engine. The well yields water from Illinoisan terrace deposits. The static water level in the well prior to the test was 17.36 feet below the measuring point, which was 0.2 foot above land surface. Five observation wells were augered along a line S 45° E from the pumped well.

Table 5 is a summary of data on location and depth of wells used in

TABLE 5.—*Data on wells used in Haddock aquifer test*

WELL	Altitude of measuring point, feet	Height of measuring point above land surface, feet	Depth of well below measuring point, feet	Distance from pumped well, feet
Pumped well	1,233.7	0.2	56.0	....
SE 1	1,233.0	0.0	31.3	10
SE 2	1,235.4	2.4	40.8	50
SE 3	1,235.9	3.0	38.4	100
SE 4	1,235.5	2.4	37.4	150
SE 5	1,235.9	3.0	35.1	300

this aquifer test; Table 6 gives the depths to water level measured during the test.

The purpose of an aquifer test is to determine the hydraulic characteristics of an aquifer, from which optimum well spacing and pumping rates may be determined. Geologic and hydrologic factors affect the data from this test to a degree that mathematical treatment is not precise; nonetheless, a reasonable estimate of aquifer characteristics may be obtained.

Cooper and Jacob (1946) have shown that as time of pumping increases sufficiently, on semilogarithmic paper the plot of drawdown at a given observation well versus time approximates a straight line. If a period of time is chosen equal to a log cycle on logarithmic paper, then the equation reduces to

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

where T is the transmissibility in gallons per day per foot throughout a 1-foot-wide strip extending the height of the saturated thickness of the aquifer, Q is the rate of discharge from the pumped well in gallons per minute, and Δs is the drawdown, in feet, per logarithmic cycle.

Figure 12 shows drawdown on the linear scale plotted against time on the logarithmic scale for observation well SE 3, which was 100 feet from the pumped well. Two gradients are seen. The steeper gradient is the

TABLE 6.—*Depths to water measured during Haddock aquifer test*

Pumped well		Observation well SE 1		Observation well SE 2		Observation well SE 3		Observation well SE 4		Observation well SE 5	
Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet
Static	17.36	Static	16.64	Static	18.85	Static	19.37	Static	18.87	Static	19.46
4	39.43	5	19.03	6	26.04	9	20.23	8	19.25	8	19.74
7	41.80	9	20.33	11	27.10	13	20.69	14	19.81	10	19.96
11	42.50	12	21.01	19	27.66	17	21.15	22	20.30	12	20.13
23	39.60	15	21.35	25	27.78	20	21.60	28	20.60	14	20.30
27	40.05	19	21.66	31	27.90	23	21.87	33	20.80	16	20.47
31	39.30	21	21.80	36	28.02	26	22.17	39	20.96	18	20.63
36	39.12	24	22.06	42	28.08	29	22.31	45	21.10	20	20.78
42	39.30	29	22.27	48	28.14	32	22.56	51	21.20	22	20.90
46	39.60	34	22.47	54	28.20	35	22.74	57	21.25	24	21.02
52	39.80	39	22.68	67	28.30	38	22.90	70	21.38	26	21.12
56	39.83	44	22.85	75	28.38	41	23.05	80	21.45	28	21.23
61	39.87	49	22.95	85	28.43	44	23.17	98	21.55	30	21.34
67	39.61	54	23.09	95	28.50	46	23.28	114	21.62	34	21.43
72	38.85	59	23.21	103	28.53	49	23.38	126	21.63	36	21.50
76	39.55	64	23.31	123	28.60	52	23.47	138	21.72	39	21.60
81	39.88	69	23.40	136	28.66	55	23.54	153	21.79	44	21.70
86	40.35	74	23.43	151	28.70	61	23.69	169	21.85	49	21.79
96	40.85	79	23.57	167	28.76	68	23.82	189	21.92	54	21.86
106	39.52	84	23.65	187	28.82	73	23.91	209	21.98	59	21.93
122	40.14	94	23.79	207	28.87	79	23.98	228	22.08	64	21.99
134	39.30(?)	104	23.93	226	28.91	83	24.04	248	22.13	69	22.05
149	40.35	121	24.16	246	28.95	96	24.18	268	22.19	74	22.08
164	40.10	135	24.39	266	29.02	101	24.22			79	22.12
184	39.85(?)	150	24.54			110	24.29			84	22.16
204	40.54	165	24.71			125	24.41			89	22.20
224	39.60	186	24.85			137	24.47			94	22.26
244	39.20(?)	206	25.02			152	24.59			109	22.30
264	40.10	225	25.17			168	24.68			119	22.34
		245	25.29			188	24.75			127	22.39
		265	25.40			208	24.85			139	22.43
						227	24.94			154	22.43
						247	25.00			170	22.54
						267	25.08			190	22.58
										210	22.64
										229	22.69
										249	22.72
										269	22.76

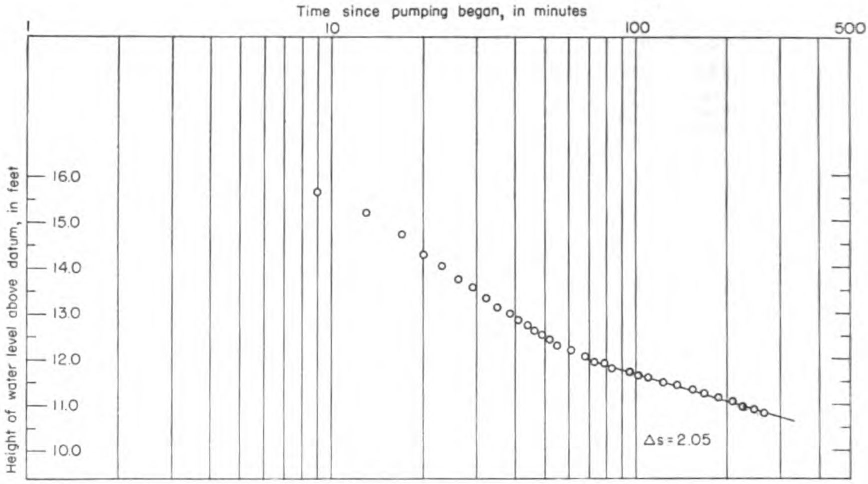

FIG. 12.—Drawdown curve of observation well SE 3 during Haddock aquifer test. Datum is 1,200 feet above sea level.

drawdown under artesian conditions. After 4 feet of drawdown under artesian conditions, the gradient becomes more gentle. The log of the test hole shows about 4 feet of silt and clay below the static water level and 34.5 feet of sand and gravel beneath the silt and clay. Consequently, nonartesian conditions began to prevail as soon as the sand in the cone of depression started to become dewatered. If the pumping test were continued much longer at the same discharge, the slope would steepen very slowly, because of dewatering, until movement of water down the hydraulic gradient would cause the slope to flatten out, or the hydrologic boundary created by the valley wall would cause it to steepen more rapidly. Thus, it is reasonable to believe that the more gentle gradient in Figure 12 is the most suitable for determining the coefficient of transmissibility, because the effects of dewatering seemingly are not appreciable. Under the conditions where $Q = 475$ gpm and $\Delta s = 2.05$, $T = \frac{(264)(475)}{2.05} = 61{,}000$ gpd per foot. As the transmissibility, T, is equal to the permeability, P, multiplied by the thickness of the saturated material, 34.5 feet, then P, in Meinzer units, equals 1,800 gpd per square foot under a hydraulic gradient of 100 percent at 60° F. The temperature of water during the test varied only between 58° and 58.5° F. The coefficient of storage, S, of an aquifer is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Reasonableness of any estimate of the coefficient of storage might be questioned, owing to wide variation in the porosity and permeability throughout the aquifer and the change from artesian to nonartesion conditions.

Delphos Test

The Delphos test was made August 12, 1958, using the city of Delphos municipal well in the SE¼ SW¼ NW¼ sec. 10, T. 9 S., R. 4 W. The well yields water from Illinoisan terrace deposits. It is 56 feet deep and is equipped with a turbine pump driven by an electric motor. Prior to the test, the static water level in the well was 37.03 feet below the base of the pump, which is 1.5 feet above land surface. Five observation wells were augered in a line N 40° W from the pumped well. Between observation well NW 1 and observation well NW 5, which are 10 and 300 feet respectively, from the pumped well, the thickness of sand decreases by 10 feet. Table 7 gives a summary of data on the wells used in this aquifer test. Table 8 contains the depths to water measured in each observation well during the Delphos aquifer test.

TABLE 7.—*Data on wells used in Delphos aquifer test*

WELL	Altitude of measuring point, feet	Height of measuring point above land surface, feet	Depth of well below measuring point, feet	Distance from pumped well, feet
Pumped well	1,324.9	1.5	56	....
NW 1	1,325.2	2.3	55	10
NW 2	1,324.9	3.7	53.8	50
NW 3	1,321.5	0.2	44.5	101
NW 4	1,323.2	1.8	45.5	151
NW 5	1,323.2	1.2	43.9	301

The municipal well was shut off for 20 hours prior to the aquifer test so that the water level could recover. Water levels in the observation wells were measured just before the test was to begin and it was found that water levels in the two observation wells nearest the supply well were still rising, and water levels in the other three observation wells were declining. An analysis of the data shows that NW 1 and NW 2 were fully penetrating wells and that the rising water was filling the dewatered sand under nonartesian conditions. Wells NW 3, NW 4, and NW 5, however, were not fully penetrating, because of caving. The aquifer thins in their direction. These three wells probably were outside of the dewatered zone and in the area of slight natural artesian pressure, but the bases of the wells were in materials of less permeability

TABLE 8.—*Depths to water measured during Delphos aquifer test*

Observation well NW 1		Observation well NW 2		Observation well NW 3		Observation well NW 4		Observation well NW 5	
Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet
Static	37.8	Static	37.6	Static	38.8	Static	39.0	Static	40.7
2	41.0	5	38.6	1	38.0	2.5	38.8	21	37.7
7	41.0	8	38.6	3	37.8	5	38.7	26	37.8
10	41.0	12	38.7	6	37.9	7.5	38.6	31	37.6
13	41.1	15	38.7	10	37.8	11	38.5	32	37.5
17	41.1	19	38.7	13	37.8	15	38.4	36	37.3
20	41.2	23	38.7	17	37.7	20	38.3	41	37.2
25	41.2	26	38.8	21	37.6	23	38.2	51	37.0
28	41.3	29	38.8	26	37.6	27	38.1	61	37.0
32	41.2	33	38.8	28	37.5	30	38.1	66	36.8
35	41.3	37	38.8	32	37.4	34	38.0	71	36.7
40	41.4	43	38.8	36	37.4	38	37.9	76	36.7
45	41.4	47	38.9	42	37.2	44	37.7	81	36.7
49	41.4	54	38.9	47	37.2	49	37.6	86	36.6
52	41.4	61	38.9	52	37.1	53	37.5	96	36.5
58	41.4	65	38.9	54	37.0	59	37.5	106	36.5
62	41.5	81	39.0	66	36.9	68	37.3	111	36.3
79	41.6	87	39.0	81	36.6	83	37.1	123	36.2
83	41.6	95	39.0	91	36.6	92	37.0	138	36.1
93	41.6	100	39.1	93	36.5	95	37.0	153	36.0
98	41.7	119	39.1	97	36.5	100	36.9	169	36.0
118	41.7	134	39.2	107	36.4	109	36.8	187	36.0
133	41.8	150	39.2	120	36.3	122	36.8	199	35.9
149	41.8	165	39.3	135	36.2	136	36.7	216	35.9
164	41.9	182	39.3	151	36.1	152	36.6	230	35.8
180	42.0	195	39.3	166	36.0	168	36.5	244	35.8
194	41.9	210	39.3	184	35.9	185	36.4	258	35.8
209	41.9	226	39.3	196	35.8	197	36.4	274	35.8
225	41.9	240	39.4	211	35.7	213	36.4	288	35.8
239	41.9	254	39.4	227	35.6	229	36.4	304	35.8
253	41.9	270	39.4	241	35.6	242	36.3	319	35.8
269	41.9	284	39.4	255	35.5	257	36.3		
283	42.0	300	39.5	271	35.5	272	36.3		
299	42.0	315	39.5	285	35.5	287	36.3		
314	42.0			301	35.4	303	36.3		
				316	35.4	318	36.3		

in the upper part of the aquifer, and hence the water levels measured in the wells were not indicative of the true piezometric surface. The aquifer test seems to support this explanation. The water levels in wells NW 1 and NW 2 declined rapidly at first but soon steadied to a very slow decline. Water levels in observation wells NW 3, NW 4, and NW 5 continued to rise throughout the test but were nearing equilibrium at the end of the test. The plot of water levels on a distance-drawdown graph on semilogarithmic paper formed a nearly straight line (Fig. 13) through

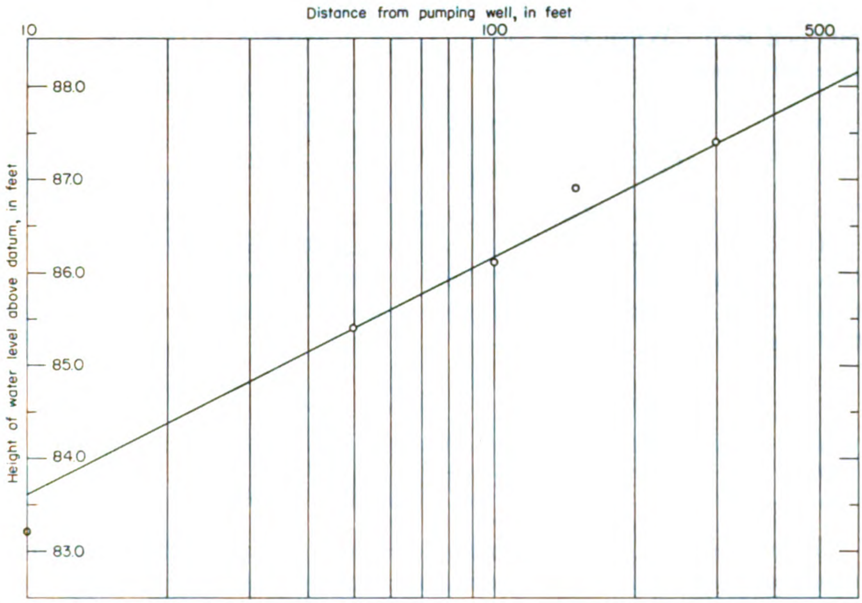

FIG. 13.—Profile of cone of depression during Delphos aquifer test. Datum is 1,200 feet above sea level.

values obtained near the end of the test, hence, pre-pumping water-level anomalies had disappeared, and inasmuch as the water levels were scarcely changing, the entire well system was nearing equilibrium. When water levels were measured the next day, there was no appreciable change in the cone of depression under pumping. It would seem, therefore, that the well under pumping has a large cone of depression around it approaching equilibrium when the pump is operating, and diminishing only slightly when the pump automatically stops for short periods. In addition, under normal automatic pump operation the piezometric surface transcends the nonartesian-artesian boundary.

An equilibrium equation by Thiem (1906) has been transformed into convenient units by Wenzel (1942, p. 81) where

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

P_f is the coefficient of permeability at the prevailing water temperature, Q is the discharge in gallons per minute, m is the average saturated thickness, in feet, between observation wells, and s_1 and s_2 are the drawdowns, in feet, in observation wells at distances of r_1 and r_2 from the pumped well. When $Q = 250$, $m = 14.4$, $s_1 = 2.6$, $s_2 = 0.6$, $r_1 = 50$, and $r_2 = 300$, then

$$P_f = \frac{(527.7)\ (250) \left(\log_{10} \frac{300}{50} \right)}{(14.4)\ (2)} = 3{,}570$$

$T = P_f\, m = (3{,}570)\ (14.4) = 51{,}000$ gpd/ft.

An easier solution is made by plotting drawdown, s, linearly and distance, r, logarithmically on semilogarithmic paper (Fig. 13). If permeability, P_f, and thickness, m, are replaced by transmissibility, T, then the equation becomes

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

where Δs is the change in drawdown per log cycle of distance, r.

$$T = \frac{(528)\ (250)}{2.6} = 51{,}000 \text{ gpd/ft.}$$

These equations are valid only if the cone of depression is in approximate equilibrium. As aquifer-test data show that the cone of depression was not appreciably altered in shape or size, the coefficients of permeability and transmissibility are believed to be fairly accurate.

State Lake Test

An aquifer test was made August 6-8, 1958, at the site of a public-supply well in a recreation area in the NW¼ NW¼ SE¼ sec. 8, T. 11 S., R. 2 W., 200 feet east of Ottawa County State Lake. The well has a diameter of 6 inches and a depth of 48.2 feet and yields water from the Dakota Formation. Prior to the test, the static water level was 17.80 feet below the top of the casing, which is 0.2 foot above land surface. Fifteen observation wells were augered in lines west, northwest, north, and east from the pumped well. All wells penetrate a thick, fine- to medium-grained, well-sorted, poorly consolidated quartzose sandstone extending from the surface to an undetermined depth below the wells.

Observation well W 2 seemed to be partly plugged throughout the test. Otherwise the correct level of the nonartesian piezometric surface was observed in all observation wells.

Table 9 is a summary of data on the wells used in this test. Table 10 gives the depths to water level during the aquifer test.

TABLE 9.—*Data on wells used in State Lake aquifer test*

Well	Altitude of measuring point, feet	Height of measuring point above land surface, feet	Depth of well below measuring point, feet	Distance from pumped well, feet
Pumped well	1,311.8	0.2	48.7	0
W 1	1,311.4	2.5	35.7	40
W 2	1,309.8	2.4	31.3	80
W 3	1,305.2	1.0	24.4	120
W 4	1,302.1	3.5	17.5	160
W 5	1,299.8	2.5	14.2	180
W 6	1,297.8	2.0	11.2	195
W 7	1,296.8	1.0	13.8	199
Lake	1,294.0	0	0	202
NW 1	1,307.1	0.6	30.5	60
NW 2	1,303.8	1.6	21.5	121
N 1	1,307.8	0.4	23.0	40
N 2	1,306.8	2.4	18.3	140
N 3	1,302.9	1.8	18.5	181
N 4	1,300.0	1.9	13.7	221
E 1	1,320.8	4.0	45.7	100
E 2	1,320.8	4.0	40.7	200

The State Lake aquifer test approached an ideal situation because the aquifer was homogeneous sandstone, there were no temporary artesian conditions, well interference, nor known source of recharge, the discharge was accurately measured, the rate of discharge could be controlled easily, and the discharge was piped back to the lake to avoid vertical recharge. The importance of vertical recharge is indicated by the fact that after a very small leak developed in the discharge line near observation well N 1, that well showed slow but continuous recharge, while other wells declined or remained steady during the last 11 hours of the test.

The water levels, measured prior to the aquifer test, showed that the nonartesian piezometric surface sloped away from the lake at the test site, and presumably the lake has been recharging the ground-water reservoir since the lake was made about 30 years ago. Well W 7, less than 3 feet from the lake, had a water level 0.3 foot below the lake

TABLE 10.—*Depths to water level measured during State Lake aquifer test*

Observation well W 1		Observation well W 2		Observation well W 3		Observation well W 4		Observation well W 5	
Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet
Static	17.76	Static	16.78	Static	11.59	Static	8.44	Static	6.07
57	18.67	58	17.04	59	11.70	60	8.45	61	6.06
120	18.93	121	17.11	122	11.80	126	8.54	128	6.17
173	18.99	175	17.25	176	11.84	177	8.52	178	6.18
243	19.07	244	17.36	245	11.90	246	8.57	247	6.19
296	19.10	297	17.37	298	11.90	299	8.56	300	6.23
359	19.11	360	17.37	361	11.88	362	8.59	363	6.24
416	19.13	417	17.38	418	11.92	419	8.60	419	6.27
478	19.21	479	17.46	480	11.91	481	8.77	482	6.34
533	19.23	535	17.49	536	11.92	538	8.70	539	6.35
593	19.22	594	17.50	596	12.04	598	8.69	599	6.34
658	19.23	659	17.49	660	12.04	661	8.71	662	6.32
720	19.36	721	17.55	722	12.05	724	8.71	725	6.32
779	19.43	783	17.57	785	12.10	789	8.72	794	6.32
896	19.44	900	17.62	903	12.11	925	8.73	926	6.31
1,022	19.51	1,026	17.66	1,027	12.14	1,052	8.74	1,055	6.32
1,184	20.03	1,187	17.87	1,191	12.24	1,194	8.78	1,195	6.35
1,259	20.26	1,261	17.95	1,263	12.29	1,264	8.78	1,266	6.35
1,310	20.31	1,311	18.00	1,313	12.32	1,315	8.80	1,316	6.39
1,425	20.40	1,426	18.10	1,427	12.38	1,428	8.85	1,429	6.43
1,543	20.42	1,544	18.11	1,545	12.40	1,546	8.88	1,547	6.46
1,669	20.63	1,670	18.23	1,671	12.47	1,672	8.93	1,673	6.47
1,790	20.60	1,791	18.28	1,792	12.48	1,793	8.95	1,793	6.47
1,906	20.65	1,907	18.30	1,908	12.53	1,909	8.96	1,910	6.56
2,028	20.57	2,029	18.33	2,030	12.56	2,031	9.03	2,032	6.60
2,138	20.70	2,140	18.39	2,143	12.61	2,145	9.05	2,148	6.60
2,332	20.63	2,335	18.41	2,339	12.66	2,341	9.08	2,345	6.63
2,454	20.64	2,456	18.44	2,460	12.67	2,461	9.10	2,464	6.64
2,575	20.63	2,578	18.45	2,581	12.68	2,583	9.10	2,586	6.66
2,727	20.60	2,728	18.46	2,729	12.71	2,731	9.12	2,732	6.65
2,810	20.60	2,811	18.47	2,812	12.71	2,813	9.11	2,813	6.67

TABLE 10.—*Depths to water level measured during State Lake aquifer test—Continued*

Observation well W 6		Observation well W 7		Observation well NW 1		Observation well NW 2		Observation well N 1	
Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet
Static	4.10	Static	3.10	Static	13.70	Static	10.28	Static	14.15
62	4.13	63	3.19	66	13.93	65	10.30	72	15.07
129	4.15	130	3.19	133	14.13	132	10.32	138	15.34
179	4.15	180	3.20	183	14.27	181	10.36	184	15.42
248	4.21	249	3.25	253	14.40	251	10.40	257	15.50
300	4.22	301	3.27	303	14.47	302	10.45	308	15.53
363	4.25	364	3.27	366	14.50	365	10.47	371	15.54
420	4.24	421	3.30	423	14.55	423	10.49	428	15.57
483	4.35	483	3.38	485	14.64	484	10.56	486	15.66
540	4.35	541	3.39	548	14.66	558	10.61	545	15.66
600	4.37	601	3.38	603	14.68	604	10.59	606	15.66
663	4.33	663	3.35	665	14.70	665	10.60	667	15.69
726	4.32	727	3.34	730	14.76	729	10.61	732	15.78
797	4.32	801	3.36	806	14.80	811	10.65	813	15.89
929	4.31	931	3.37	907	14.84	910	10.67	914	15.91
1,058	4.32	1,060	3.37	1,031	14.90	1,033	10.68	1,036	15.97
1,200	4.35	1,202	3.39	1,208	15.16	1,205	10.77	1,211	16.55
1,267	4.36	1,269	3.46	1,273	15.29	1,271	10.81	1,275	16.72
1,317	4.37	1,318	3.47	1,329	15.37	1,327	10.84	1,330	16.81
1,430	4.42	1,431	3.47	1,433	15.52	1,432	10.89	1,433	16.90
1,548	4.42	1,549	3.48	1,551	15.58	1,550	10.92	1,554	16.95
1,674	4.48	1,675	3.54	1,677	15.69	1,676	10.97	1,678	17.16
1,794	4.51	1,795	3.57	1,797	15.79	1,796	10.99	1,798	17.13
1,910	4.58	1,911	3.61	1,914	15.83	1,913	11.06	1,915	17.14
2,033	4.61	2,034	3.64	2,040	15.86	2,038	11.10	2,042	17.14
2,150	4.62	2,151	3.63	2,157	15.92	2,155	11.14	2,159	17.22
2,347	4.62	2,350	3.64	2,365	15.96	2,353	11.19	2,368	17.16
2,465	4.62	2,468	3.66	2,475	15.96	2,471	11.21	2,477	17.15
2,586	4.62	2,589	3.65	2,597	15.97	2,593	11.24	2,601	17.14
2,733	4.63	2,735	3.67	2,738	15.95	2,736	11.26	2,740	17.11
2,814	4.65	2,815	3.68	2,817	15.96	2,816	11.27	2,818	17.09

TABLE 10.—*Depths to water level measured during State Lake aquifer test—Concluded*

Observation well N 2		Observation well N 3		Observation well N 4		Observation well E 1		Observation well E 2	
Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet	Time since pumping began, minutes	Depth to water from measuring point, feet
Static	13.25	Static	9.39	Static	6.57	Static	27.58	Static	29.03
70	13.37	69	9.35	68	6.59	73	27.85	75	29.98
137	13.45	136	9.39	134	6.58	140	27.88	141	30.04
185	13.46	187	9.39	188	6.59	191	27.91	193	29.99
256	13.52	255	9.46	255	6.63	260	27.93	261	30.07
307	13.53	306	9.49	305	6.65	309	28.00	310	30.02
370	13.53	369	9.47	368	6.64	372	27.98	374	30.03
427	13.55	426	9.49	425	6.69	429	27.98	431	30.04
487	13.63	488	9.58	489	6.76	491	28.06	493	30.09
552	13.65	549	9.60	556	6.75	560	28.09	562	30.11
608	13.67	609	9.60	610	6.78	612	28.07	614	30.12
668	13.70	669	9.62	670	6.78	671	28.11	673	30.14
733	13.71	734	9.62	735	6.80	738	28.18	742	30.14
816	13.77	818	9.60	820	6.81	825	28.21	828	30.14
916	13.75	918	9.66	920	6.82	947	28.24	950	30.18
1,039	13.79	1,041	9.68	1,042	6.82	1,076	28.30	1,079	30.21
1,213	13.87	1,215	9.73	1,217	6.85	1,171	28.42	1,175	30.21
1,276	13.92	1,277	9.76	1,278	6.85	1,281	28.50	1,282	30.24
1,332	13.94	1,334	9.78	1,335	6.86	1,338	28.54	1,340	30.25
1,434	14.00	1,435	9.81	1,436	6.89	1,438	28.62	1,440	30.31
1,555	14.04	1,556	9.87	1,557	6.91	1,560	28.74	1,562	30.29
1,680	14.09	1,681	9.90	1,682	6.94	1,684	28.75	1,685	30.33
1,799	14.15	1,800	9.94	1,801	6.96	1,805	28.77	1,806	30.36
1,917	14.19	1,917	9.98	1,918	6.98	1,921	28.78	1,923	30.34
2,043	14.23	2,044	9.97	2,045	7.05	2,048	28.82	2,049	30.38
2,162	14.28	2,164	10.07	2,166	6.98	2,170	28.88	2,172	30.38
2,371	14.34	2,373	10.13	2,375	7.13	2,380	28.92	2,383	30.45
2,479	14.36	2,482	10.15	2,485	7.16	2,488	28.94	2,491	30.47
2,603	14.38	2,605	10.17	2,607	7.17	2,610	28.96	2,611	30.48
2,742	14.40	2,743	10.19	2,747	7.18	2,750	28.97	2,751	30.51
2,819	14.42	2,820	10.21	2,821	7.19	2,823	29.00	2,824	30.53

surface. At the end of the test, the lake had risen 0.15 foot, but the water level in well W 7 was 1.03 feet below the lake surface.

The well was pumped at 55 gpm for 1,098 minutes, and a cone of depression developed around the well and intersected the lake. The discharge rate was then increased to the maximum capacity of the well, 83 gpm, from 1,098 to 2,238 minutes. The well was then pumped at 70 gpm from 2,238 to 2,827 minutes, the end of the test.

Representative drawdown curves, illustrated by water-level measurements in wells W 2 and W 3, are shown in Figure 14. The changes in

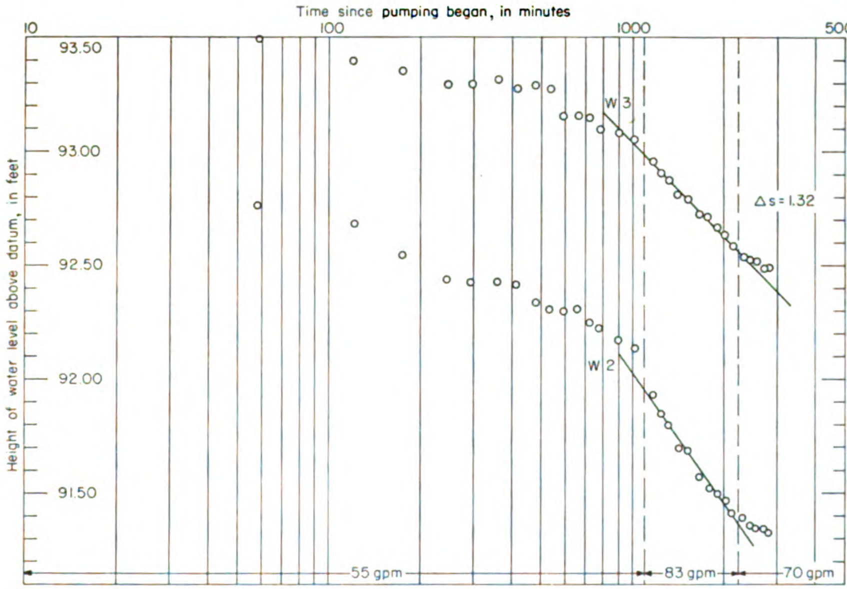

FIG. 14.—Drawdown of water levels in observation well W 2 and W 3 during State Lake aquifer test. Datum is 1,200 feet above sea level.

slope are readily observed to be coincident with changes in discharge. Equilibrium was approached near the end of the test. Although the nonartesian aquifer was being dewatered, use of the Theis modified nonequilibrium formula gives a reasonable estimate of transmissibility at well W 3, 120 feet from the pumped well. If the slope, Δs, is 1.32 feet, and discharge, Q, is 83 gpm, then

$$T = \frac{(264)\,(83)}{1.32} = 17{,}000 \text{ gpd/ft.}$$

Transmissibility computed from data at the end of the test, when the cone was approaching equilibrium, may be more reliable. Figure 15

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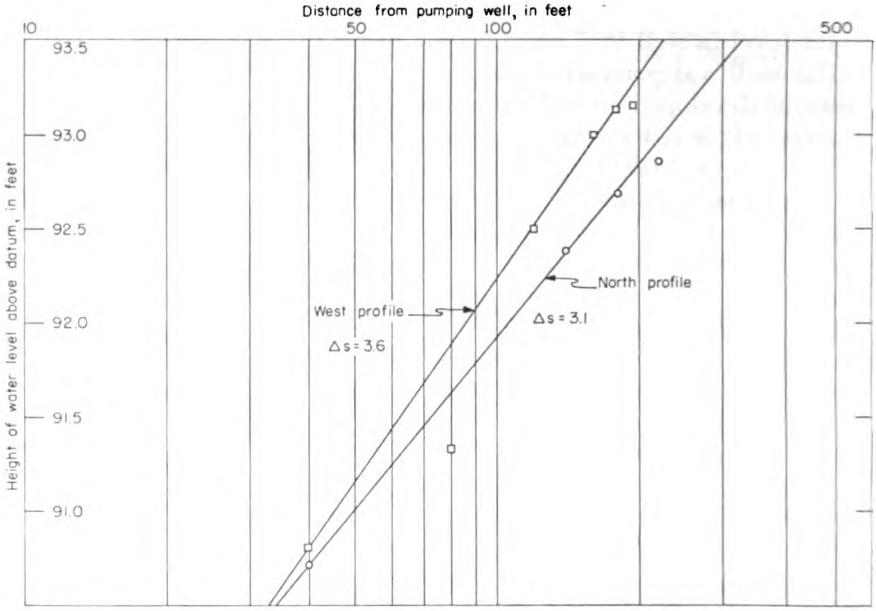


FIG. 15.—Profiles of cone of depression around pumped well being recharged by lake 200 feet away, during State Lake aquifer test. Datum is 1,200 feet above sea level.

shows the north and west profile of the cone of depression; the drawdown is plotted linearly against the distance of observation wells from the pumped well plotted logarithmically.

A modified form of the Thiem equation is

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

If Q = 70 gpm and s = 3.1 feet, then

$$T = \frac{(528)\ (70)}{3.1}$$

or T equals 12,000 and P_f equals 380.

HYDROLOGY

The hydrology of an area primarily involves precipitation and runoff. A statistical approach to the hydrology was used in this study because of the wide variations in magnitude with respect to time. Although insufficient time has passed for collecting a complete set of data, the period of record is long enough to permit a reasonable estimate of hydrologic behavior.

Precipitation

Data on precipitation are collected and published by the U. S. Weather Bureau. A graph of annual precipitation at Minneapolis from 1931 through 1957 is shown in Figure 16. The extremes are widely separated, ranging from 15.36 inches in 1934 to 54.89 inches in 1951. Monthly

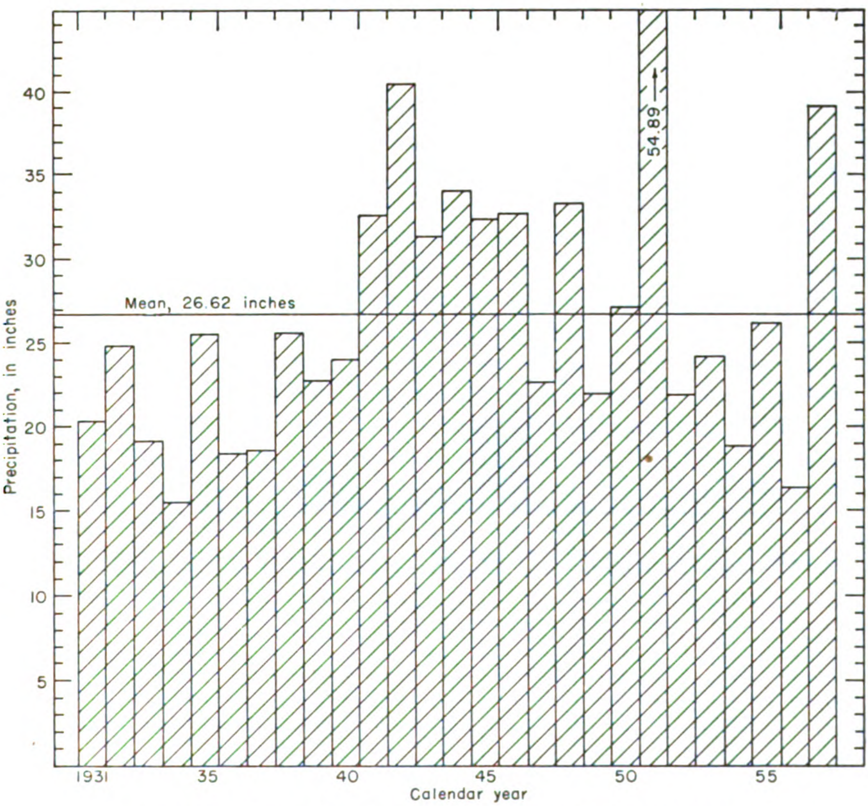


Fig. 16.—Annual precipitation at Minneapolis, 1931-1957.

extremes and average monthly precipitation are shown in Figure 17. From the same period of record (1931-57), a frequency curve was constructed (Fig. 18) on logarithmic-probability paper. The frequency curve indicates that during 1 year in 10, Minneapolis has had about 40 inches of precipitation, and conversely, that during 1 year in 10, Minneapolis has had about 17 inches of precipitation. The data, although of relatively short duration, are sufficient to give a reasonable frequency

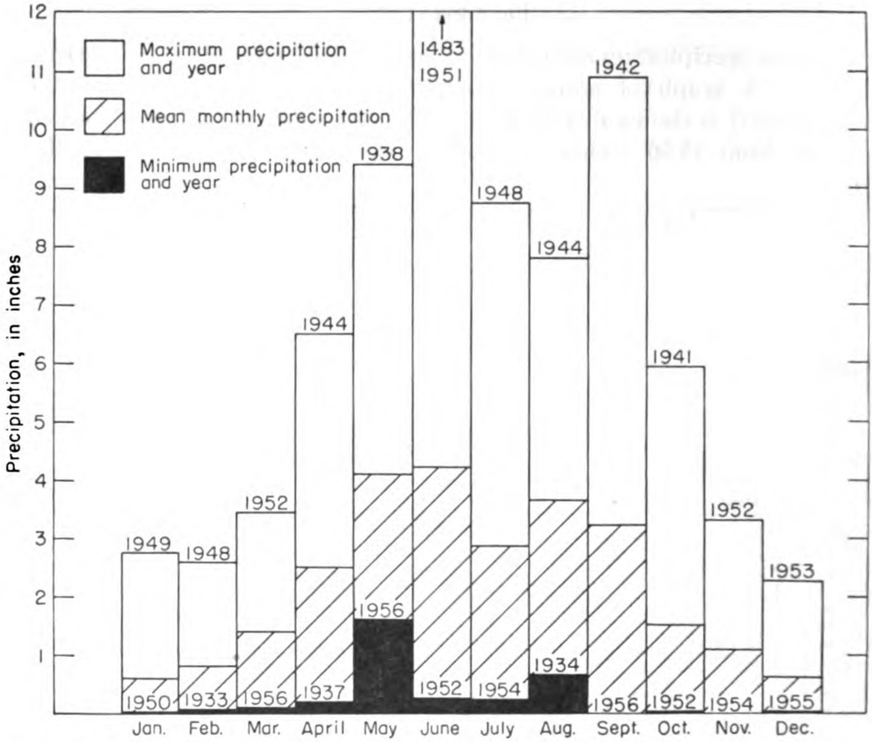


Fig. 17.—Monthly extremes and mean precipitation at Minneapolis, 1931-1957.

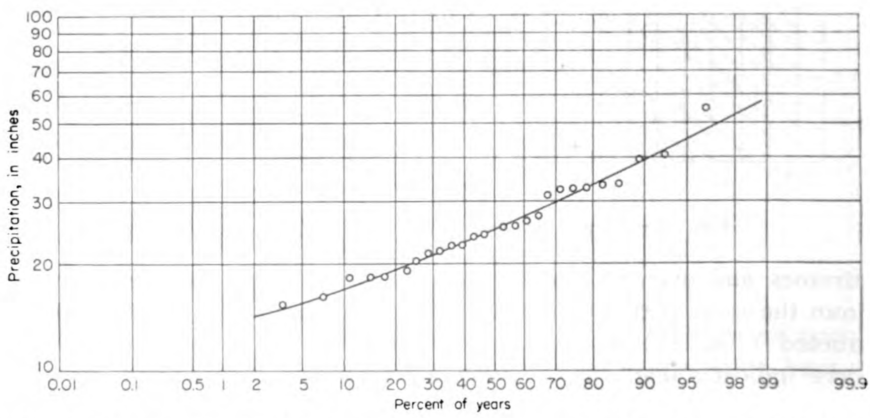


Fig. 18.—Annual precipitation frequency curve at Minneapolis showing percentage of years in which precipitation is less than given amount.

distribution. The frequencies were computed by the Kimball method using the equation

$$F = \left(\frac{m}{n+1} \right) 100$$

where n is the total number of items, m is the order number, and F is the percentage of years during which the precipitation is equal to, or greater than, the precipitation of order number m (Kimball, 1946).

Runoff

Two surface-water gaging stations are operated in Ottawa County by the U. S. Geological Survey in co-operation with the Kansas State Board of Agriculture and the Board of Water Resources. One station is in the NW¼ sec. 31, T. 12 S., R. 1 W., on the downstream side of the left pier of the county highway bridge across Solomon River, ¾ mile west of Niles. The other station is in the SE¼ sec. 16, T. 12 S., R. 5 W., on the downstream side of the left pier of the highway bridge across Saline River, ½ mile south of Tescott. All records are published in the U. S. Geological Survey Water-Supply Papers. Records are available for the Niles station from May 1897 to November 1903 and from October 1917 to the present. Records are available for the Tescott station from September 1919 to the present. The duration curves for daily flows and low-flow frequency curves were obtained from reports published by the Kansas Water Resources Board (Furness, 1959, 1960).

The annual runoff in acre-feet is shown for Solomon River (Fig. 19)

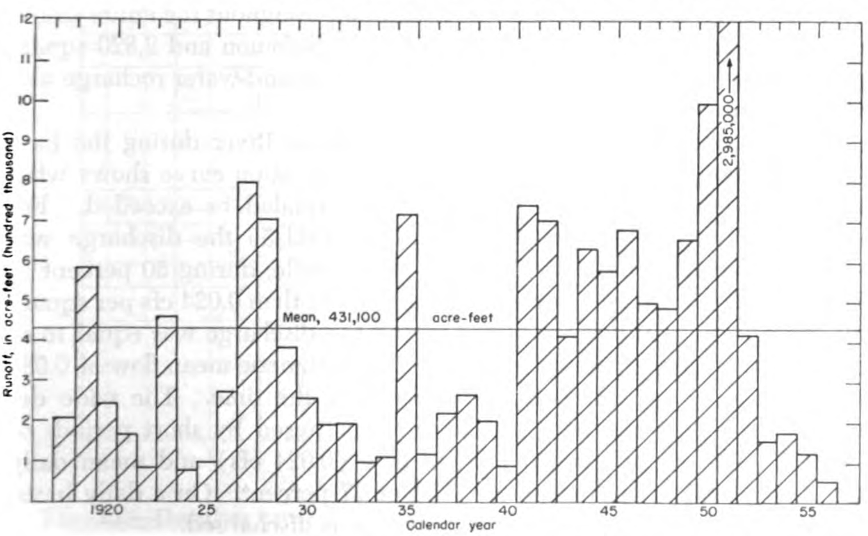


Fig. 19.—Annual runoff of Solomon River near Niles, in acre-feet.

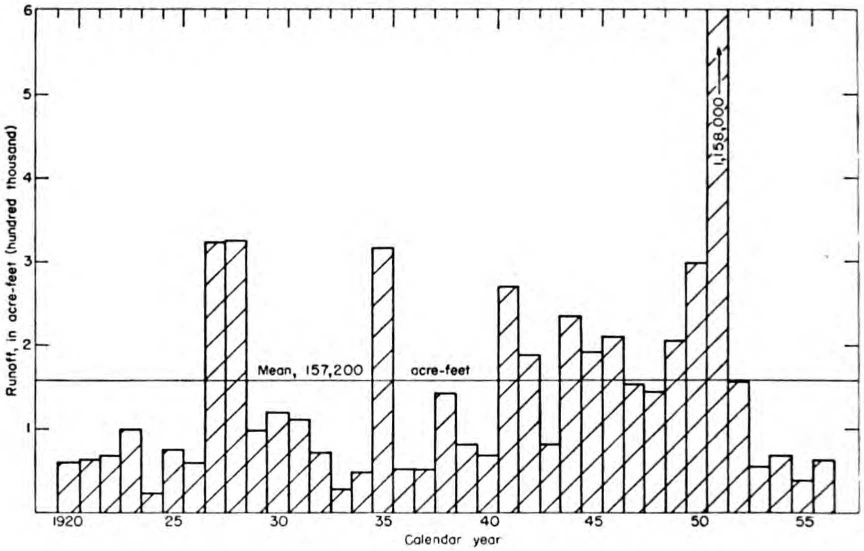


FIG. 20.—Annual runoff of Saline River near Tescott, in acre-feet.

in calendar years from 1918 to 1956 and for Saline River (Fig. 20) from 1920 to 1956. The mean annual discharge is 431,100 acre-feet in the Solomon and 157,200 acre-feet in the Saline. These hydrographs have the same general pattern as the precipitation graph (Fig. 16) but differ in detail. Precipitation was measured at one point, Minneapolis, whereas river discharge is a reflection of precipitation throughout the entire drainage area, which is 6,770 square miles for the Solomon and 2,820 square miles for the Saline. Evapotranspiration and ground-water recharge also partly account for the difference.

The duration curve for daily flow in Solomon River during the base period 1921-56 is shown in Figure 21. This duration curve shows what percentage of time a given discharge was equaled or exceeded. For example, during 90 percent of the period 1921-56 the discharge was equal to or greater than 0.006 cfs per square mile, during 50 percent of the period the discharge was equal to or greater than 0.024 cfs per square mile, and during 10 percent of the period the discharge was equal to or greater than 0.16 cfs per square mile. The arithmetic mean flow of 0.088 cfs occurs only approximately 16 percent of the time. The wide departure between mean and median flows is caused by short periods of flooding. The ratio between median flow (0.024 cfs) and mean daily flow (0.088 cfs) is approximately 0.27, or 27 percent. On a daily basis, only about one-fourth of the mean daily flow is discharged.

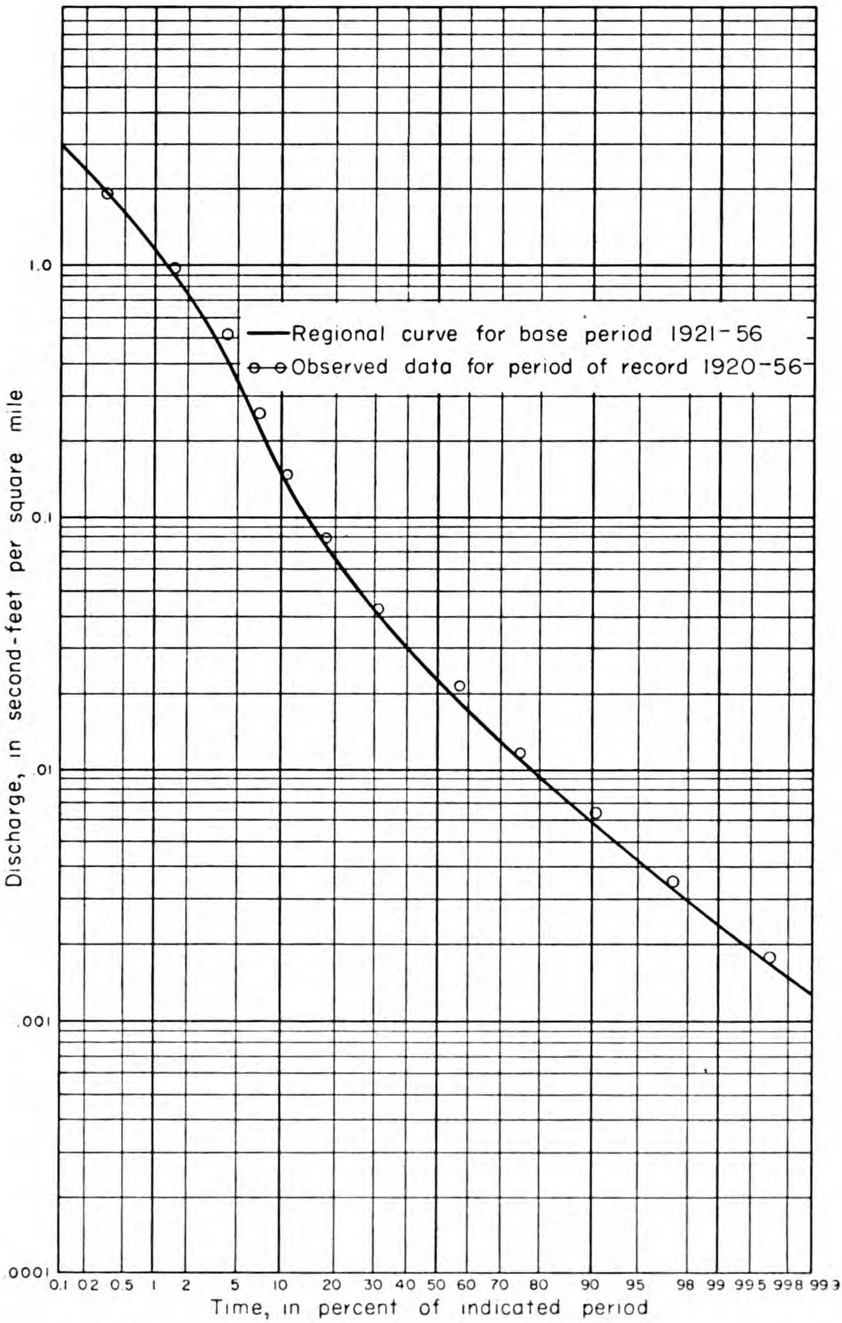
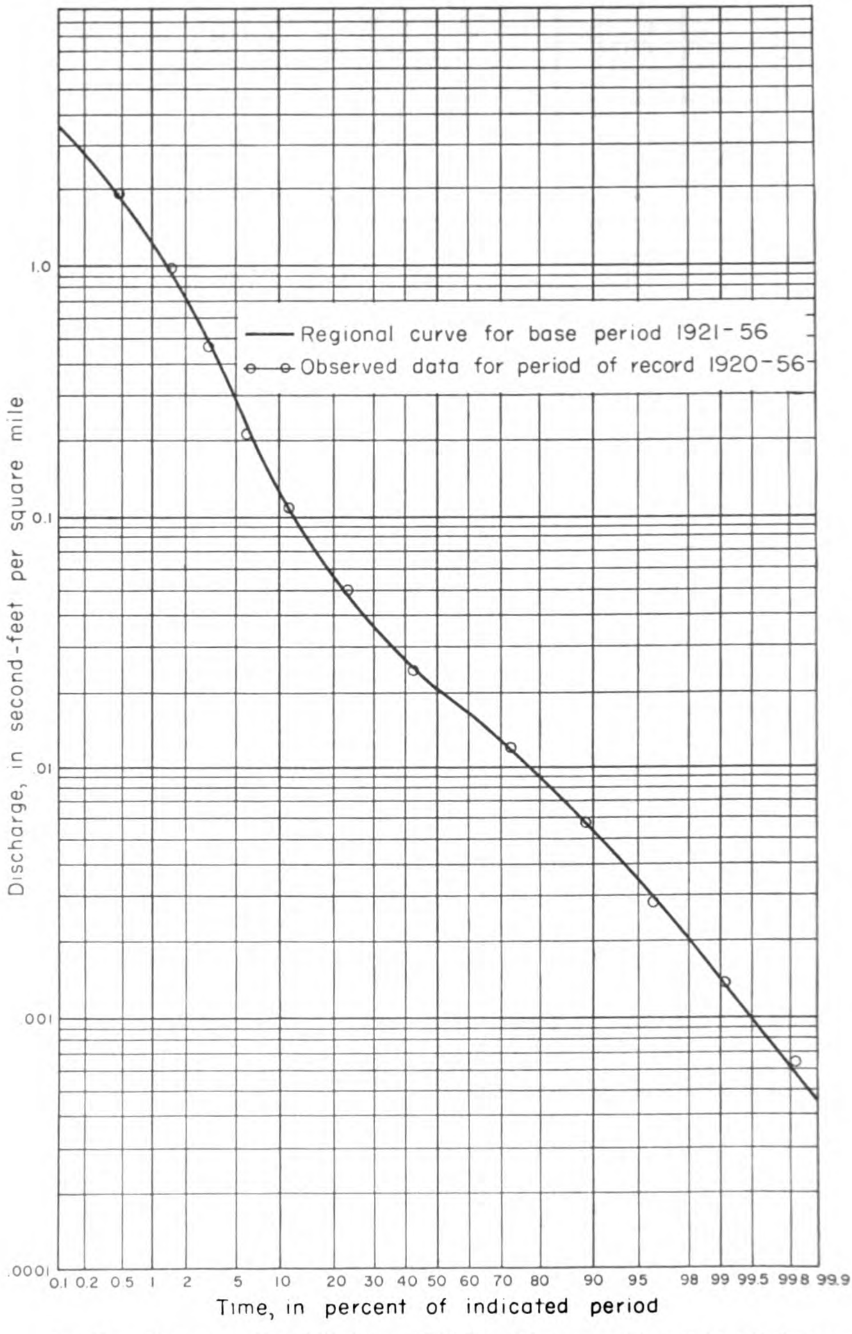


FIG. 21.—Duration curve for daily flows of Solomon River near Niles under natural conditions prior to operation of reservoirs upstream (total drainage area, 6,770 square miles). (From Furness, 1959, fig. 52.)



22.—**Duration curve for daily flows of Saline River near Tescott (total drainage area, 2,820 square miles). (From Furness, 1959, fig. 44.)**

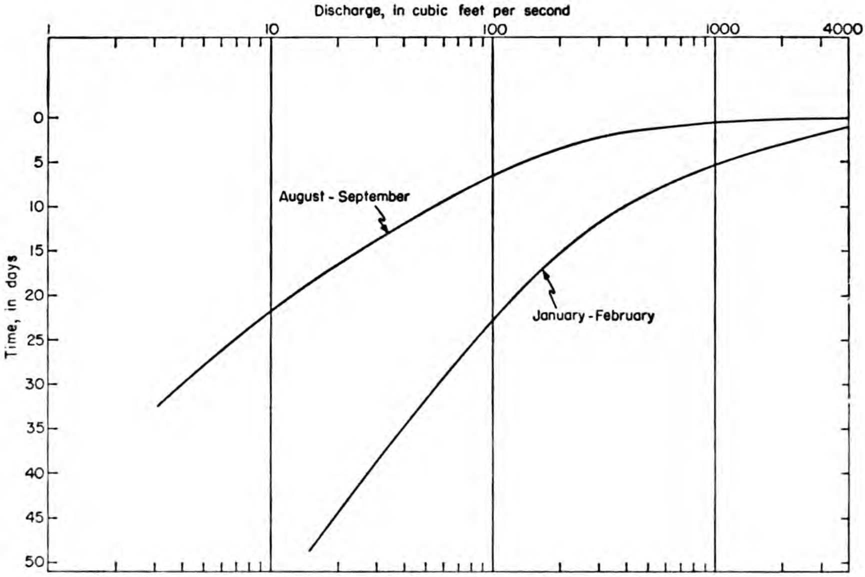


FIG. 23.—Base-flow recession curves for Solomon River near Niles.

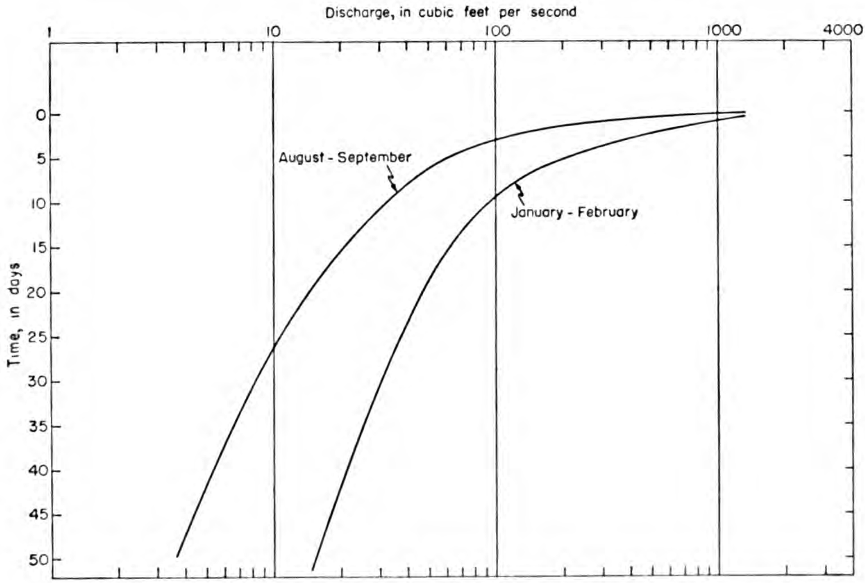


FIG. 24.—Base-flow recession curves for Saline River near Tescott.

The duration curve for daily flow in Saline River during the base period 1921-56 is shown in Figure 22. The drainage area of Saline River is only 42 percent as large as the drainage area of Solomon River. The median daily flow of the Saline is 0.02 cfs per square mile. The mean daily flow is 0.077 cfs per square mile and occurs approximately 15 percent of the time. The ratio between the median and mean daily flow is 0.27, or 27 percent. Close agreement between Saline and Solomon hydrologic characteristics shows similarity in geologic, climatic, and vegetative control of runoff.

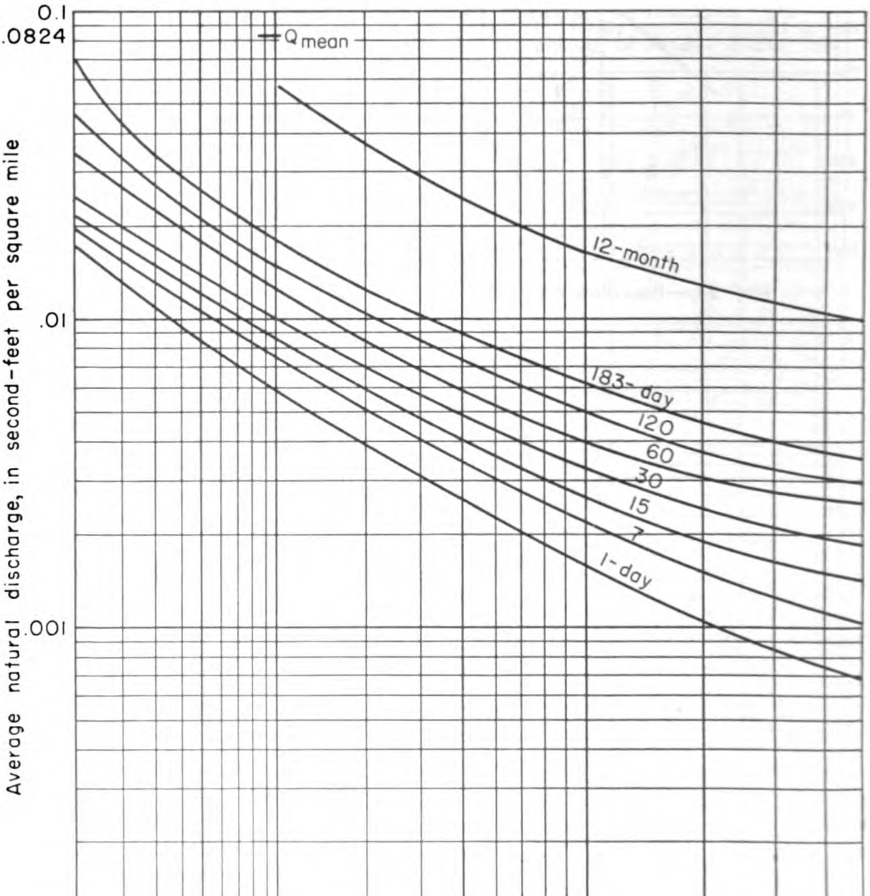


FIG. 25.—Low-flow frequency curves for Solomon River near Niles (total drainage area, 6,770 square miles). (From Furness, 1960, fig. 52.)

The base-flow recession curves show the average rate at which flow will decrease without recharge by precipitation. The base flow of Solomon and Saline Rivers was sustained by ground-water discharge into the rivers minus evapotranspiration losses. Base-flow recession curves are constructed from discharge records from as many years as necessary to include a wide range of decreasing flow rates. Various discharge curves are connected to form a smooth curve. For each river, a curve was constructed from January and February data and another curve was constructed from August and September data. The difference in curves

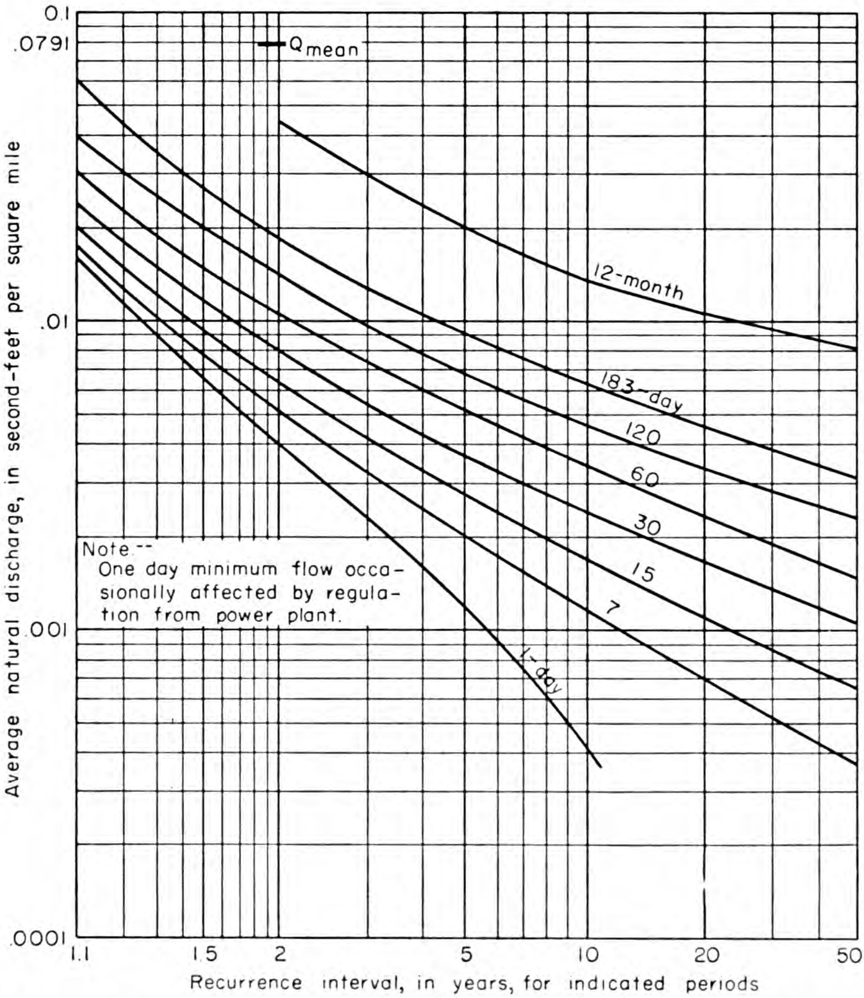


FIG. 26.—Low-flow frequency curves for Saline River near Tescott (total drainage area, 2,820 square miles). (From Furness, 1960, fig. 44.)

reflects differences in evapotranspiration rates and in water viscosity between summer and winter. The difference in rate of change of slopes between Solomon River (Fig. 23) and Saline River (Fig. 24) is caused by many factors including the difference in size of the drainage areas. Solomon River has the larger drainage area, and it has a larger ground-water reservoir to sustain flow for longer periods. Thus, Solomon River has a flatter base-flow recession curve than Saline River.

The low-flow frequency curves show the recurrence interval in years that a given period of low flow, in cubic feet per second, would be expected. Low-flow frequency curves are shown for Solomon River (Fig. 25) and Saline River (Fig. 26). Flood data for momentary peak discharges are plotted for Solomon River (Fig. 27) and Saline River (Fig. 28). Flood-frequency data for Kansas streams are given by Ellis and Edelen (1960). These graphs show the percentage of years in which a flood will be less than the given amount. Only discharges greater than 3,800 cfs for the Solomon and 1,300 cfs for the Saline were used. Only one flood per year was used. The number of floods plotted was 34 for the Solomon and 32 for the Saline. The Kimball method, previously described, was used in plotting the frequencies. The magnitude of the 1951 flood was so great compared to the size of other floods that it does not fall near the curve. If there were another 70 or 80 years of record,

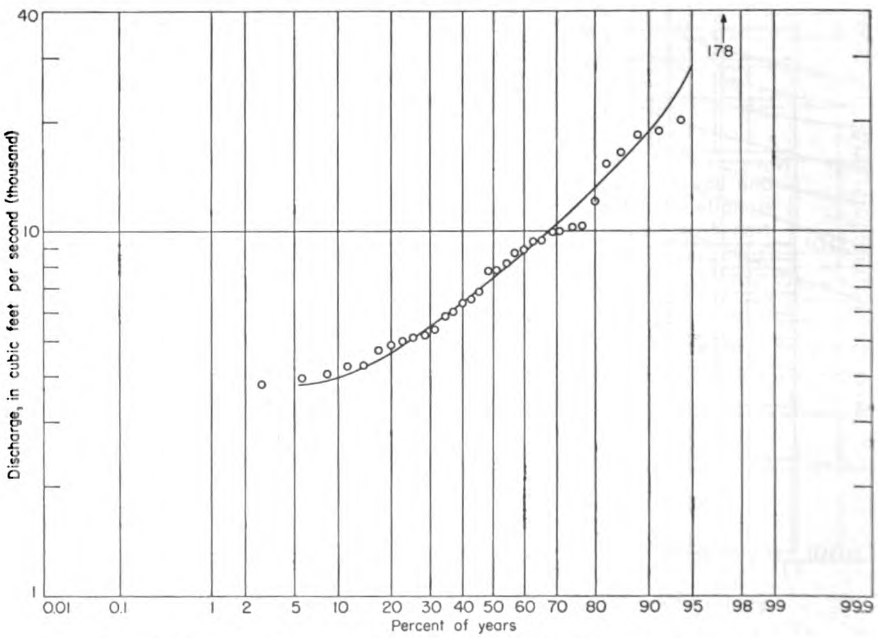


Fig. 27.—Peak annual discharge frequency curve for Solomon River near Niles.

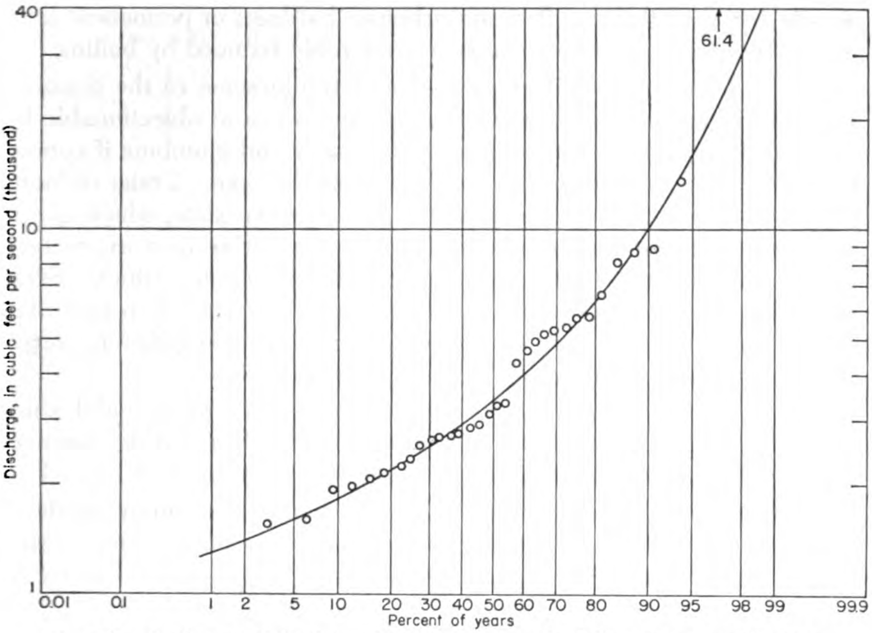


FIG. 28.—Peak annual discharge frequency curve for Saline River near Tescott.

the data should be sufficiently spread to include the 1951 flood on the curve.

CHEMICAL QUALITY OF WATER

Water in its natural state is never completely pure. The following discussion will deal with the common types of dissolved solids in water and how they can be removed. Part of the discussion is adapted from Standard Methods (1955). The water samples were analyzed by Howard Stoltenberg, chemist, Sanitary Engineering Laboratory, Division of Sanitation, Kansas State Board of Health, in Topeka. The water samples were not tested bacteriologically.

DISSOLVED SOLIDS

Hardness.—Hardness is caused by calcium and magnesium, but dissolved iron, manganese, aluminum, and other metals add to water hardness. Dissolved calcium and magnesium react with soap to form a sticky curd. The soap that combines with calcium and magnesium is thus wasted. Metallic cations unite with anions to form a hard scale in pipes. Hardness is decreased in water-treatment plants by the addition of lime ($Ca(OH)_2$) and soda ash (Na_2CO_3) or, on a domestic or small commercial scale, by other chemical water softeners. If the hardness is greater than the alkalinity, that amount of hardness equivalent to the alkalinity is called carbonate hardness or temporary hardness; any amount of hardness in excess of this is called noncarbonate hardness or permanent hardness. Temporary hardness can be considerably reduced by boiling.

Iron and manganese.—One of the most troublesome of the dissolved solids in water is iron. Dissolved manganese is just as objectionable but not as common. Both cause staining of laundry and plumbing if concentrations of both cations together exceed about 0.3 ppm. Under reducing conditions, iron exists in natural water in the ferrous state, which is relatively soluble. Ferrous iron is oxidized to ferric iron upon exposure to the air. Ferric oxide is the rust that precipitates upon settling. Ferric oxide may also be precipitated by *Crenothrix* bacteria. Iron and manganese may be removed by aeration, chemical precipitation, superchlorination, and use of special ion-exchange materials.

Silica.—Most natural water contains some soluble or colloidal silica, which is not physiologically harmful. Colloidal silica may be removed by coagulation and filtration, but soluble silica is not easily removed.

Alkalinity.—Carbonate, bicarbonate, and hydroxide impart alkalinity to natural water. Carbonate is rarely found in ground water. Alkalinity is decreased by precipitating the bicarbonate with lime or by increasing the acidity.

Sulfate.—Sulfate is a common constituent of natural water. Solution of the gypsum ($CaSO_4 \cdot 2H_2O$), anhydrite ($CaSO_4$), and small quantities of barite ($BaSO_4$) in the rocks is an abundant source of sulfate in water. Dissolved sulfate in quantities much greater than 250 ppm is likely to have a cathartic effect on the human body. Sulfate is not ordinarily removed from water supplies in treatment.

Chloride.—Chloride, derived from solution of mineral matter, is one of the most common anions in water. Water having a chloride concentration in excess of 250 ppm is not recommended for human consumption, but many waters containing more can and are being used. Ordinarily, chloride is not removed from water supplies in treatment.

Nitrate.—Nitrogen in water may be derived from many sources. Usually, nitrogen is reported as an equivalent of nitrate, which is the most stable phase of biological oxidation in the nitrogen cycle. Nitrite is an intermediate stage of oxidation or reduction in the nitrogen cycle. Surface waters generally contain negligible quantities of nitrate but ground water may contain enough to constitute a health hazard. Small amounts of nitrite in surface water usually indicate pollution. Nitrite is seldom found in ground water. Organic nitrogen, supplied to water by proteins, amino acids, and polypeptides, which are all products of biological processes, usually indicates some degree of pollution. Ammonia nitrogen is a product of microbiological activity and may be regarded as chemical evidence of pollution in raw surface water. In ground water, ammonia nitrogen is probably a result of a simple reduction process. Generally speaking, any form of nitrogen in water would imply that some biological process has introduced it, although some nitrate could be dissolved from inorganic minerals. Water containing more than 90 ppm of nitrate (as NO_3) may cause infant cyanosis (methemoglobinemia) or "blue babies" if it is used in the preparation of formula (Metzler and Stoltenberg, 1950). Nitrate cannot be removed by boiling.

Fluoride.—Most natural water contains a small amount of dissolved fluoride. If the fluoride concentration is greater than 1.5 ppm, it may cause "mottled enamel" in children's teeth. Water containing much less than 1.0 ppm does not give optimum protection from dental cavities. Fluoride is added to many water supplies in order to increase the concentration to about 1.0 ppm.

Specific Conductance

Specific conductance is a measure of the capacity of a fluid to conduct an electric current. Conductance, the reciprocal of resistance, is often

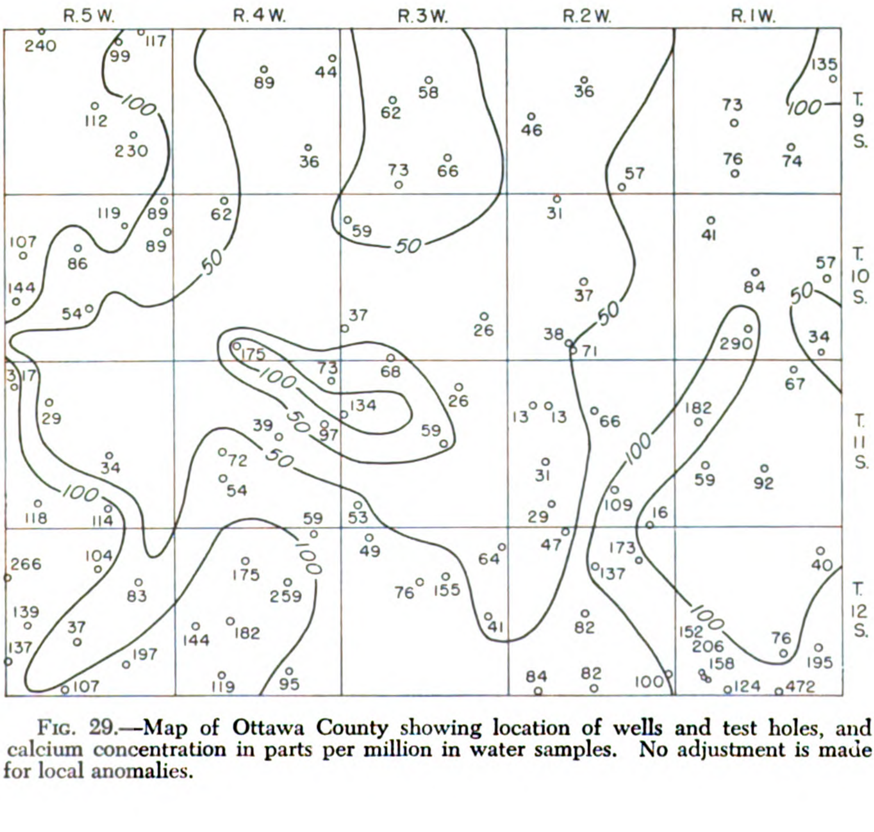


Fig. 29.—Map of Ottawa County showing location of wells and test holes, and calcium concentration in parts per million in water samples. No adjustment is made for local anomalies.

expressed in micromhos per centimeter. As the specific conductance is closely related to the sum of dissolved anions and cations, it is a convenient method for quickly determining the approximate amount of dissolved solids. Conductance in micromhos is multiplied by a factor ranging from about 0.55 to 0.75 to give parts per million of dissolved solids. The proper factor is determined by chemically analyzing water similar to that to be tested and comparing the dissolved-solids content with the specific conductance. The average factor for Ottawa County is 0.6.

Specific conductance can be used as an aid in determining recharge from a body of surface water to a pumped well if there is a marked difference in conductances between surface and ground waters.

Dissolved Solids in Ground Water

Concentrations of dissolved solids in ground water in Ottawa County fall in a general areal pattern, except for local anomalies. Concentrations of calcium (Fig. 29), magnesium (Fig. 30), bicarbonate (Fig. 31),

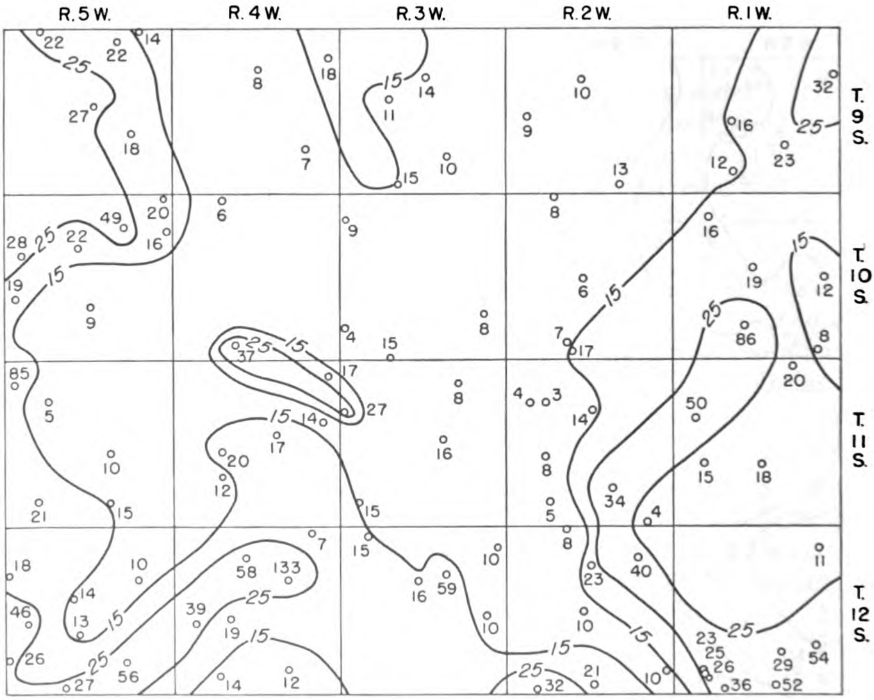


Fig. 30.—Map of Ottawa County showing location of wells and test holes, and magnesium concentration in parts per million in water samples. No adjustment is made for local anomalies.

and sulfate (Fig. 32) show that water in the middle part of the Dakota Formation and in the terraces is generally good. The major exception is water of poor quality in the silty terrace deposit at the confluence of Salt Creek and Solomon River. Wells that penetrate a terrace deposit or the Dakota Formation but also reach or approach the Wellington Formation are likely to yield water of poor quality. Water from wells in the upper part of the Dakota is generally not as good as that in the middle part of the Dakota.

The chloride concentration shows a distribution pattern similar to those plotted. Nitrate and fluoride concentrations do not seem to fit any logical pattern. Dissolved iron is very irregular in distribution and believed subject to local control; almost all water from wells contains appreciable amounts of dissolved iron. The distribution of dissolved silica is almost uniform throughout the county. Chemical analyses of water from wells in Ottawa County are given in Table 11.

Generally, the fact that a well may be in either an artesian or nonartesian aquifer of the Dakota has no bearing on the quality of water.

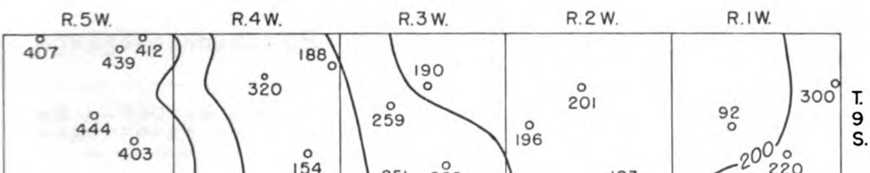


Fig. 31.—Map of Ottawa County showing location of wells and test holes, and bicarbonate concentration in parts per million in water samples. No adjustment is made for local anomalies.

Table 11.—*Analyses of water from typical wells in Ottawa County*

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

Well	Depth, feet	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		
																Total	Carbonate	Noncarbonate
9-1-12ddb	107.5	Dakota Formation	11-13-57	56	756	7.5	1.6	135	32	73	300	346	12	0.8	1.7	468	246	222
9-1-21bcc	56.0	do.	11-13-57	57	455	8.5	14	73	16	48	92	34	93	0.2	137	248	76	172
9-1-26bcb	91.5	do.	11-13-57	56	472	9.0	7.0	74	23	56	220	176	24	0.5	1.8	279	180	99
9-1-33bcb	29.3	do.	11-13-57	56	571	12	0.93	76	12	112	220	100	126	0.6	24	239	180	59
9-2-9dcd	99.6	do.	12-11-57	56	243	25	8.7	36	10	35	201	29	8.0	0.2	1.0	131	131	0.0
9-2-19aad	64.3	do.	6-5-58	58	238	21	17	46	9.0	25	196	32	7.0	0.6	0.7	152	152	0.0
9-2-35cbc	87.0	do.	12-10-57	56.5	316	12	0.69	57	13	35	183	58	34	0.2	17	196	150	46
9-3-10ccd	87.1	do.	12-11-57	58	290	14	12	58	14	22	190	61	15	0.4	12	202	156	46
9-3-17daa	166.6	do.	12-11-57	56	285	13	9.3	62	11	28	259	30	12	0.2	0.8	200	200	0.0
9-3-27dad	65.6	do.	12-11-57	57	319	25	12	66	9.6	32	222	49	27	0.1	1.0	204	182	22
9-3-33cbb	126.7	do.	6-5-58	58	334	18	3.1	73	15	23	251	65	10	0.4	5.8	244	206	38
9-4-10bcd	56.0	Illinoisan terrace	5-31-58	59	379	36	0.02	89	8.3	32	320	23	19	0.1	15	256	256	0.0
9-4-12aba	42.0	Dakota Formation	12-10-57	57	270	16	47	44	18	24	188	59	14	0.3	1.5	184	154	30
9-4-26aad	55.4	do.	6-5-58	57	251	21	0.5	36	7.3	38	154	28	20	0.4	24	120	120	0.0
9-5-2aaa	13.4	Wisconsinan terrace	5-22-58	57	566	25	3.0	117	14	68	412	96	42	0.2	1.0	350	338	12
9-5-2bcc	77.0	Dakota Formation	12-17-57	56	590	12	11	99	22	88	439	124	27	0.4	1.5	338	338	0.0
9-5-5baa	77.0	do.	5-21-58	55	1,130	16	4.7	240	22	105	407	482	50	0.7	13	690	334	356
9-5-15cdc	99.4	do.	12-18-57	57	591	13	4.5	112	27	64	444	139	9.0	0.4	8.4	390	364	26
9-5-23ddc	11.4	Alluvium	5-21-58	52	884	16	0.38	230	18	40	403	337	26	0.4	19	648	330	318
10-1-5ccd	78.3	Dakota Formation	11-13-57	56	295	9.0	32	41	16	45	205	24	41	0.8	17	168	168	0.0
10-1-16ddd	98.0	do.	11-13-57	56	400	18	0.04	84	19	35	312	40	43	0.3	6.6	288	256	32
10-1-24baa	66.4	do.	11-13-57	57	305	19	0.57	57	12	36	259	30	12	0.3	11	192	192	0.0
10-1-28dcc	42.2	do.	11-13-57	57	2,430	16	0.18	290	86	347	246	700	328	0.3	544	1,077	202	875
10-1-36cbb	42.4	do.	11-14-57	57	207	13	4.0	34	8.5	30	185	5.8	12	0.7	12	120	120	0.0
10-2-5aba	100.5	do.	12-10-57	56	213	23	1.9	31	7.9	34	178	9.5	17	0.2	2.9	110	110	0.0
10-2-21aab	82.3	do.	12-10-57	56	245	14	1.2	37	5.7	43	167	33	22	0.4	8.0	116	116	0.0
10-2-33bca	19.6	do.	11-26-57	59	177	12	11	38	7.1	13	133	17	10	0.4	14	124	109	15
10-2-33cab	19.7	do.	11-26-57	58	392	12	0.12	71	17	39	206	56	46	0.1	49	247	169	78
10-3-6ccc	69.0	do.	6-5-58	54.5	396	25	8.6	59	9.0	60	137	83	67	0.4	25	184	112	72
10-3-25bca	58.8	do.	12-11-57	56	161	7.5	19	26	8.5	23	153	8.2	11	0.2	0.9	100	100	0.0
10-3-30cbc	27.2	Wisconsinan terrace	6-5-58	56.5	200	17	0.67	37	4.3	28	148	20	17	0.4	3.1	110	110	0.0
10-3-32ddc	28.4	do.	6-5-58	57	394	32	0.20	68	15	34	139	28	68	0.2	80	231	114	117
10-4-5aad	35.4	Dakota Formation	12-11-57	59	264	25	0.26	62	6.2	22	224	16	13	0.1	10	180	180	0.0
10-4-33bdd	16.8	Illinoisan terrace	12-13-57	57	2,560	25	3.1	175	37	739	503	282	1,055	0.2	1.8	588	412	176
10-5-1aab	73.0	Dakota Formation	5-22-58	57	507	11	8.1	89	20	64	329	100	33	0.6	27	304	270	34
10-5-9dcd	162.0	do.	5-27-58	58	544	10	20	86	22	84	381	111	40	0.5	2.6	305	305	0.0
10-5-11bab	57.4	do.	12-17-57	57	813	13	0.40	119	49	99	393	149	137	0.4	53	498	322	176
10-5-12aad	92.0	do.	5-22-58	57	438	13	1.4	89	16	46	312	94	20	0.4	6.2	288	256	32

10-5-18aba	96.0	Dakota Formation	12-18-57	56	506	22	59	107	28	35	400	88	26	0.4	2.2	382	328	54
10-5-19cda	34.6	do	12-18-57	57	667	25	0.23	144	19	59	390	98	64	0.2	66	437	320	117
10-5-27bbb	49.2	do	5-27-58	56	327	17	1.5	54	9.1	55	276	23	23	0.3	9.7	172	172	0.0
11-1-2bad	7.8	Wisconsinan terrace	11-13-57	57	415	15	0.06	67	20	57	322	74	20	0.6	2.4	249	249	0.0
11-1-18aaa	40.2	Dakota Formation	11-14-57	56	1,140	25	9.2	182	50	111	293	609	18	0.6	1.4	660	240	420
11-1-20ccc	24.7	Wisconsinan terrace and Dakota Formation	11-14-57	57	388	28	0.11	59	15	45	198	107	6.0	0.4	30	208	162	46
11-1-22ccc	20.2	do	11-14-57	57	720	40	0.78	92	18	113	270	93	72	0.4	159	304	222	82
11-2-7add	75.7	Dakota Formation	11-26-57	57	98	13	0.78	13	3.8	14	71	6.6	5.0	0.1	7.1	48	48	0.0
11-2-8dbb	48.2	do	11-26-57	58.5	90	9	10	13	3.3	14	70	7.8	5.0	0.2	3.1	46	46	0.0
11-2-10cbc	94.3	do	11-26-57	58	467	14	1.0	66	14	75	215	64	62	0.3	66	222	176	46
11-2-20bdc	15.7	do	11-26-57	60	251	19	0.38	31	8.4	48	200	27	16	0.3	2.6	112	112	0.0
11-2-27ada	55.8	do	11-26-57	58	713	7.5	8.4	109	34	88	307	283	39	0.6	1.0	412	252	160
11-2-32abb	70.7	do	11-26-57	58	179	17	8.5	29	4.8	23	110	13	14	0.2	24	92	90	2
11-2-36ccc	19.2	do	11-26-57	59	123	16	0.22	16	3.9	17	73	9.5	5.5	0.2	19	56	56	0.0
11-3-2cdc	58.1	do	11-27-57	57.5	190	5.5	50	26	7.6	28	85	14	32	0.4	34	96	70	26
11-3-7ccc	46.8	Wisconsinan terrace	12-10-57	56	754	25	4.7	134	27	108	514	83	122	0.1	1.8	446	422	24
11-3-15ddc	47.2	Dakota Formation	11-27-57	57	381	12	1.2	59	16	58	288	51	22	0.3	21	213	213	0.0
11-3-31aba	41.0	do	6- 3-58	56	374	16	0.54	53	15	61	256	51	34	0.3	18	194	194	0.0
11-4-1dbd2	152.4	do	10- 8-58	....	478	21	1.4	73	17	73	253	88	76	0.3	5.3	252	207	45
11-4-13bad	43.7	Wisconsinan terrace	6-13-58	57	408	25	4.3	97	14	34	395	30	12	0.3	1.2	300	300	0.0
11-4-15daa	47.0	Dakota Formation	6- 3-58	57	263	27	0.64	39	17	22	178	29	11	0.1	30	168	146	22
11-4-20aad	75.0	do	6- 3-58	56	469	16	18	72	20	49	110	229	26	0.3	2.8	262	90	172
11-4-29aaa	91.0	do	6- 3-58	58	285	12	3.5	54	12	23	116	105	20	0.3	1.5	184	95	89
11-5-6ccd	49.7	do	12-18-57	59	1,860	13	1.4	317	85	101	215	223	231	0.0	779	1,140	176	964
11-5-8adc	100.0	do	6- 4-58	58	156	18	1.1	29	4.8	13	72	43	10	0.3	2.2	92	59	33
11-5-22ada	95.6	do	6- 4-58	58	195	25	3.0	34	9.5	15	124	28	13	0.2	8.9	124	102	22
11-5-32baa	19.6	do	6- 4-58	55	704	15	0.12	118	21	97	354	166	63	0.6	49	381	290	91
11-5-34aad	172.2	do	12-19-57	57	641	17	3.5	114	15	88	285	177	78	0.3	12	346	234	112
12-1-1ccd	11.2	Wisconsinan terrace	11-14-57	57	235	9.5	1.8	40	11	22	88	58	32	0.2	19	145	72	73
12-1-25bcb	52.0	Undifferentiated Pleistocene	11-14-57	57	934	34	0.06	195	54	32	264	258	179	0.2	62	708	216	492
12-1-27add	48.8	do	11-15-57	57	386	27	0.04	76	29	23	368	19	19	0.2	12	308	302	6.0
12-1-32bbc1	39.7	Wisconsinan terrace	11-15-57	57	920	21	0.18	206	35	34	264	462	15	0.2	17	658	216	442
12-1-32bbc2	56.0	do	11-25-57	57	709	21	0.38	158	26	32	256	306	16	0.2	24	501	210	291
12-1-32bbd	40.1	do	11-15-57	56	690	22	0.09	152	23	36	261	254	22	0.1	53	474	214	260
12-1-32ddd	73.8	Undifferentiated Pleistocene	11-15-57	56	636	16	5.1	124	36	32	249	288	16	0.2	1.2	458	204	254
12-1-34dcd	43.5	do	11-14-57	57	2,000	19	2.7	472	52	67	256	1,240	25	0.6	1.1	1,391	210	1,181
12-2-4bba	13.7	Dakota Formation	11-25-57	59	276	22	0.11	47	7.6	34	166	29	17	0.6	37	148	136	12
12-2-10bcc	38.0	do	11-25-57	57	826	24	0.38	137	23	98	320	109	82	0.1	195	436	262	174
12-2-11abb	16.6	Dakota Formation	11-26-57	55	1,300	19	0.50	173	40	185	276	285	164	0.8	301	596	226	370
12-2-21aba	26.7	Wisconsinan terrace	11-25-57	57	370	28	2.2	82	9.6	38	339	37	7.0	0.2	0.9	244	244	0.0
12-2-32ccc	75.7	Dakota Formation	11-25-57	58	620	23	7.5	84	32	65	140	302	26	0.4	19	341	115	226
12-2-34ccb	44.4	Illinoisan terrace	11-25-57	58	546	25	1.4	82	21	85	350	75	75	0.2	16	291	279	12
12-2-36aac	45.8	Wisconsinan terrace	11-25-57	57	433	21	4.8	100	10	42	349	77	10	0.1	0.7	290	286	4.0
12-3-1dba	47.0	Dakota Formation	5-17-58	....	292	22	0.06	64	10	27	259	21	13	0.2	7.1	200	200	0.0
12-3-5bca	53.2	do	5-26-58	58	315	25	0.17	49	15	26	102	40	44	0.1	66	184	84	100
12-3-9ddd	61.8	do	5-24-58	57	783	17	23	76	16	209	681	84	42	0.5	3.1	256	256	0.0
12-3-10dad	69.3	do	11-27-57	57	1,540	6.5	65	155	59	294	67	498	491	0.5	1.5	629	55	574
12-3-24bad	30.0	do	5-26-58	58	268	13	5.4	41	9.6	43	204	40	16	0.3	5.3	142	142	0.0
12-4-1bbc	100.0	do	6- 3-58	58	330	17	38	59	6.6	36	83	134	24	0.2	12	174	68	106

TABLE 11.—*Analyses of water from typical wells in Ottawa County—Concluded*

Well	Depth, feet	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ Total	Carbonate	Noncarbonate
12-4-9abd	92.8	Dakota Formation	5-26-58	58	1,330	13	8.4	175	58	152	78	359	225	0.2	310	675	64	611
12-4-11cdd	105.5	do	12-19-57	57	1,840	13	4.9	259	133	159	468	618	271	0.4	159	1,192	384	808
12-4-19daa	24.5	do	12-19-57	58	772	19	0.69	144	39	58	324	259	56	0.1	37	520	266	254
12-4-21bbc	38.0	do	6- 3-58	57.5	825	16	0.06	182	19	52	316	53	86	0.4	261	532	259	273
12-4-32ada	22.2	Wisconsinan terrace	6- 3-58	57	448	29	3.8	119	14	24	423	42	11	0.1	1.2	354	347	7.0
12-4-35bab	34.0	Illinoisan terrace	6- 3-58	57	513	32	1.1	95	12	79	456	42	27	1.0	1.3	286	286	0.0
12-5-7cbc	34.6	Wisconsinan terrace	6- 4-58	56	1,120	23	3.9	266	18	83	356	366	151	0.4	40	738	292	446
12-5-11dcd	59.0	Dakota Formation	6- 4-58	58	398	22	9.3	83	10	45	307	32	26	0.2	29	248	248	0.0
12-5-16bdd	49.5	Illinoisan terrace	4-15-58	....	495	26	0.03	104	14	49	350	89	18	0.1	23	317	287	30
12-5-19ada	41.5	Dakota Formation	5-20-58	58	972	13	0.45	139	46	133	384	316	118	0.6	17	536	315	221
12-5-26dcd	23.0	Wisconsinan terrace	5-20-58	57	1,360	20	9.4	197	56	165	268	376	223	0.4	190	722	220	502
12-5-28aba	42.0	Dakota Formation	5-20-58	58	235	22	0.17	37	13	27	189	28	14	0.4	0.4	146	146	0.0
12-5-30cbc	85.0	do	5-20-58	57	746	25	3.7	137	26	74	259	165	116	0.7	75	449	212	237
12-5-33cca	64.0	do	5-20-58	57.5	522	16	0.18	107	27	38	323	126	40	0.3	8.8	378	265	113

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. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.

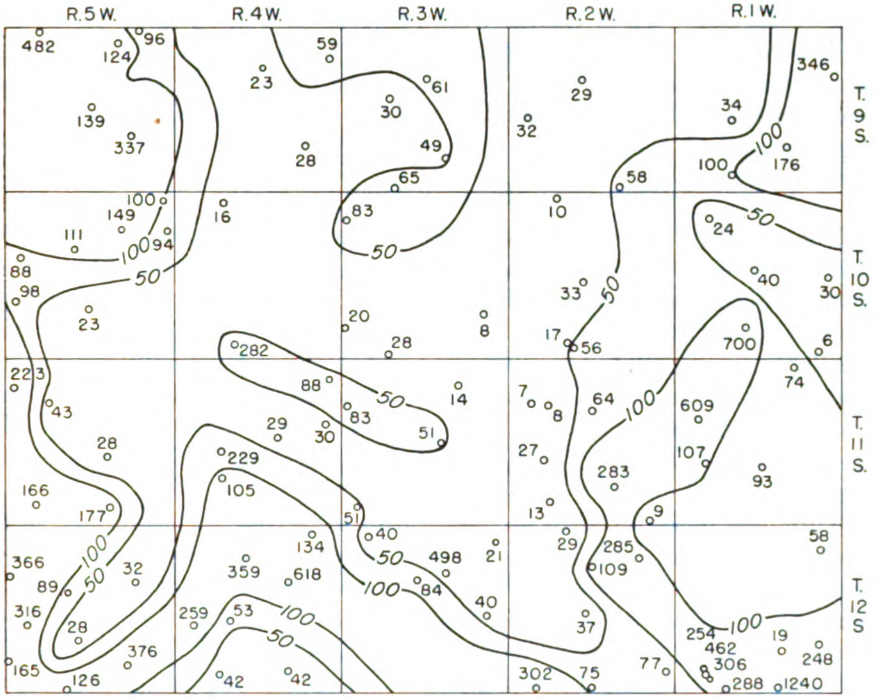


Fig. 32.—Map of Ottawa County showing location of wells and test holes, and sulfate concentration in parts per million in water samples. No adjustment is made for local anomalies.

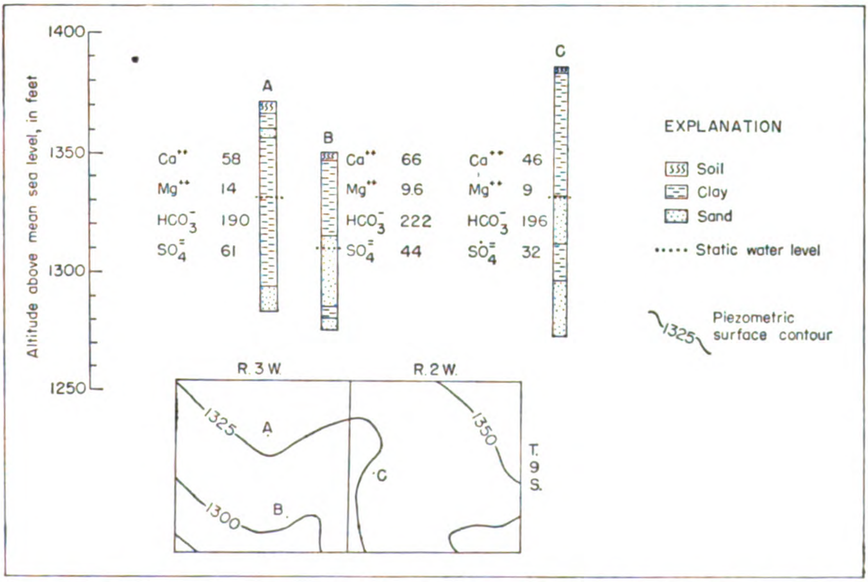


Fig. 33.—Graphic logs and locations of artesian and nonartesian wells showing minor variations in ionic concentrations in water.

Figure 33 shows three typical wells in northern Ottawa County. Well A is an artesian well, B is nonartesian, and C may be either artesian or nonartesian. The wells are a few miles apart, yet there is close agreement in the quantities of dissolved solids. This situation seems prevalent throughout the county.

Dissolved Solids in Surface Water

The quantity of dissolved solids in surface water is given in Tables 12 and 13 for Solomon and Saline Rivers, respectively. The sampling station on Solomon River is at Beloit, in Mitchell County, about 20 miles northwest of Ottawa County. The records at this station, the only data available, are presented to give some indication of the quality of water farther downstream. The sampling station on Saline River is at the gaging station half a mile south of Tescott. These data were compiled and published by the Division of Sanitation, Kansas State Board of Health (1958).

Turbidity increases with an increase in discharge because of greater sediment-carrying capacity of the river. Increased discharge proportionately decreases the percentage of dissolved solids per unit volume. Flood water (precipitation) is relatively free of dissolved solids, and the discharge of ground water containing more dissolved solids is diminished by a rise in river level. Where a river is hydraulically connected to ground water under artesian pressure, the discharge of ground water to the river will be decreased because of a decrease in slope of the piezometric surface. Where the river is hydraulically connected to ground water under nonartesian conditions, the river will discharge to ground water. Flood water or discharge in appreciable excess of base flow is of very good chemical quality except for turbidity or suspended solids.

Water for Irrigation Use

The following discussion is adapted from *Soil, the Agriculture Yearbook of 1957* (Bower and Fireman, 1957), *Agriculture Handbook 60* (U. S. Salinity Laboratory Staff, 1954), U. S. Department of Agriculture, and ground-water reports of the State Geological Survey of Kansas.

Crops require a certain amount of water and mineral matter for growth. If dissolved solids in irrigation water are excessive, they cause dehydration of vegetation, and sodium disperses clay particles, reducing aeration and percolation of water in the soil, which will eventually cause the soil to become unproductive. Saline soils contain excessive amounts of soluble salts, which consist mainly of sodium, calcium, magnesium, chloride, and sulfate, and secondarily of potassium, bicarbonate, carbonate, nitrate, and boron. Alkali soils contain an excessive amount of ab-

Table 12.—*Analyses of water from Solomon River at waterworks intake at Beloit*

Analyzed by Division of Sanitation, Kansas State Board of Health.[a] Dissolved constituents given in parts per million [b]

Date	Discharge (cfs)	Turbidity	Dissolved solids TS	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Fluoride (F)	Hardness as $CaCO_3$		
														Total	Carbonate	Noncarbonate
11-14-56	0	60	2,679	9.0	0.37	144	51	781	410	471	1,020	0.8	0.5	568	336	232
12-10-56	0.2	5	1,779	16	0.54	155	38	449	488	329	550	1.2	0.4	542	400	142
1-22-57	6.6	20	2,037	8.0	0.22	158	46	533	486	382	670	1.3	0.3	583	398	185
2-19-57	9.7	70	1,242	5.0	0.43	94	29	325	307	246	390	2.2	0.3	353	252	101
3-19-57	9.3	40	1,300	3.0	0.43	101	32	334	307	268	410	1.0	0.3	383	252	131
4-17-57	22	90	553	7.0	0.39	91	18	81	249	150	80	2.8	0.4	301	204	97
5-15-57	1,910	8,000	130	9.0	....	29	5.7	9.0	112	16	3.0	2.7	0.3	96	92	4.0
6-19-57	2,150	4,500	127	11	....	29	4.8	8.5	110	14	2.0	3.1	0.2	92	90	2.0
7-16-57	1,420	800	215	16	....	43	8.4	19	146	40	14	2.2	0.2	142	120	22
8-20-57	154	200	385	9.0	0.85	62	9.1	65	193	72	70	2.8	0.2	192	158	34
9-18-57	126	200	580	11	0.64	99	17	85	273	134	94	5.8	0.2	317	224	93
10-22-57	....	120	729	16	0.41	120	19	115	333	164	127	4.2	0.2	278	273	105
11-25-57	....	15	759	15	0.29	124	20	120	351	176	125	6.2	0.3	392	288	104
12-10-57	....	20	764	7.5	0.33	114	26	125	334	187	135	4.9	0.3	392	274	118

[a] From *Chemical Quality of Surface Waters in Kansas, 1957.*

[b] One part per million is equivalent to 1 pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

TABLE 13.—*Analyses of water from Saline River at gaging station south of Tescott*

Analyzed by Division of Sanitation, Kansas State Board of Health.[a] Dissolved constituents given in parts per million[b]

DATE	Discharge (cfs)	Turbidity	Dissolved solids TS	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Fluoride (F)	Hardness as $CaCO_3$		
														Total	Carbonate	Noncarbonate
10- 9-56..	5.8	70	4,424	10	0.55	179	81	1,358	342	685	1,940	2.1	0.5	780	280	500
11-17-56..	8.6	60	2,463	6.5	0.35	113	42	749	281	382	1,030	1.8	0.5	454	230	224
12-14-56..	9.2	5	5,065	11	0.26	193	93	1,574	449	741	2,230	1.3	0.5	864	368	496
1-23-57..	8.6	20	5,613	4.5	0.26	184	108	1,767	442	849	2,480	1.5	0.6	903	362	541
2-18-57..	20	20	3,969	4.0	0.18	141	74	1,242	332	597	1,745	2.6	0.5	656	272	384
3-20-57..	16	70	4,117	5.0	0.53	155	80	1,270	342	652	1,785	0.8	0.5	716	280	436
4-24-57..	71	250	2,215	5.0	1.2	140	44	615	257	413	870	0.8	0.3	531	211	320
5-16-57..	2,400	6,000	219	7.5	....	39	5.5	34	139	29	33	2.4	0.2	120	114	6.0
6-21-57..	5,440	3,000	162	11	....	34	5.6	15	120	23	10	4.0	0.2	108	98	10
7-23-57..	871	6,000	772	11	....	80	14	180	171	156	242	4.2	0.4	257	140	117
8-20-57..	326	500	2,116	10	2.7	148	43	568	268	412	800	2.9	0.4	546	220	326
10-25-57..	....	3,600	1,060	7.5	....	99	19	263	202	195	372	4.0	0.5	325	166	159
11-26-57..	....	20	1,954	13	0.41	162	43	494	366	376	680	5.3	0.4	580	300	280
12-13-57..	....	25	2,090	10	0.38	167	44	540	377	398	740	5.3	0.4	598	309	289

[a] From *Chemical Quality of Surface Waters in Kansas, 1957.*
[b] One part per million is equivalent to 1 pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

sorbed sodium; in soils, sodium ion is exchangeable with calcium and magnesium and will persist after most soluble salts are removed. Soluble salts can be removed from soil by leaching, and absorbed sodium can be removed by replacing it by three types of chemical amendments. These are soluble calcium salts (calcium chloride and calcium sulfate or gypsum), calcium salts of low solubility (calcium carbonate or limestone), and acids or acid formers (sulfuric acid, sulfur, and iron and aluminum sulfate). The choice of chemical amendments depends on their solubility in available water and on the salinity and pH of the soil.

Irrigation water may be classified from data on the total concentration of soluble salts and the sodium-adsorption ratio (SAR). The most convenient measure of the amount of dissolved salts is the electrical (specific) conductance. The SAR may be determined by the formula

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

in which the concentrations are expressed in equivalents per million. The nomogram (Fig. 34) will readily solve this equation for the SAR if the sodium, in milliequivalents per liter, is plotted on scale A, and the sum of calcium and magnesium, in milliequivalents per liter, is plotted on scale B. A line connecting these points will pass through the SAR scale and give the SAR value at the intersection. The suitability of water for irrigation may then be determined by plotting the SAR value (sodium hazard) and the conductivity value (salinity hazard) on the diagram in Figure 35.

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

Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Crops of moderate salt tolerance, such as potatoes, corn, wheat,

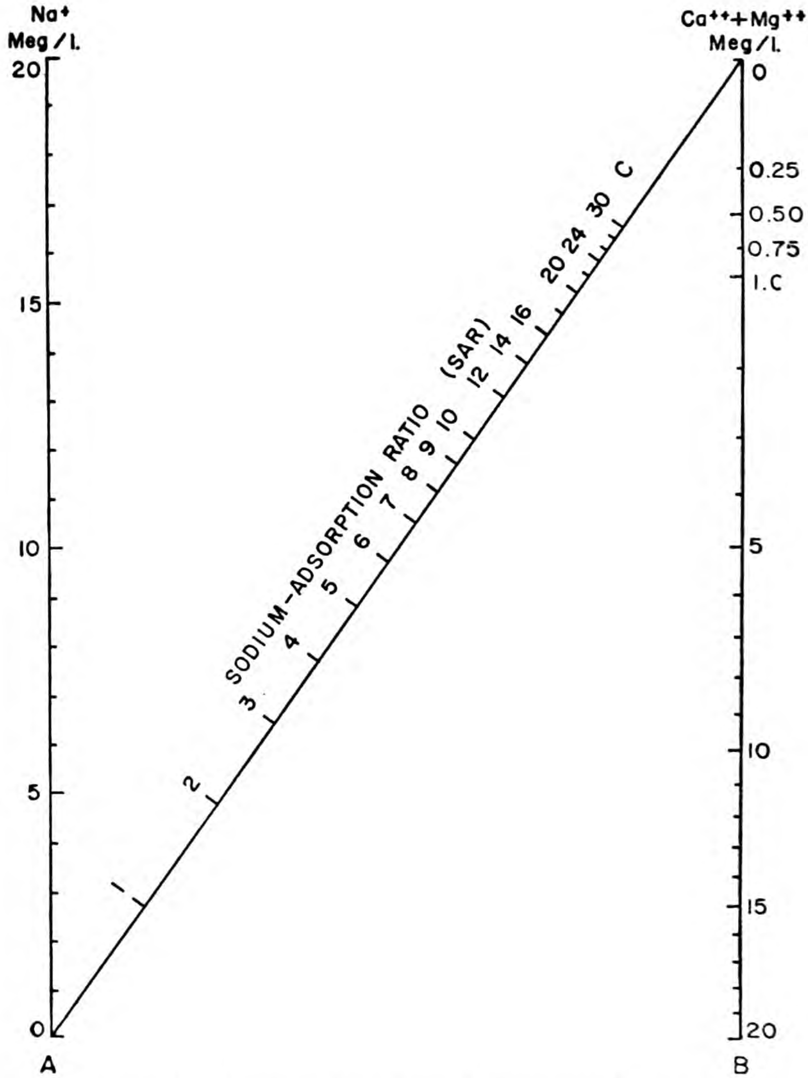


FIG. 34.—Nomogram for sodium-adsorption ratio of water.

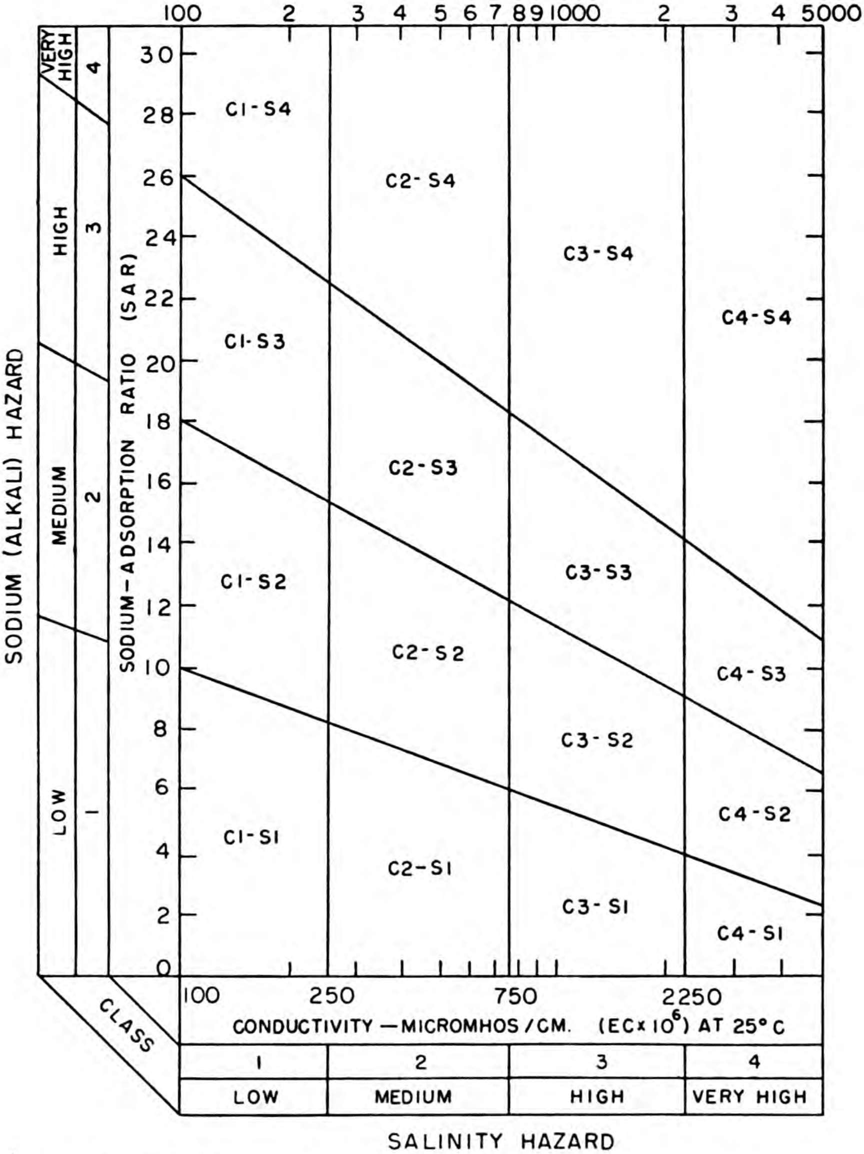


Fig. 35.—Classification of irrigation waters. (After U. S. Salinity Laboratory Staff, 1954.)

oats, and alfalfa, can be irrigated with C2 water without special practices. High-salinity water (C3) cannot be used on soils with restricted drainage. Very high salinity water (C4) can be used only on certain crops and then only if special practices are followed. Thus, it is clear that good drainage, careful soil management, proper irrigation techniques, and good water are necessary for prolonged satisfactory irrigation.

Water quality is sufficiently variable in Ottawa County to warrant careful examination prior to extensive irrigation. The water from the few irrigation wells in Ottawa County was not analyzed.

SUMMARY OF KANSAS WATER LAW

The following information is summarized from the *Report on the Laws of Kansas Pertaining to the Beneficial Use of Water* (Kansas Water Resources Board, 1956) and *The Kansas Law of Water Rights* (Hutchins, 1957).

From the time Kansas was originated, as a territory in 1854 and as a state in 1861, until 1945, water litigation was based on two separate doctrines. The first to be applied was the common-law riparian doctrine. Basically, it stated that water rights were attached to the land contiguous to stream banks and were real property rights. At first this was interpreted to mean that the riparian owner was entitled to have the water course flow through his lands undiminished in quantity and unaltered in quality. In time, this was altered to mean that upper riparian owners were permitted to use stream water on their land and for domestic purposes as long as they were not wasteful of water and used it with reasonable regard to the effect on other riparian owners of the same stream.

Ground-water law was more perplexing. Different sets of rules covered different situations without particular regard to physical principles of ground-water flow.

The common-law riparian doctrine is modified by the American, or reasonable-use, doctrine which follows the philosophy that a man must use his property in such a manner as not to injure that of another. Directly applied to water, the appropriation doctrine states that all unused water belongs to all the people of the state. The first person to divert water from a surface or ground source and use it for beneficial purposes has a better right to continue using the same amount than a person who starts, at a later date, to use water from the same source. Simply stated, the first in time is first in right. Virtually everywhere that the appropriation doctrine is followed, it is verified that the use must be a beneficial one.

In 1945, the Kansas legislature provided an effective means of acquiring appropriation rights by creating a water-appropriation act. A brief summary of the procedure for acquiring an appropriation right is given in *Kansas Water Resources Board*, Bulletin 3, 1957, pages 8 and 9:

> To obtain the right to appropriate and use a certain amount of water, a person must apply in writing to the Chief Engineer of the Division of Water Resources of the Kansas State Board of Agriculture for a certain amount of water from a named source. If the Chief Engineer finds that the appropriation would be in the public interest, he approves the application and tells the person to proceed with the diversion and application of water to a beneficial use within reasonable limitations and within a reasonable time. When the applicant constructs his diversion works and starts using the water, he is required to notify the Chief Engineer. If after an inspection, the Chief Engineer finds that the applicant has completed the appropriation as authorized, he issues a certificate of appropriation in duplicate. The applicant is supposed to record one copy with the register of deeds of the county where the point of diversion is located. The duplicate of the record stays in the Chief Engineer's office. The applicant then has an appropriation right.

The Water Appropriation Act of 1945 and amendments of 1957 (primarily concerning definition of terms, duties and procedures of personnel involved, appropriation priorities, and the mechanics of appropriation) provide an adequate framework for blending equity by law with physical principles of water behavior.

RECORDS OF WELLS

Information pertaining to 199 wells in Ottawa County is tabulated in Table 14. The well-numbering system used in this report is described on page 9.

TABLE 14.—*Records of wells in Ottawa County*

WELL (1)	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Altitude of land surface, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS
9-1-3bba	E. R. Ducksworth	Dr	93.2	6	GI	Sandstone	Dakota Formation	Cy, W	N	1,395.1	75.78	8- 1-57	Abandoned.
9-1-6dbd	Sarah Goren	Dr	72.3	6	GI	do	do	Cy, W	D	1,406.7	52.69	8-14-57	
9-1-9ccc	George Gray	Dr	63	6	GI	do	do	Cy, W	S	1,395.4	39.50	8-14-57	
•9-1-12ddb	Benjamin Bull	Dr	107.5	6	GI	do	do	Cy, E	S	1,298.8	41.24	8- 7-57	
9-1-15bba	Elizabeth Lyne	Dr	29.3	6	GI	do	do	Cy, W	S	1,349.7	8.49	8- 1-57	
9-1-19bcb	Harry Ponton	Dr	83.7	6	GI	do	do	Cy, W	S	1,422.1	70.22	8-14-57	
•9-1-21bcc	Emma Hazlett	Dr	56.0			do	do	Cy, W	D, S	1,398.6	50.60	8-14-57	
•9-1-26bcb	O. U. Need	Dr	91.5	8	GI	do	do	Cy, W	D, S	1,412.4	45.99	8- 7-57	
•9-1-33bcb	W. Greer	Dr	29.3			do	do	Cy, H	D	1,393.5	18.50	8-14-57	
9-1-35cdd	P. W. Russell	DD	180	6	GI	do	do	Cy, E	S	1,325.6	41.70	8- 7-57	
9-2-5cbc	B. Wilkins	Dr	112.9	6	GI	do	do	Cy, E	S	1,388.5	50.61	8-21-57	
•9-2-9dcd	George Koster	DD	99.6	6	I	do	do	Cy, W	S	1,350.4	67.22	8-21-57	
9-2-11bcc	J. L. Fuller	Dr	68.1	6	GI	do	do	Cy, W	D, S	1,394.7	47.20	8-14-57	
•9-2-19aad	A. Tennyson	Dr	64.3	6	GI	do	do	Cy, W	D	1,386.4	55.10	8-21-57	
9-2-20aaa	Frank Shroyer	Dr	51.7	6	GI	do	do	J, E	D	1,355.9	22.82	8-21-57	
9-2-22aaa	Lawrence Heald	Dr	109.0	6	GI	do	do	Cy, W	S	1,379.4	58.80	8-14-57	
9-2-27cca	C. C. Leive	Dr	85.9	6	GI	do	do	Cy, W	N	1,425.6	78.46	8- 1-57	Abandoned.
9-2-30dad	Wayne Kreigh	Du	39.5			do	do	Cy, W	D, S	1,367.5	31.34	8-20-57	
•9-2-35cbc	Ernest Geist	Dr	87.0	6	GI	do	do	Cy, W	D, S	1,436.3	80.15	8-14-57	
9-2-36aaa	Roy Shannon	Dr	142.5	6	GI	do	do	Cy, W	D, S	1,465.5	113.45	8-14-57	
9-3-1bcb	A. Santner	Dr	71.7	6	GI	do	do	N	N	1,451.2	60.84	8-21-57	Abandoned.
9-3-1ccd	Miles Allen	Dr	128.3	6	GI	do	do	Cy, W	D, S	1,454.8	122.90	8-21-57	
•9-3-10ccd	Leo LaPlant	Dr	87.1	6	GI	do	do	Cy, W	S	1,371.1	39.28	8-21-57	
•9-3-17daa	Roy Halberstad	Dr	166.6	5.62	I	do	do	Cy, E	D, S	1,404.8	90.3	12-11-57	
9-3-21bbd	A. Tasker	Dr	121.8	6		do	do	Cy, W	S	1,411.7	89.50	8-24-57	
9-3-24dcc	R. W. Thomas	Dr	81.3	6	GI	do	do	Cy, T	S	1,373.3	57.96	8-21-57	
•9-3-27dad	Wesleyan Methodist Church	Dr	65.6	7	GI	do	do	J, E	D	1,353.8	44.98	8-21-57	
9-3-29ccc	A. Hurdig	DD	28.3			do	do	J, E	S	1,358.9	23.54	8-24-57	
•9-3-33cbb	Herbert Crossen	Dr	126.7	8	OW	do	do	Cy, E	D, S	1,377.2	95.85	8-24-57	
9-4-3bcd	L. Ballou	Dr	57.4			Sand	Illinoisan terrace deposit	T, P	I	1,338.5	40.00	12-11-57	
•9-4-10bcd	City of Delphos	Dr	56			do	do	T, E	P	1,321.9	35.53	6- 9-58	Yield 250 gpm.
•9-4-12aba	Ethyl Thurston	Dr	42.0	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,307.4	37.54	12-12-57	
9-4-18dba	Ellis Paramore	Dr	48.5			do	do	T, E	I	1,294.8	18.00	12-12-57	

9-4-18dca	do	Dr	40.0			do	do	T, E	I	1,290.3	16.90	12-12-57	
•9-4-26aad	Vern Clintsman	Du	55.4			do	do	Cy, W	S	1,330.1	55.2	12-12-57	
9-5-1dca	J. W. Studt	Du	27.0			do	do	Cy, H	D	1,325.5	17.55	12-12-57	
•9-5-2aaa	W. Butler	Du	13.4			Sand	Illinoisan terrace deposit	Cy, W	S	1,312.0	12.45	5-22-58	
•9-5-2bcc	C. Stricklett	Dr	77.0	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,363.5	63.04	12-17-57	
•9-5-5baa	A. Kozar	Dr	77.0	6	GI	do	do	Cy, W	S	1,442.4	14.61	5-21-58	
9-5-6bbb	F. Hirsch	Dr	69.9	6	GI	do	do	Cy, W	S	1,452.3	31.64	12-17-57	
•9-5-15cdc	Mrs. O. Holtz	Dr	99.4	6	GI	do	do	Cy, W	S	1,538.0	75.28	12-17-57	
9-5-16bbc	E. Lynch	Dr	177.1	6	GI	do	do	Cy, W	S	1,514.2	23.80	12-17-57	
9-5-16ddc	C. T. Marler	Dr	176.5	6	GI	do	do	Cy, W	S	1,626.9	167.00	5-21-58	
•9-5-23ddc	A. Hurtig	DD	11.4	6	GI	do	do	Cy, W	S	1,428.9	2.12	5-21-58	
9-5-25aad	E. Paramore	Du	36.9			do	do	Cy, W	D, S	1,350.5	13.27	12-12-57	
9-5-27cdc	M. Shaffer	Dr	145.4	6	GI	do	do	Cy, W	S	1,581.5	115.3	5-21-58	
9-5-29cbc	F. Srna	Dr	97.2	4	S	do	do	Cy, W	S	1,486.7	49.48	12-18-57	
10-1-4cdd	Minnie Saler	Dr	113.1	6	GI	do	do	Cy, W	D	1,417.2	59.20	8- 7-57	
•10-1-5cdd	Hattie Ackerman	Dr	78.3	6	GI	do	do	Cy, W	S	1,438.5	46.20	11-13-57	
10-1-7abb	H. E. Rothfuss	Dr	105.5	6	GI	do	do	Cy, W	S	1,433.4	51.50	8-13-57	
•10-1-16ddd	W. D. Johnson	Dr	98.0	6	GI	do	do	Cy, W	D	1,441.5	77.3	8- 7-57	
•10-1-24baa	Howard D. Ferguson	Du	66.4			do	do	Cy, W	D, S	1,427.7	61.48	8- 7-57	
10-1-27aaa	James Faidley	Dr	126.0	6	GI	do	do	Cy, W	S	1,443.6	58.00	8- 7-57	
•10-1-28dcc	James J. Riley	DD	42.2			do	do	Cy, W	S	1,351.7	28.97	8-13-57	
•10-1-36cbb	Rosetta Stout	Dr	42.4	6	GI	do	do	Cy, W	D, S	1,437.3	28.13	8-17-57	
•10-2-5aba	D. F. Sanders	Du	100.5			do	do	Cy, G	D, S	1,432.7	95.31	8-20-57	
10-2-6ddd	L. Lash and E. Gappat	Du	82.65			do	do	Cy, W	D, S	1,403.9	77.45	8-20-57	
10-2-10dda	E. Windhorst	Dr	104.1	6	GI	do	do	Cy, W	N	1,452.2	87.16	8-14-57	Abandoned.
10-2-20ccd	Fred Harder	Du	86.0			do	do	Cy, W	S	1,391.3	78.26	8-20-57	
•10-2-21aab	A. J. Foster	Dr	82.3	6	GI	do	do	Cy, W	S	1,429.0	74.00	8-20-57	
10-2-27daa	C. A. Goodfellow	Dr	127.6	6	GI	do	do	Cy, W	N	1,401.0	36.74	8-17-57	Abandoned.
10-2-28acd	G. Windhorst	Dr	118.1	6	GI	do	do	Cy, W	S	1,406.2	62.10	8-20-57	
10-2-31dab	G. F. Becky	Du	81.7			do	do	Cy, W	S	1,378.9	72.96	8-20-57	
•10-2-33bca	E. Windhorst	Dr	19.6	6	GI	do	do	J, E	D	1,384.0	15.22	8-20-57	
•10-2-33cab	Santa Fe R. R.	Du	19.7			do	do	Cy, H	D	1,372.0	16.86	8-20-57	
10-3-2bcc	E. Yowell	Dr	67.6	6	GI	do	do	Cy, E	D, S	1,349.6	51.86	8-21-57	
•10-3-6ccc	Dinah Hartley	Dr	69.0	6	GI	do	do	Cy, W	D, S	1,322.7	55.43	8-24-57	
10-3-17bbb	Joseph Jagger	Dr	51.3	6	GI	do	do	Cy, E	D, S	1,309.4	40.41	12-10-57	
10-3-23bbc	Arthur Johnson	Du	55.0			do	do	N	N	1,315.5	46.56	8-21-57	Abandoned.
•10-3-25bca	W. H. Harder	Dr	58.8	6	GI	do	do	Cy, W	S	1,333.9	32.90	8-21-57	
10-3-27ccc	J. Bremmerman	Dr	23.5	6	GI	do	do	Cy, T	D	1,278.0	16.04	8-22-57	
•10-3-30cbc	Charles Carlson	Dr	27.2			do	do	Cy, W	S	1,250.6	12.95	8-24-57	
•10-3-32ddc	C. B. Schur	Du	28.4			do	do	J, E	D	1,258.8	21.14	12- 7-57	
10-3-34bbb	Richard Chappell	Dr	63	6	GI	do	do	Cy, W	D, S	1,298.5	54.40	8-22-57	
10-3-35bbd	E. Barrett	Du	75.6			do	do	Cy, W	D, S	1,353.5	68.52	8-21-57	
•10-4-5aad	Vincent Steinbrock	Du	35.4			do	do	Cy, E	D	1,293.1	29.64	12-12-57	
10-4-19dcc	James Hansen	Dr	73.1	6	GI	do	do	Cy, W	S	1,321.7	64.49	12-13-57	
10-4-25bcb	Reva Struthers	Du	36.6	6	GI	Sand	Undifferentiated Pleistocene deposits	Cy, H	N	1,275.5	31.45	12- 3-57	Abandoned.
•10-4-33bdd	E. Delcamp	Du	16.8			do	Wisconsinan terrace deposit	Cy, E	S	1,254.3	11.00	12-13-57	

TABLE 14.—*Records of wells in Ottawa County—Continued*

WELL (1)	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Altitude of land surface, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS
10-4-34aad	A. Carter	Du	26.7			Sand	Wisconsinan terrace deposit	Cy, H	N	1,259.1	24.49	12- 3-57	Abandoned.
*10-5-1aab	J. W. King	Dr	73.0	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,375.3	34.75	5-22-58	
10-5-3bbc	G. Eiler	Dr	79.8	6	GI	do	do	Cy, W	S	1,470.9	42.04	12-16-57	
10-5-5cbb	W. Nelson	Dr	149.6	6	GI	do	do	Cy, W	S	1,393.6	78.76	12-18-57	
*10-5-9dcd	do	Dr	162.0	6	GI	do	do	Cy, W	S	1,417.6	107.79	5-22-58	
10-5-11aba	C. P. Rensink	Dr	178.8	7	GI	do	do	N	N	1,447.4	124.84	12-17-57	Abandoned.
*10-5-11bab	C. A. Brion	Du	57.4			do	do	Cy, E	S	1,439.1	50.92	12-16-57	
*10-5-12aad	E. G. Maholland	Dr	92.0	6	GI	do	do	Cy, W	S	1,387.7	80.00	5-22-58	
*10-5-18aba	Clarence Becker	Dr	96.0	6	GI	do	do	J, E	D	1,348.5	44.60	12-18-57	
*10-5-19cda	Mrs. Frank Burger	Du	34.6			do	do	Cy, W	D, S	1,313.3	29.05	12-18-57	
10-5-23ccb	D. Lott and C. Atchley	Dr	52.5	6	GI	do	do	Cy, N	N	1,299.7	23.15	12-16-57	Abandoned.
10-5-25cdc	Mrs. Jane Zeck	Dr	28.4	6	GI	Sand	Undifferentiated Pleistocene deposits	Cy, W	S	1,280.2	14.51	12-13-57	
*10-5-27bbb	Ada Cemetery	Dr	49.2	6	GI	Sandstone	Dakota Formation	Cy, W	D	1,326.0	41.03	5-22-58	
10-5-34dcd	L. Mull	Du	28.4			do	do	Cy, W	S	1,286.3	22.32	12-13-57	
*11-1-2bad	Ray O. Smith	Du	7.8			Sand	Wisconsinan terrace deposit	Cy, W	D, S	1,369.9	4.24	8- 8-57	
11-1-5dcd	L. B. Bingham	Dr	43.4	6	GI	do	do	Cy, H	D	1,265.5	24.81	8-13-57	
11-1-16ccc	Glen Richards	Dr	144.0			Sandstone	Dakota Formation	Cy, H	S	1,289.7	69.8	8-13-57	
*11-1-18aaa	William Luthi	Du, D	40.2	6	GI	do	do	Cy, H	D, S	1,254.1	24.97	8-13-57	
*11-1-20ccc	Y. Jennings	Du	24.7			Sand	Dakota Formation and Wisconsinan terrace deposit	Cy, W	S	1,246.7	11.05	8-13-57	
*11-1-22ccc	Warren Neaderhiser	Du	20.2			do	do	Cy, E	D, S	1,302.6	8.61	8- 8-57	
11-1-24dcc	C. T. Bell	Du	13.9			do	do	N	N	1,342.3	4.06	8- 8-57	Abandoned.
11-1-26adb	Paul Reed	Du	27.1			do	Wisconsinan terrace deposit	Cy, W	S	1,319.0	16.24	8- 8-57	
11-1-28ddd	E. Neaderhiser	Du	30.0			do	do	Cy, W	S	1,260.0	13.16	8-13-57	
11-2-2ccc	C. C. Morris	Dr	77.1	6	GI	Sandstone	Dakota Formation	N	N	1,420.6	57.94	8-17-57	Abandoned.
*11-2-7add	Williams	Dr	75.7	6	GI	do	do	Cy, H	D	1,344.7	47.09	8-19-57	
*11-2-8dbb	State of Kansas	Dr	48.2	6	GI	do	do	Cy, H	D	1,311.5	18.34	11-26-57	
*11-2-10cbc	John H. Heck	Dr	94.3	6	GI	do	do	Cy, E	D, S	1,408.7	90.51	8-17-57	
*11-2-20bdc	Wayne Peck	Dr	15.7	6	GI	do	do	Cy, W	D	1,275.7	14.38	8-19-57	
11-2-26bcb	Ray Slick	Du	11.0			do	do	Cy, H	D, S	1,305.0	8.59	8-17-57	
*11-2-27ada	Dan Startzman	Dr	55.8	6	GI	do	do	Cy, H	S	1,307.1	22.40	8-17-57	
*11-2-32abb	Thesa Quinn	Du	70.7			do	do	Cy, W	S	1,327.8	65.49	8-19-57	

*11-2-36ccc	Merrill C. White	Dr	19.2	6	GI	do.	do.	Cy, H	D	1,297.7	10.52	8-17-57	
*11-3-2cdc	W. J. Gibbs	Dr	58.1	6	GI	do.	do.	Cy, H	D, S	1,338.8	28.72	8-22-57	
11-3-5ccd	Ted Blackstone	Dr	72	6	GI	do.	do.	Cy, W	D, S	1,294.9	64.2	12-2-57	
*11-3-7ccc	E. G. Maholland	B	46.8	6	GI	Sand	Wisconsinan terrace deposit	Cy, W	D, S	1,245.7	26.30	12-10-57	
11-3-10cdd	Howard Weis	Dr	117.7	6	GI	Sandstone	Dakota Formation	Cy, E	S	1,320.7	89.22	8-22-57	
11-3-13ccc	W. J. Lott	Dr	43.0	6	I	Sand	Dakota Formation and Wisconsinan terrace deposit	VC, E	D	1,267.5	6.66	8-22-57	
*11-3-15ddc	Will Beck	Dr	47.2	6	I	Sandstone	Dakota Formation	Cy, W	D	1,298.6	39	8-22-57	
11-3-21bdd	R. A. Haddock	Dr	56.0	18	OW	Sand	Illinoisan terrace deposit	T, P	I	1,233.4	17.99	8-2-57	
11-3-26bab	Earl Nickolas	Du	24.0	....	N	do.	Wisconsinan terrace deposit	Cy, W	S	1,244.8	21.30	8-22-57	
*11-3-31aba	E. Kibler	Du	41.0	....	N	Sandstone	Dakota Formation	Cy, W	S	1,283.1	31.73	12-3-57	
11-4-1dbd1	City of Minneapolis	Dr	109.8	14	S	do.	do.	T, E	P	....	....	8-16-57	Supply well pumping 100 ft. to N.
*11-4-1dbd2	do.	Dr	152.4	12	S	do.	do.	T, E	P	1,263.3	41.58	8-16-57	
11-4-7aba	Carl E. Pickrell	Dr	47.3	6.	GI	do.	do.	Cy, W	S	1,277.7	31.12	12-13-57	
*11-4-13bad	Marcus Henry	Dn	43.7	1.5	GP	Sand	Wisconsinan terrace deposit	Cy, W	S	1,247.7	20.65	6-5-58	
*11-4-15daa	George Copeland	Dr	47.0	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,270.7	36.86	5-24-58	
11-4-16aaa	Louis Miller	D, D	73.0	....	....	do.	do.	Cy, E	N	1,299.2	65.30	12-3-57	Abandoned.
*11-4-20aad	D. Scharplaz	Dr	75	....	....	do.	do.	Cy, W	S	1,359.6	49.3	6-3-58	
*11-4-29aaa	K. A. Baccos	Dr	91.0	6	GI	do.	do.	Cy, W	S	1,413.8	66.94	5-24-58	
11-4-29ddc	L. A. McNalley	Dr	56.5	6	GI	do.	do.	Cy, W	S	1,387.1	39.19	12-19-57	Abandoned.
11-4-34aac	Amos A. Nelson	Dr	81.4	6	GI	do.	do.	Cy, E	S	1,321.1	69.71	12-3-57	
*11-5-6ccd	F. E. MacMillan	Dr	49.7	6	GI	do.	do.	Cy, W	S	1,352.7	35.59	12-18-57	
*11-5-8adc	G. F. Schmidt	Dr	100.0	6	GI	do.	do.	Cy, W	S	1,398.7	76.68	6-4-58	
11-5-15ada	Frank Rosser	Du	89.2	....	N	do.	do.	Cy, W	N	1,363.3	82.00	12-13-57	Abandoned
11-5-19dbb	O. M. Vermillion	Dr	83.5	6	GI	do.	do.	Cy, W	S	1,446.1	55.96	12-18-57	
*11-5-22ada	F. W. Schmidt	Dr	95.6	6	GI	do.	do.	Cy, W	S	1,360.2	77.48	6-4-58	
*11-5-32baa	F. E Scidmore	Dr	19.6	8	GI	do.	do.	Cy, W	S	1,370.4	18.48	6-4-58	
*11-5-34aad	Northern Natural Gas Co.	Dr	172.2	10	S	do.	do.	T, E	I	1,415.9	122.23	12-19-57	
11-5-36aaa	J. Bremerman	Du	42.6	....	N	do.	do.	Cy, W	S	1,410.2	37.61	8-28-57	
*12-1-1ccd	George Burgess	Du	11.2	....	N	Sand	Wisconsinan terrace deposit	Cy, W	S	1,266.3	2.72	8-8-57	
12-1-2add	H. Krebs	Du	55.8	....	N	Sandstone	Dakota Formation	Cy, W	N	1,296.2	14.03	8-8-57	Abandoned.
12-1-7ccc	C. Hoover	Dr	27.3	6	I	Sand	Wisconsinan terrace deposit	J, E	D	1,217.3	20.30	8-9-57	
12-1-20abb	I. Monk	Du	13.8	....	N	do.	Undifferentiated Pleistocene deposits	Cy, W	D, S	1,269.7	12.09	8-13-57	
12-1-21aaa	Iva A. Monk	Dr	17.6	6	GI	do.	do.	N	N	1,271.5	12.82	8-8-57	Abandoned.
*12-1-25bcb	B. L. Janssen	Du	52.0	6	GI	do.	do.	Cy, W	D, S	1,268.3	50.77	8-8-57	
*12-1-27add	Oren H. Janssen	Dr	48.8	4	GI	do.	do.	Cy, W	S	1,235.7	20.78	8-8-57	
*12-1-32bbc1	Ellsworth Boyle	Dr	39.7	6	GI	do.	do.	Cy, H	N	1,198.6	28.29	8-9-57	Abandoned.
*12-1-32bbc2	C. E. Kellogg	Dr	56.0	6	GI	do.	do.	J, E	D	1,199.9	24.65	8-9-57	
*12-1-32bbd	George Hoffman	Du	40.1	......	....	do.	Wisconsinan terrace deposit	Cy, H	D	1,199.7	31.68	8-9-57	
*12-1-32ddd	Farnk Callahan	Dr	73.8	6	I	do.	do.	Cy, W	S	1,201.6	35.5	8-9-57	
12-1-33bad	J. E. Sullivan	Dr	47.8	6	GI	do.	Undifferentiated Pleistocene deposits	Cy, W	N	1,212.0	17.11	8-9-57	
*12-1-34dcd	Gerald Webb	Dr	43.5	4	GI	do.	do.	Cy, W	S	1,208.0	36.68	8-8-57	
12-1-36ccb	Mrs. Flanagan Ferris	Dr	41.7	....	....	do.	do.	Cy, W	S	1,214.2	22.4	8-8-57	

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TABLE 14.—*Records of wells in Ottawa County—Concluded*

WELL (1)	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Altitude of land surface, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS
*12-2-4bba	James Cherry	Du	13.7			Sandstone	Dakota Formation	J, E	D, S	1,265.1	15.50	8-19-57	
*12-2-10bcc	W. D. Smith	Du, Dn	38			do	do	Cy, W	S	1,224.3	20	8-19-57	
*12-2-11abb	L. Kinyon	Du	16.6			do	do	Cy, H	N	1,247.9	13.76	8-19-57	Abandoned.
12-2-18aac	W. D. Neaderhiser	Dn	42	2	GP	Sand	Wisconsinan terrace deposit	Cy, E	D	1,215.1	25	8-19-57	
*12-2-21aba	Herman Hohensee	Du	26.7			do	do	Cy, H	D	1,205.9	14.34	8-19-57	
12-2-23dda	City of Verdi	Dr	47.4	6.5	GI	do	do	N	N	1,201.0	22.20	8-19-57	New.
12-2-28aca	Oscar Seim	Dr	48.3	6	GI	do	do	Cy, H	N	1,218.3	29.28	8-19-57	Abandoned.
12-2-30ccc	R. D. Hensley	Dr	39.7	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,305.6	11.53	5-24-58	
*12-2-32ccc	Clarence A. Watkins	Dr	75.7	6	GI	do	do	Cy, W	D, S	1,336.7	45.22	8-23-57	
12-2-34bab	Bernard Gans	Dr	73.7	6	GI	Sand	Illinoisan terrace deposit	Cy, E	S	1,213.1	37.01	8-19-57	
*12-2-34ccb	Rena Kumle	Dr	44.4	6	GI	do	do	Cy, W	S	1,225.8	17.20	11-25-57	
*12-2-36aac	Mrs. Elmore Little	Dr	45.8	6	GI	do	Wisconsinan terrace deposit	Cy, H	D	1,191.8	22.10	8-19-57	
*12-3-1dba	City of Bennington	Dr	47.0	6	I	do	Illinoisan terrace deposit	T, E	P	1,237.6	18.90	8-16-57	Abandoned.
12-3-4bba	Frank Ewart	Dr	91.2	6	GI	Sandstone	Dakota Formation	Cy, E	S	1,275.8	65.02	12-3-57	
*12-3-5bca	G. B. Markley	Du	53.2		N	do	do	Cy, W	S	1,261.9	36.62	5-26-58	
*12-3-9ddd	B. R. McHatton	Dr	61.8	6	GI	do	do	Cy, H	D	1,269.0	44.76	5-24-58	
*12-3-10dad	Ralph J. Crow	Dr	69.3	6	I	do	do	Cy, H	N	1,233.7	34.64	8-22-57	
12-3-19bbc	John Briggs	Dr	109.9	6	GI	do	do	Cy, W	S	1,320.1	81.30	8-23-57	
12-3-20aaa	J. Harold Reed	Dr	61.4	6	GI	do	do	Cy, W	S	1,289.4	27.80	8-23-57	
*12-3-24bad	D. and A. W. Dodge	Dr	30.0	6	GI	do	do	Cy, W	S	1,236.4	20.06	5-26-58	
12-3-26adc	Fred Hamilton	Dr	60.6	6	P	do	do	J, E	D	1,330.7	37.86	8-22-57	
12-3-27aab	E. Gerard	Du	43.2			do	do	Cy, H	S	1,304.6	14.14	8-23-57	
12-3-29ccb	R. B. Smith	Dr	94.3	6	I	do	do	Cy, W	S	1,365.4	58.96	8-23-57	
12-3-34cbc	Frank Ahring	Dr	82.5	6	GI	do	do	Cy, W	S	1,296.8	28.73	8-23-57	
12-3-35ddd	L. Watson	Dr	40.0	6	GI	do	do	Cy, W	D	1,342.6	33.04	8-23-57	
12-3-36ddc	Mary Siler	Dr	72	6	GI	do	do	J, E	D	1,329.2	36	8-23-57	
12-4-1aaa	Richard Johnson	Du	51.0			do	do	J, E	D, S	1,285.2	42.78	8-23-57	
*12-4-1bbc	Kenneth Lancaster	Dr	100.0	6	GI	do	do	Cy, W	S	1,332.9	87.22	6-3-58	
12-4-7aaa	Richard Diedrick	Dr	118.7	8	GI	do	do	J, E	S	1,360.8	94.75	8-28-57	
*12-4-9abd	C. Dewey	Dr	92.8	6	GI	do	do	Cy, G	S	1,351.9	75.30	5-26-58	
*12-4-11cdd	C. Eikelberger	Dr	105.5	6	GI	do	do	Cy, W	S	1,361.1	69.17	12-19-57	
*12-4-19daa	P. G. Kepple	Du	24.5		N	Sand	Illinoisan terrace deposit	Cy, W	D, S	1,202.3	18.17	12-19-57	
*12-4-21bbc	P. B. Reed	Dr	38	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,300.4	22.85	6-3-58	

12-4-22ccc	V. E. Dunn	Du	21.3	....	N	do	do	Cy, W	S	1,278.9	16.38	8-28-57	
12-4-23aad	S. C. Nelson	Dr	77.0	8	GI	do	do	Cy, W	S	1,320.4	30.80	6-3-58	
*12-4-32ada	R. Thompson	Du	22.2	....	....	Sand	Wisconsinan terrace deposit	Cy, W	N	1,276.2	13.20	6-3-58	Abandoned.
*12-4-35bab	G. A. Schetrompf	Dn	34	2	GP	do	Illinoisan terrace deposit	Cy, H	D	1,254.3	13	6-3-58	
12-5-4bbc	P. C. Kepple	Dr	20.2	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,322.3	14.89	8-2-57	
*12-5-7cbc	F. Hake	Dr	34.6	6	GI	Sand	Wisconsinan terrace deposit	Cy, H	D	1,310.2	9.83	6-4-58	
*12-5-11dcd	Fred Berkley	Dr	59.0	6	GI	Sandstone	Dakota Formation	J, E	D	1,343.0	42.80	6-4-58	
12-5-15bca	City of Tescott	Dr	41.8	1.25	GP	Sand	Illinoisan terrace deposit	N	P	1,290.7	15.80	8-16-57	
*12-5-16bdd	do	Dr	49.5	8	S	do	do	T, E	P	1,296.0	13.11	8-16-57	
*12-5-19ada	Hope E. McFarland	Dr	41.5	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,304.9	9.32	5-20-58	
*12-5-26dcd	H. Leeburg	Dr	23	6	GI	Sand	Wisconsinan terrace deposit	Cy, H	N	1,293.5	16.90	5-20-58	Abandoned.
*12-5-28aba	R. Fischer	Dr	42.0	6	GI	Sandstone	Dakota Formation	Cy, W	S	1,313.2	18.97	5-20-58	
*12-5-30cbc	H. J. Berkley	Dr	85.0	6	GI	do	do	Cy, W	S	1,392.0	77.22	5-20-58	
*12-5-33cca	V. H. Phillip	Dr	64.0	6	GI	do	do	Cy, W	S	1,364.2	30.84	5-20-58	

1. Well-numbering system described in text.
2. B, bored well; DD, dug and drilled well; Dn, driven well; Dr, drilled well; Du, dug well; Du Dn, dug and driven well.
3. Reported depths of wells below land surface given in feet; measured depths given in feet and tenths.
4. B, brick; C, concrete; GI, galvanized sheet iron; GP, galvanized-iron pipe; N, none; R, rock; S, heavy steel or iron; T, tile; W, wood.
5. Method of lift: B, bucket; C, centrifugal; Cy, cylinder; E, endless chain with buckets; F, natural flow; J, jet; N, none; P, pitcher; T, turbine. Type of power: E, electric; G, gas engine; H, hand operated; T, tractor; W, windmill.
6. D, domestic; I, irrigation; In, industrial; N, not being used; O, observation; P, public supply; S, stock.
7. Measured depths to water in wells are given in feet, tenths, and hundredths; reported depths to water are given in feet. Depths to water in uncased test holes given in feet or feet and tenths.

* Chemical analysis given in Table 11.

LOGS OF WELLS AND TEST HOLES

The logs of 111 test holes and wells that were drilled in Ottawa County (Pl. 7) are given on the following pages. The holes were drilled mainly in the river valleys to determine the saturated thickness and character of the sediments, but a few were drilled to determine the thickness and extent of lithologic units. Logs of some very shallow holes are omitted. The test holes were drilled by the State Geological Survey.

9-2-18abb.—Sample log of test hole in NW NW NE sec. 18, T. 9 S., R. 2 W., on south side of road at north ¼ cor.; augered April 22, 1958. Depth to water, 36.5 feet; altitude of land surface, 1,353.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	5	5
Clay, silty, brown	10	15
Silt, clayey, brown	12	27
Sand, clayey, dark red	1	28
Sand, silty, clayey, brown	2	30
Silt, clayey, brown	4	34
CRETACEOUS		
Dakota Formation		
Clay, bluish gray	4	38
Clay, silty, brown	4	42
Silt, gray, saturated	13	55
Sand, silty, gray and brown	10	65

9-3-8ccc.—Sample log of test hole in SW SW SW sec. 8, T. 9 S., R. 3 W., at northeast corner of road intersection; augered April 23, 1958. Dry hole; altitude of land surface, 1,376.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	2	2
Clay, silty, light brown	7	9
Silt, yellowish brown	2	11
Silt, light brown	1	12
CRETACEOUS		
Dakota Formation		
Silt, light gray, hard	3	15

9-3-15aab.—Sample log of test hole in NW NE NE sec. 15, T. 9 S., R. 3 W., at south side of road 0.2 mile west of cor.; augered April 22, 1958. Depth to water, 20.9 feet; altitude of land surface, 1,346.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, brown	7	7
Silt, clayey, light brown, and fine sand	13	20
Silt, brown	5	25
Clay, silty, brown	5	30

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota Formation		
Clay, dark gray	27	57
Sandstone, coarse grained	1	58

9-3-17aba.—Sample log of test hole in NE NW NE sec. 17, T. 9 S., R. 3 W., 5 feet south of road; augered April 23, 1958. Dry hole; altitude of land surface, 1,392.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, silty, clayey, dark brown	5	5
Clay, silty, light brown	3	8
CRETACEOUS		
Dakota Formation		
Clay, some silt, light brown to pink	1	9

9-3-20bbb.—Sample log of test hole in NW NW NW sec. 20, T. 9 S., R. 3 W., at southeast edge of road intersection; augered April 22, 1958. Dry hole; altitude of land surface, 1,376.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, dark brown	2	2
Silt, clayey, light brown	3	5
Clay, silty, brown	2	7
Clay, light brown and pink	2	9
Silt, red	2	11
Silt, light brown	6	17
CRETACEOUS		
Dakota Formation		
Clay, silty, pink and white mottled	1	18

9-3-25cdd.—Sample log of test hole in SE SE SW sec. 25, T. 9 S., R. 3 W., at north side of road at south ¼ cor.; augered April 22, 1958. Depth to water, 14.2 feet; altitude of land surface, 1,318.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, light brown	5	5
Silt, clayey, dark brown	5	10
Silt, clayey, light brown	6	16
Clay, grayish brown	5	21
CRETACEOUS		
Dakota Formation		
Clay, bluish gray, dry	15	36
Clay, gray	14	50
Sand, fine to medium, and silt	20	70

9-3-27dad.—Drillers log of well drilled by J. G. Lassey for Wesleyan Methodist Church in SE NE SE sec. 27, T. 9 S., R. 3 W.; drilled August 8-9, 1947. Depth to water, 45 feet; altitude of land surface, 1,353.8 feet.

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota Formation		
Top soil	3	3
Gumbo, tight	3	6
Clay, red, soft	29	35
Sand, unconsolidated	21	56
Sand and gravel	9	65
Clay, blue	5	70
Sand	5	75

9-4-8cca.—Sample log of test hole in NE SW SW sec. 8, T. 9 S., R. 4 W., at depression 5 feet north of road, 75 feet west of bridge; augered April 17, 1958. Depth to water, 15.1 feet; altitude of land surface, 1,292.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, silty, medium brown	5	5
Silt, some clay and fine sand, quartzose, medium light brown	5	10
Silt, some clay, light brown	10	20
Silt, much fine rounded quartzose sand, thin hard zone at 28 feet, light brown	10	30
Silt, much fine to medium sand, light grayish brown	20	50
Silt, hard, some fine to medium sand, some dark minerals, medium to light gray; chert pebbles	0.5	50.5

9-4-8ccc.—Sample log of test hole in SW SW SW sec. 8, T. 9 S., R. 4 W., in center of road junction triangle; augered April 17, 1958. Depth to water, 23.7 feet; altitude of land surface, 1,300.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, some fine quartzose silt, medium to light brown	5	5
Silt, clayey, light brown	2	7
Clay, some silt, light brown	8	15
Clay, silty, light brown	5	20
Clay, sparse silt, light brown	15	35
Clay, silty, some fine to medium subrounded sand, light brown	15	50
Silt, clayey, much fine to medium subrounded quartzose sand, light brown	8	58
CRETACEOUS		
Dakota Formation		
Clay, dry, blue gray	1	59

9-4-10bcd.—Sample log of test hole in SE SW NW sec. 10, T. 9 S., R. 4 W., 10 feet northwest of Delphos Supply well; augered August 12, 1958. Depth to water, 35.5 feet; altitude of land surface, 1,321.9 feet. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, clayey, brown	5	5
Silt, clayey, light brown	10	15
Silt, clayey, reddish brown; some coarse sand	5	20
Clay, brown	5	25
Clay, silty, light brown	5	30
Silt, sandy, light brown	5	35
Sand, medium, rounded, light brown	5	40
Sand, medium to coarse, light brown	11	51
CRETACEOUS		
Dakota Formation		
Silt, hard, reddish brown	2	53

9-4-10ddc.—Sample log of test hole in SW SE SE sec. 10, T. 9 S., R. 4 W., 10 feet north of road; augered April 18, 1958. Depth to water, 35 feet; altitude of land surface, 1,325.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, clayey silt, dark brownish black	4	4
Clay, silty, light brown	6	10
Illinoisan terrace deposits		
Silt, much clay, light brown	2	12
Clay, some silt, light brown	2	14
Silt, some fine sand, angular to rounded, light brown	4	18
Sand, very fine to medium, angular to subrounded, quartzose, light brown	2	20
Sand, medium, some silt and clay, angular to subrounded, quartzose, partial hematite coating, reddish brown	9	29
Sand, medium to very coarse, much silt and clay, reddish brown	2	31
Sand, medium, some clay and silt, subangular, quartzose, unconsolidated, partial hematite coating, reddish brown	4	35
Silt, much medium sand, reddish brown	10	45
Clay, some silt and sand, indurated, very light brown	6	51
CRETACEOUS		
Dakota Formation		
Clay, some silt, mottled red, yellow, and light and dark gray	4	55

9-4-10ddd.—Sample log of test hole in SE SE SE sec. 10, T. 9 S., R. 4 W., 25 feet northwest of road intersection; augered April 18, 1958. Dry hole; altitude of land surface, 1,328.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, clayey silt, medium brown	1	1
Silt, (loess), angular, reddish brown	6	7
Silt, some clay and sand, quartzose, medium brown	6	13

Illinoisan terrace deposits	Thickness, feet	Depth, feet
Sand, medium, subangular to subrounded, quartzose, hematite coated, brownish red	2	15
Silt, some clay and sand, hematite coated, reddish brown	2	17
Silt, some clay and sand (very fine to medium), medium brown	5	22
Silt, quartzose, even textured, yellowish brown	3	25
Silt, much clay, light yellowish brown	2	27
CRETACEOUS		
Dakota Formation		
Clay, silty, very hard, brownish yellow	3	30

9-4-11ddd.—Sample log of test hole in SE SE SE sec. 11, T. 9 S., R. 4 W., 20 feet northwest of road intersection; augered April 23, 1958. Dry hole; altitude of land surface, 1,360.1 feet.

NEOGENE—Pleistocene Undifferentiated deposits	Thickness, feet	Depth, feet
Silt, clayey, dark brown	2	2
Silt, clayey, medium brown	3	5
Silt, some fine sand, reddish brown	2	7
Sand, fine to medium, brownish red	8	15
Clay, silty, some fine sand, reddish brown	1	16
Sand, clayey, silty, brownish red	2	18
Sand, medium to coarse, brownish red	4	22
Sand, much silt, yellow and gray	2	24
CRETACEOUS		
Dakota Formation		
Silt, hard, yellow	1	25

9-4-13aaa.—Sample log of test hole in NE NE NE sec. 13, T. 9 S., R. 4 W., at center of road intersection; augered April 23, 1958. Dry hole; altitude of land surface, 1,338.4 feet.

NEOGENE—Pleistocene Wisconsinan terrace deposits	Thickness, feet	Depth, feet
Clay, silty, light brown	7	7
Silt, clayey, yellowish brown	4	11
Silt, light gray	1	12
Silt, grayish green	3	15
Silt, yellowish brown	3	18
CRETACEOUS		
Dakota Formation		
Clay, light gray, hard	2	20

9-4-13ddd.—Sample log of test hole in SE SE SE sec. 13, T. 9 S., R. 4 W., 20 feet west northwest of road intersection; augered April 23, 1958. Depth to water, 35.8 feet; altitude of land surface, 1,389.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, silty, clayey, dark brown	3	3
Silt, clayey, medium brown	3	6
Silt, clayey, light brown	2	8
Silt, clayey, grayish green	3	11
Silt, much clay, medium brown	1	12
Silt, much clay, yellowish brown	4	16
Silt, some clay, dry, yellowish brown	4	20
Silt, some clay, dry, very light brown	10	30
Sand, fine to medium, yellowish brown	9	39
Silt, much clay, greenish brown	6	45
Sand, fine to medium, saturated, yellowish brown	8	53
CRETACEOUS		
Dakota Formation		
Clay, hard, dry, mottled shades of brown	1	54

9-4-15abb.—Sample log of test hole in NW NW NE sec. 15, T. 9 S., R. 4 W., 15 feet south of road; augered April 18, 1958. Depth to water, 28.4 feet; altitude of land surface, 1,321.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, silty, clayey, dark brown	5	5
Clay, silty, medium brown	7	12
Clay, silty, reddish brown	2	14
Silt, clayey, dry, reddish brown	1	15
Sand, much silt and clay, fine to coarse, unconsolidated, brownish red	3	18
Sand, medium to very coarse, some gravel, quartzose, some feldspathic, brownish red	7	25
Sand, very coarse, and fine gravel, unconsolidated, saturated near base	6	31
Sand, medium to coarse, light brown	4	35
Sand, coarse to very coarse, unconsolidated, quartzose, some feldspathic	8	43
Sand, medium to coarse, yellow brown	3	46
Sand, fine to medium, light brown	3	49
Sand, fine to medium, yellowish green	1	50
Sand, coarse to very coarse, and fine gravel, saturated, quartzose, some feldspathic	12.5	62.5
CRETACEOUS		
Dakota Formation		
Clay, hard, mottled light red and gray	0.5	63

9-4-15bba.—Sample log of test hole in NE NW NW sec. 15, T. 9 S., R. 4 W., 3 feet south of road; augered April 18, 1958. Depth to water, 23.8 feet; altitude of land surface, 1,310.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clayey silt and road fill, dark brown	7	7
Clay, silty, medium gray	3	10
Clay, silty, some rounded medium sand grains, light reddish brown	5	15
Silt, clayey, some rounded medium sand grains, light brown,	10	25
Silt, clayey, medium dark brown	5	30
Sand, fine to medium, quartzose, gray	3	33
Sand, coarse to very coarse, some silt, subrounded, quartzose, sparse feldspar, unconsolidated, brownish white	9.5	42.5
CRETACEOUS		
Dakota Formation		
Clay, silty, mottled red and gray	0.5	43

9-4-16baa.—Sample log of test hole in NE NE NW sec. 16, T. 9 S., R. 4 W., on west side of Maple St. 20 feet south of county route 404, Delphos; augered April 17, 1958. Depth to water, 23 feet; altitude of land surface, 1,301.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, some silt, medium brown	4	4
Clay, some silt, light brown	4	8
Clay, silty, light brown	4	12
Sand, silty, very fine to coarse, subrounded, quartzose, reddish brown. Some pink feldspar	3	15
Sand, fine to coarse, subangular to rounded, feldspathic, yellowish brown	3	18
Sand, fine to coarse, light yellowish brown	2	20
Sand, medium to very coarse, dry	3	23
Sand, medium to very coarse, saturated, feldspathic, light yellowish brown	9	32
CRETACEOUS		
Dakota Formation		
Clay, indurated, red and gray mottled	3	35

9-4-16bdd.—Drillers log of test hole drilled by O. S. Fent for City of Delphos in SE SE NW sec. 16, T. 9 S., R. 4 W., at west side of elevator; drilled August 5, 1954. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, dark gray	3	3
Silt and clay, compact, light gray brown	3	6
Silt, compact, light gray	3	9
Silt, sandy, brown	3	12
Sand, fine to medium, silty	3	15

	Thickness, feet	Depth, feet
Silt, brown and white	3	18
Sand, fine to medium	3	21
Sand, coarse to fine, and fine to medium gravel, some coarse,	9	30
CRETACEOUS		
Dakota Formation		
Clay, dark gray	2	32

9-4-16daa.—Drillers log of test hole drilled by O. S. Fent for City of Delphos in NE NE SE sec. 16, T. 9 S., R. 4 W., about 50 feet south of old city wells; drilled July 23, 1954. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Fill, silt, and sand	12	12
Sand, fine to medium	16	28
Sand, medium to fine, some coarse	2	30
CRETACEOUS		
Dakota Formation		
Clay, red and white	5	35
Clay, light gray	8	43
Sandstone, hard, pyritic	2	45
Sandstone, fine, silty, light gray	2	47
"Quartzite", sandstone, hard, calcareous	1	48

9-4-17aaa.—Sample log of test hole in NE NE NE sec. 17, T, 9 S., R. 4 W., 3 feet south of road, 0.1 mile west of corner; augered April 17, 1958. Depth to water, 18.0 feet; altitude of land surface, 1,301.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, some silt, medium to light brown	4	4
Clay, some silt, medium to light brown	11	15
Clay, some silt, medium brown	5	20
Silt, much clay, medium to light brown	5	25
Silt, clayey, light brown	10	35
Clay, silty, light brown	2	37
Illinoisan terrace deposits		
Silt, some clay, some fine quartzose and dark-mineral sand	2.5	39.5
CRETACEOUS		
Dakota Formation		
Clay, silty, blue gray. Contains flecks (less than 1 mm) of organic residue	0.5	40

9-4-18baa.—Sample log of test hole in NE NE NW sec. 18, T. 9 S., R. 4 W., 5 feet south of road; augered April 17, 1958. Depth to water, 21.8 feet; altitude of land surface, 1,299.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, silty, dark to medium brown	5	5
Clay, silty, light brown	5	10
Silt, clayey, angular, quartzose, light brown	5	15

	Thickness, feet	Depth, feet
Clay, silty, light brown	5	20
Clay, silty, very light brown	5	25
Clay, much fine silt, sparse sand, very light brown	12	37
Illinoisan terrace deposits		
Clay, hard, very silty, brownish gray	3	40
Silt, clayey, much sand, fine to coarse, medium gray	9	49
CRETACEOUS		
Dakota Formation		
Clay, hard, dark gray	0.5	49.5

9-4-18dba.—Drillers log of well drilled by George Cox for Ellis Paramore in NE NW SE sec. 18, T. 9 S., R. 4 W.; drilled April 26, 1956. Depth to water, 48.5 feet; altitude of land surface, 1,294.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Surface soil	3	3
Clay	12	15
Clay, soft	10	25
Clay, soft; trace of fine sand	5	30
Gravel, fine to coarse	15	45
CRETACEOUS		
Dakota Formation		
Clay, red and gray	5	50

9-4-24bbb.—Sample log of test hole in NW NW NW sec. 24, T. 9 S., R. 4 W., at southeast edge of road intersection; augered April 23, 1958. Depth to water, 21.9 feet; altitude of land surface, 1,319.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	7	7
Clay, silty, light grayish brown	3	10
Silt, clayey, light brown	5	15
Silt, clayey, dark brown	5	20
CRETACEOUS		
Dakota Formation		
Clay, silty, bluish gray	8	28
Clay, red and gray mottled	2	30

9-4-32abb.—Sample log of test hole drilled by U. S. Bureau of Reclamation in NW NW NE sec. 32, T. 9 S., R. 4 W.; drilled August 8, 1958. Depth to water, 10.0 feet. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, clayey, soft, dark	1.7	1.7
Silt, soft, brown	0.8	2.5
Clay, light, soft, brown	1	3.5
Silt, soft, brown to light brown	3.5	7

	Thickness, feet	Depth, feet
Silt, clayey, soft, light brown	1	8
Clay, light, soft, light brown	1	9
Clay, medium, compact, light brown	4	13
Clay, light, soft, light brown	2	15
Silt, clayey, soft, light brown	2	17
Silt, very soft, light brown	8	25
Silt, sandy, very soft, light brown	3	28
Sand, silty, fine, some medium, silt in layers, soft, brown	3	31
Silt, sandy, sand in layers, soft, brownish gray	3.5	34.5
Sand, fine, silty, some sandy silt bands, soft, brownish gray,	3	37.5
Sand, fine and medium, some coarse, dirty, loose, gray	10	47.5
Silt, sandy, clayey, soft, iron sulfide concretion, blue gray	0.7	48.2
CRETACEOUS		
Dakota Formation		
Sand, fine, silty, very compact, gray	0.6	48.8

9-4-33abb.—Sample log of test hole drilled by U. S. Bureau of Reclamation in NW NW NE sec. 33, T. 9 S., R. 4 W.; drilled August 5, 1958. Depth to water, 23.6 feet. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, soft, dark	1	1
Silt, soft, grayish brown	1.3	2.3
Silt, clayey, brownish gray	1.7	4
Clay, light, soft, gray	1	5
Clay, medium, compact, dark gray	2	7
Silt, clayey, soft, brown	0.5	7.5
Silt, soft, brown	6.5	14
Silt, sandy, soft, light brown, few limy nodules	7	21
Silt, slightly sandy, soft, light brown	5	26
Sand, silty, fine, soft, light brown	0.5	26.5
Silt, silty fine sand seams, soft, light brown	3.5	30
Silt, soft, blue gray	1.2	31.2
Sand, fine and medium, very dirty, brownish gray	3.8	35
Sand, fine and medium, very dirty silt chunks and clayey silt chunks, grayish brown	2	37
Silt, soft, blue gray, fine, some medium sand layers, gray	3	40
Sand, fine and medium, some coarse, few limestone fragments, slightly dirty, gray	3	43
Silt, sandy layers, soft, blue gray	2.5	45.5
Sand, fine to medium, dirty, gray	1.4	46.9
Silt, clayey, soft, blue gray	1.1	48
Sand, fine to coarse, gravel and limestone pebbles, dirty, gray	8.3	56.3
CRETACEOUS		
Dakota Formation		
Shale, trace of iron sulfide, firm, blue gray, thin seams of fine gray to red sand	2	58.3

9-4-33bba.—Sample log of test hole drilled by U. S. Bureau of Reclamation in NE NW NW sec. 33, T. 9 S., R. 4 W.; drilled August 8, 1958. Depth to water, 18.9 feet. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, soft, dark	1	1
Clay, soft, dark	2	3
Clay, soft, dark brown	1.3	4.3
Silt, soft, light brown	5.2	9.5
Silt, clayey, soft, light brown	1	10.5
Silt, soft, light brown	1	11.5
Clay, soft, light brown	1.5	13
Silt, clayey silt layers, soft, light brown	3	16
Clay, light brown	2	18
Silt, clayey silt layers, soft, light brown	2	20
Clay, light, soft, grayish brown	3	23
Silt, clayey, soft, brown	2	25
Silt, clayey silt layers, soft, brown	3.5	28.5
Clay, light to medium, soft, dark brownish gray	3	31.5
Clay, light, soft, gray	1.5	33
Silt, clayey, soft, gray	1.5	34.5
Silt, soft, light gray	2	36.5
Sand, fine, silty, soft, gray	0.5	37
Sand, fine and medium, some coarse, packed, dirty, brown,	4.5	41.5
Silt, soft, blue gray	1.5	43
Sand, fine and medium, some coarse, packed, dirty, grayish brown	5	48
Sand, fine to coarse, loose, slightly dirty, gray	3.6	51.6
CRETACEOUS		
Dakota Formation		
Sand, fine, packed, firm, light gray	0.8	52.4

9-4-35aaa.—Sample log of test hole in NE NE NE sec. 35, T. 9 S., R. 4 W., 20 feet southwest of intersection; augered April 22, 1958. Depth to water, 38.0 feet; altitude of land surface, 1,302.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, silty clay, dark brown	5	5
Soil, clayey silt, some medium quartz sand, medium brown,	2	7
Silt, some clay, reddish brown	5	12
Sand, medium coarse, subrounded, quartzose, hematitic coating, reddish brown	9	21
Sand, medium coarse, subrounded, quartzose, unconsolidated, light brown	10	31
Sand, medium coarse, some silt and clay, moist, light brown,	9	40
Sand, coarse to very coarse, (much interstitial silt and clay), subrounded, quartzose, very sparse feldspar, saturated, light brown	7	47
CRETACEOUS		
Dakota Formation		
Clay, mottled red and gray	1	48

9-4-36ccc.—Sample log of test hole in SW SW SW sec. 36, T. 9 S., R. 4 W., 20 feet east northeast of intersection; augered April 22, 1958. Dry hole; altitude of land surface, 1,306.3 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, silty, dark brown	2	2
Clay, silty, light brown	6	8
Silt, much clay, medium brown	2	10
Clay, some silt, light brown	2	12
Silt, some clay, light brown	8	20
Clay, silty, light brown	2	22
Silt, clayey, light brown	2	24
Clay, some silt, light brown	1	25
Clay, silty, light brownish gray	2	27
Silt, clayey, light grayish brown	3	30
Clay, silty, light grayish brown	2	32
Silt, much clay, light grayish brown	2	34
Sand, medium coarse, some silt, dry	1	35
Kansan Stage(?) deposits		
Silt, fine to medium sand, and some clay, dry, light grayish white	1	36
Sand, medium to very coarse, clean, dry	2	38
Sand, medium to very coarse, dry, feldspathic, light brown,	2	40
Silt, much clay, light gray	2	42
Clay, much silt, light gray	1	43
Sand, medium to very coarse, and fine gravel	11	54
CRETACEOUS		
Dakota Formation		
Silt, clayey, hard, medium brown	1	55

9-4-36ddd.—Sample log of test hole in SE SE SE sec. 36, T. 9 S., R. 4 W., at northwest edge of intersection; augered April 22, 1958. Dry hole; altitude of land surface, 1,329.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	5	5
Silt, clayey, light grayish brown	2	7
Clay, silty, light brown	3	10
Silt, clayey, light brown	1	11
Silt, light gray	1	12
CRETACEOUS		
Dakota Formation		
Sand, fine to coarse, dry	1	13

9-5-7ddd.—Sample log of test hole in SE SE SE sec. 7, T. 9 S., R. 5 W., about 100 yards west of cor.; drilled February 25, 1958. Depth to water, 132.0 feet; altitude of land surface, 1,597.3 feet.

	Thickness, feet	Depth, feet
CRETACEOUS		
Carlile Shale		
Silt, sandy, brown	3	3
Limestone, impure, brownish yellow	3	6
Shale, clayey, bentonitic, dark green	10	16
Greenhorn Limestone		
Limestone, chalky, white	4	20
Limestone, crystalline, hard, white	2	22
Limestone, hard, iron stained, brown	2	24
Limestone, chalky, soft, white	6	30
Limestone, crystalline and chalky beds, white	6	36
Shale, clayey, calcareous, gray	4	40
Limestone, hard and soft beds	10	50
Shale, calcareous, dark gray	5	55
Limestone, gray chalky and white crystalline beds	13	68
Limestone, chalky; bentonite; pyrite	2	70
Limestone, shaly, gray	10	80
Shale, calcareous, gray; thin tan limestone bed	5	85
Limestone, hard, white; bentonite	5	90
Graneros Shale		
Shale, noncalcareous, black	15	105
Shale, fissile, black; bentonite	14	119
Shale, black; pyrite	1	120
Shale, fissile, black	8	128
Dakota Formation		
Clay, hard, yellow; pyrite	12	140
Clay, sandy, lignitic, gray	10	150
Clay, light gray	11	161
Sand, fine, subrounded, quartzose	29	190
Clay, lignitic, light gray	11	201
Clay, lignitic, hard, dark green	14	215
Sand, fine, well rounded, quartzose	6	221
Clay, light gray	4	225
Clay, red and red-gray mottled	15	240
Clay, white	7	247
Clay, shaly, dark gray	5	252
Clay, white and red-yellow mottled	10	262
Clay, white; pyrite zone	11	273
Clay, red	4	277
Clay, white and red mottled	14	291
Clay, white and red, lignitic	19	310
Clay, red and white; thin black shale stringers	9	319
Sand, fine to medium, quartzose	46	365
Clay, white	5	370

9-5-12dcc.—Sample log of test hole in SW SW SE sec. 12, T. 9 S., R. 5 W., 5 feet north of road; augered April 17, 1958. Depth to water, 20.0 feet; altitude of land surface, 1,310.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, very silty, medium brown	8	8
Clay, silty, light brown	3	11
Clay, silty, light reddish brown	5	16
Illinoisan terrace deposit		
Clay, very silty, almost equal amounts of each, sparse fine sand, reddish brown	9	25
Clay, very silty, light reddish brown	13	38
Silt, clayey, some fine sand, light brown	1	39
CRETACEOUS		
Dakota Formation		
Clay, hard, mottled red and gray	1	40

9-5-12ddd.—Sample log of test hole in SE SE SE sec. 12, T. 9 S., R. 5 W., 25 feet north northwest of center of intersection; augered April 17, 1958. Depth to water, 22.0 feet; altitude of land surface, 1,299.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, some silt, medium brown	8	8
Clay, silty, medium to light brown	5	13
Clay, silty, light brown	15	28
Clay, some silt, light brown	2	30
CRETACEOUS		
Dakota Formation		
Clay, hard, medium gray	3	33

9-5-14ccd.—Sample log of test hole in SE SW SW sec. 14, T. 9 S., R. 5 W., about 20 yards southeast of southernmost curve in road; drilled March 24, 1958. Depth to water, 112.5 feet; altitude of land surface, 1,604.9 feet.

	Thickness, feet	Depth, feet
CRETACEOUS		
Greenhorn Limestone		
Clay, silty, dark brown	6	6
Limestone, chalky, soft, white and yellow brown	4	10
Limestone, thin crystalline and chalky beds, white	20	30
Limestone, thin hard crystalline and soft chalky beds; thin bentonite beds	12	42
Graneros Shale		
Shale, fissile, noncalcareous; thin pyrite zones	18	60
Shale, fissile, thin pyrite zones, black	17	77
Dakota Formation		
Clay, dark gray	13	90
Clay, soft and hard zones, gray	20	110
Clay, gray; pyrite zones	10	120
Sand, fine, quartzose	47	167
Clay, light gray	22	189

	Thickness, feet	Depth, feet
Clay, red and gray mottled; pyrite zones	16	205
Silt, light brown, hard zones	32	237
Clay, light gray	6	243
Clay, red and gray mottled	30	273
Clay, greenish gray, thin pyrite zones	11	284
Sand, subangular, fine, quartzose	14	298
Clay, red	9	307
Clay, light gray	4	311
Sand, fine, quartzose	4	315
Clay, red, hard and soft zones	17	332
Clay, shaly, hard, dark gray	4	336
Clay, white	11	347
Clay, shaly, hard, dark greenish gray	14	361
Clay, red	3	364
Clay, light gray	6	370
Clay, red and gray mottled	14	384
Sand, fine, subangular, unconsolidated, quartzose	6	390
Clay, red; some pyrite	3	393
Clay, light gray	12	405
Kiowa Shale		
Shale, silty, grayish green; some pyrite	31	436
Sand, fine, subrounded, quartzose	8	444
Shale, clayey, fissile, dark green	1	445

10-2-28acd.—Drillers log of well drilled by J. G. Lassey for Fred Windhorst in SE SW NE sec. 28, T. 10 S., R. 2 W.; drilled February 21-22, 1951. Depth to water, 62.10 feet; altitude of land surface, 1,406.2 feet.

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota Formation		
Soil and subsoil	5	5
Clay, yellow	10	15
Shale, gray	45	60
Clay, siliceous, gray	5	65
Sandrock, gray	2	67
Clay, blue	23	90
Clay, yellow	5	95
Clay, gray	15	110
Sandstone, cap rock	10	120
Clay, blue	1	121

10-3-8dcc.—Sample log of test hole in SW SW SE sec. 8, T. 10 S., R. 3 W., on north side of road at intersection; augered April 21, 1958. Depth to water, 14.0 feet; altitude of land surface, 1,279.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	2	2
Silt, light brown	5	7

	Thickness, feet	Depth, feet
Clay, silty, dark brown	3	10
Clay, brown	5	15
Clay, silty, light brown	2	17
CRETACEOUS		
Dakota Formation		
Clay, hard, dry, blue gray	1	18
Sand, medium, unconsolidated	12	30

10-3-17acb.—Sample log of test hole in NW SW NE sec. 17, T. 10 S., R. 3 W., about 100 feet west of bridge on south side of road; augered April 21, 1958. Depth to water, 13.0 feet; altitude of land surface, 1,278.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Recent alluvium		
Clay, sandy, brown	7	7
Silt, light brown	2	9
Sand, fine to medium, dry	3	12
Sand, clayey	4	16
Clay, silty, dark brown	4	20
CRETACEOUS		
Dakota Formation		
Clay, light gray	13	33
Sand, medium, unconsolidated	22	55

10-3-18aaa.—Sample log of test hole in NE NE NE sec. 18, T. 10 S., R. 3 W., on south edge of road at intersection; augered April 21, 1958. Depth to water, 45.2 feet; altitude of land surface, 1,313.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, dark brown	3	3
Clay, light brown	2	5
Silt, clayey, brown	5	10
Clay, brown	3	13
Clay, silty, light brown	4	17
Sand, medium, well sorted, dry	3	20
Clay, silty, reddish brown	1	21
Sand, medium to coarse	3	24
Clay, silty, light brown	6	30
Silt, clayey, brown	12	42
Sand, clayey, coarse	3	45
Sand, silty, brown	2	47
CRETACEOUS		
Dakota Formation		
Sand, medium to coarse, saturated	6	53

10-3-18abb.—Sample log of test hole in NW NW NE sec. 18, T. 10 S., R. 3 W., 3 feet south of county road; augered April 22, 1958. Dry hole; altitude of land surface, 1,322.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, silty, clayey, dark brown	5	5
Clay, silty, medium to dark brown	3	8
Silt, sandy, some clay, soil structure, yellowish brown	5	13
Sand, medium to coarse, quartzose, well sorted, yellowish brown	1	14
CRETACEOUS		
Dakota Formation		
Clay, hard, white to green	2	16
Clay, hard, light red	1	17

10-3-18ccc.—Sample log of test hole in SW SW SW sec. 18, T. 10 S., R. 3 W., about 10 feet northeast of road intersection; augered April 18, 1958. Dry hole; altitude of land surface, 1,306.3 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, dark brown	5	5
Silt, clayey, brown	2	7
Clay, silty, light yellowish green	7	14
Silt, clayey, light brown	3	17
Clay, yellowish green, hard	1	18
Sand, medium to coarse, well sorted, unconsolidated	7	25
Sand, coarse, and gravel, dry	9	34
Sand, medium, brown	4	38
CRETACEOUS		
Dakota Formation		
Siltstone, hard, light brown, dry	2	40

10-3-18cdc.—Sample log of test hole in SW SE SW sec. 18, T. 10 S., R. 3 W., 10 feet north of road in farm road; augered April 21, 1958. Dry hole; altitude of land surface, 1,318.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, dark brown	1	1
Clay, silty, light brown	4	5
Clay, silty, medium brown	4	9
Clay, much silt, dark brown	1	10
Clay, very silty, medium brown	2	12
Silt, some clay, light brown	1	13
CRETACEOUS		
Dakota Formation		
Clay, red and gray mottled	5	18

10-3-19aaa.—Sample log of test hole in NE NE NE sec. 19, T. 10 S., R. 3 W., on south side of road about 0.1 mile west of cor.; augered April 21, 1958. Depth to water, 11.0 feet; altitude of land surface, 1,271.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, brown	7	7
Silt, sandy, dry, brown	6	13
Sand, fine, and silt, light brown	3	16
Sand and gravel	7	23
CRETACEOUS		
Dakota Formation		
Silt, clayey, brown	2	25

10-3-19abb.—Sample log of test hole in NW NW NE sec. 19, T. 10 S., R. 3 W., on south side of road at north ¼ cor.; augered April 21, 1958. Depth to water, 30.6 feet; altitude of land surface, 1,295.0 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, brown	5	5
Silt, light brown	2	7
Silt, much sand, reddish brown	6	13
Clay, silty, light reddish brown	6	19
Silt, light brown	8	27
Sand, medium, reddish brown	3	30
Sand, medium and coarse, saturated	7	37
CRETACEOUS		
Dakota Formation		
Clay, red and gray mottled	1	38

10-4-2ddd.—Sample log of test hole in SE SE SE sec. 2, T. 10 S., R. 4 W., 15 feet west northwest of intersection; augered April 22, 1958. Dry hole; altitude of land surface, 1,307.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clayey silt, dark brown	3	3
Clay, silty, light brown	2	5
Clay, much silt, light brown	2	7
Clay, silty, light to medium brown	2	9
Silt, much clay, some fine rounded sand, light brown	2	11
Silt, clayey, some fine to medium sand, light brown	1	12
Sand, fine to coarse, silty, quartzose, light brown	2	14
Silt, clayey, and fine to medium sand, light brown	8	22
Clay, some silt, very light brown	3	25
Clay, sparse silt, very light brown	3	28
Clay, sparse silt, very light gray	2	30
Clay, silty, very light gray	2	32
Kansan Stage deposits		
Volcanic ash (Pearlette Ash), weathered, some silt	1	33

	Thickness, feet	Depth, feet
Clay, silty, some ash, very light gray	5	38
Sand, medium to coarse, some clay, light gray	2	40
Clay, silty, light gray	1	41
Sand, medium to coarse, quartzose, some feldspar	3	44
Sand, medium to very coarse, quartzose, some coarse feldspar; some fine gravel; limestone pebbles containing disseminated black flecks, may be derived from Greenhorn Limestone	6	50
Sand, medium to very coarse, subrounded, quartzose; some fine gravel, some feldspar pebbles	5	55
CRETACEOUS		
Dakota Formation		
Clay, hard, light brown	1	56

10-4-12aaa.—Sample log of test hole in NE NE NE sec. 12, T. 10 S., R. 4 W., at southwest edge of intersection; augered April 23, 1958. Dry hole; altitude of land surface, 1,317.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	5	5
Clay, silty, grayish green	7	12
Silt, sandy, light brown	5	17
Silt, sandy, brown	7	24
Silt, sandy, light brown	12	36
Sand, coarse, silty, yellowish brown	8	44
CRETACEOUS		
Dakota Formation		
Clay, gray, hard, dry	1	45

10-4-12ddd.—Sample log of test hole in SE SE SE sec. 12, T. 10 S., R. 4 W., 15 feet west northwest of intersection; augered April 18, 1958. Dry hole; altitude of land surface, 1,323.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, clayey silt, dark brown	2	2
Clay, silty, hematitic flecks, light gray	5	7
Clay, silty, indurated, medium brown	7	14
Clay, silty, light brown	3	17
Sand, medium, well sorted, subrounded, quartzose; carbonaceous encrustations, light brown	2	19
CRETACEOUS		
Dakota Formation		
Clay and much well-rounded quartzose silt, indurated, medium pink	1	20

10-4-24dcc.—Sample log of test hole in SW SW SE sec. 24, T. 10 S., R. 4 W., on north edge of road 0.4 mile west of cor.; augered April 18, 1958. Dry hole; altitude of land surface, 1,292.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, brown	5	5
Clay, silty, light brown	3	8
Clay, silty, brown	4	12
Clay, sandy, dark brown	4	16
CRETACEOUS		
Dakota Formation		
Clay, sandy, silty	9	25

10-4-25cdc.—Sample log of test hole in SW SE SW sec. 25, T. 10 S., R. 4 W., 0.3 mile east of cor. on north edge of road; augered April 23, 1958. Dry hole; altitude of land surface, 1,275.4 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, clay, some silt, medium brown	5	5
Clay, silty, medium brown	5	10
Illinoisan terrace deposits		
Silt, much clay, sparse fine sand, medium brown	4	14
Sand, fine to medium, much silt, medium brown	4	18
Silt, much clay, medium brown	4	22
Silt, well sorted, coarse, quartzose, reddish brown	7	29
Sand, fine to medium, hematite coating	7	36
Sand, much silt and clay, reddish brown	4	40
Clay, hard, light and dark brown	3	43
CRETACEOUS		
Dakota Formation		
Clay, hard, bluish gray	1	44

10-4-25ddd.—Sample log of test hole in SE SE SE sec. 25, T. 10 S., R. 4 W., 5 feet north of road 50 feet west of intersection; augered April 23, 1958. Depth to water, 22.0 feet; altitude of land surface, 1,258.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, very silty, dark brown	5	5
Clay, silty, light brown	8	13
Clay, silty, very light brown	7	20
Clay, some silt, sparse fine sand, light brown	5	25
Clay, grayish brown	1	26
Silt, much clay, medium brown	4	30
Clay, some silt, sparse fine sand	9	39
Silt, much clay, some fine to medium sand, grayish brown,	4	43
CRETACEOUS		
Dakota Formation		
Clay, silty, sandy, hard, medium gray	2	45

10-4-26aaa.—Sample log of test hole in NE NE NE sec. 26, T. 10 S., R. 4 W., on southwest side of road curve; augered April 8, 1958. Depth to water, 29.5 feet; altitude of land surface, 1,273.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Clay, silty, brown	4	4
Silt, clayey, brown, dry	2	6
Clay, silty, light brown	8	14
Silt, light brown	6	20
Sand and gravel, dry	9	29
Sand, unconsolidated, saturated	6	35
CRETACEOUS		
Dakota Formation		
Clay, silty, gray and brown, indurated	5	40

10-4-26abb.—Sample log of test hole in NW NW NE sec. 26, T. 10 S., R. 4 W., 10 feet south of road; augered April 8, 1958. Depth to water, 26.1 feet; altitude of land surface, 1,271.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, silty, dark gray	3	3
Clay, silty, light brown	4	7
Clay, silty, some fine to medium sand, light brown	5	12
Silt, light brown, and medium-gray clay	4	16
Sand, medium, unconsolidated, dry, reddish brown	9	25
Sand, medium to very coarse, some fine gravel	14	39
CRETACEOUS		
Dakota Formation		
Clay, hard, dark gray	11	50

10-4-26bbb.—Sample log of test hole in NW NW NW sec. 26, T. 10 S., R. 4 W., at northwest edge of road curve; augered April 8, 1958. Depth to water, 24.1 feet; altitude of land surface, 1,268.3 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Clay, silty, dark brown	3	3
Silt, light brown	9	12
Silt, clayey, brown	5	17
Silt, clayey, light brown, dry	10	27
Sand and gravel, very coarse	7	34
CRETACEOUS		
Dakota Formation		
Clay, silty, gray	6	40

10-4-27dcc.—Sample log of test hole in SW SW SE sec. 27, T. 10 S., R. 4 W., 15 feet north of road at east end of bridge; augered April 24, 1958. Depth to water, 21.5 feet; altitude of land surface, 1,262.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Recent alluvium		
Silt, well sorted, quartzose, some dark minerals, medium to light brown	18	18
Silt, well sorted, some clay, light brown	2	20
Wisconsinan terrace deposits		
Sand, fine to medium, much silt	5	25
Silt, much fine to medium sand	15	40
Silt, much fine to medium sand, thin clay zone at 44 feet, light gray	4	44
CRETACEOUS		
Dakota Formation		
Sand, medium to coarse, some silt, very few dark minerals,	26	70

10-4-28cdd.—Sample log of test hole in SE SE SW sec. 28, T. 10 S., R. 4 W., on north edge of road; augered April 24, 1958. Depth to water, 10.0 feet; altitude of land surface, 1,254.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, silty, dark brown	5	5
Clay, silty, light brown	10	15
Silt, clayey, light brown	4	19
Silt, clayey, some fine sand, light brown	11	30
Silt, some clay, light brown	9	39
Silt, some fine sand, dark minerals	7	46
CRETACEOUS		
Dakota Formation		
Sand, fine to medium, much silt	9	55
Sand, fine to coarse, some silt and clay	10	65

10-4-28ddd.—Sample log of test hole in SE SE SE sec. 28, T. 10 S., R. 4 W., 30 feet west northwest of intersection; augered April 24, 1958. Depth to water, 20 ± feet; altitude of land surface, 1,259.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, silty, dark brown	2	2
Silt, clayey, light brown	3	5
Silt, much clay, medium brown	2	7
Silt, much clay, light brown	6	13
Clay, very silty, light brown	7	20
Silt, angular, quartzose, some feldspar, chlorite(?), and dark minerals, some clay, light brown	27	47

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota Formation		
Sand, coarse, gray; contains pyrite	3	50
Clay, hard, light gray	12	62
Pyrite zone	1	63
Sand, very fine; pyrite present	37	100

10-4-29cdd.—Sample log of test hole in SE SE SW sec. 29, T. 10 S., R. 4 W., 5 feet north of road; augered April 24, 1958. Depth to water, 8.8 feet; altitude of land surface, 1,257.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, silty, dark gray	5	5
Silt, clayey, medium brown	10	15
Clay, much silt, saturated, light brown	10	25
Silt, clayey, saturated, light brown	10	35
Illinoisan terrace deposits		
Silt and medium sand, light gray and brown	10	45
CRETACEOUS		
Dakota Formation		
Sand, medium to coarse, and silt, bluish gray	10	55

10-4-30dcc.—Sample log of test hole in SW SW SE sec. 30, T. 10 S., R. 4 W., 5 feet north of road; augered April 24, 1958. Depth to water, 27.9 feet; altitude of land surface, 1,280.3 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Soil, silty, clayey, medium brown	5	5
Silt, some clay, light brown	2	7
Silt, clayey, medium brown	5	12
Wisconsinan terrace deposits		
Silt, some clay, reddish brown	5	17
Silt, some clay, medium brown	3	20
Silt, much clay, light brown	7	27
Silt, some clay, reddish brown	2	29
Illinoisan terrace deposits		
Sand, fine, silty, light brown	4	33
Sand, fine to medium, light brown	14	47
Clay, very hard, light gray	1	48

10-4-30ddd.—Sample log of test hole in SE SE SE sec. 30, T. 10 S., R. 4 W., 50 feet north and 200 feet west of cor.; augered April 24, 1958. Depth to water, 15.0 feet; altitude of land surface, 1,259.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, silty, dark brown	2	2
Clay, silty, medium brown	8	10
Silt, clayey, light brown	6	16
Clay, silty, medium brown	4	20

	Thickness, feet	Depth, feet
Silt, some clay, light brown	7	27
Silt, much fine sand, light brown	3	30
Illinoisan terrace deposits		
Clay, very silty, grayish brown	5	35
Silt, much clay, dark gray	10	45
Clay, greenish gray	2	47
CRETACEOUS		
Dakota Formation		
Sand, medium to coarse, some fine, light brown	3	50
Sand, medium to coarse, saturated	10	60

10-4-33bbb.—Sample log of test hole in NW NW NW sec. 33, T. 10 S., R. 4 W., 20 feet southeast of intersection; augered April 24, 1958. Depth to water, 11.7 feet; altitude of land surface, 1,257.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, clay, silty, dark brown	2	2
Clay, silty, medium brown	3	5
Clay, silty, light brown	4	9
Clay, silty, medium brown	5	14
Illinoisan terrace deposits		
Silt, some fine sand, light brown	1	15
Clay, much silt, light brown	10	25
Silt, clayey, some fine sand	5	30
Silt, some clay and fine sand, light brown	10	40
Silt, much fine to medium sand	9	49
CRETACEOUS		
Dakota Formation		
Sand, fine to very coarse, some silt, quartzose, light brown,	7	56
Clay, hard, bluish gray	1	57

10-4-35aaa.—Sample log of test hole in NE NE NE sec. 35, T. 10 S., R. 4 W., on south edge of road 75 feet west of intersection; augered April 23, 1958. Depth to water, 20.5 feet; altitude of land surface, 1,265.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, silty, dark brown	3	3
Clay, silty, light brown	5	8
Clay, silty, medium brown	2	10
Sand, medium to very coarse, quartzose, subangular to rounded, some silt	6	16
Sand, medium to very coarse, quartzose, some feldspar, much silt	6	22
Sand, medium to very coarse, angular to rounded, silty	3	25
Sand, fine to very coarse, clayey, silty, some feldspar; dark minerals include tourmaline and magnetite	10	35
CRETACEOUS		
Dakota Formation		
Clay, silty, hard, light brown	1	36

10-4-35abb.—Sample log of test hole in NW NW NE sec. 35, T. 10 S., R. 4 W., on north edge of road; augered April 23, 1958. Depth to water, 26 + feet; altitude of land surface, 1,265.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Soil, clay, silty, medium brown	5	5
Silt, clayey, medium brown	2	7
Silt, some clay, dry, medium brown	6	13
Silt, clayey, brownish red	2	15
Clay, silty, medium dark brown	2	17
Clay, silty, light brown	2	19
Silt, much clay, yellow	1	20
Silt and fine sand, dry, yellowish brown	3	23
Silt and fine sand, light brown	6	29
Sand, medium, some silt, saturated	4	33
CRETACEOUS		
Dakota Formation		
Clay, light brown and gray	1	34

10-4-35bbb.—Sample log of test hole in NW NW NW sec. 35, T. 10 S., R. 4 W., 15 feet southeast of intersection; augered April 23, 1958. Depth to water, 25.0 feet; altitude of land surface, 1,264.0 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Soil, silt, some fine to medium sand, and some clay, medium brown	5	5
Sand, fine to medium, much silt	2	7
Clay, much silt, medium brown	3	10
Clay, silty, light brown	5	15
Silt, some clay, light brown	3	18
Illinoisan terrace deposits		
Sand, fine to medium, subrounded, quartzose, clean	7	25
Sand, coarse to very coarse, and fine to medium gravel, quartzose, some feldspar, magnetite, calcite, and dark minerals, saturated	10	35
CRETACEOUS		
Dakota Formation		
Clay, hard, dry, gray	0.5	35.5

10-5-4ddd.—Sample log of test hole in SE SE SE sec. 4, T. 10 S., R 5 W., about 100 feet west of cor.; drilled April 14, 1958. Depth to water, 80.0 feet; altitude of land surface, 1,483.4 feet.

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota Formation		
Silt, clayey, brown	3	3
Clay, silty, light brown	2	5
Clay, light gray	5	10
Silt, light brown	3	13
Clay, light gray	15	28
Silt, light brown	6	34

	Thickness, feet	Depth, feet
Clay, gray	4	38
Silt, sandy, light brown	6	44
Clay, light gray	3	47
Clay, red and gray mottled	6	53
Clay, light gray	5	58
Clay, yellow and red mottled	4	62
Sand, very fine to fine, quartzose	18	80
Sand, fine, subrounded, quartzose	10	90
Sand, medium, subangular to rounded	20	110
Sand, medium to coarse, unconsolidated	8	118
Clay, light gray	2	120
Sand, medium, unconsolidated, quartzose	61	181
Clay, light and dark gray, lignitic; pyrite zones	35	216
Sand, fine, unconsolidated	9	225
Clay, light gray and red, lignitic	11	236
Clay, gray, hard	10	246
Sand, very fine to fine, unconsolidated	39	285
Silt, clayey, lignitic, gray	16	301
Clay, shaly, dark greenish gray	9	310
Shale, fissile, black	3	313
Clay, light gray	20	333
Clay, yellowish brown	1	334
Clay, light gray	6	340
Clay, reddish brown	3	343
Clay, red and gray mottled and gray	7	350
Clay, reddish brown	3	353
Kiowa Shale		
Shale, clayey, grayish green, hard	17	370
Clay, sandy, light gray, fissile	10	380
Sand, fine, quartzose; pyrite	7	387
Clay, white, soft; sandy zones	9	396
Sand, fine to medium, quartzose	19	415
Clay, light gray, hard	6	421

10-5-25bcc.—Sample log of test hole in SW SW NW sec. 25, T. 10 S., R. 5 W., at east edge of road 0.5 mile south of cor.; augered April 29, 1958. Depth to water, 23.0 feet; altitude of land surface, 1,287.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	7	7
Silt, clayey, reddish brown	5	12
Silt, clayey, light brown	8	20
Silt, clayey, medium brown	5	25
Silt, brown, and fine sand	5	30
Sand, fine to medium, and light-brown clay	5	35
CRETACEOUS		
Dakota Formation		
Sand, medium, light gray and brown, silty	8	43
Clay, sandy, bluish gray	5	48

10-5-25dcc.—Sample log of test hole in SW SW SE sec. 25, T. 10 S., R. 5 W., at north edge of road 0.5 mile west of cor.; augered April 24, 1958. Depth to water, 18.5 feet; altitude of land surface, 1,275.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	5	5
Clay, silty, brown	2	7
Silt, brown	3	10
Wisconsinan terrace deposits		
Silt, clayey, light brown	6	16
Illinoisan terrace deposits		
Sand, fine, and silt	4	20
Sand, fine and medium	30	50
Sand, medium and coarse	18	68
CRETACEOUS		
Dakota Formation		
Sand, clayey, gray	2	70

10-5-26aaa.—Sample log of test hole in NE NE NE sec. 26, T. 10 S., R. 5 W., at southwest edge of intersection; augered April 29, 1958. Dry hole; altitude of land surface, 1,301.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, brown	5	5
Silt, clayey, light brown	3	8
Silt, reddish brown	7	15
Silt, clayey, brown	10	25
CRETACEOUS		
Dakota Formation		
Clay, red and gray mottled	5	30

10-5-35aaa.—Sample log of test hole in NE NE NE sec. 35, T. 10 S., R. 5 W., at west edge of road about 50 feet south of cor.; augered April 29, 1958. Depth to water, 13.3 feet; altitude of land surface, 1,270.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	5	5
Clay, silty, brown	2	7
Silt, clayey, brown	5	12
Silt, brown	8	20
Silt, light brown	5	25
Illinoisan terrace deposits		
Sand, fine to medium	10	35
CRETACEOUS		
Dakota Formation		
Silt, light gray	1	36

10-5-36aaa.—Sample log of test hole in NE NE NE sec. 36, T. 10 S., R. 5 W., about 100 feet south of intersection; augered April 24, 1958. Depth to water, 7.8 feet; altitude of land surface, 1,261.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Recent alluvium		
Silt, clayey, brown	5	5
Wisconsinan terrace deposits		
Silt, brown	8	13
Illinoisan terrace deposits		
Sand, fine, and silt	11	24
Clay, gray, hard	4	28

10-5-36bcc.—Sample log of test hole in SW SW NW sec. 36, T. 10 S., R. 5 W., on east side of road; augered April 29, 1958. Depth to water, 9.6 feet; altitude of land surface, 1,266.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Clay, silty, dark brown	5	5
Silt, much clay, medium to dark brown	5	10
Silt, clayey, medium brown	8	18
Silt, clayey, grayish brown	2	20
Silt, some clay, light brown	10	30
Silt and fine sand, grayish brown	10	40
Sand, fine to medium, saturated	16	56
CRETACEOUS		
Dakota Formation		
Clay, sandy, gray and green	4	60

10-5-36ccc.—Sample log of test hole in SW SW SW sec. 36, T. 10 S., R. 5 W., about 10 feet northeast of cor.; augered April 29, 1958. Depth to water, 10.0 feet; altitude of land surface, 1,271.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, light brown	5	5
Silt, brownish gray	2	7
Clay, silt, and fine sand, light brown	4	11
Silt, light brown	14	25
Silt and fine sand, light brown	5	30
Silt and fine sand, light gray	28	58
CRETACEOUS		
Dakota Formation		
Sand, medium, silty, gray	12	70

11-2-8dbb.—Sample log of test hole in NW NW SE sec. 8, T. 11 S., R. 2 W., at west edge of road, 40 feet west of public well, east side of lake, near center sec. 8; augered May 28, 1958. Depth to water, 14.7 feet; altitude of land surface, 1,308.9 feet. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota Formation		
Sand, fine to medium, poorly consolidated, yellowish brown,	45	45

11-3-21bdd.—Sample log of test hole in SE SE NW sec. 21, T. 11 S., R. 3 W., 10 feet southeast of irrigation well and about 60 feet south of railroad tracks; augered Oct. 13, 1958. Depth to water, 16.6 feet; altitude of land surface, 1,233.0 feet. (Location not shown on Plate 7.)

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, clayey, dark brown	2	2
Silt, brown	3	5
Silt, clayey, brown	2	7
Silt, light brown	6	13
Silt, brown	7	20
Sand, fine, silty, clayey, light brown	10	30
Sand, fine to medium	5	35
Sand, medium	10	45
Sand, medium to coarse	5	50
Sand, coarse, and fine gravel	5	55
Gravel, coarse	0.5	55.5
CRETACEOUS		
Dakota Formation	0.3	55.8

11-3-25cdd.—Sample log of test hole in SE SE SW sec. 25, T. 11 S., R. 3 W., at north side of road about 0.45 mile east of cor.; augered April 30, 1958. Depth to water, 19.6 feet; altitude of land surface, 1,247.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	5	5
Clay, silty, brown	5	10
Illinoisan terrace deposits		
Sand, medium, silty, reddish brown	5	15
Silt, light brown	6	21
Sand, medium to coarse, light brown	9	30
Sand, coarse, and gravel	8	38
CRETACEOUS		
Dakota Formation		
Clay, dry, hard, dark gray	1	39

11-3-26dcc.—Sample log of test hole in SW SW SE sec. 26, T. 11 S., R. 3 W., on north edge of road about 0.45 mile west of cor.; augered April 30, 1958. Depth to water, 13.4 feet; altitude of land surface, 1,232.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, clayey, dark brown	8	8
Silt, light brown	12	20
Clay, sandy, and greenish-gray mottled clay	5	25
Clay, sandy, light brown	5	30
Sand, fine, light brown, and clay	10	40
CRETACEOUS		
Dakota Formation		
Sand, medium, yellowish brown	10	50
Sand, medium to coarse	8	58
Clay, hard, gray	1	59

11-3-26ddd.—Sample log of test hole in SE SE SE sec. 26, T. 11 S., R. 3 W., about 50 feet west of cor.; augered April 30, 1958. Depth to water, 11.5 feet; altitude of land surface, 1,234.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, light brown	2	2
Illinoisan terrace deposits		
Silt, clayey, dark brown	3	5
Clay, silty, brown	3	8
Clay, silty, light grayish green	1	9
Silt, reddish brown	6	15
Clay, sandy, reddish brown	7	22
Clay, sandy, dark brown	2	24
Sand, fine, light brown	8	32
CRETACEOUS		
Dakota Formation		
Clay, hard, dark gray	1	33

11-3-27dcc.—Sample log of test hole in SW SW SE sec. 27, T. 11 S., R. 3 W., at north edge of road 0.5 mile west of cor.; augered April 30, 1958. Depth to water, 11.6 feet; altitude of land surface, 1,226.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Clay, silty, dark brown	6	6
Sand, medium, brown	18	24
Clay, green and gray	8	32
Clay, grayish brown	5	37
Sand, fine, light brown	8	45
Sand, fine to medium, gray	8	53
CRETACEOUS		
Dakota Formation		
Clay, dry, gray	1	54

11-3-28ddd.—Sample log of test hole in SE SE SE sec. 28, T. 11 S., R. 3 W., at north edge of road at intersection; augered April 30, 1958. Depth to water, 18.9 feet; altitude of land surface, 1,227.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	5	5
Silt, brown	5	10
Silt, light brown	10	20
Silt, clayey, light brown	12	32
Clay, sandy, bluish gray	1	33
Illinoisan terrace deposits		
Sand, coarse, and gravel, gray	22	55
Clay, sandy, gray	9	64
CRETACEOUS		
Dakota Formation		
Sand, medium, gray	6	70

11-3-32aad.—Sample log of test hole in SE NE NE sec. 32, T. 11 S., R. 3 W., at northwest corner of intersection about 0.25 mile south of cor.; augered April 30, 1958. Depth to water, 23.6 feet; altitude of land surface, 1,231.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, brown	5	5
Silt, grayish brown	3	8
Silt, brown	7	15
Silt, clayey, brown	13	28
Sand, fine, silty, light brown	12	40
Sand, fine, grayish brown	10	50
Sand, fine to coarse, light brown	10	60
Sand, coarse, and gravel	5	65
CRETACEOUS		
Dakota Formation		
Sand, fine to medium, unconsolidated	5	70

11-3-33abb.—Sample log of test hole in NW NW NE sec. 33, T. 11 S., R. 3 W., at south edge of intersection 0.5 mile west of cor.; augered April 30, 1958. Depth to water, 20.3 feet; altitude of land surface, 1,233.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, light brown and gray	8	8
Silt, light brown, dry	15	23
Silt, light grayish brown	3	26
Sand, fine, and silt	4	30
Sand, medium to coarse	10	40
Sand, fine to medium, light gray	10	50
Sand, medium to coarse, and gravel	5	55
Gravel, fine to coarse	5	60
CRETACEOUS		
Dakota Formation		
Sand, medium to coarse, light brown	10	70
Sand, medium, well sorted, quartzose, poorly consolidated; contains pyrite	20	90

11-3-35bbb.—Sample log of test hole in NW NW NW sec. 35, T. 11 S., R. 3 W., at east edge of road about 20 feet south of cor.; augered April 30, 1958. Depth to water, 11.7 feet; altitude of land surface, 1,228.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	5	5
Clay, silty, light brown	13	18
Silt, light brown	5	23
Illinoisan terrace deposits		
Clay, grayish green, mottled with rust	3	26
Silt, light brown	14	40

	Thickness, feet	Depth, feet
Sand, fine to medium, silty, grayish brown	10	50
Sand, medium to coarse, light brown	2	52
CRETACEOUS		
Dakota Formation		
Sand, fine to coarse, yellowish brown	18	70

11-5-34aad.—Drillers log of well drilled by Layne-Western Co. for Northern Natural Gas Co. in SE NE NE sec. 34, T. 11 S., R. 5 W.; drilled 1953. Depth to water, 122.3 feet; altitude of land surface, 1,415.9 feet.

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota Formation		
Clay fill	1	1
Clay, gray	4	5
Shale, sandy, brown	13	18
Shale, sandy, sticky, yellow	4	22
Shale, sandy, gray and red	4	26
Shale, sandy, gray	1	27
Shale, sandy, blue	2	29
Shale, sandy, yellow, red, white	1	30
Shale, sandy, yellow	1.5	31.5
Shale, yellow; sandstone boulders	0.5	32
Shale, white; sandstone streaks	4	36
Shale, blue	9	45
Shale, blue and red, very hard	6.5	51.5
Shale, blue and red; sandstone streaks	43.5	95
Shale, blue, and fine sand	6	101
Sand, fine, hard	5	106
Shale, blue, and sand streaks	16	122
Sand and shale	9	131
Sandstone, soft	7	138
Sandstone, hard	29	167
Clay	1	168
Sandstone, soft and medium	22	190

12-1-6aaa.—Sample log of test hole in NE NE NE sec. 6, T. 12 S., R. 1 W., on south side of stream about 0.1 mile south of cor.; augered May 2, 1958. Depth to water, 12.3 feet; altitude of land surface, 1,221.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, light brown	17	17
Clay, brown	3	20
Silt, light brown	15	35
Sand, fine, silty, light gray	8	43
CRETACEOUS		
Dakota Formation		
Clay, light and dark gray	1	44

12-1-7ddd.—Sample log of test hole in SE SE SE sec. 7, T. 12 S., R. 1 W., at edge of road about 0.1 mile west of cor.; augered May 11, 1958. Dry hole; altitude of land surface, 1,253.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	4	4
Clay, silty, brown	2	6
Silt, light brown	3	9
Silt, clayey, dark brown	3	12
CRETACEOUS		
Dakota Formation		
Clay, pink and white mottled	3	15

12-1-13ccc.—Sample log of test hole in SW SW SW sec. 13, T. 12 S., R. 1 W., at edge of road; augered May 11, 1958. Dry hole; altitude of land surface, 1,278.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	3	3
Silt, light gray	4	7
Silt, grayish brown	3	10
Silt, light brown	4	14
Silt, yellowish brown	7	21
PERMIAN—Leonardian		
Wellington Formation		
Clay, light red	2	23
Clay, yellowish green	4	27
Shale, clayey, red and green mottled	3	30

12-1-18ddd.—Sample log of test hole in SE SE SE sec. 18, T. 12 S., R. 1 W., at west edge of road about 30 feet north of cor.; augered May 2, 1958. Depth to water, 16.2 feet; altitude of land surface, 1,253.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, light brown	6	6
Silt, clayey, brown	4	10
Silt, sandy, brown	5	15
Sand, fine, light gray	2	17
Sand, coarse, yellowish brown	1	18
Sand, fine, silty, light reddish brown	3	21
PERMIAN—Leonardian		
Wellington Formation		
Shale, hard, yellowish green	4	25

12-1-22ddc.—Sample log of test hole in SW SE SE sec. 22, T. 12 S., R. 1 W., at edge of road about 0.2 mile west of cor.; augered May 11, 1958. Dry hole; altitude of land surface, 1,269.3 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	3	3
Clay, silty, light brown	3	6
Silt, sandy, brown	3	9
Silt, sandy, light brown	5.5	14.5
PERMIAN—Leonardian		
Wellington Formation		
Shale, clayey, hard	0.5	15

12-1-26aaa.—Sample log of test hole in NE NE NE sec. 26, T. 12 S., R. 1 W., at edge of intersection; augered May 5, 1958. Dry hole; altitude of land surface, 1,272.0 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, light brown	8	8
Clay, silty, sandy, brown	3	11
Silt, clayey, reddish brown	3	14
Silt, clayey, sandy, light brown	4	18
Silt, clayey, light brown	3	21
Sand, medium, reddish brown	1	22
Silt, clayey, sandy, light brown	18	40
Clay, silty, sandy, light brown	6	46
Silt, sandy, light gray	9	55
Sand, fine, silty, light brown	9	64
PERMIAN—Leonardian		
Wellington Formation		
Shale, clayey, silty, grayish green	4	68
Shale, clayey, dark gray	0.5	68.5

12-1-27cdd.—Sample log of test hole in SE SE SW sec. 27, T. 12 S., R. 1 W., at edge of road about 0.5 mile east of cor.; augered May 5, 1958. Dry hole; altitude of land surface, 1,250.0 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, brown	4	4
Silt, light brown	9	13
Sand, fine, silty, reddish brown	5	18
Sand, fine, silty, light brown	7	25
PERMIAN—Leonardian		
Wellington Formation		
Shale, clayey, grayish green	5	30
Limestone, fine grained, dark gray	0.1	30.1

12-1-29bcb.—Sample log of test hole in NW SW NW sec. 29, T. 12 S., R. 1 W., at edge of road about 0.3 mile south of cor.; augered May 5, 1958. Depth to water, 8.9 feet; altitude of land surface, 1,229.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, brown	9	9
Silt, light reddish brown	4	13
Silt, light brown	3	16
Clay, silty, light olive brown	4	20
Clay, soft, brown	4	24
PERMIAN—Leonardian		
Wellington Formation		
Shale, green and brown mottled	4	28

12-1-31abc.—Sample log of test hole in SW NW NE sec. 31, T. 12 S., R. 1 W., near center of intersection in north-central part of sec.; augered May 2, 1958. Depth to water, 13.0 feet; altitude of land surface, 1,188.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Clay, silty, dark brown	5	5
Clay, silty, brown	5	10
Clay, brown	5	15
Silt, clayey, brown	5	20
Sand, fine, silty, brown	4	24
Clay, dark gray	3	27
Silt, gray	13	40
Sand, fine, silty, gray	13	53
Sand, coarse, and gravel	10	63
PERMIAN—Leonardian		
Wellington Formation		
Shale, light and dark gray	2	65

12-1-34bbb.—Sample log of test hole in NW NW NW sec. 34, T. 12 S., R. 1 W., at edge of intersection; augered May 2, 1958. Depth to water, 14.0 feet; altitude of land surface, 1,230.4 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Clay, silty, light brown	7	7
Sand, medium, clayey, reddish brown	7	14
Sand, medium, clayey, light brown	6	20
Illinoisan terrace deposits		
Clay, sandy, light brown	13	33
Sand, fine to medium, light brown	4	37
PERMIAN—Leonardian		
Wellington Formation		
Shale, hard, dry, light green	1	38

12-2-5add.—Sample log of test hole in SE SE NE sec. 5, T. 12 S., R. 2 W., at edge of road about 0.5 mile south of cor.; augered May 1, 1958. Depth to water, 6.6 feet; altitude of land surface, 1,231.0 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, sandy, dark brown	5	5
Sand, medium, poorly sorted	3	8
Sand, medium, clayey	5	13
Sand, fine to medium	7	20
Illinoisan terrace deposits		
Sand, coarse, well sorted, yellowish brown	15	35
CRETACEOUS		
Dakota Formation		
Clay, greenish gray	1	36

12-2-6dcc.—Sample log of test hole in SW SW SE sec. 6, T. 12 S., R. 2 W., at north edge of road about 0.5 mile west of cor.; augered May 1, 1958. Depth to water, 10.0 feet; altitude of land surface, 1,214.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, clayey, dark brown	2	2
Clay, silty, dark brown	3	5
Clay, silty, light brown	3	8
Sand, medium, well sorted, brown	4	12
Sand, medium, well sorted, light brown	23	35
CRETACEOUS		
Dakota Formation		
Sand, fine to medium, semiconsolidated	10	45

12-2-8abb.—Sample log of test hole in NW NW NE sec. 8, T. 12 S., R. 2 W., at edge of road about 0.5 mile west of cor.; augered May 1, 1958. Depth to water, 6.0 feet; altitude of land surface, 1,209.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Clay, silty, grayish brown	5	5
Sand, fine, brown	5	10
Sand, clayey, grayish brown	5	15
Clay, silty, light brown	7	22
Clay, light and dark gray, mottled	4	26
Clay, dark gray, contains silt and sand	4	30
Sand, fine, silty, light gray	15	45
CRETACEOUS		
Dakota Formation		
Clay, sandy, hard, gray	1	46

12-2-9baa.—Sample log of test hole in NE NE NW sec. 9, T. 12 S., R. 2 W., at edge of road about 0.5 mile east of cor.; augered May 1, 1958. Depth to water, 14.2 feet; altitude of land surface, 1,224.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, light brown	5	5
Silt, sandy, reddish brown	5	10
Silt, clayey, light brown	6	16
Illinoisan terrace deposits		
Sand, fine, light brown	6	22
Silt, clayey, light brown	3	25
Silt, light brown	20	45
Sand, medium to coarse, and gravel	7	52
CRETACEOUS		
Dakota Formation		
Clay, red and gray mottled, hard	1	53

12-2-9bbc.—Sample log of test hole in SW NW NW sec. 9, T. 12 S., R. 2 W., at edge of road about 0.25 mile south of cor.; augered May 1, 1958. Depth to water, 12.6 feet; altitude of land surface, 1,212.0 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, sandy, dark brown	5	5
Silt, clayey, light brown	10	15
Clay, silty, grayish brown	4	19
Clay, silty, grayish brown mottled with rust	6	25
Clay, sandy, silty, light brown	10	35
Sand, fine, silty, light gray	5	40
Sand, fine to medium, light gray	10	50
CRETACEOUS		
Dakota Formation		
Clay, sandy, bright heliotrope	1	51

12-2-9ddd.—Sample log of test hole in SE SE SE sec. 9, T. 12 S., R. 2 W., at northwest edge of intersection; augered May 1, 1958. Depth to water, 13.0 feet; altitude of land surface, 1,213.3 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Sand, fine, medium brown	7	7
Sand, fine, yellowish brown	6	13
Silt, brown	3	16
Silt, light brown	9	25
Sand, fine, silty, light brown	21	46
CRETACEOUS		
Dakota Formation		
Sandstone, well cemented	1	47

12-2-10dcc.—Sample log of test hole in SW SW SE sec. 10, T. 12 S., R. 2 W., at edge of road about 0.5 mile west of cor.; augered May 2, 1958. Depth to water, 5.8 feet; altitude of land surface, 1,210.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Clay, silty, light gray	5	5
Sand, fine, silty, brown	10	15
Sand, fine, light brown	20	35
Sand, medium to coarse, light brown	4	39
CRETACEOUS		
Dakota Formation		
Clay, sandy, dry, gray	1	40

12-2-13cdd.—Sample log of test hole in SE SE SW sec. 13, T. 12 S., R. 2 W., at edge of road about 0.5 mile east of cor.; augered May 2, 1958. Depth to water, 16.8 feet; altitude of land surface, 1,198.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Clay, silty, dark brown	7	7
Clay, silty, light brown	4	11
Silt, light brown	9	20
Sand, fine, silty, light brown	7	27
Illinoisan terrace deposits		
Clay, grayish brown, rust mottled	3	30
Sand, fine, silty, light gray	17	47
Sand, coarse, and gravel	1	48
CRETACEOUS		
Dakota Formation		
Clay, red and gray, mottled	1	49

12-2-15aaa.—Sample log of test hole in NE NE NE sec. 15, T. 12 S., R. 2 W., near center of intersection; augered May 2, 1958. Depth to water, 16.1 feet; altitude of land surface, 1,217.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Undifferentiated deposits		
Silt, clayey, dark brown	4	4
Silt, light brown	5	9
Sand, fine, silty, reddish brown	4	13
Illinoisan terrace deposits		
Clay, silty, brown	3	16
Silt, clayey, light brown	4	20
Silt, clayey, yellowish brown	6	26
Sand, fine to medium, light brown	4	30
Sand, medium, light brown	7	37
CRETACEOUS		
Dakota Formation		
Clay, yellow, brown, gray	1	38

12-2-15bcc.—Sample log of test hole in SW SW NW sec. 15, T. 12 S., R. 2 W., at edge of road about 0.5 mile south of cor.; augered May 1, 1958. Depth to water, 11.2 feet; altitude of land surface, 1,204.5 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, clayey, dark brown	4	4
Clay, silty, light brown	2	6
Silt, light brown	5	11
Silt, light brown and gray	4	15
Clay, silty, light brown	5	20
Sand, fine, light brown	10	30
Sand, fine to medium, yellowish brown	10	40
Sand, medium, yellowish brown	10	50
CRETACEOUS		
Dakota Formation		
Clay, hard, dry, bluish gray	1	51

12-2-15ccc.—Sample log of test hole in SW SW SW sec. 15, T. 12 S., R. 2 W., near center of intersection; augered May 1, 1958. Depth to water, 14.1 feet; altitude of land surface, 1,202.9 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Clay, silty, dark brown	3	3
Clay, silty, light gray	5	8
Silt, light brown	12	20
Sand, fine, light brown	30	50
Sand, coarse, and gravel	4	54
PERMIAN—Leonardian		
Wellington Formation		
Shale, light greenish gray	1	55

12-2-16bbb.—Sample log of test hole in NW NW NW sec. 16, T. 12 S., R. 2 W., at intersection; augered May 1, 1958. Depth to water, 13.8 feet; altitude of land surface, 1,206.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	5	5
Clay, silty, dark brown	5	10
Silt, sandy, light brown	5	15
Clay, silty, light brown	2	17
Clay, light gray	3	20
Sand, medium to coarse, silty	15	35
Sand, medium, light brown	5	40
Sand, medium to coarse	5	45
Sand, coarse, and gravel	1	46
CRETACEOUS		
Dakota Formation		
Clay, hard, dry, light gray	1	47

12-2-23aaa.—Sample log of test hole in NE NE NE sec. 23, T. 12 S., R. 2 W., at edge of road; augered May 2, 1958. Depth to water, 11.9 feet; altitude of land surface, 1,199.3 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Silt, clayey, dark brown	5	5
Sand, very fine, silty, reddish brown	5	10
Silt, clayey, light brown	5	15
Sand, fine, silty, light brown	5	20
Sand, fine to medium, light brown	15	35
Sand, coarse, light brown	2	37
CRETACEOUS		
Dakota Formation		
Clay, hard, dry, gray	3	40

12-2-25ccc.—Sample log of test hole in SW SW SW sec. 25, T. 12 S., R. 2 W., at edge of road; augered May 2, 1958. Depth to water, 14.0 feet; altitude of land surface, 1,192.1 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Clay, silty, dark brown	8	8
Silt, clayey, light brown	8	16
Sand, fine, silty, light brown	3	19
Illinoisan terrace deposits		
Clay, brown	8	27
Silt, light brown	3	30
Silt, sandy, light brown	9	39
Sand, coarse, and gravel	16	55
PERMIAN—Leonardian		
Wellington Formation		
Shale, light gray	3	58

12-2-27ddd.—Sample log of test hole in SE SE SE sec. 27, T. 12 S., R. 2 W., about 100 feet west of cor.; augered May 2, 1958. Depth to water, 13.3 feet; altitude of land surface, 1,193.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Illinoisan terrace deposits		
Clay, silty, dark brown	6	6
Clay, silty, light brown	4	10
Silt, light brown	7	17
Sand, very fine, light brown	11	28
Clay, brown	4	32
Clay, dark gray	2	34
Silt, light brown	6	40
Sand, coarse, brown	15	55
PERMIAN—Leonardian		
Wellington Formation		
Shale, dark gray	2	57

12-3-2ddd.—Sample log of test hole in SE SE SE sec. 2, T. 12 S., R. 3 W., about 30 feet west of cor.; augered May 1, 1958. Depth to water, 19.6 feet; altitude of land surface, 1,220.7 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	4	4
Clay, silty, brown	7	11
Clay, silty, light brown	5	16
Silt, light brown	6	22
Clay, light brown	6	28
Silt, light brown	17	45
Silt, light grayish brown	5	50
Sand, fine to medium	5	55
Sand, fine to coarse, gray	2	57
CRETACEOUS		
Dakota Formation		
Sand, medium to coarse, light brown	6	63
Clay, hard, dry, gray	2	65

12-5-14cbc.—Sample log of test hole in SW NW SW sec. 14, T. 12 S., R. 5 W., about 0.3 mile north of cor.; augered April 29, 1958. Depth to water, 14.5 feet; altitude of land surface, 1,289.8 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, light gray	5	5
Clay, silty, light gray	5	10
Silt, light brown	6	16
Sand, fine, silty, light brown	21	37
CRETACEOUS		
Dakota Formation		
Clay, sandy, bluish gray	1	38

12-5-22ddd.—Sample log of test hole in SE SE SE sec. 22, T. 12 S., R. 5 W.; at west edge of road about 250 feet north of cor.; augered April 29, 1958. Depth to water, 9.2 feet; altitude of land surface, 1,284.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, dark brown	4	4
Silt, clayey, brown	4	8
Silt, light brown	3	11
Silt, clayey, light brown	4	15
Clay, silty, brown	4	19
Sand, fine to medium, silty	29	48
Gravel, coarse	3	51
CRETACEOUS		
Dakota Formation		
Clay, hard, gray	2	53

12-5-23bbb.—Sample log of test hole in NW NW NW sec. 23, T. 12 S., R. 5 W., at east edge of road; augered April 29, 1958. Depth to water, 13.5 feet; altitude of land surface, 1,288.6 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, light gray	10	10
Silt, sandy, light brown	15	25
Sand, fine to medium	15	40
Sand, medium to coarse	10	50
Gravel, fine to coarse	2	52
CRETACEOUS		
Dakota Formation		
Clay, hard, dry, bluish gray	2	54

12-5-23bcc.—Sample log of test hole in SW SW NW sec. 23, T. 12 S., R. 5 W., at east edge of road about 0.5 mile south of cor.; augered April 29, 1958. Depth to water, 7.6 feet; altitude of land surface, 1,285.2 feet.

	Thickness, feet	Depth, feet
NEOGENE—Pleistocene		
Wisconsinan terrace deposits		
Silt, clayey, light gray	9	9
Clay, silty, light brown	13	22
Sand, fine to medium, light brown	29	51
Gravel, fine to coarse	1	52
CRETACEOUS		
Dakota Formation		
Clay, bluish gray	2	54

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