Geology and Ground-Water Resources of Clay County, Nebraska

By C. F. KEECH *and* V. H. DREESZEN

With a section on Chemical Quality of the Water

By F. H. RAINWATER

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By C. F. Keech and V. H. Dreeszen

ABSTRACT

This report presents the results of a cooperative investigation of the ground-water resources of Clay County, Nebr., by the Geological Survey, U. S. Department of the Interior, and the Conservation and Survey Division, University of Nebraska. The fieldwork of the investigation, which constitutes a part of a statewide program of ground-water studies in Nebraska, was done during the summer of 1954.

Clay County is about 24 miles square and in 1950 had a population of 8,700. The general physiography of the county is that of an almost level southeastward-sloping depositional plain, the original surface of which has been slightly modified by stream erosion and wind action. The Little Blue River is the only perennial stream in the county. Ephemeral streams which flow only during and after heavy rains include the West Fork of the Big Blue River and School, Big Sandy, and Little Sandy Creeks. The climate is subhumid, the normal annual precipitation being about 25 inches. Agriculture is the principal industry in the county and corn is the most important crop. More than 21,000 acres was irrigated from water pumped from 257 wells in 1954. Corn, alfalfa, and grain sorghums are the principal irrigated crops.

Clay County is in the southeastern part of the loess-plains region of Nebraska and is immediately west of the glaciated region. Sand and gravel and associated silt and clay deposits of Quaternary (Pleistocene) and Tertiary age mantle the area. The thickest deposits of sand and gravel are in two broad buried channels, one in the northern part and one in the southern part of the county. The Pleistocene sand and gravel yields water readily to wells and is the principal source of ground water in the county. The deposits of Tertiary age, which consist principally of partly consolidated fine-textured continental deposits, also are saturated and yield water to some wells.

The deposits of Quaternary and Tertiary age rest on an eroded, uneven bedrock surface of rocks of Cretaceous age. The Ogallala formation of Tertiary age overlies truncated northwestward-dipping strata of Cretaceous age—in ascending order, the Niobrara formation, Carlile shale, Greenhorn limestone, and Graneros shale. No wells or test wells are known to have been drilled into formations older than the Graneros shale. The rocks of Cretaceous age have little significance as potential sources for ground water in Clay County.

The water available to wells in the county is derived entirely from precipitation on the area or areas immediately west and north. The conclusion is reached that recharge by infiltration of precipitation through the soil is considerable and probably averages about 1.5 inches per year.

The use of ground water for irrigation has increased greatly since 1952, and more ground water probably could be used without a serious lowering of the water table. A map showing the thickness of the water-bearing materials indicates that although most of the county has enough underlying water-bearing material to support irrigation wells parts of the county have little or none.

Studies of the quality of ground water show that the water has a relatively low mineral content and is of the calcium bicarbonate type; mineralization, as measured by specific conductance, ranged from 317 to 691 micromhos (approximately 210 to 450 ppm of dissolved solids). The quality is affected appreciably by local conditions in the proximity of each well, but countywide water-quality patterns, which are related to water movement and recharge, geology, and hydraulics of water-bearing material, are apparent. The water is hard but, with the exception of some water having high concentrations of iron, is usable for most domestic purposes. Irrigation water in some parts of the county contains sufficient calcium to maintain the present levels of crop productivity and soil tilth, but the addition of calcium to the soil may be helpful in other areas. Calculated leaching requirements were determined for each of the water samples taken during the investigation.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The investigation on which this report is based is part of a long-term cooperative program of study of the ground-water resources of Nebraska that was begun in 1930 by the U. S. Geological Survey and the Conservation and Survey Division, University of Nebraska. It is the fifth of a series of detailed local investigations that have been made under that program. Several reports that deal with special phases of the investigations have been published separately. In addition, hydrologic data obtained in Nebraska during these investigations have been published in a number of papers by the Federal and State agencies and in technical journals.

In 1945 the scope of ground-water investigations in Nebraska was much expanded by the Geological Survey as part of the program by the U. S. Department of the Interior for the development of the water resources of the Missouri River basin. A series of investigations, which together cover most of the State, have been made under this program. Most of these have been of the reconnaissance type to ascertain, among other things, areas where more intensive studies are needed.

Prior to World War II, ground water in Clay County was used chiefly for domestic, stock, and public supplies, and demands for large amounts of water were few. However, since about 1946 many farmers have begun irrigating with water pumped from wells. The progressive increase in the use of ground water for irrigation in Clay

County, and in much of the rest of Nebraska as well, has created a need for ground-water studies to obtain an adequate understanding of the quantity and quality of the available supply, the probable safe yield of the ground-water reservoir, and the possibility of developing additional supplies. This report provides basic data that should prove useful in the future, for the pumping of large quantities of ground water is likely to raise many quantitative problems. At the present time (1954) ground-water development in Clay County is less than the optimum. It is reasonable to assume, however, that at some future time the progressively increasing use of ground water will lower the regional water table so much that pumping lifts will be markedly increased, and in localities where the saturated layer of water-bearing sand and gravel is thin the water supply may be depleted to a point where it would be inadequate for irrigation.

Investigation of the quality of the ground-water resources was designed (1) to determine the chemical type and concentration of the water; (2) establish the general relationship of water quality to water movement and recharge, geology, hydraulics of the water-bearing material, and pumping; (3) evaluate the water in terms of suitability for domestic and irrigation uses; and (4) point out certain precautionary measures relative to drainage and calcium requirements for successful long-term irrigation. Water samples were collected from 45 wells, 4 of which were sampled prior to the irrigation season and again near the end of the season to ascertain changes in water quality due to prolonged pumping.

All water samples were analyzed by the U. S. Geological Survey.

The investigation was made under the general direction of A. N. Sayre, chief of the Ground Water Branch of the U. S. Geological Survey, and E. C. Reed, State geologist and director of the Conservation and Survey Division of the University of Nebraska. Studies of the chemical quality of the ground water were made under the general direction of S. K. Love, chief of the Quality of Water Branch of the U. S. Geological Survey.

LOCATION AND EXTENT OF THE AREA

Clay County is in an area of upland plains about midway between the Platte and Republican Rivers in southeastern Nebraska (fig. 1). The county is bounded on the north by Hamilton County, on the east by Fillmore County, on the south by Nuckolls County, and on the west by Adams County. Clay Center, the county seat, is 21 miles south and 72 miles west of Lincoln, the State capital. The county is about 24 miles square and includes an area of 571 square miles, or 365,440 acres.

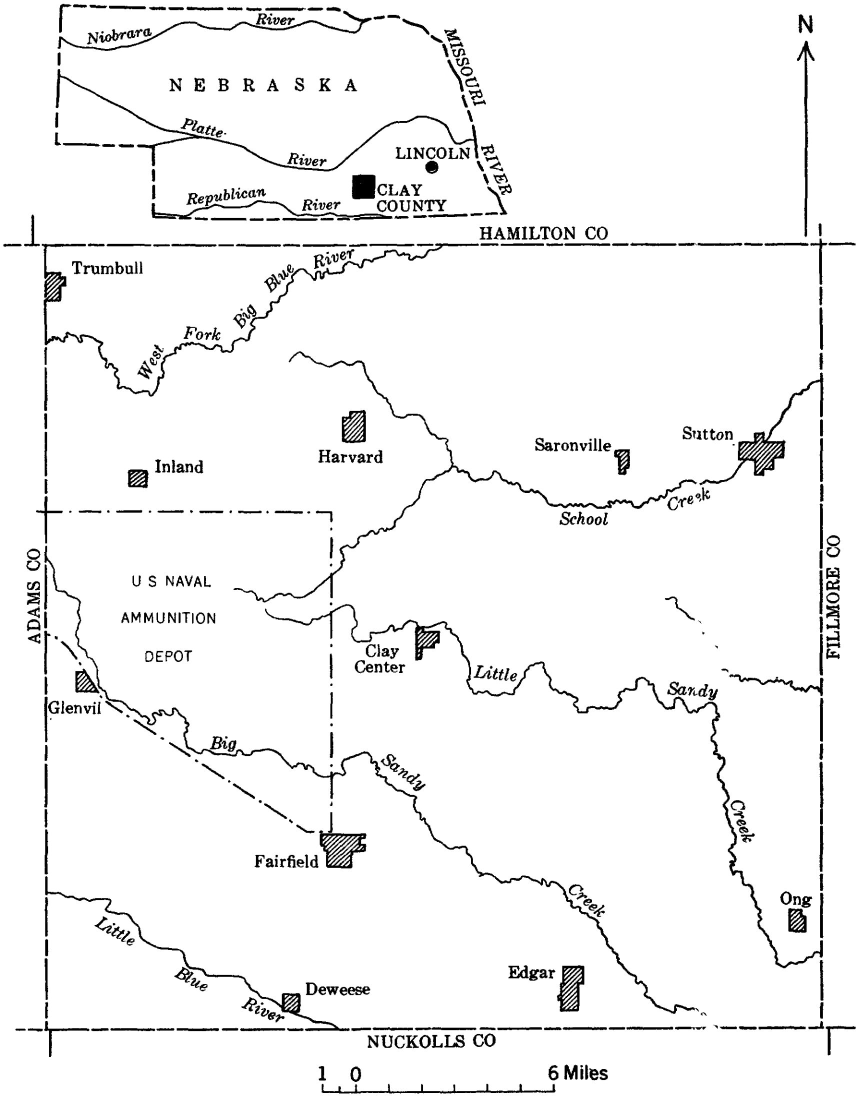

FIGURE 1.—Index map of Clay County, Nebr.

PREVIOUS INVESTIGATIONS

The earliest investigation of the ground-water resources of an area including Clay County was made by Darton (1898), who described the physiography, geology, and ground water in a portion of southeastern Nebraska. Lugn and Wenzel (1938) studied the western half of Clay County as part of an investigation of the ground-water resources of south-central Nebraska. Unpublished reports of geologic and hydrologic data by Reed (1948b), consisting of maps showing types of land, configuration of the water table, depth to water, thickness of the saturated materials, and geologic cross sections, are available in the open file at the University of Nebraska. Extensive test drilling was done in Clay County during several periods from 1940 through 1949 by the Conservation and Survey Division of the University of Nebraska in cooperation with the U. S. Geological Survey. The field logs of test holes, location map, and altitudes of the ground surface at the test-hole sites are published in a county report (Schreurs and Keech, 1953).

METHODS OF INVESTIGATION

A review of data collected during previous investigations indicated that additional information was needed for the present investigation; these data were collected during the summer and fall of 1954.

All irrigation and public-supply wells were inventoried to obtain data on the wells that withdraw large quantities of water from the ground-water reservoir. The data collected included the depth of the well, the amount and use of the water pumped, the depth to water, the date of drilling, the yield, and the location of each well. (See table 12.) Information concerning well casings, pumps, power supplies, pumping costs, drilling methods, and distribution systems was collected. Water samples from representative wells were analyzed in the U. S. Geological Survey laboratory, Lincoln, Nebr., to determine the chemical properties of the ground water.

Well drillers, farmers, soil conservationists, and superintendents of public water supplies were interviewed to obtain information on the use of water in the county, and all available well and test-hole records were obtained. Persons using ground water for irrigation were interviewed to obtain data concerning irrigation practices, present and past water use, type of crops grown, and plans for additional wells or increased use of ground water. The withdrawal of water by domestic and stock wells was estimated.

A few wells were selected as observation wells, and periodic depth-to-water measurements have since been made in them to determine the fluctuations of the water table.

WELL-NUMBERING SYSTEM

Wells and test holes are numbered in this report according to their location within the system of land subdivision of the U. S. Bureau of Land Management. The first numeral in the number indicates the township; the second, the range; and the third, the section. The lowercase letters that follow the section number indicate the position of the well within the section; the first letter indicates the quarter section and the second letter, the quarter-quarter section. The 160-acre and 40-acre subdivisions of the section are lettered a, b, c, and d in a counterclockwise direction, beginning in the northeast quarter. Figure 2 illustrates this well-numbering system.

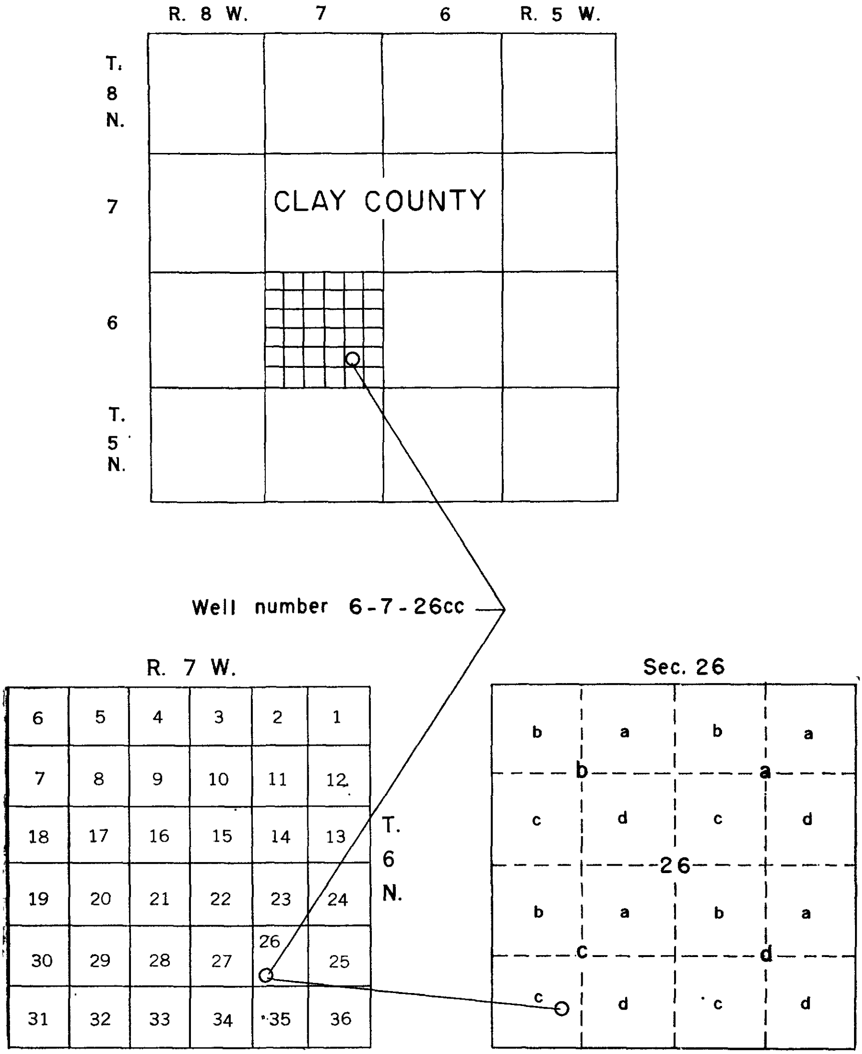

FIGURE 2.—Sketch showing well-numbering system.

ACKNOWLEDGMENTS

Appreciation is expressed to the many farm operators, well drillers, and other persons who cooperated and assisted in the collection of the field data. Personnel of the U. S. Soil Conservation Service at Clay

Center, Nebr., provided much information regarding the names of well owners and the locations of wells in the county; municipal officials furnished information concerning wells and distribution systems of municipal supplies. Special acknowledgment is due Arthur Erickson, chief geologist, Northern Natural Gas Co., for making available the logs of seismic shot holes.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Clay County is in the southeastern part of the loess-plains region of Nebraska. The general physiography of the county is that of an almost level southeastward-sloping depositional plain, the original surface of which has been slightly modified by stream erosion and wind action. Most of the county is covered to a considerable depth with loess, locally called "yellow clay." Most of the county is an upland; the remainder consists of narrow terraces and flood plains along the streams. The uplands are flat or gently undulating but are modified locally by shallow basins. In a few places, especially along the tributaries of the Little Blue River, Big Sandy Creek, and the West Fork of the Big Blue River in the southwestern and northwestern parts of the county, stream erosion has produced steep slopes along ravines eroded into the loess. Alluvial terraces and bottom lands are best developed along the Little Blue River in the southern part of the county, the West Fork of the Big Blue River in the northern part, and School Creek in the northeastern part. The alluvial surfaces generally are flat, though locally they are modified by abandoned stream channels, small depressions, and slight elevations. The alluvial surfaces along the West Fork of the Big Blue River and most of the larger creeks are 20 to 60 feet below the adjoining uplands. The Little Blue River, however, is more deeply entrenched; its valley floor is 100 to 120 feet below the uplands.

The flood plains along all the streams except the Little Blue River are very narrow. Most of the terraces lie 5 to 20 feet above the stream channels and are underlain by alluvium deposited by the streams when they were flowing at higher levels.

Drainage of Clay County is effected chiefly through the Little Blue and Big Blue Rivers and their tributaries. The Little Blue River and School Creek north of Sutton flow perennially, but all other streams are dry most of the year and flow only after periods of precipitation. The West Fork of the Big Blue River, naturally an intermittent stream, now flows perennially because water from the Hastings, Nebr., sewage-treatment plant is discharged into the stream at a point about 5 miles west of the Adams-Clay County line.

CLIMATE

The climate of Clay County is characterized by the great seasonal extremes typical of southeastern Nebraska. The normal winter is long and cold, and the summer is very warm. The normal spring is cool and has an appreciable amount of precipitation; and the fall season is long, with moderate temperature and occasional periods of rainy weather.

More than half the annual precipitation normally is in the form of local thundershowers during May, June, July, and August. The spring and early summer rains usually are well distributed, although drought periods are not uncommon. The distribution of precipitation normally is less uniform in late summer and early fall than in spring and early summer. The late-summer droughts frequently occur when corn, which is the principal crop, is tasseling. Because this is a critical time in corn growth, irrigation is almost always needed for full crop development, even in years when the total annual precipitation is above normal. The average annual snowfall is about 25 inches, and the snowfall usually is greatest during February and March.

Precipitation records have been maintained at Clay Center, Nebr., since 1891 except for the years 1911, 1913, and 1914. In figure 3, Clay Center was assumed to have received during 1911, 1913, and 1914 the same amount of precipitation as Hastings, Nebr., which is about 16 miles northwest from Clay Center and is the nearest town where records were kept. Figure 3 shows the annual precipitation and the cumulative departure from average precipitation at Clay Center. The downward trend of the cumulative-departure curve from 1920 to 1940 shows that the annual precipitation during this period generally was below the average for the period of record. The curve indicates also that the drought that usually is associated with the 1930's actually began in Clay County about 1920, became increasingly severe in the early thirties, and reached its climax in 1940. Nevertheless, many of the crop failures during this period were not due entirely to the deficiency in annual precipitation but were caused in part by the unfavorable distribution of precipitation during the year.

Prevailing winds are from the south during the summer months and from the northwest during the winter months; however, frequently they blow from other directions. The winds usually are moderate to strong and during the summer months are often accompanied by high temperatures and low humidity, both of which cause rapid loss of soil moisture by evapotranspiration. Winds, sometimes accompanied by hail, that are strong enough to damage property and trees occasionally occur with thunderstorms.

The average temperature in Clay County is about 50°F. Temperatures of more than 100°F are common in midsummer, and in winter they often drop below zero; lows of −25°F have been recorded. Average growing season is about 155 days. May 2 is the average

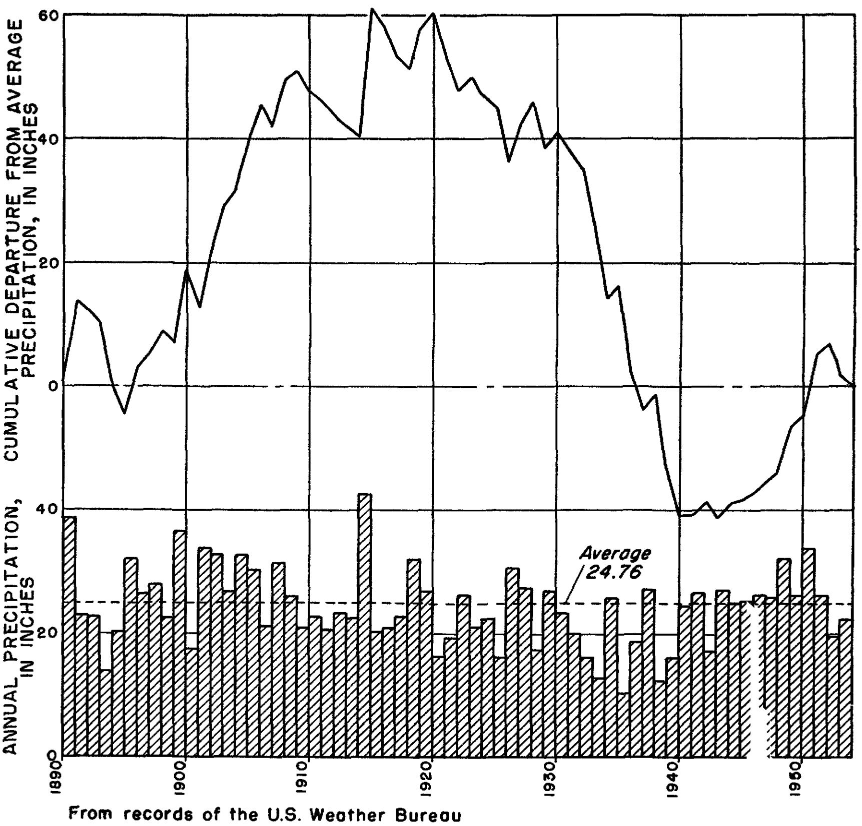

FIGURE 3.—Annual precipitation and cumulative departure from average precipitation at Clay Center.

date of the last killing frost in the spring; a killing frost has occurred as late as May 29. The average date of the first killing frost in the fall is October 4, although the earliest date was September 20.

The following table shows temperature and precipitation data for Clay Center.

Summary of temperature and precipitation records at Clay Center from 1891 to 1954

[From records of the U. S. Weather Bureau]

Month	Temperature (°F)			Precipitation (inches)		
	Mean	Minimum	Maximum	Mean	Totals for the driest year (1936)	Totals for the wettest year (1915)
January	24.9	−25	69	0.48	0.50	1.15
February	29.8	−21	78	.81	.16	3.08
March	39.2	−7	88	1.01	.13	2.20
April	51.0	6	93	2.63	.29	1.51
May	60.4	28	102	3.64	2.64	6.09
June	71.4	42	106	3.83	1.19	8.43
July	78.0	42	113	3.08	.13	11.82
August	76.0	41	110	2.92	2.03	3.05
September	67.1	27	103	2.78	2.19	3.72
October	54.7	7	92	1.76	.27	.89
November	39.5	−4	80	.92	0	.42
December	28.4	−21	72	.61	.78	.60
Year	51.7	−25	113	24.47	10.31	42.96

POPULATION

Clay County was organized in 1871, when the population was about 356. By 1880 the population had increased to 11,294, and in 1920 the census reported 14,486 inhabitants, all classed as rural. The population decreased after the late 1920's and by 1950 had dwindled to 8,700, or 15.2 persons per square mile as compared with 17.3 for the entire State of Nebraska.

The population of Clay Center, the county seat, was 824 in 1950; that of Sutton, the largest town, was 1,353, Harvard had 774 and Fairfield, 503.

TRANSPORTATION

Transportation facilities in Clay County are good. The main line of the Chicago, Burlington & Quincy Railroad extends east and west across the northern part of the county, and branch lines of the Burlington and the Union Pacific Railroads serve the southern parts of the county. No point in the county is more than 8 miles from a railroad station.

Two hard-surfaced Federal and State highways cross the county. U. S. Highway 6 traverses the county east and west through Sutton and parallels the north boundary of the Hastings Naval Ammunition Depot; State Highway 14 bisects the county north and south through Clay Center. State Highway 74, a road that is gravel surfaced except for 3 miles of hard surface connecting Fairfield with Highway 14, crosses the county east and west through Fairfield. Four miles of hard-surfaced State Highway 19 connects the town of Edgar with Highway 14. Improved roads are laid out on nearly all section lines; many of these are gravel surfaced.

Telephone lines and rural mail routes serve all parts of the county.

A State-owned airport at Harvard has concrete runways that are long enough for commercial planes, and a small airport with sod runways, which can accommodate small aircraft, is situated 2 miles east of Clay Center.

AGRICULTURE AND SOILS

Agriculture is the chief occupation in Clay County; corn, wheat, alfalfa, grain sorghum, and oats are the principal crops. According to the annual State census of agriculture, the more than 260,000 acres of crops grown during 1952 had a market value of more than $11,000,000; 12,210 acres was irrigated with water from wells. The field survey for this report determined that the acreage irrigated from wells during 1954 was 26,232. The comparative value of the agricultural products of Clay County for 1952 is shown in the following table:

Comparative values of agricultural products of Clay County for 1952

[From annual State census of agriculture]

Crops produced			Livestock on farms		
Crop	Acres	Value	Livestock	Number	Value
Corn	94,180	$5,211,620	Cattle (other than milk cows)	20,310	$3,292,250
Wheat	103,960	4,403,180	Milk cows	4,200	1,062,600
All hay	20,080	896,120	Swine	24,780	755,790
Oats	27,590	253,850	Chickens	162,220	209,260
Sorghum	4,740	161,920	Horses	880	31,680
Others	9,606	[1] 118,180	Sheep	2,440	66,280
Total	260,156	$11,044,870	Total		$5,417,860

[1] Estimated.

Most of the soils of Clay County are suited to all crops common to the region; however, the soils in the shallow depressions in the uplands range in agricultural value according to the drainage conditions. Some of the soils in the depressions are suitable only for hay and pasture. Most of the soils of Clay County are underlain by a "claypan" (a term used locally) that ranges in depth below the land surface from about 28 inches in well-drained uplands to about 6 inches in the poorly drained areas, and it ranges in thickness from about 8 inches in the well-drained lands to about 20 inches in the poorly drained lands. According to the U. S. Bureau of Chemistry and Soils, the claypan condition has been caused by the chemical and physical action on the soils of water from precipitation entering or standing on the surface. The relatively impervious soils in the depressions collect and retain surface water after periods of precipitation, and the soils in these areas are in advanced stages of leaching and concentration of clay in the subsoils. The claypan layer under the well-drained uplands is barely developed and consists of a very heavy silt loam or heavy clay loam about 12 inches thick.

The claypan in the subsoils of Clay County is particularly significant to persons using ground water for irrigation because it retards the downward percolation of water. If too much water is applied to lands not having good surface drainage, local waterlogging of the soil often results and salinization of the soil above the claypan may impair its productivity. Continued saturation of the soil may destroy the structure and alter the permeability of the subsoil to the degree that recharge to the ground-water reservoir from precipitation is reduced.

MINERAL RESOURCES

Except for ground water, Clay County has no known mineral resources of significant economic importance. Some sand and gravel is obtained from deposits of Pleistocene age in the valley of the Little Blue River near Deweese. Preliminary exploration for petroleum has been done, but no deep test holes have been drilled.

GEOLOGY

STRATIGRAPHIC UNITS AND THEIR WATER-BEARING PROPERTIES

The stratigraphic units at and near the land surface in Clay County consist of mantle rock of silt, clay, sand, and gravel of Quaternary (Pleistocene) age. These unconsolidated sediments were deposited on a relatively uneven, eroded bedrock surface. (See fig. 4.) The bedrock in the county is of Cretaceous and Tertiary age. The Ogallala formation, a stream-and-wind deposit of Tertiary age, is the youngest bedrock in Clay County; it immediately underlies the Quaternary deposits throughout most of the county. The rocks of Cretaceous age underlie the Pleistocene and Tertiary strata and are, in order from youngest (uppermost) to oldest (lowermost), the Niobrara formation, Carlile shale, Greenhorn limestone, Graneros shale, and Dakota sandstone.

The Cretaceous rocks consist of beds of shale, chalky limestone, and some sandstone which dip gently to the northwest. These were eroded to an eastward-sloping surface prior to the deposition of the Ogallala formation. As a result, the Ogallala formation of Tertiary age or the deposits of Pleistocene age lie on the older Cretaceous rocks in eastern Clay County and on the younger Cretaceous rocks in western Clay County. The Cretaceous rocks are underlain by a considerable thickness of older limestones, shales, sandstones, dolomites, and similar types of sedimentary rocks of Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian age. The older rocks are in turn underlain by igneous or metamorphic rocks.

The possibilities of developing large supplies of water from the Quaternary mantle rock are excellent in much of Clay County. However, the possibilities of developing water from wells in the rocks of Tertiary and greater age are limited.

A generalized section of the stratigraphic units that constitute the mantle rock and the underlying Tertiary and Cretaceous rocks in Clay County is shown by table 1, which gives their range in thickness, lithologic character, and importance as sources of water supply.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

DAKOTA SANDSTONE

The Dakota sandstone underlies Clay County at a considerable depth. It consists of a series of interbedded shale and sandstone. No test holes or wells sufficiently deep to penetrate the Dakota are known to have been drilled in the county. Tests drilled for oil and gas in adjoining counties indicate that the average thickness of the Dakota in Clay County probably is about 350 feet. The formations of Cretaceous age dip northwestward, and the depth to the upper surface of the Dakota sandstone increases from about 460 feet below the land surface in the southeastern corner of the county to about 950 feet in the northwestern corner.

In general, less than half the total thickness of the Dakota sandstone in the vicinity of Clay County is sandstone. The sandstone generally is fine to medium grained and is moderately to loosely cemented. The quality of the water contained in the sandstones in the Dakota in Clay County is not known. However, analyses of water from the Dakota sandstone in Seward, Saline, Lancaster, and Jefferson Counties, which are east of Clay County, indicate that mineralization of the water in the Dakota sandstone increases westward and with depth below the land surface. The water in the Dakota sandstone in Clay County probably is too highly mineralized to be suitable for irrigation or domestic use and may be unsuitable even for livestock.

UPPER CRETACEOUS SERIES

GRANEROS SHALE

The Graneros shale lies immediately above the Dakota sandstone and is present beneath all of Clay County. It is the uppermost Cretaceous unit found in the subsurface in the deeper part of the buried channel in the southeastern part of the county. (See pl. 1.) It is present below the younger Cretaceous strata at progressively greater depths northward and westward throughout the remainder of Clay

TABLE 1.—*Generalized section of the stratigraphic units and their water-bearing properties, Clay County*

System	Series		Stratigraphic unit	Thickness (feet)	Character and distribution	Water supply
Quaternary	Recent		Surficial alluvium, loess, and soil.	0–5±	Widespread soils; flood-plain deposits of clay, silt, sand, and gravel; isolated wind deposits of silt and clay.	Significant only as a transmitting agent in recharge of the ground-water reservoir.
	Pleistocene	Wisconsin stage	Peorian and younger loesses.	0–30	Wind deposits of yellowish-gray clayey silt including, in this report, the alluvial and colluvial clayey silt mantle of the terraces along stream valleys aud in depressions in the upland; underlie nearly the entire county.	Do.
			Terrace deposits and Todd Valley sand.	0–30	Valley and terrace deposits of sand and gravel in stream valleys; present principally along the Little Blue River valley.	Yield some water to wells.
		Illinoian and Sangamon stages	Loveland formation.	0–30	Principally wind deposits of brown silt and clay containing sandy lenses and local basal sand; capped by fossil soil. Present in nearly the entire county.	Significant only as a transmitting agent in recharge of the ground-water reservoir.
			Crete formation.	(?)	Channel-fill deposit of sand and gravel; no deposits of this age yet recognized in Clay County, but they may be present.	Water bearing, if present below the water table.
		Kansan and Yarmouth stages	Sappa formation.	5–60	Aqueous-eolian stratified deposits of silt, clay, sand, and gravel; colors of silt and clay vary from brownish gray to light yellowish gray and light gray; capped by and contains a buried soil in some places; underlies the entire county.	Occurs above the water table in much of the county. Significant principally as a transmitting agent in recharge of the ground-water reservoir.
			Grand Island formation.	0–100	Stream-deposited sand and gravel containing a fairly persistent layer of clay and silt of aqueous-eolian origin; underlies most of the county.	Yields abundant water.
		Nebraskan, Aftonian and Kansan stages	Red Cloud sand and gravel, and Holdrege formation, undifferentiated.	0–170	Stream-deposited sand and gravel and some nonpersistent layers of clay and silt of probable aqueous-eolian orgin. Holdrege and Red Cloud formations not differentiated because of insufficient evidence for separation of the units; underlie much of the county. The Fullerton formation of wind-and-stream-deposited clay and silt may be present in some places between the Red Cloud and Holdrege.	Do.
Tertiary	Pliocene		Ogallala formation.	0–200	Brownish-gray and gray silt, sandy silt, and clayey silt containing lenses of sand and, locally, a basal gravel; partly calcareous but principally unconsolidated; underlies all the county except over parts of the highest ridges of Cretaceous bedrock.	Not a known source of water supply; may yield water to some domestic wells.

Cretaceous	Upper Cretaceous	Niobrara formation.	0-380	Yellow and light- to dark-gray marine chalky shale and chalk; underlies much of the county.	Do.
		Carlile shale.	0-285	Medium- to dark-gray marine shale, calcareous in the lower part; underlies most of the county.	Not a source of water supply to wells.
		Greenhorn limestone.	0-25	Gray fossiliferous limestone interbedded with calcareous shale; underlies all but the extreme southeastern part of the county.	Do.
		Graneros shale.	40-65	Dark-gray shale, calcareous in the upper part; underlies all the county.	Do.
	Lower Cretaceous	Dakota sandstone.	300-400	Interbedded clay shale, sandy shale, and sandstone; underlies all the county.	Contains mineralized water; wells in Clay County are not sufficiently deep to reach this formation.

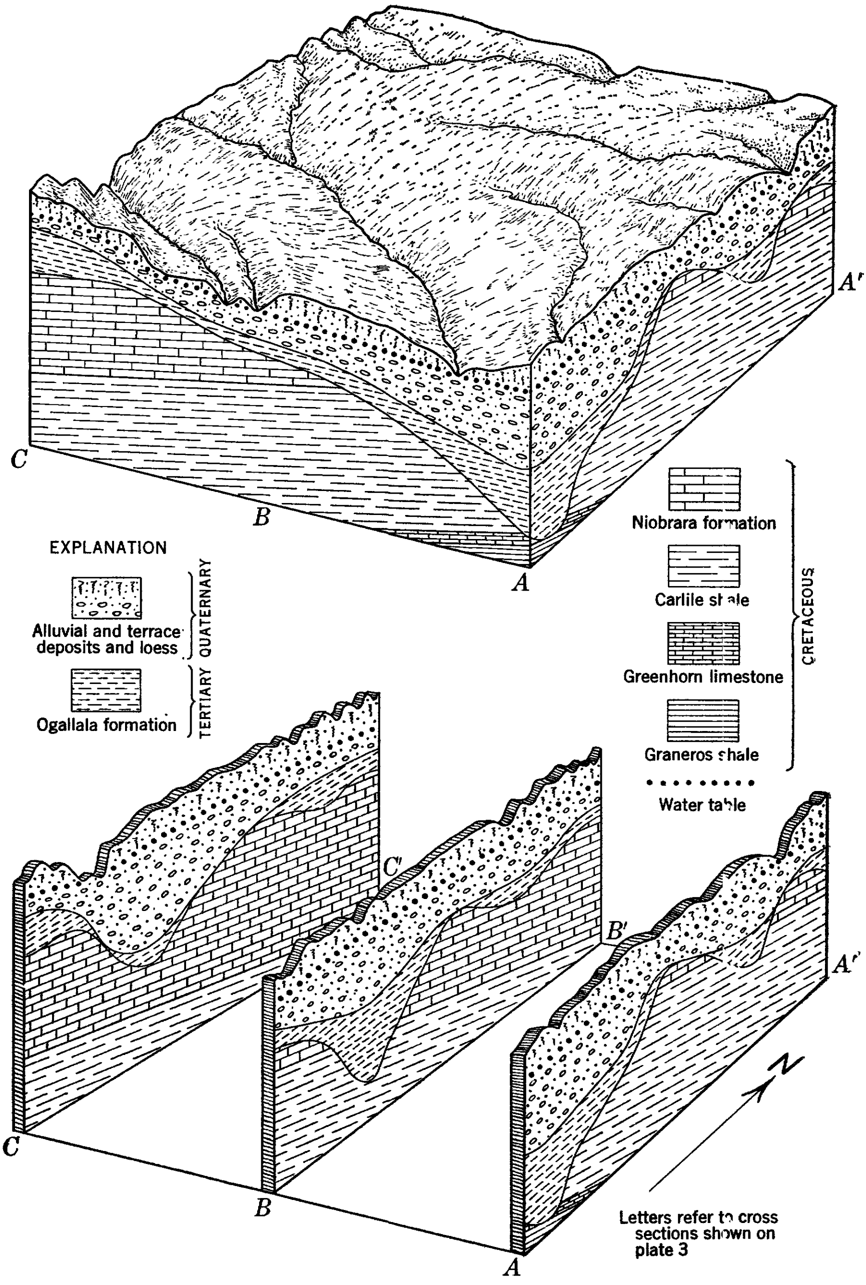

FIGURE 4.—Block diagram and generalized geologic sections, Clay County.

County. The drill bit entered the Graneros shale in only one test hole, 5–4–30bb, where 20 feet of the upper calcareous portion of the Graneros was penetrated. The Graneros shale consists of about equal thicknesses of an upper dark-gray calcareous shale containing thin limestone layers and of a lower noncalcareous dark-gray shale. The average thickness of the Graneros shale, where not eroded, in Clay County and vicinity is probably about 65 feet; the shale is relatively impervious and is not a water-yielding formation in the county.

GREENHORN LIMESTONE

A sequence of interbedded gray fossiliferous limestone and calcareous shale named the Greenhorn limestone immediately overlies the Graneros shale. However, the Greenhorn limestone was not penetrated in any of the test holes in Clay County. The formation has been removed by erosion from the deeper part of the buried channel in the southeastern corner of the county. (See pl. 2.) The formation is present under the remainder of Clay County, but it is the uppermost Cretaceous unit only in the southeastern part of the county around the outer portion of the area mapped as Greenhorn limestone and Graneros shale, undifferentiated. (See pl. 1.) The average thickness of the Greenhorn limestone where not eroded in the Clay County area is about 25 feet. The limestone is relatively impervious and is not considered to be a potential aquifer in the county.

CARLILE SHALE

Overlying the Greenhorn limestone, the Carlile shale is present in all of Clay County except in the southeastern part where it was removed by erosion after Cretaceous time. (See pl. 1.) The formation was penetrated by the drill in several test holes in the buried-channel area in the southern half of the county, in one test hole east of Harvard, 8–7–36dd, and in several test holes in the northern half of eastern Clay County. The Carlile shale in Clay County is approximately 285 feet thick at places where all the formation is represented.

The lower 70 to 90 feet of the Carlile shale, known as the Fairport chalky shale member, consists of dark-gray calcareous shale interbedded with thin layers of fossiliferous limestone. The drill penetrated the Fairport in only two test holes, 6–6–31bb and 5–5–1dd. The shale in test hole 5–5–1dd is oxidized to a yellow and yellow-gray color. The Blue Hill shale member of the Carlile overlies the Fairport chalky shale member and is principally a medium- to dark-gray noncalcareous clay shale; its thickness ranges from about 195 to about 215 feet in Clay County. The Blue Hill shale member was weathered to light gray to the depths it was penetrated in test holes 5–6–19bb and 6–6–18bb. Thin ironstone-claystone layers or concretions were interbedded with the shale in these test holes. Locally, a fine-grained sandstone known as the Codell sandstone member is present in the upper few feet of the Carlile shale in Nebraska (Condra and Reed, 1943, p. 17). The upper 5 feet of the Carlile shale in test hole 6–8–19bc was in part coarse silty to very fine sandy shale and may represent the Codell member. Underlying the Niobrara formation in test hole 8–7–36dd, a 1-foot layer of noncalcareous, argillaceous sandstone that contains very fine quartz sand grains was penetrated by the drill between the depths of 383.5 and 384.5 feet. The sandstone contained a few pyrite grains and grains of rounded siliceous dark claystone or ironstone 1 to 2 millimeters in diameter. No sandy shale or sandstone was present in the upper part of the Carlile shale in test holes drilled along the east Clay County line. (See pl. 2, sec. *A–A′*.)

The Carlile shale is not known to yield water to wells in Clay County and cannot be considered a potential aquifer because of its fine texture and low permeability.

NIOBRARA FORMATION

The Niobrara formation is a yellow and light- to dark-gray chalky shale and chalk. It immediately overlies the Carlile shale and is the youngest Cretaceous formation in Clay County. During post-Cretaceous and pre-Tertiary time, the Niobrara formation was removed by erosion from the deeper part of the buried channel in southern Clay County and from much of the east half of the buried channel in the northern part of the county. A part of the formation was removed by pre-Tertiary or pre-Pleistocene erosion in the remainder of the county. The Niobrara formation in Clay County is thickest in the northwestern part of the county, where it is estimated to be about 380 feet thick.

The Niobrara formation has been subdivided into two members, the Fort Hays limestone member below and the Smoky Hill chalk member above, but no attempt is made to differentiate them in this report. The less argillaceous and lighter colored chalk and chalky shale in the basal part of the formation, from 355 feet to 383.5 feet in test hole 8–7–36dd, probably is correlative with the Fort Hays. Five additional test holes, 8–5–1dd, 8–5–24dd, 7–4–19cc, 6–4–6cc, and 6–8–19bcc, were drilled through the lower part of the Niobrara formation and penetrated material that probably represents the Fort Hays.

The upper part of the Niobrara formation is oxidized to colors of yellow, white, orange, and yellow-gray over the buried ridges and the side slopes of the buried valleys. The maximum thickness of oxidized shale penetrated during test drilling was in test hole 6–4–6cc in east-central Clay County. The entire Niobrara formation in this test hole, 56.5 feet, was oxidized to a light color—yellow except for some white in the upper 19 feet and the lower 4.5 feet.

No wells in Clay County are known to obtain water from the Niobrara formation. A few stock or domestic wells in east-central and northeastern Clay County, where water is not available from the deposits of Tertiary or Quaternary age, may be obtaining water from the Niobrara formation. Normally, the Niobrara formation is not an important source of water for wells; however, records on file at the Conservation and Survey Division, University of Nebraska, show that small yields are obtained from this formation in Nuckolls County, which adjoins Clay County to the south, and in a few other local areas in the State. The water in the formation is believed to be contained in crevices and solution channels, principally in the upper few feet. Crevices or solution channels are more common in the highly weathered shale, but they are not everywhere present. The permeable zones in the Niobrara formation can be detected by a loss of drilling fluid during drilling in hydraulically drilled test holes. For example, circulation of drilling fluid was lost completely while drilling in the chalk in test hole 8–5–24dd. The water from the Niobrara formation probably is more highly mineralized than water from the overlying formations of Tertiary and Quaternary age.

TERTIARY SYSTEM

PLIOCENE SERIES

OGALLALA FORMATION

A rather extensive deposit of relatively fine-textured sedimentary rocks of continental origin immediately overlies the Cretaceous bedrock in much of Clay County. This unit is believed to be the Ogallala formation, equivalent to the Seward facies of that formation as described by Condra, Reed, and Gordon (1950, p. 15). The Ogallala formation in Clay County consists principally of unconsolidated light-brown and light brown-gray silt, clayey silt, and sandy silt. Beds of fine sand, some of it silty, and thin marly layers are present in the formation; present locally is a basal sand and gravel commonly containing many fragments reworked from Cretaceous bedrock. The silt was found to be partly consolidated in some test holes. Silty clay was the dominant material of the Ogallala formation in test holes 5–5–1dd, 5–4–30bb, and 4–5–12aa in southeastern Clay County. The Ogallala formation in these test holes is predominantly medium gray in color; its color is commonly light and medium gray in the lower part of the formation in other test holes where the formation is comparatively thick. The calcareous content of the Ogallala in this area varies considerably; much of the formation is slightly calcareous, but noncalcareous layers, relatively thin marly limestone layers, and calcareous nodules are common. Small calcareous root casts were present in the upper part of the formation in test holes 8–9–12aa and 8–8–19cc in northwestern Clay County. A few small snail and pelecypod shells were recovered from the basal sand and gravel in test hole 6–8–19bcc south of Glenvil, Nebr., and snail and pelecypod fragments were present in the upper part of the formation in test hole 6–6–31bb in south-central Clay County and at places in test holes 5–4–30bb and 4–5–12aa in the southeastern part of the county.

The Ogallala formation is lithologically similar to some of the finer textured formations of Pleistocene age and is not readily distinguishable from those formations where they immediately overlie the Ogallala, except where the upper surface of the Ogallala is oxidized.

The deposits of the Ogallala formation are believed to have formed a relatively flat plain by the end of Pliocene time. Although the formation subsequently was extensively eroded, it underlies much of Clay County; it is discontinuous over the buried ridge of Cretaceous rocks extending from the vicinity of test hole 7–9–12aa south of Trumbull southeastward to Clay Center; it has been removed or is thin over most of the ridge extending east from Clay Center to the Clay-Fillmore County line. The formation is relatively thin over the ridge of Cretaceous rocks in northern Clay County extending from Trumbull through Eldorado and eastward across the county; it was removed by erosion from the north side of the buried valley northeast of Sutton in early to middle Pleistocene time. The deposits of the Ogallala formation are thickest in the buried valley in southern Clay County, where the maximum thickness penetrated by the drill was 192.5 feet, in test hole 6–6–31bb northeast of Fairfield.

A few domestic wells may obtain water from a sandy facies of the Ogallala formation or from a basal rubbly layer in the areas of high bedrock. The formation in Clay County is not an important aquifer, however, because of its generally fine texture and relatively low permeability. Where coarse-textured sediments occur in the lower part of the formation in the buried valleys, they are overlain by comparatively thick coarse-textured deposits of Pleistocene age which yield water so readily that wells do not need to be drilled to the Ogallala.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

The relatively flat plain that existed at the end of Pliocene time was extensively eroded during early Pleistocene time to a surface of broad ridges and valleys. A map showing the configuration of the surface at the base of the Pleistocene was prepared from the logs of test holes, wells, and seismic-survey shot holes. (See pl. 3.) The early Pleistocene surface probably was modified locally by erosion during Pleistocene time; however, it is believed that the map showing the configuration of the base of the Pleistocene also closely approximates the pre-Pleistocene surface. The two terms "base of the Pleistocene" and "pre-Pleistocene" therefore are used synonymously in the remainder of this report.

The drainage pattern of the pre-Pleistocene surface is similar to that of the pre-Tertiary surface. The buried channels and the ridges are broader on the pre-Pleistocene surface, but the position of their axes is nearly the same, indicating that the Cretaceous bedrock influenced the retention of the ridges, and erosion of the less resistant deposits of Pliocene age resulted in the formation of broad channels. There are two principal buried channels in the pre-Pleistocene surface in Clay County, one in the northern part and one in the southern part of the county. (See fig. 4 and pl. 2.) A bedrock ridge divides the channel areas and extends from near the center of T. 7 N., R. 8 W., on the Clay-Adams County line, eastward to a point just north of Clay Center, then eastward to the Clay-Fillmore County line. An irregular bedrock high is present near the north Clay County line from Trumbull to the northeastern corner of the county, where it forms a broad buried hill.

The bedrock is relatively high in southwestern Clay County also. The bedrock surface is shown to be more highly dissected in southwestern Clay County than elsewhere (see pl. 1), but this is because more detailed information is available from seismic shot hole logs, not necessarily because the surface is actually rougher. Undoubtedly, much of the information is subject to some error, but it is believed that the principal features shown on the map are correct. A relatively restricted pre-Tertiary channel is shown to be present just north of Deweese, trending eastward and southeastward and crossing the Clay-Nuckolls County line south of Edgar. Some evidence indicates that the area immediately north and west of Edgar may be underlain by a considerably higher bedrock ridge than that shown on the areal geologic and the pre-Pleistocene maps. (See pls. 1 and 3.) Irrigation wells are comparatively shallow in this area, and Lugn (1935, p. 35) noted that "shale bedrock" had been reported in the vicinity of Edgar. "Yellow clay and lime rock" that was logged in irrigation test well 5-6-22da (see table 9) between the depths of 153 and 155 feet may be a part of the Niobrara formation that remains as an outlier. The "clay" logged in the same test well between the depths of 136 and 153 feet may be a part of the Ogallala formation.

The broad buried channels shown by the contours on plate 3 are the areas of greatest thickness of Pleistocene sand and gravel. The approximate depth to the base of the most favorable water-bearing materials can be obtained by subtracting the altitude shown on this map from the altitude of the land surface at the same location. More test drilling is needed to determine the possibilities for developing large-capacity wells at specific localities in the vicinity of the buried bedrock highs than is required in other parts of Clay County.

Deposits of Pleistocene age mantle all Clay County. These deposits consist of alluvial sand or sand and gravel, alluvial and colluvial silt and clay, eolian silt, and some eolian sand. Relatively thick water-saturated sand and gravel channel-fill deposits underlie all the county except over parts of the higher bedrock ridges; this sand and gravel yields nearly all the ground water used in Clay County. The windblown deposits of loess mantle the sand and gravel and older deposits; they are the surficial material that covers all the county except some steep slopes along the major stream valleys and are the parent material of the fertile soils in the county. Although deposited during the glacial and interglacial stages of the Pleistocene epoch, the Pleistocene sediments were deposited just west of and outside the glaciated region of Nebraska. Buried glacial till, which is considered to be Kansan in age by Condra, Reed, and Gordon (1950, fig. 8), is present in Fillmore County, less than 12 miles east of the Clay-Fillmore County line.

The Pleistocene deposits of the extensive periglacial area of Nebraska, which includes Clay County, have been studied by many persons. The classification of the periglacial deposits that has evolved is based on correlation with the glacial deposits in eastern Nebraska and other glaciated areas. The scarcity of exposures of deposits of middle to early Pleistocene age over much of the periglacial and adjacent glaciated areas makes exact correlation between the glacial and periglacial deposits difficult. The first comprehensive study of the Pleistocene geology of Nebraska was made by Lugn (1935, p. 1–213), who used data from available logs of wells and test holes in his study and report. Data from many additional test holes were available to Condra, Reed, and Gordon (1950, p. 1–74) in their correlation of the Pleistocene deposits between the glacial and periglacial areas in Nebraska and in their classification of the Pleistocene (1950, p. 10–13). More precise correlation of some of the periglacial deposits with the glacial deposits in Nebraska will require additional study.

Correlation of the deposits of Pleistocene age in Clay County is generalized to some extent in this report. If more than one interpretation is possible, the simpler interpretation, assuming conformable relationship between units, is used.

HOLDREGE FORMATION AND RED CLOUD SAND AND GRAVEL, UNDIFFERENTIATED

The Holdrege formation is the oldest recognized deposit of Pleistocene age in the periglacial area of Nebraska. It consists of sand and gravel deposited when the Nebraskan glacier was advancing and the Nebraskan till was being deposited; the formation may include some sand and gravel deposited during the retreat of the Nebraskan ice. The eastward-flowing streams aggraded their valleys with sand and gravel as the glacier in eastern Nebraska diverted the streams southward.

The Fullerton formation of silt, clay, and, locally, fine sand of fluvial-eolian origin was deposited during the Aftonian interglacial stage on the partially eroded sand and gravel plain of the Holdrege formation (Condra, Reed, and Gordon, 1950, p. 18–19). No persistent deposit of fine-textured sediments in Clay County can be definitely correlated with the Fullerton formation. Silt and clay in test hole 4–5–12aa between the depths of 90 and 106 feet (see sec. *A–A′*, pl. 2) and in test hole 4–9–1aa between the depths of 80 and 103 feet (see sec. *C–C′*, pl. 2) may be the Fullerton formation. However, it is believed more probable that the material in test hole 4–5–12aa is a silt and clay member of the Red Cloud sand and gravel, which is Kansan in age. The Fullerton formation may not have been deposited in this area, it may have been removed by erosion, or it may be present in an unrecognized relationship.

No attempt was made to differentiate the stratigraphically younger Red Cloud sand and gravel from the Holdrege formation because the Fullerton formation, which in normal stratigraphic relationship would be present between the Holdrege and Red Cloud formations, was not definitely recognized.

The Red Cloud sand and gravel, described by Schultz, Reed, and Lugn (1951), consists of sand and gravel deposited in the periglacial area at the time of the advance of the Kansan glacier. The Red Cloud sand and gravel is believed to be present in Clay County because of the close proximity of the county to the glaciated area and because the county lies in a major drainageway of Pleistocene time. Much of the material designated as the Holdrege and Red Cloud (see pl. 2) may be only the Red Cloud.

The Holdrege and Red Cloud, as used in this report, are differentiated from the overlying Grand Island formation principally on the basis of differences in texture. The unit, particularly in the upper part, is finer textured than the overlying sand and gravel of the Grand Island formation. The Holdrege and Red Cloud unit in the main buried channel in southern Clay County can be subdivided into an upper sand or sand containing some gravel, a middle relatively coarse-textured sand and gravel, and a lower sand. The greatest thickness of the unit penetrated by the drill, 170 feet, was in test hole 5-4-30bb, in southeastern Clay County. (See sec. *A-A'*, pl. 2.) Layers of silt and clay are interbedded with the sand and gravel in the lower half of the unit in the southeastern part of the county.

The major pre-Pleistocene valleys were aggraded to a considerable depth and much of the side slopes and lower buried ridges were covered by the Holdrege formation and Red Cloud sand and gravel. These formations are absent over much of the northern quarter of Clay County, over the higher parts of the bedrock ridge through the central part of the county, and over the bedrock high in the southwestern part of the county.

The Holdrege and Red Cloud unit is saturated and is a good to excellent source of ground water. The deposits of this unit generally are finer textured than those of the overlying Grand Island formation, but they are comparatively well sorted and yield water to many irrigation wells in Clay County.

GRAND ISLAND FORMATION

The current (1956) usage in Nebraska of the name Grand Island formation is as redefined by Schultz, Reed, and Lugn (1951, p. 548-549); that is, the formation includes the sand and gravel deposited during "the retreat and waning of the Kansan ice sheet (late Kansan) and early Yarmouth (Sappa) time." The Grand Island formation in Clay County is believed to be correlative with the sand and gravel lying in channels eroded into and through the Kansan till in central and northern Fillmore County (Reed, 1953).

The Grand Island formation consists principally of comparatively coarse-textured sand and gravel. A silt and clay member divides the formation in the western half to two-thirds of the county. (See secs. *B-B'* and *C-C'*, pl. 2.) The silt and clay layer is absent along the Clay-Fillmore County line (see sec. *A-A'*, pl. 2), but the average thickness (75 to 100 feet) of the Grand Island formation is retained through the main buried channel. A silt and clay layer was penetrated between the depths of 63 and 75 feet in test hole 7-5-3da at Sutton in the sequence assigned to the Grand Island formation (table 9). The thickest layer of the silt and clay was penetrated in test hole 7-7-25dd in central Clay County, where it was 30.5 feet thick and present between the depths of 103 and 133.5 feet. The upper 14 feet of this member in test hole 7-7-25dd consists of calcareous, unoxidized clay and silty clay and contains many snail shells, a few specimens of which are on file in the office of the Conservation and Survey Division, University of Nebraska.

The upper 5 to 10 feet of the sand and gravel of the Grand Island formation, both above and below the silt and clay member, generally is a sand or is finer grained than the underlying sand and gravel. The upper part of the Grand Island formation is exposed on slopes along the Little Blue River valley.

Sand and gravel deposits of the upper part of the Grand Island formation and the overlying Sappa formation are exposed in a sand and gravel pit near the center of the east line of sec. 9, T. 5 N., R. 8 W.; however, the contact between the Sappa and the Grand Island is not easily discernible. A lens of partly altered volcanic ash, whose thickness ranges from a featheredge to 1½ feet and which is about 6 feet long, is exposed about 5 feet above the water level in the northwestern corner of the sand and gravel pit. The altitude (by altimeter) of the ash lens is 1,720 feet, and the altitude of the top of the middle sand and gravel member of the Sappa formation is 1,780 feet above mean sea level; thus the distance from the top of the middle member of the Sappa formation to the volcanic ash is 60 feet, a greater thickness than the combined thickness of the middle and lower members of the Sappa formation. The altitude of the ash lens and the thickness of the sand and gravel above it suggests that the ash may be in, and near the top of, the silt and clay member of the Grand Island formation. (See test hole 5–8–6bb, sec. *C–C′*, pl. 2.) Because only one ash layer has been recognized to date in the Pleistocene deposits, possibly the silt and clay member correlated in this report as a part of the Grand Island formation actually may be a part of the Sappa formation. (See discussion of the Sappa formation.) If the silt and clay member is proved to be a part of the Sappa formation, then the sand and gravel above it could be the middle sand and gravel member of the Sappa formation or possibly the Crete formation.

The maximum thickness of the Grand Island formation in Clay County is about 100 feet (see test hole 5–5–1dd, sec. *A–A′*, pl. 2) and the average thickness over most of the county is between 60 and 80 feet. The formation is absent over much of the bedrock ridge east of Clay Center and is thin or absent in much of the county south of the Little Blue River; it is thin over the bedrock ridges north of Sutton and north and northeast of Trumbull. Most of the Grand Island formation is saturated and is an excellent aquifer. All large-capacity wells in Clay County obtain water in part from the Grand Island formation, and many of the wells obtain water principally from that formation.

SAPPA FORMATION

The name Sappa formation was proposed by Reed (1948a) as a replacement for the name Upland formation (Lugn, 1935, p. 119). The formation overlies the Grand Island formation and is considered by Condra, Reed, and Gordon (1950, p. 22) to be Yarmouth or late

Kansan in age. Reed (1948a) described the Sappa formation at its type locality in Sappa Township, Harlan County, and specifically designated the type locality as the SW¼NE¼ sec. 11, T. 2 N., R. 20 W. Reed and Schultz (1951, p. 2, 3) described the Pleistocene stratigraphy at the type locality as follows:

1. Peorian loess; 25 feet.
2. Loveland loess: red-brown silt to sandy silt with dark-colored Sangamon soil in upper few feet; transitional to underlying Crete in lower 1½ feet; thickness, 12 feet.
3. Crete sand and gravel, red-brown; limited to channels cut into Sappa formation; thickness, absent to 2 feet 6 inches.
4. Sappa formation; 25 feet 2 inches:
    a. Upper silt member: upper 5 feet 9 inches greenish-gray silt, clayey in middle part; lower 7 feet light green-gray sandy silt, laminated in lower part; aggregate thickness, 12 feet 9 inches. (In next ravine to west the dark Yarmouth soil developed on the top of this member has been preserved from erosion but removed at this locality.)
    b. Middle sand and gravel member: gray sand with gravel streaks, fine to medium coarse-grained cross-bedded to laminated, grading downward into a fine gravel with erosional base; thickness, 4 feet 6 inches to 5 feet 9 inches.
    c. Pearlette volcanic ash member, erosional top: upper 1 foot 9 inches to 3 feet is massive white volcanic ash; next below is 2 to 4 inches of clay partings interstratified with volcanic ash resting on a 2-foot bed of white massive volcanic ash; the basal 7 to 9 inches consists of laminated volcanic ash; aggregate thickness, 4 feet 10 inches to 6 feet 1 inch.
    d. Lower silt member: greenish-gray sandy silt, becoming sandier in lower part, transitional to underlying Grand Island formation; thickness, 1 foot 10 inches.
5. Grand Island sand and gravel formation, only upper part exposed: sand, gray, fine-grained in upper part with dark-colored laminae in upper 8 inches, coarser in lower part; 1 foot 2 inches to 12 feet 6 inches exposed above base of ravine.

Lugn (1935, p. 126) described an exposure of 6 to 8 feet of grayish-green sandy clay in a roadside bank about 1 mile north of Eldorado in northern Clay County and referred to it as the Upland formation. He also stated (1935, p. 126–127):

> The Upland gray-green sandy clay was found to be 25 to 30 feet thick, one of its thickest known occurrences, in a deep irrigation well about 2 miles north of Eldorado, in the northwest ¼ of sec. 34, T. 9 N., R. 6 W. The well is 90 feet deep, and the remainder of it is entirely in the Grand Island sand and gravel.

The Sappa formation in test hole 9–7–36dd (see sec. *B–B′*, pl. 2), which is about 3½ miles west of the irrigation well noted by Lugn, is 28 feet thick. A description based on microscopic examination of samples of the Loveland and Sappa formations in test hole 9–7–36dd is as follows (see also table 9):

	Thickness (feet)	Depth (feet)
Loveland formation:		
Silt, moderately clayey and slightly sandy, dark brownish-gray	3.5	22
Silt, very clayey, dark-brown	2	24
Silt, very clayey, medium-brown	6	30
Silt, moderately clayey, medium-brown	5	35
Silt, moderately clayey and slightly sandy, medium-brown; contains very fine to fine sand and a trace of medium sand	3	38
Silt, moderately clayey and slightly sandy, light- and medium-brown; contains coarse-textured silt and very fine to fine sand; contains a few dense limy nodules and some white limy areas	2	40
Silt, moderately clayey and very slightly sandy, medium-brown; contains very fine to fine sand and a trace of medium sand; contains white limy areas	5	45
Sappa formation:		
Silt, moderately clayey and very slightly sandy, light brownish-gray; contains very fine to fine sand and a few white limy areas	2	47
Silt, very clayey, light brownish-gray; contains a trace of very fine to fine sand; contains many dense limy nodules and white limy areas below 49 feet	8	55
Silt, slightly clayey and moderately sandy, light brownish-gray; contains very fine to fine sand and some medium sand	5	60
Silt, slightly clayey and moderately sandy, interbedded with some silty sand, light brownish-gray; texture of sand grades from very fine to fine and some medium to coarse	8	68
Silt, moderately clayey and slightly sandy, medium-brown; contains very fine to fine sand; contains a few limy nodules to 70 feet	5	73

The material from 45 to 60 feet in test hole 9–7–36dd is believed to be the upper silt member of the Sappa formation, the material from 60 to 68 feet is the middle sand and gravel member, and the more weathered material from 68 to 73 feet is the lower silt member. These three members are present throughout most of Clay County. The Pearlette ash member of the Sappa formation (Frye, Swineford, and Leonard, 1948, p. 513) was not definitely recognized in Clay County.

A lens of volcanic ash that is believed to be in the Grand Island formation was observed in a sand and gravel pit in southwestern Clay County near the center of the east line of sec. 9, T. 5 N., R. 8 W. Dr. Ada Swineford, geologist and petrographer, Kansas State Geological Survey, examined a sample of this ash and stated (written communication, 1955) that, although the ash is weathered and the evidence is inconclusive, a few fresh shards have an index of refraction of about 1.499±0.002, the same as that of material in the Pearlette ash member of the Sappa formation. However, according to Dr. Swineford, the shape of the shards is unlike that of any she has

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previously seen, in that many consist only of bubble junctures with no glass between them.

If, as suggested on page 25, the silt and clay member of the Grand Island lying at the level of the volcanic ash lens actually is Sappa, then the middle sand and gravel member and the upper silt member of the Sappa, as discussed below, more likely would be considered to be a part of the Crete and Loveland formations. A re-examination of the correlation of the lower silt member of the Sappa, as discussed below, would also be necessary if further regional study of the Clay County area proves the above to be true. The lower silt member in parts of the county is thin or discontinuous, and the sand and gravel below it generally is coarse textured and thick. In the areas where this silt member is thin, it may prove to be a lens within sand and gravel of Illinoian age.

The lower silt member of the Sappa formation in Clay County usually ranges in thickness between 5 and 15 feet. It was not present in several test holes; the maximum thicknesses recorded were 22.5 feet in test hole 7–7–25dd north of Clay Center and 43 feet in test hole 7–4–19cc in the east-central part of the county. An alternate correlation of the deposits between the depths of 40 and 47 feet in test hole 7–4–19cc is with part of the Loveland formation rather than part of the Sappa formation; the lower 43 feet of silt and clay between the depths of 47 and 90 feet may represent all the Sappa formation rather than only its lower member.

No exposure of the lower silt member of the Sappa formation was found in Clay County. A 2-foot thickness of brown-gray fossil soil that overlies as much as 2 feet of light-gray sandy silt is exposed south of test hole 4–5–12aa and along the north slope of Big Sandy Creek in the northwest corner of sec. 8, T. 4 N., R. 4 W., in Thayer County. This exposure of soil and silt is believed to be the lower member; it is overlain by the Loveland formation, which contains small gravel in its lower 1 or 2 feet; and it is underlain by sand and gravel of the Grand Island formation.

The lower part of the Sappa formation is water saturated in the northeastern and central parts of the county, but the formation lies above the water table in the remainder of the county. Where saturated, the formation may yield some water to wells, but its principal significance is as a transmitting agent in recharge to the ground-water reservoir.

The middle sand and gravel member of the Sappa formation is present in most of Clay County; it is absent or thin in north-central and in east-central Clay County. (See secs. *A–A′* and *B–B′*, pl. 2.) The maximum thickness of the member found in the test holes is about 30 feet. The middle member consists of comparatively coarse-textured sand and gravel; the lower part of the member contains as much as 50 percent gravel. The sand and gravel grades upward into sand, and in places the sand grades into the sandy silt and silt of the upper member of the Sappa.

The upper silt member of the Sappa formation consists of brown, gray, and yellow-gray silt, silty clay, and sandy silt. The deposit is in part a loess, and a fossil soil overlies it in some localities. The upper member is not readily distinguishable from the overlying brown clayey silts of the Loveland formation in places where the buried soil and subsoil were removed prior to the deposition of the Loveland.

A silty clay layer containing much secondary calcium carbonate, believed to represent a fossil subsoil of the upper member of the Sappa, is present in test holes 8–5–1dd, 8–7–36dd, 9–7–36dd, 6–8–19bcc, and 8–7–36dd. A dark-brown fossil soil, 3.5 feet thick, is present on the upper silt member in test hole 8–8–19cc; a dark soil, 2 feet thick, is present on the member in test hole 8–9–12aa.

The upper silt member of the Sappa formation is exposed at several places in southwestern Clay County along the eroded side slope of the Little Blue River valley. An exposure in a road cut and ravine in the southeast corner of the SW¼ sec. 6, T. 5 N., R. 8 W., consists of 6 to 8 feet of very light-gray and yellow-gray marl, moderately clayey silt, and sandy silt. Snail, pelecypod, and bone fragments were found in the lower part of the exposure. Here the altitude, by altimeter, of the base of the upper silt member is 1,798 (±5) feet above mean sea level. Two and one-half feet of light-gray clayey to slightly sandy silt, capped by 8 inches of dark-gray fossil soil and overlying fine to medium sand, is present in a road ditch in the SW¼NE¼ sec. 7, T. 5 N., R. 8 W.; here, the altimeter altitude of the base of the upper member is 1,778 (±5) feet.

The maximum thickness of the upper silt member of the Sappa formation recorded in Clay County is 28.5 feet, in test hole 6–6–31bb. Here, the material penetrated in the lower part of the hole includes 10 feet of silty sand, which may be a part of the middle sand and gravel member. The upper member underlies most of Clay County; however, it was removed by erosion in the Little Blue River valley and is thin or absent in south-central and southeastern Clay County in test holes 5–6–19bb, 5–5–1dd, and 5–4–30bb and in irrigation well 5–6–32cc. (See sec. *A A′* and *B–B′*, pl. 2.)

CRETE FORMATION

The Crete formation is described by Condra, Reed, and Gordon (1950, p. 24–25) as a channel-fill deposit of sand and gravel that is believed to be Illinoian in age. They state:

In general the Crete formation is limited in its occurrence to channels associated with but generally broader than our present well-developed valleys. In

some cases it extends under the valley bottomlands and lower terraces where the overlying Loveland formation has been removed by post-Loveland or pre-Todd Valley erosion and the Todd Valley sand and Peorian loess often cap it. In some cases post-Loveland erosion in the inner parts of the valley have completely removed the Crete so that it occurs only as channel remnants along the valley side slopes.

The Crete formation has not been definitely recognized in Clay County although it has been suggested on pages 25 and 28 that the middle sand and gravel member of the Sappa formation and the upper part of the Grand Island formation, as discussed in this report, may actually be of Illinoian age. Remnants of the formation may be present, however, along the slopes of the major stream valleys or as a part of the alluvium of these valleys. A deposit of sand that contains a small amount of gravel, and which is identified as the middle member of the Sappa formation, crops out along the south slopes of School Creek northeast of Sutton in the northeast corner of sec. 25, T. 8 N., R. 5 W. (See *A–A′*, pl. 2.) The Loveland formation and a thin light-brown clayey silt layer that is identified as the upper member of the Sappa overlie the sand. However, the lower clayey silt layer of the deposit may be an alluvial phrase of the overlying Loveland formation and the sand thus may be a part of the Crete formation.

LOVELAND FORMATION

The Loveland formation consists principally of silt and clay; it includes a valley phase and an upland phase that are separated in some places by a colluvial or slope phase. The stratified silts and clays of the valley phase grade upward into the colluvial phase and into the loess of the upland phase. The Loveland formation was deposited either during late Illinoian time or during the Sangamon interglacial stage (Condra, Reed, and Gordon, 1950, p. 26). The formation crops out in places along the side slopes of the major drainageways in Clay County.

The Loveland formation is believed to have been deposited primarily by wind action. The formation mantles all the county except where it has been removed by erosion in the major stream valleys. The maximum thickness of the Loveland in Clay County is about 30 feet.

A dark brownish-gray fossil soil, the thickness of which ranges from less than a foot to 4 feet, caps the Loveland formation. A well-developed clayey subsoil, which in places is several feet thick, is present in much of the area. The color of the clayey subsoil usually is medium brown to reddish brown and that of the lower part of the formation is light to medium brown.

The entire formation appears to have been leached of any orginal calcareous material, but calcareous nodules and secondary white calcareous areas are present in some places in the lower part of the formation. Sand is a major constituent of the Loveland formation only locally. Fine- to coarse-grained sand is present in the basal part of the formation in test holes along the Clay-Fillmore County line (see sec. *A–A′*, pl. 2) and in test hole 7–9–12aa (see sec. *C–C′*, pl. 2). Some gravel particles are present in the basal sandy silt in test hole 7–9–24dd. The basal part of the formation in several test holes contains very sandy silts.

It has been suggested (p. 28) that the upper silt member of the Sappa formation, as correlated in this report, may be a part of the Loveland formation.

The formation lies above the water table throughout Clay County. Thus, it is significant only as a transmitting agent in recharge of the ground-water reservoir.

TODD VALLEY SAND AND YOUNGER TERRACE DEPOSITS

A complex series of events which included valley cutting, alluviation, terrace formation, eolian erosion and deposition, and stream piracy characterize the Wisconsin glacial stage of the Pleistocene epoch. The correlation table of Condra, Reed, and Gordon (1950, p. 12) shows four cycles of erosion, alluviation, and eolian action correlative to the four substages of Wisconsin glaciation.

No detailed study of the terraces along the major drainageways in Clay County was attempted. It is presumed that evidence of the various substages of the Wisconsin glacial stage may be found in the valleys of these drainageways by detailed mapping and test drilling.

A fossil soil capping a coarse-textured sand and gravel was penetrated by test hole 5–8–19bb. (See sec. *C–C′*, pl. 2.) This terrace fill may represent the Todd Valley sand of Iowan age which Condra, Reed, and Gordon (1950, p. 12 and 30) indicate as representing the most widespread alluviation of the Wisconsin stage.

Where present and saturated, these deposits are capable of yielding some water to wells.

PEORIAN AND YOUNGER LOESSES

The term Peorian loess as now used in Nebraska (Condra, Reed, and Gordon, 1950, p. 12) includes eolian and some alluvial silt deposited during the interval from early Iowan to pre-Mankato time. The Bignell loess, which can be differentiated from the Peorian loess in some places in Nebraska, is similar to and includes, in part, reworked Peorian loess (Condra, Reed, and Gordon, 1950, p. 33). It is considered to be Mankato to Recent in age. The Peorian and

Bignell loesses are believed to be derived from exposed silty alluvium along the large rivers and from other similar sources. They mantle the Loveland formation and older deposits and become progressively thinner away from the major source areas.

The post-Loveland loess mantling the upland and terraces, including some colluvial-alluvial silt and clay in depressions and in the valleys, is designated the Peorian and younger loesses in this report. Research beyond the scope of this report would be necessary to differentiate between the restricted Peorian and Bignell loesses in the uplands and to ascertain the age of the loess mantle on the terraces along the valleys.

The Peorian and younger loesses mantle the upland surface and are present throughout Clay County except on the steepest slopes along the major valleys. The loess consists of fine- to coarse-textured silt and clayey silt; the upper part of the formation is light brown and light brownish gray and the middle part is light gray and light yellowish gray. The lower part of the loess, ranging in thickness from a few inches to about 2 feet, has a brown tint. Calcium carbonate has been leached from the upper few feet of the loess in most areas of the county. The middle part of the unit in some test holes and the lower part of the unit in a few test holes were slightly calcareous. In other test holes the middle part of the unit was essentially noncalcareous but contained some secondary calcareous material, principally in the form of small calcareous nodules. The thickness of the loess in Clay County ranges from less than a foot to 30 feet and averages about 20 feet. A nearly uniform thickness of loess mantles the older rocks.

Maximum thickness of Peorian and younger loesses that were penetrated by the drill was in test hole 6–9–1dd, where the unit is 30 feet thick. This test hole was drilled in a large depression near Glenvil. Here the upper 6 feet of material is a colluvial-eolian silty clay which may be correlative with the Bignell loess. A fossil soil is present between the depths of 6 and 8 feet.

Basinlike depressions are common throughout much of Clay County. Roberts and Gemmell (1927, p. 11) state:

> Most of the depressions range from 1 to 40 acres in size, but a few large areas include more than 500 acres. One of the larger areas is 3 miles west of Harvard and another is 3 miles south of Clay Center.

The origin of these depressions is not known definitely. The soils map of Clay County and the topographic map of the area indicate a somewhat parallel alinement of depressions, particularly in the southern half of the county. Frye (1950, p. 13) suggests that the formation of similar depressions in Kansas may have been partly controlled by earlier erosional valleys. Valleys eroded during both pre-Loveland and post-Loveland time probably have controlled in part the occurrence of the depressions in Clay County; however, wind scour principally in Iowan time is believed to have been the dominant agent in their formation.

The Peorian and younger loesses lie above the water table and yield no water to wells. However, the loess deposits and the soils developed on them are important because they transmit infiltrating precipitation toward the zone of saturation. Recharge probably is greatest when rains first fall after the soils have shrunk and cracked during a period of drought. When rains fall on the dried soils, water quickly enters the cracks and runs down to their lowermost parts, which may be below the root zone. After the soils become wet, the swelling of colloids closes the cracks. Further recharge is diminished because the groundmass of the loess and soils developed on it are relatively impermeable.

RECENT SERIES

The deposits of late Pleistocene age grade into those of Recent age with no sharp line of demarcation. The topsoil, surficial windblown loess, and alluvial and colluvial clay, silt, and sand and gravel constitute the deposits of Recent time. The eolian and colluvial deposits probably are thin, perhaps only a few inches thick in their maximum development over the uplands. Alluvial material consisting of reworked sediments of Pleistocene age may be as much as 5 feet thick in the major valleys.

GROUND WATER

PRINCIPLES OF OCCURRENCE

All water beneath the surface of the earth is termed subsurface water. Below some level beneath the land surface the permeable rocks generally are saturated with water under hydrostatic pressure. The subsurface water in the zone of saturation is called ground water, whereas subsurface water above the zone of saturation is called suspended subsurface water, or vadose water. Ground water is the part of subsurface water that is available through wells and springs.

The ground water that is available through wells in Clay County is derived almost entirely from precipitation that falls as rain or snow within the area or in areas immediately to the west and north. Part of the water that falls as rain or snow is carried away by surface runoff and discharged as streamflow, and part of it evaporates or is transpired by growing vegetation. The part that escapes runoff, evaporation, and transpiration percolates slowly downward through the soil and underlying strata and eventually joins the body of ground water in the zone of saturation.

The rocks that form the crust of the earth generally are not solid throughout but contain numerous open spaces called voids or interstices. These spaces are the receptacles that contain ground water. They range in size from microscopic openings to the large caverns developed in limestones. The ratio, expressed as a percentage, of the volume of the open spaces or voids to the total volume of the rock is the porosity of the rock. When considering problems of ground-water supply, knowledge of the porosity of the water-bearing materials is desirable; however, the permeability of the materials, rather than their porosity, controls the amount of water that can move through them. The permeability of a rock is its capacity for transmitting water under pressure and is governed by the size, shape, and arrangement of the openings. For example, a bed of fine silt or clay may have a relatively high porosity, but because of the small size of the particles each opening is very small. Because molecular attraction holds a thin layer of water on the surface of each grain, these layers of water are not free to move and they may fill or almost fill the openings of fine-textured sediments. Thus the permeability, or water-transmitting capacity of the material, is very low even though its porosity, or water-holding capacity, is quite high. Likewise, larger openings that are not connected may produce a high porosity and a low permeability. Water moves most freely through a rock that has relatively large and well-connected openings.

Three common types of openings or interstices and the relation of rock texture to porosity are shown by figure 5.

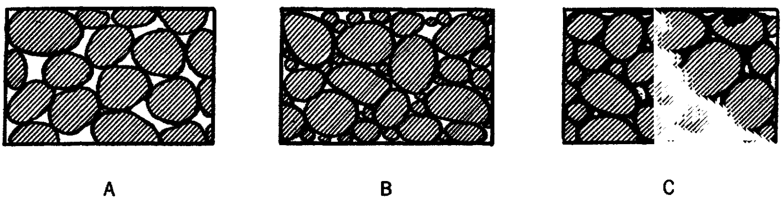

FIGURE 5.—Diagram showing three types of rock interstices and the relation of rock texture to porosity: *A*, well-sorted sedimentary deposits having a high porosity; *B*, poorly sorted sedimentary deposits having low porosity; *C*, well-sorted sedimentary deposits whose porosity has been diminished by the deposition of mineral matter in the interstices.

THE WATER TABLE AND DIRECTION OF GROUND-WATER MOVEMENT

Ground water moves slowly through the voids in the rocks at right angles to the slope of the water table (see pl. 4); the slope of the water table is controlled by the permeability and thickness of the water-bearing materials, the topography, local variations in the quantity of recharge and discharge, and the stratigraphy and structure of the rock formations. The ground water is eventually discharged through springs or wells, through seeps into streams, or by evaporation and transpiration.

The water table is defined as the upper surface of the zone of saturation except where that surface is formed by an overlying impermeable body (Meinzer, 1923, p. 32). The water table is also the boundary between the zone of saturation and the zone of aeration. It is not level but generally is a sloping surface having many irregularities, which are caused by several factors. In places where the amount of recharge is exceptionally high, the water table may rise and form a mound or low ridge from which the water slowly spreads out. In material of low permeability these mounds or ridges may be pronounced, but in very permeable material they generally are small. Depressions in the water table may indicate places where the ground water is discharging, as along streams that are below the normal level of the water table or in places where water is withdrawn by wells or vegetation.

Plate 4 shows the shape and slope of the water table in Clay County by lines that connect points of equal elevation on the water table. Water levels were measured in 254 wells to provide control for the construction of the water-table contour map. Pertinent information regarding the wells is included in the table of well records (table 12). These data should be useful to future investigators who may wish to observe water levels of the future in these same wells for the purpose of comparison with data presented in this report. The altitude of the land surface at the wells was determined by altimeter surveys from bench marks previously established by the U. S. Geological Survey and the U. S. Coast and Geodetic Survey.

The water table in Clay County slopes generally in a southeasterly direction at an average gradient of about 6 feet to the mile. Contour lines that bend upgradient or toward the west indicate depressions or troughs in the water table. The most pronounced trough occurs in the valley of the Little Blue River and is due to discharge of ground water into the river. The degree of slope of the water table is indicated by the spacing of the contour lines. Where the contour lines are spaced far apart, as in the vicinity of Glenvil, a relatively gentle slope is indicated, whereas closely spaced contour lines, as near Deweese, indicate a steep gradient.

HYDROLOGIC PROPERTIES OF THE WATER-BEARING MATERIALS

POROSITY AND SPECIFIC YIELD

The amount of water that can be stored in an aquifer (a water-bearing material or rock) depends upon the porosity of the aquifer.

A rock is said to be saturated when all its interstices are filled with water.

Ground-water storage within an aquifer may be construed to be one of two quantities: (1) the total amount of water within the pore spaces of the aquifer, or (2) the amount of the stored water that will move out of the pore spaces under the force of gravity (storage that is available to wells, springs, and streams). Part of the water in all rocks is held by the force of molecular attraction, which in fine-grained rocks is great enough to hold most of the water against the force of gravity.

The relation between mobile water and fixed water in an aquifer is expressed by the term "specific yield" of the aquifer. The specific yield of an aquifer is defined by Meinzer as the "ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume." This means that if 1 cubic foot of saturated water-bearing material will yield by draining under the force of gravity a volume of water of 0.20 cubic foot, the specific yield of that water-bearing material is 20 percent, and under natural conditions recharge of 0.20 foot of water over an area of an unconfined aquifer will produce a rise of the water table of 1 foot. Conversely, a decline of the water table in this aquifer of 1 foot indicates the loss of water equivalent to a thickness of water of 0.20 foot distributed over the area of decline.

Another term used often in discussing hydrologic properties of aquifers is the coefficient of storage, or storage coefficient. By definition, the coefficient of storage of an aquifer is the volume of water it releases from, or takes into, storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The coefficient of storage is about equal to the specific yield under water-table conditions as they exist in Clay County.

PERMEABILITY AND TRANSMISSIBILITY

The amount of water a given rock can hold is determined by its porosity, but the rate at which it will transmit water is determined by its permeability. The permeability of a water-bearing material is measured by the rate at which the formation will transmit water through a given cross section under a given difference in head per unit of distance. The coefficient of permeability in Meinzer units, or meinzers, may be expressed as the rate of flow of water in gallons per day (gpd) through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60° F (Wenzel, 1942, p. 7). The field coefficient of permeability is the same except that it is not corrected for temperature.

Gravel is the best water-bearing and water-yielding material in Nebraska. Gravel deposits of uniform texture have high porosity, high permeability, and high specific yield. Sand ranks next to gravel as an ideal aquifer. However, sand has smaller interstices, conducts water less readily, and yields a smaller proportion of its water to wells. Fine sand particles are readily carried into wells by water and may create difficult problems during the drilling, development, and pumping of wells.

Practically all the ground water used in Clay County is pumped from sand and gravel beds of Pleistocene age. Most of these beds consist of relatively well-sorted sand and gravel and where they are sufficiently thick they are capable of supplying large amounts of water to properly constructed wells.

The permeability of water-bearing materials may be determined by laboratory tests of samples of the materials, by determinations of ground-water velocity in the field, and by pumping tests made on wells that withdraw water from the materials. The physical properties of the geologic formations in the valley of the Platte River were determined by Lugn and Wenzel (1938, p. 96). These strata extend under Clay County and are believed to represent the water-bearing materials for all large wells in the county. The average coefficient of permeability as computed in a 48-hour pumping test near Grand Island in the valley (13 miles north of the northwest corner of Clay County) was 997 gpd per square foot. The average coefficient of permeability, as determined in the hydrologic laboratory, of 19 samples of the water-bearing material obtained during the drilling of a well at the location of the test was 1,200 gpd per square foot.

The coefficient of transmissibility is a factor similar to the coefficient of permeability and is defined as the number of gallons of water per day transmitted through a strip of the aquifer 1 mile wide and extending the height of the water-bearing formation (aquifer) under a hydraulic gradient of 1 foot per mile. The coefficient of transmissibility is equal to the field coefficient of permeability multiplied by the thickness of the aquifer, in feet.

To approximate the coefficient of transmissibility, E. C. Reed, State geologist of Nebraska, devised a system that is based on many tests made in Nebraska in connection with the cooperative statewide test-drilling program, and this system has proved reliable in predicting yields of many wells developed in the unconsolidated aquifers of Pleistocene age. Each lens or layer of material drilled in the test hole is closely examined, classified, and assigned a coefficient of permeability within a range as follows:

Material	*Gallons per day per square foot*
Clay and silt	0- 100
Sand, very fine, silty	100- 300
Sand, fine to medium	300- 400
Sand, medium	400- 600
Sand, medium to coarse	600- 800
Sand, coarse	800- 900
Sand, very coarse	900-1, 000
Sand and gravel	1, 000-2, 000

After each lens or column of material of similar physical characteristics is assigned a coefficient of permeability, each coefficient is multiplied by the thickness, in feet, of that material. This number is an estimate of the coefficient of transmissibility for that material. Then, the sum of the coefficients of transmissibility of all saturated beds is considered to be the coefficient of transmissibility for the aquifer. (See fig. 6.)

RATE OF GROUND-WATER MOVEMENT

Ground water is in motion nearly everywhere. The rate of movement is proportional to the permeability of the water-bearing medium and the slope of the water table. Even in sand and gravel the water percolates along tortuous paths between grains, and the rate of movement under natural conditions is very slow.

If the permeability and the porosity of the water-bearing materials are known and the slope of the water table has been determined, the average velocity of the water percolating through the materials can be computed by use of the following formula:

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

where

v=velocity, in feet per day;
P=permeability, in gallons per day (gpd) per square foot;
I=slope as a ratio; and
p=porosity.

The average permeability at the site of test hole 6-6-31bb is estimated to be 992 gpd per square foot. The slope is 0.00131 (see pl. 4) and the porosity is about 0.30. By substituting these values in the formula, the velocity is computed as 0.58 foot per day, or approximately 200 feet per year. A rate of flow of this general magnitude may be considered to be typical in Clay County.

When a well is pumped, a depression in the water table is formed around the well and a hydraulic gradient is established toward the well

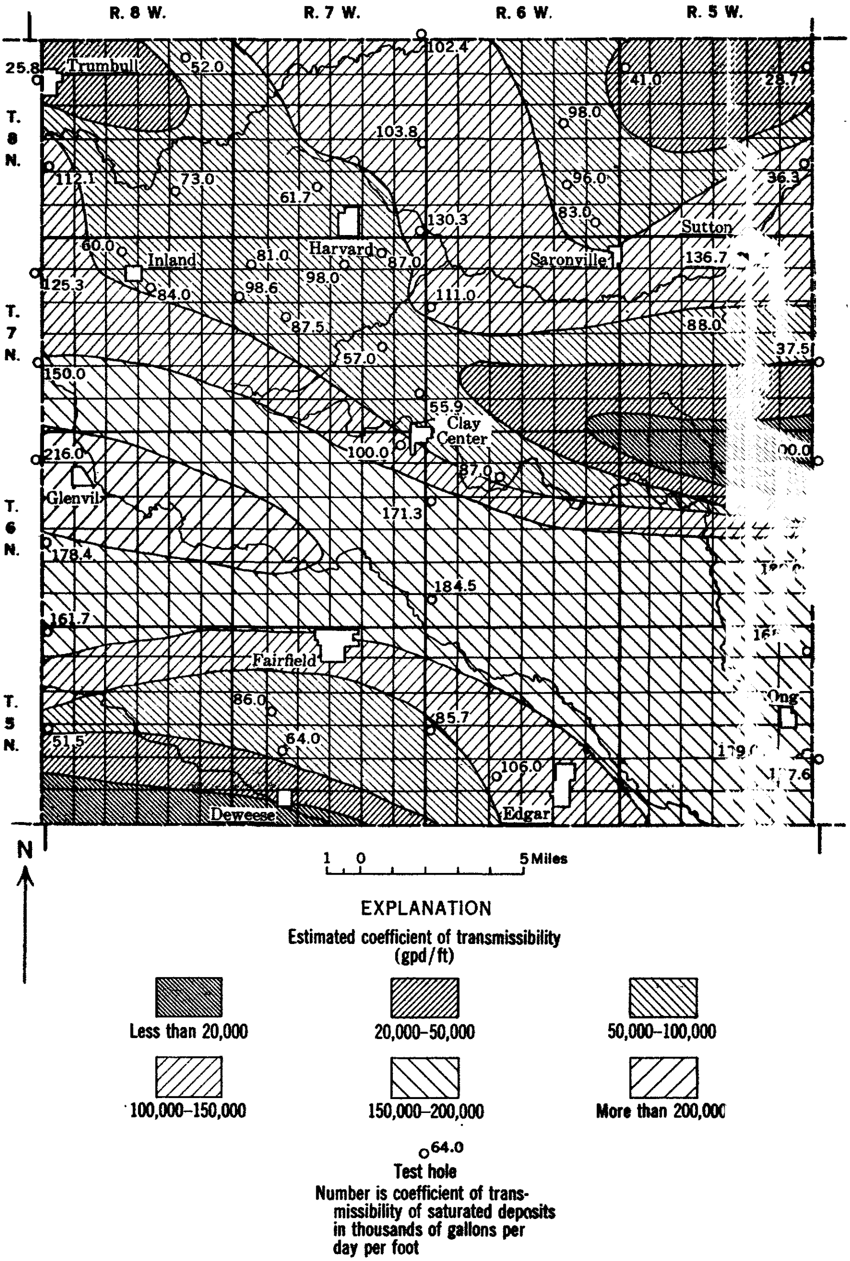

FIGURE 6.—Map of Clay County showing the estimated coefficient of transmissibility of the saturated deposits.

from all directions. This gradient is steep near the well and causes the water to move toward the well much more rapidly than under natural conditions.

DEPTH TO WATER

The depth to the water table beneath the land surface of Clay County ranges from less than 5 feet in the valley alluvium of the Little Blue River to about 120 feet in the southwest corner of the county. Depths to water of 75 to 95 feet are typical in most of the upland. In general, the depth to the water table below the land surface decreases from west to east. West of Glenvil the depth to water is about 115 feet; at Trumbull, about 100 feet; at Clay Center and Fairfield, about 80 feet; at Harvard, Edgar, and Ong, about 75 feet; and at Sutton, about 60 to 80 feet. (See pl. 4.)

The depth to water and the probable drawdown of the water level in a well are important factors to consider when planning to pump water from the well for irrigation, because the cost of pumping a given quantity of water varies directly with the distance the water must be lifted. Much more power is required to pump water from deep wells on the upland than from shallow wells on the valley floor where the water table is shallow. Likewise, pumping water from an improperly developed well, which does not yield the maximum amount of water with the least amount of drawdown, is uneconomical.

FLUCTUATIONS OF THE WATER TABLE

The stage of the water table is an indication of the quantity of water in a ground-water reservoir. In general, the water table rises when the amount of recharge exceeds the amount of discharge and declines when the discharge is greater than the recharge.

For example, precipitation that percolates through the soil to the water table, seepage that reaches the underground reservoir from surface streams whose channels are above the water table, and underflow from adjacent areas to the west and northwest cause the water table to rise in the county when they exceed the rate at which ground water is discharged from the county. Whether recharge exceeds discharge depends largely upon relatively local precipitation, either in the county or in areas immediately west of it.

Discharge of water from the ground-water reservoir by evaporation, absorption by growing vegetation, pumping from wells, outflow into surface streams, and underflow into adjacent areas depletes the ground-water storage and causes a decline of the water table when it exceeds the recharge.

The rate and magnitude of the fluctuations of the water table are governed by the rate and magnitude at which the underground reservoir is replenished or depleted. Seven wells were selected for observations of the character and magnitude of water-level fluctuations in the county. Periodic measurements of water levels in five of the wells were begun in 1954; measurements had been made previously at intervals in two of the wells—well 5-7-32ac was first visited in 1936 and well 5-6-26bd in 1948. Records of the water levels have been published in annual water-supply papers of the U. S. Geological Survey.

Hydrographs of the water levels in the seven wells and a graph of the monthly precipitation at Clay Center are shown in figure 7.

The water levels in wells 6-8-17ba, 8-6-12bb, and 8-8-17ab show the effect upon the ground-water reservoir of heavy withdrawals of ground water for irrigation. In 1954 the majority of well operators began to irrigate about June 20, and water levels declined until August. Heavy rains occurred in most parts of the county on August 1 and again on August 6, and irrigation in most areas ceased. Water levels in wells in these areas began a rising trend that continued until the spring of 1955, when pumping for irrigation began again. The water level in well 6-8-17ba does not show a rise until October 1954 because heavy withdrawals of ground water for irrigation were made from this well during the fall of that year.

Wells 5-5-11ba, 5-6-26ba, 5-7-32ac, and 7-5-35cd are in areas where withdrawals of ground water are relatively small, and the hydrographs show that the amount of ground water in storage at those points remained relatively unchanged during the irrigation season. Well 5-7-32ac is near the Little Blue River and the water level in the well approximates the stage of the river.

A recording gage had been installed on well 5-6-26bd in June 1948 and removed in June 1950, and a daily record of water-level fluctuations in this well and the cumulative departure from normal precipitation at Clay Center for the period that the recording gage was in operation are shown graphically in fig. 8. Comparison of the two graphs shows a definite influence of precipitation upon the water table at the site of the well.

GROUND-WATER STORAGE

Surface reservoirs have been constructed along streams in Nebraska to reduce flood crests and to store water for release as needed for irrigation or power. The term "reservoir" as applied to storage of surface water can be applied just as well to underground storage. Both types of reservoirs have the same general purpose for man, in that they tend to smooth out the great daily, seasonal, and annual fluctuations of the amount of water supplied by precipitation. Nature has provided beneath Clay County a vast natural ground-water reservoir that absorbs water chiefly during periods of surplus and gradually releases it to seeps, springs, wells, and areas of evapotranspiration. The ground-water reservoir is the source of all natural streamflow in Clay County during rainless periods.

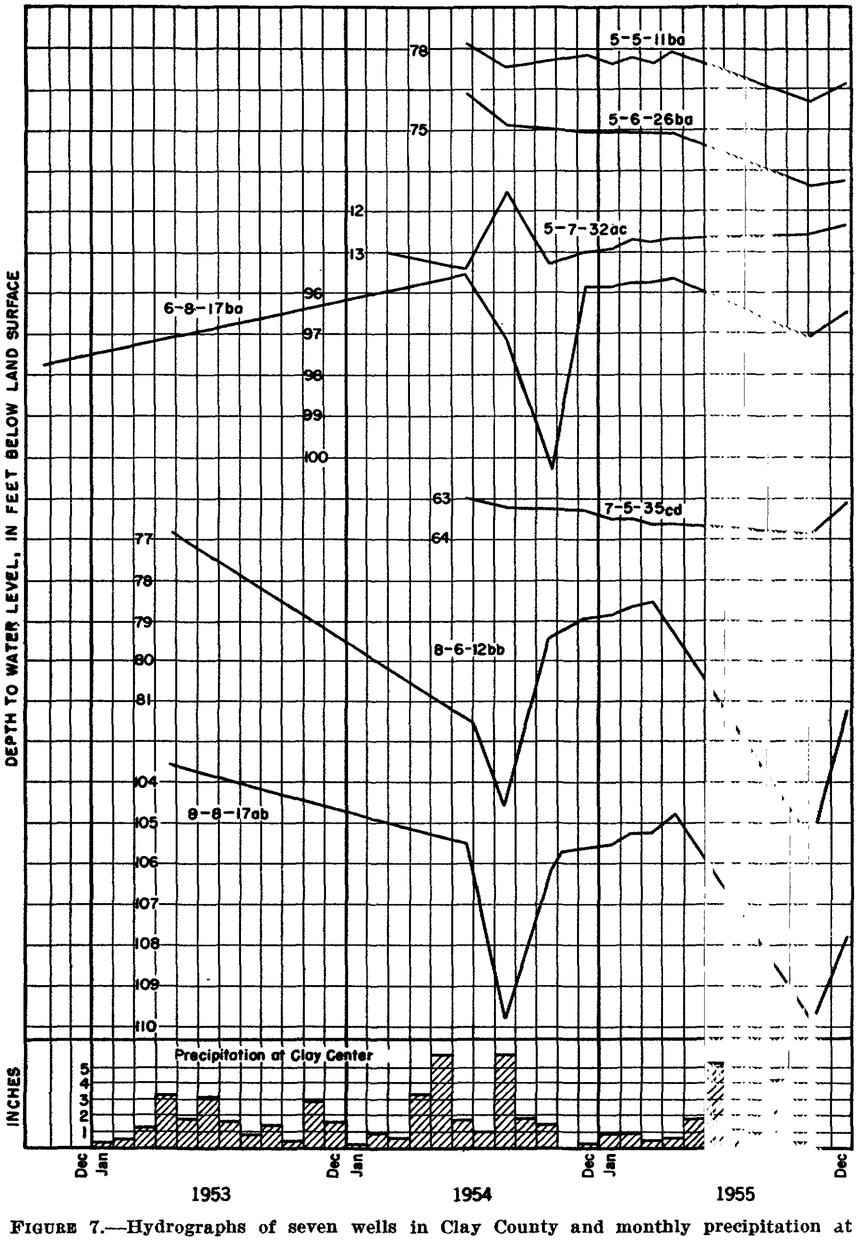

FIGURE 7.—Hydrographs of seven wells in Clay County and monthly precipitation at Clay Center.

The ground-water reservoir in Clay County contains thick deposits of unconsolidated, saturated sand and gravel which average more than 110 feet in thickness. The saturated sand and gravel are not known to contain water under pressure, and it is assumed that

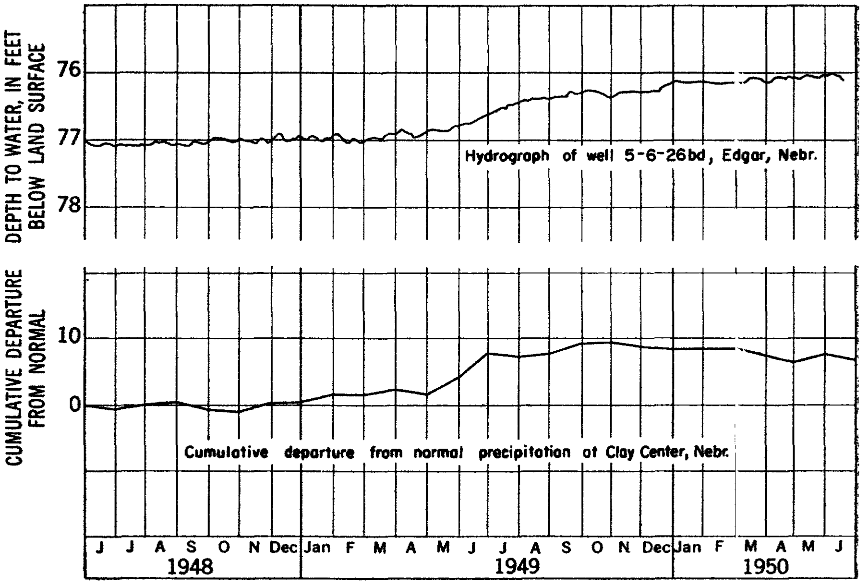

FIGURE 8.—Fluctuations of the water level in a well at Edgar and the cumulative departure from normal precipitation at Clay Center.

water-table conditions prevail practically everywhere. If it is assumed that the specific yield of the sand and gravel is 20 percent, which may be a conservative figure, the reservoir contains more than 8 million acre-feet of available water, or about twice as much as can be stored in the larger surface-water reservoirs in Nebraska. This large ground-water reservoir is affected only to a small extent by variations in the rate of annual precipitation, and for this reason it is especially desirable as a source of water for irrigation.

The amount of storage in a ground-water reservoir is, however, no indication of that reservoir's capabilities for sustained yield to wells and springs. The perennial yield is limited by the average annual recharge to the reservoir, just as the useful yield of a surface reservoir is limited by inflow into it.

GROUND-WATER RECHARGE

Recharge is the addition of water to the ground-water reservoir and may be accomplished in several ways. All ground water within the unconsolidated sediments beneath Clay County is derived from water that falls as rain or snow either within the area or within nearby areas to the west and northwest. Once water becomes a part of the ground-water body it moves down the slope of the water table, later to be discharged farther downgradient. The ground-water reservoir beneath Clay County is recharged primarily by infiltration

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of local precipitation through the soil. Other sources of recharge in this area are seepage from streams and from water ponded in depressions and subsurface inflow from areas to the west and northwest.

RECHARGE BY UNDERFLOW

The movement of ground water in Clay County is, in general, from west to the northeast, east, and southeast. Most of the water that enters the county by underflow crosses the Adams-Clay County line. The amount moving into the county can be estimated by use of the formula $Q=TIL$. Q represents the quantity of water in gallons per day that moves through the aquifer; T is the coefficient of transmissibility; I is the hydraulic gradient of the water table; and L is the length of aquifer being considered.

The average coefficient of transmissibility (T) is estimated to be about 110,000 gpd per foot. The hydraulic gradient (I) is about 0.001, and the length of aquifer being considered (L) is the length of the west line of Clay County, or about 125,000 feet.

Therefore, $Q=110{,}000 \times 0.001 \times 125{,}000=$ approximately 10,000 acre-feet per year.

Although water is moving into Clay County by underflow, the water thus obtained does not add to the average net amount in storage in the county because ground water also moves out of the county by underflow to the east and south, and the outflow is somewhat greater than the inflow.

RECHARGE FROM PRECIPITATION

The average annual precipitation in Clay County is about 25 inches, but only a small part of this water reaches the zone of saturation, the remainder being lost through evaporation, transpiration, and surface runoff without ever reaching the water table. The amount of water added to or discharged from the ground-water reservoir is reflected in the fluctuations of the water levels in wells, as demonstrated by the hydrograph of well 5–6–26bd at Edgar. The well is 86 feet deep and the depth of water below the land surface is about 76 feet. It is situated on the upland near the ground-water divide between the Little Blue River and Big Sandy Creek, where recharge occurs only from precipitation. A recording gage was installed on this well on June 5, 1948, and a continuous record of the water-level fluctuations in the well was obtained until the recorder was removed on June 17, 1950. The precipitation during this period was 8 inches above normal, and the water level in the well rose about 0.9 foot. The cumulative departure from normal precipitation for the period of the hydrograph is shown (see fig. 8) for comparison with the fluctuations of the water level in the well. If the storage coefficient of the upper part of the zone of saturation is known, the gain in ground-water storage for the period can be estimated. Assuming that the coefficient of storage is 0.20, the gain in storage was 2.2 inches of water for the 2-year period. A gain in storage of 2.2 inches would amount to about 120 acre-feet (about 38,000,000 gallons) per square mile.

Most of the water that enters the county by lateral movement from areas to the west and northwest moves southeastward and northeastward (see pl. 4), and relatively little of it reaches the eastern border of Clay County. The water-table contour lines on plate 4 indicate that about three-fifths of the water percolating into the county moves to discharge areas along the Little Blue River in the county or to the south and southeast of the county; something like a fifth of the water moves north or northeast to the Big Blue River drainage, and about a fifth continues across the county to its eastern border.

The shape of the water table indicates that precipitation on the land surface in Clay County must account for a substantial part of the water in the water-bearing sands and gravels. For the purpose of illustration, figure 9 was constructed. It shows the principal contour lines on the water table, across which the direction of ground-water movement is shown by flow lines drawn at right angles to the contour lines. The flow lines in the central uplands diverge from the western area, even though the slope of the water table is about constant across the central uplands of the county. This spreading out of the flow lines shows that if all the ground water in the county originated as underflow from the west, then either the saturated materials become progressively thinner or the permeability of the materials becomes progressively smaller from west to east.

If one or both of the above conditions does not exist, then the cause for divergence of the flow lines must be recharge from local precipitation on the upland, creating a mound on the water table. Test drilling shows that the thickness of the saturated materials does not become progressively less from west to east, except for a narrow ridge east of Clay Center, and analyses of the test-hole samples indicate that the permeability of the water-bearing materials does not become significantly less from west to east. Thus, the spreading of the flow lines must be due to recharge from precipitation.

The amount of water contributed by recharge from precipitation can be computed. The procedure used is as follows: Sections *A* and *B* on figure 9 were selected in such a way that they lie between the same pair of flow lines. Because the flow lines diverge from west to east, section *B* is longer than section *A*. The transmissibility of the saturated water-bearing formation at each section was estimated from analyses of materials obtained from test holes near each section. The average gradient at each section was measured from

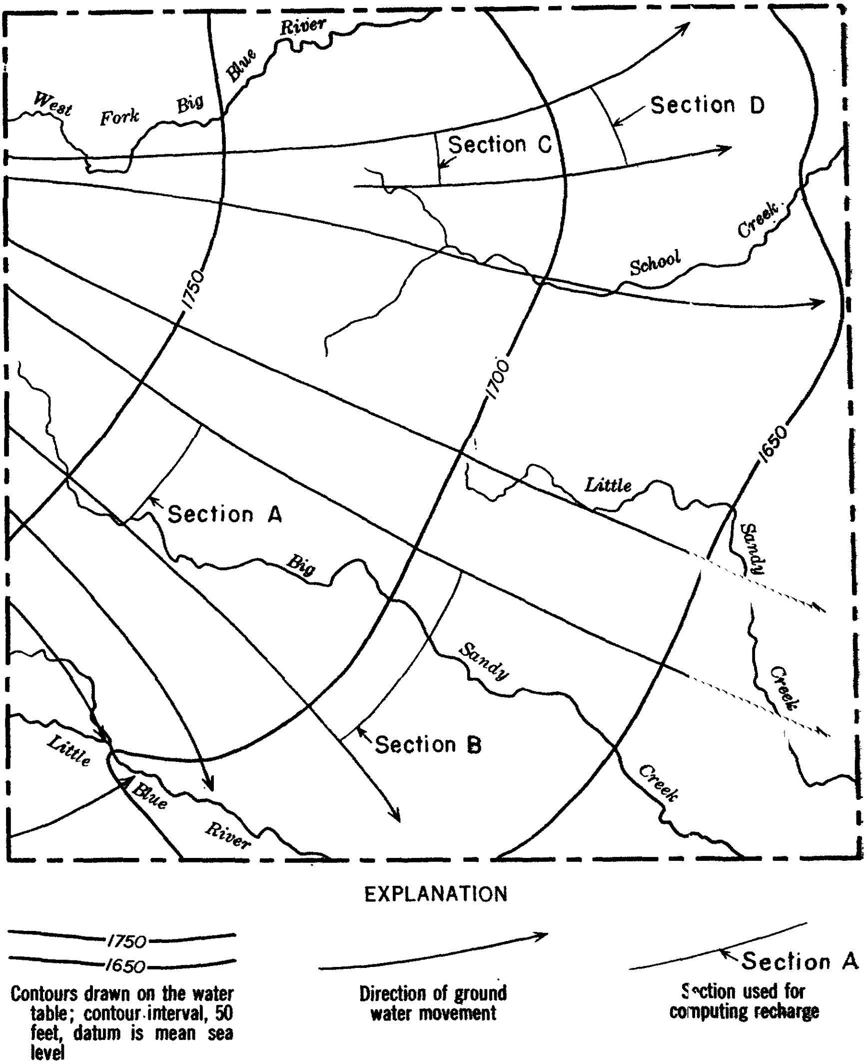

FIGURE 9.—Map of Clay County showing the contour of the water table and the direction of ground-water movement.

the water-table contour map. (See pl. 4.) The transmissibility multiplied by the average gradient, multiplied by the length of the section, equals the quantity of water crossing each section within a given time.

Examination of the test-hole samples indicates that the transmissibility at section *A* is about 200,000 gpd per foot. At section *B* it is about 135,000 gpd per foot. The gradient of the water table at section *A* is about 0.00088; at section *B* it is about 0.0013. The length of section *A* is 19,000 feet; the length of section *B* is 39,000 feet.

The quantity of water crossing section *A* each day is expressed as follows:

Quantity = Transmissibility × slope × length of the section
= 200,000 × 0.00088 × 19,000
= 3,200,000 gpd

Similarly, the quantity of water crossing section *B* each day is:

Quantity = 135,000 × 0.0013 × 38,000
= 6,800,000 gpd, or 3,600,000 gpd more than the quantity flowing through section *A*.

The 3,600,000 gpd, or about 11 acre-feet per day, represents the recharge between sections *A* and *B* that necessarily originated on the land surface of the area between the sections. Recharge at the rate of 11 acre-feet per day equals about 4,000 acre-feet per year; the area included by the sections and flow lines is about 30,000 acres; therefore, the average annual rate of recharge over the area is about 1.6 inches.

The area between sections *A* and *B* may be considered to be typical of the upland areas of the county in the Little Blue River basin, and hence the annual ground-water recharge computed for this area probably is typical of much of the county. In a few places, especially along the Little Blue River, the West Fork of the Big Blue River, and the lower reaches of Big Sandy Creek and School Creek, where stream erosion has produced pronounced rolling relief, runoff of water after rains is rapid and the recharge to the ground-water reservoir probably is small. However, because all streams except the Little Blue River and the lower reaches of the West Fork of the Big Blue and of School Creek are above the water table, recharge by seepage from the beds of these streams when water is flowing through them may compensate for the loss of recharge caused by rapid runoff from the steep slopes.

The amount of recharge from the land surface is dependent on the permeability of the soil. In the area north of School Creek, including the area between sections *C* and *D* in figure 9, much of the soil is a heavy silty clay that when wet is tough and plastic and when dry is very hard and compact. This type of soil occurs in large basinlike valleys beginning west of Harvard and extending southeast to Clay Center and thence east to the county line, as well as in the area between section *C* and *D*. Recharge from the land surface in these areas is somewhat less than on other lands in the county. An estimate of the magnitude of the recharge through these soils was computed for the area lying between sections *C* and *D*. The amount of ground water crossing section *C* was computed to be about 910,000 gpd (120,000 × 0.0010 × 7,600) and at section *D*, 1,500,000 gpd (90,000 × 0.0012 × 14,000), or 590,000 gpd more than the quantity flowing across section *C*. The computed annual recharge over the 10.4 square miles included by the sections and flow lines was 660 acre-feet, or 1.0 inch; this is about 0.6 inch less than the annual recharge between sections *A* and *B*.

RECHARGE FROM SEEPAGE

Recharge to the water table from ephemeral streams whose beds are above the water table occurs during the brief period in which the streams flow after rains. Some of the streams have beds of sand and gravel which become saturated. Much of this water descends to the water table. In this report, the recharge from the ephemeral streams is considered to be a part of the recharge from precipitation discussed in the preceding pages. The West Fork of the Big Blue River is above the water table in Clay County and it is naturally an ephemeral stream, but because it carries a small flow of waste water from the sewage-disposal plant upstream at Hastings it is now perennial. The flow of the waste water in the stream was observed on November 14, 1954, to diminish as it traversed the county. This indicates that water is being lost by seepage into the stream bed, because loss of water by evapotranspiration could not have been a significant factor at that time of year.

Most of the upland plain is fairly well drained; however, water occasionally collects in the large depressions in its surface. The water that collects in these depressions remains on the surface from a few days to several months. The depressions are underlain by a dense claypan layer, so that recharge from them to the water table probably is less than it is on the remainder of the upland (p. 47).

RECHARGE FROM IRRIGATED LANDS

Except for a small amount of land along the Little Blue River that is irrigated with water pumped from the river, all irrigation in the county is done with water pumped from wells. The seepage from these irrigated lands represents a source of recharge to the groundwater reservoir. It is estimated that the amount does not exceed an average of 10 percent of the water applied to the land. During 1954, recharge from this source is estimated to have been about 2,600 acre-feet. (See table 3.)

GROUND-WATER DISCHARGE

Gound water is discharged from Clay County by transpiration through vegetation, evaporation, wells, streams, and underflow. The rate at which it is discharged varies with many factors, but especially with the differences in the rate of recharge and the season of the year. Local differences in conditions cause more ground water to be discharged in some parts of the county than in others. For example, more water is being pumped from wells in some areas than in others.

DISCHARGE BY TRANSPIRATION AND EVAPORATION

In addition to being evaporated from moisture in the soil, water may be taken into the roots of plants directly from the zone of saturation or from the capillary fringe extending upward from it and discharged from the plants by transpiration (Meinzer, 1923, p. 48). But except in the Little Blue River valley and along the lower reaches of School Creek, where the water table is shallow and ground water is discharged by these processes, the depth to the water table in Clay County is so great that there is no transpiration or evaporation from the zone of saturation or from the capillary fringe.

DISCHARGE BY SPRINGS AND SEEPS

A relatively small amount of ground water is discharged by springs along the banks of the Little Blue River in the southwestern part of Clay County. The springs emerge from saturated sand and gravel of the Sappa formation. The yields of the springs were not measured, but most do not exceed 1 gallon per minute.

The diffused seepage of water into the Little Blue River, not concentrated enough to form springs, is one of the principal methods of discharge of ground water in Clay County. The channel of the Little Blue River is lower than the water table in the adjacent upland areas; hence, ground water moves toward the river and discharges into the stream channel.

The amount of ground water discharged into the Little Blue River can be estimated from measurements of the flow of the stream. On February 12, 1953, the flow of the Little Blue River at Deweese, Nebr., was about 78 cubic feet per second (cfs), and at a measuring station 6 miles downstream from Deweese the rate of flow was about 87 cfs. The difference, or the increase in flow from ground-water contribution to the stream, was about 9 cfs, or about 1.5 cfs per mile, which would amount to about 1,100 acre-feet per year for each river mile.

In Clay County, the Little Blue River traverses a distance of about 10 miles; therefore, the amount of ground water discharged into it in Clay County probably is of the order of 10,000 acre-feet per year.

DISCHARGE BY UNDERFLOW

Ground water in Clay County percolates slowly in the direction of the maximum slope of the water table and toward the areas of natural ground-water discharge. (See explanation under "Recharge from precipitation" and fig. 9.) Ground water that is not used within the county or is not intercepted by the Little Blue River or the lower reaches of School Creek percolates into the adjacent counties to the north, east, and south. The amount of water that moves out of the county by underflow is estimated to be in the magnitude of 28,000 acre-feet per year.

DISCHARGE BY WELLS

The most obvious and important discharge of ground water in Clay County is through wells. About 30,000 acre-feet of water is estimated to have been pumped during 1954, of which more than 26,000 acre-feet was pumped for irrigation. (See table 3.) All domestic water supplies and most of the livestock water supplies in the county are pumped from wells, but the amount of water discharged for these purposes is comparatively small.

The irrigation season in Clay County usually begins in June and ends in September, but its length varies from year to year, depending upon the distribution of precipitation.

When wells are pumped, the water table declines around each of the pumped wells and assumes a form similar to an inverted cone. This depression in the water table is known as the cone of depression, and the distance that the water level is lowered in the well is called the drawdown. The greater the pumping rate in a well, the greater is the drawdown. When pumping stops, the cone of depression gradually refills with water that moves into it from areas adjacent to the limits of the cone of depression, and the regional water table declines slightly. Most wells are pumped intermittently, and while a cone of depression is being formed in one part of the area another cone may be filling in some other part of the area. After the end of the pumping season, the regional water table gradually assumes a form similar to the form it had before the pumping season began; however, the regional water table will be lower than it would have been if there had been no pumping.

The capacity of a well can be defined as the maximum rate at which it will yield water after the pumping water level becomes approximately stabilized. The capacity depends upon the quantity of water available, the thickness and permeability of the aquifer, and the construction and condition of the well. The capacity of a well generally is expressed in gallons per minute.

The specific capacity of a well is its rate of yield per unit of drawdown and is generally determined by dividing the capacity in gallons per minute by the drawdown in feet. Thus, for example, if a well is pumped at a rate of 1,000 gallons per minute and the water level in the well is drawn down 10 feet below the static water level, the well has a specific capacity of 100.

WELL CONSTRUCTION

Most of the wells in Clay County, except a few driven wells in the valley of the Little Blue River, are drilled by jetting or hydraulic-rotary methods. Livestock and domestic water supplies commonly are obtained from small-diameter wells that are jetted, or "washed," into the aquifer. The large-diameter wells required for irrigation and public water supplies are drilled by hydraulic-rotary methods. These methods consist of rotating a bit to cut the earth materials and circulating thick muddy water into and out of the hole to remove the drill cuttings. The cuttings are carried to the land surface by suspension in the muddy fluid. Some hydraulic-rotary drilling rigs circulate, by pressure pumps, the mud down through the drill stem and up through the annular space between the drill stem and the hole. Others allow the drilling fluid to run by gravity into the well through the annular space between the drill stem and the hole, and pump, by suction pumps, the circulating mud and suspended drill cuttings up through the drill stem to the land surface. The latter method is called the reverse-hydraulic, or reverse-rotary, method and is commonly used to construct irrigation wells in Clay County.

All wells in Clay County obtain water from unconsolidated deposits. Wells in these deposits are cased to the bottom of the drill hole with galvanized-iron, steel, or concrete-tile casing to prevent caving of the walls. The casing that is below the water table is perforated, or a well screen is installed in place of blank casing, to allow water to enter the well. The selection of the proper size of perforations is very important and may determine the capacity and life of a well. If the perforations are too large, fine material may filter through and fill the well; if the perforations are too small, they may become clogged and hamper or prevent the free entrance of water. When the well is developed[1] the coarser particles that remain around the screen form a natural gravel packing, which increases the effective diameter and therefore the capacity of the well.

The irrigation and municipal wells are artificially gravel packed. To construct a well of this type, a hole about 36 inches in diameter is drilled and a well screen or perforated-steel or concrete casing, having an inside diameter of 18 inches, is centered opposite the water-bearing beds; enough unperforated casing is then added to reach the land surface. The annular space between the casing and the hole is filled with well-sorted gravel that has a grain size larger than that of the

[1] The term "development," as applied to a well, refers to various practices, such as surging and overpumping, that are designed to increase the yield.

water-bearing material. The envelope of gravel that then surrounds the well increases the effective diameter of the well. Because the effective diameter is larger than it would have been if the well were drilled only large enough to accommodate the screen or perforated casing, the velocity of the water entering the gravel pack from the aquifer is reduced and, thus, movement of sand into the well is reduced. If the water-bearing formation is relatively coarse and uniform in texture, addition of a gravel pack around the well may not increase the yield appreciably.

Irrigation wells generally are drilled to penetrate about 50 feet of saturated sand and gravel. If the thickness of the saturated sand and gravel is less than about 50 feet, the wells are drilled through the entire aquifer. Commonly, a concrete platform upon which the pump and power unit are mounted is placed around the top of the casing; many installations are protected by small wooden or sheet-metal buildings constructed over the platform.

The depth of the irrigation wells ranges from about 100 to 240 feet. The following table shows the range in depth for 229 wells in Clay County.

Number of wells	*Depth (feet)*	*Number of wells*	*Depth (feet)*
1	100–110	40	170–180
0	110–120	28	180–190
4	120–130	8	190–200
8	130–140	10	200–210
13	140–150	2	210–220
39	150–160	1	220–230
74	160–170	1	230–240

METHOD OF LIFT AND TYPES OF PUMPS

Most domestic and stock wells in Clay County are equipped with cylinder pumps operated by windmills, electric motors, gasoline engines, or, for a few, hand power. The cylinder or working barrel of most cylinder pumps is below the water level and is of the lift type, which discharges water at the land surface or into storage tanks. A few wells are equipped with jet pumps, which use a stream of water under pressure to raise additional water.

The pumps in irrigation and public-supply wells are, with few exceptions, deep-well turbines having 2 to 5 stages; belted, gear-head, or direct drives; and electric motors or internal combustion engines that use propane, butane, diesel fuel, tractor fuel, natural gas, or gasoline. Stationary propane, tractor-fuel, and natural-gas powerplants are the most common, although some pumps are powered by farm tractors.

EFFECT OF GROUND-WATER DISCHARGE ON GROUND-WATER STORAGE AND STREAMFLOW

Before the ground-water resources of an area are developed, the natural discharge of ground water equals the natural recharge, and the ground-water reservoir is said to be in equilibrium. Changes in either the recharge or the discharge by artificial means will affect the other and establish the water table at a level different from its level prior to the time its equilibrium under natural conditions was disturbed. The net effect that development of the ground-water resources of the area has upon the water table, the quantity of water stored in the reservoir, and the flow of perennial streams is governed by the quantity of water discharged from wells, the distribution of the discharging wells, and changes, if any, in the amount of recharge to the ground-water reservoir.

As of 1955, the effect of the development of ground water in Clay County on the total amount stored in the ground-water reservoir has been small, but if new irrigation or other large-capacity wells continue to be constructed at a continually increasing annual rate (see fig. 11), a significant lowering of the water table in the more intensely developed areas will undoubtedly occur.

Heavy additional development of the ground-water resources may result in a lowering of the water table to the extent that most of the present pumping plants will require modification or replacement to maintain desired yields. Permanent lowering of the water table by as much as 10 feet might not require modification of wells or pumping equipment much in excess of that necessitated by normal depreciation and obsolescence; however, a lowering of the water table of more than about 10 feet would require a deepening of the domestic and livestock wells, most of which penetrate only the top 10 to 15 feet of the aquifer, and would require the irrigation and municipal pumps to be reset at a lower level in the wells and perhaps the deepening of some wells. Power supplied to pumps would need to be increased, or yields would be reduced, and pumping costs would increase in proportion to the greater lift of water.

In the following estimate of the number of years that may elapse before the water table is lowered an average of 10 feet, only that part of Clay County in which extensive irrigation is likely to occur is considered. Of the 365,000 acres in the county, not more than 256,000 acres is considered potentially suitable for irrigation from wells; in the remainder of the county, the aquifers are not sufficiently thick to supply sufficient water, the land is too rough for irrigation, or the land is out of crop production because it is within the boundaries of the U. S. Naval Ammunition Depot. A canvass made in 1954 of all irrigation systems showed that more than 21,000 acres was being irrigated

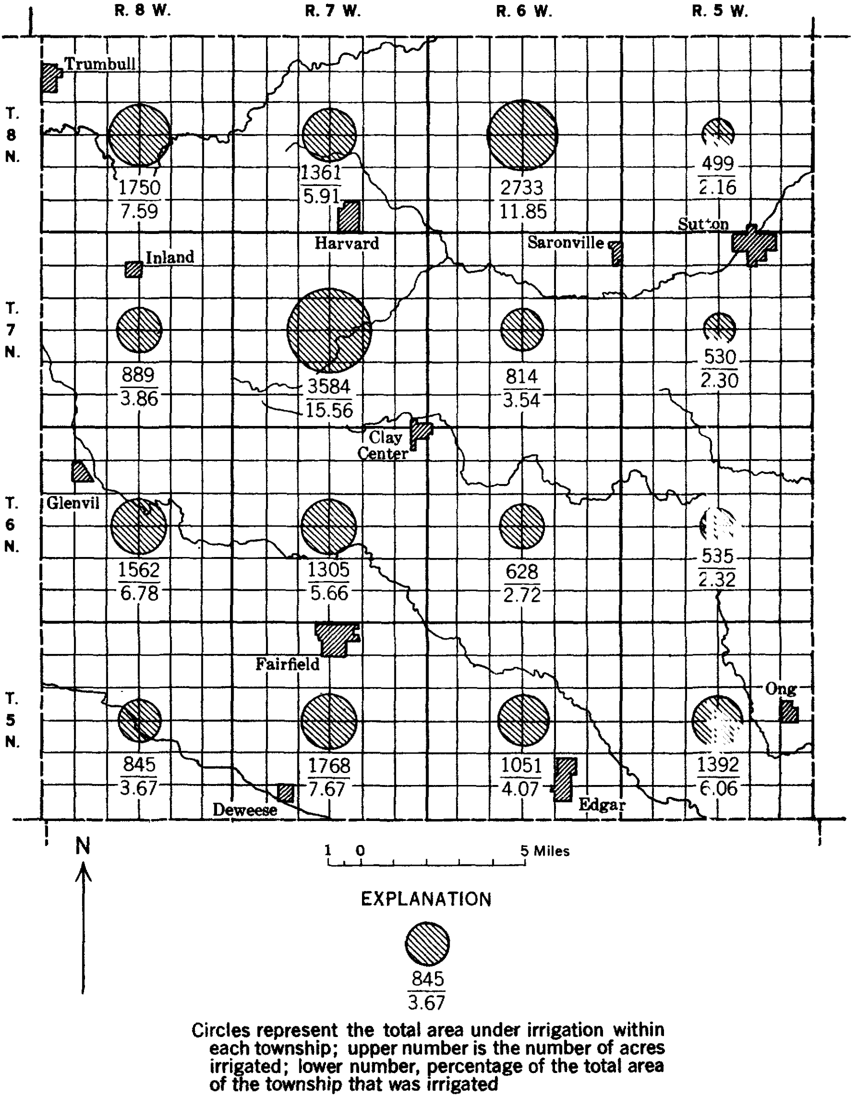

FIGURE 10.—Map of Clay County showing the amount of land irrigated by wells in each township in 1954.

and that new land was developed during 1953 and 1954 at the rate of about 4,000 acres per year. (See fig. 10.)

A formula may be used to estimate the time required to lower the water table 10 feet if the development of new irrigation continues into the future at the 1953–54 rate of 4,000 acres per year, the consumptive use of water is assumed to be 1.0 acre-foot per acre irrigated, the recharge from precipitation is 1.6 inches or 0.13 acre-foot per acre per year on all irrigable land (see section on "Recharge from precipitation"), and the coefficient of storage is 0.20. The formula is as follows:

$$yA+\left(\frac{yA_1+y^2A_1}{2}\right)=St+Ry$$

where

A=acre-feet used in 1954 (see table 3);

A_1=annual increase in amount of water pumped, in acre-feet;

St=acre-feet of water stored in 1954 in the upper 10 feet of the aquifer beneath the irrigable land;

R=recharge from precipitation on irrigable area, in acre-feet per year;

y=time in years to lower water table 10 feet.

Clearing the above formula, it becomes:

$$2yA+yA_1+y^2A_1=2St+2Ry$$

substituting the assumed or estimated values, it becomes:

$$(2\times 21{,}000y)+4{,}000y+4{,}000y^2 = (2\times 512{,}000)+(2\times 256{,}000\times 0.13\times y)$$

or:

$$4{,}000y^2-20{,}560y-1{,}024{,}000=0$$

or:

$$y^2-5.14y-256=0$$

solving for y by the formula:

$$y=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$$

$$y=19 \text{ years}$$

Thus, the estimated minimum period of time required to lower the water table sufficiently to necessitate extensive modification of present pumping systems is about 19 years; the period will exceed 19 years if the increased recharge by underflow from areas surrounding the area of decline and the decreased natural discharge resulting from a lowered water table are considered. Also, the rate of development may not continue at the high rate of 1953-54. The total pumpage of ground water during 1952 was less than 1,500 acre-feet, and prior to 1952 it was even less.

The annual recharge from precipitation on the irrigable land is estimated to be about 33,000 acre-feet. Thus, if new wells are pumped at the same yearly rate as the 257 wells were pumped during 1954, a total of about 400 wells can be supplied by the annual recharge from precipitation upon the irrigable land.

Because pumping lowers the water table in the vicinity of the pumped wells, ground water is induced to move into the areas of the depressed water table from outside the areas of development. Movement of ground water into these areas will supply some wells in addition to the approximately 400 that can be sustained by annual recharge from precipitation on the area considered to be irrigable, and it also will increase the time in years (19), as computed in preceding paragraphs, required to lower the water table 10 feet.

The streams in the areas of present and potential development of ground water for irrigation are ephemeral. The perennial streams are bordered by the more rolling land, which is difficult and expensive to irrigate; therefore, development of irrigation on lands close to the perennial streams probably will not be extensive. Pumping ground water for irrigation will eventually reduce the base flow of streams by approximately the amount of consumptive use, but the change will be gradual because of the distance from the pumped areas to the streams.

A decline of the water table to an extent requiring modification of many of the existing wells probably will not occur over the entire county for at least 19 years if the present irrigation practices and rate of annual increase of well installations continue. However, local overdevelopment may occur in a shorter time where wells are too closely spaced.

UTILIZATION OF GROUND WATER

DOMESTIC AND LIVESTOCK SUPPLIES

Most of the rural residents of Clay County obtain water for domestic and livestock uses from small wells equipped with force pumps. Some pumps are driven by small gasoline or electric motors or are operated by hand, but the majority are powered by windmills; however, many farmsteads in the county are now served with electricity, and windmills are being replaced by electrically powered pumps.

Wells commonly are drilled 10 to 15 feet below the water table and cased with 2- to 4-inch pipe or with 5½-inch galvanized-steel casing that is perforated below the water table. The yields of these wells generally are not more than 5 gallons per minute. Only in a few localities of small area is the aquifer of such low permeability or small thickness that even domestic and stock wells cannot be obtained. The amount of water discharged by these wells as compared with that pumped for irrigation is relatively small; it is estimated to be less than 2,000 acre-feet per year.

PUBLIC SUPPLIES

Seven towns and villages have municipal water supplies comprising wells, storage reservoirs, and distribution systems. The typical public-supply well is cased with 8-inch or larger steel casing and is pumped with a deep-well turbine powered by an electric motor. Common practice is to maintain a standby gasoline engine to supply power should the electrical power be disrupted. The towns in Clay County that have public water systems are Clay Center, Edgar, Fairfield, Glenvil, Harvard, Sutton, and Trumbull. Deweese, Inland, Ong, and Saronville do not have public water-supply systems. All the towns obtain water from deep wells; none of the water is chlorinated or softened.

Recent increases in domestic uses of water for modern plumbing, sanitary facilities, and air conditioning have necessitated the expansion of the public water supplies and distribution systems of most towns.

Data on the municipal water supplies are given in table 2.

INDUSTRIAL SUPPLIES

The amount of ground water used for industries is small. In most places, the water is obtained from the public-supply systems.

The quality of the water is good for most industrial purposes, and the quantity available at or in the vicinity of all principal towns is adequate for industrial expansion.

Water used by the railroads is purchased from the municipalities. Six deep wells, each having a capacity of about 1,000 gpm, supply water to the U. S. Naval Ammunition Depot, including the needs for fire protection. Records of these wells are given in table 12.

IRRIGATION SUPPLIES

The greatest use of ground water in Clay County is for irrigating field crops, principally corn and alfalfa. During the canvass made in 1954, 257 irrigation wells were inventoried and the type of crops, the number of acres irrigated, and the amount of water pumped for

TABLE 2.—*Public water supply of principal towns in Clay County, 1954*

Town	Number of wells	Combined capacity of well pumps (gallons per minute)	Reservoir		Distribution			Consumption per day	
			Capacity (gallons)	Type	Length of mains (miles)	Number of hydrants	Number of taps	Maximum (gallons)	Average (gallons)
Clay Center	2	1,000	80,000	Standpipe	11	34	500	1,440,000	360,000
Edgar	2	400	80,000	do	15	125	385	400,000	200,000
Fairfield	2	300	50,000	do	5	27	250	400,000	30,000
Glenvil	1	250	50,000	do	4	30	100	100,000	20,000
Harvard	4	1,000	100,000	do	20	47	650	250,000	150,000
Sutton	2	1,800	90,000	do	20	90	500	350,000	150,000
Trumbull	1	200	5,000	Pneumatic underground tank		19	66	40,000	10,000

irrigation were ascertained. The cost of some of the wells and their equipment was also obtained; these data are shown in the following table:

Cost of representative irrigation wells in Clay County, as reported by owners

Year drilled	Depth of well (feet)	Cost of drilling well and installing pump and powerplant	Year drilled	Depth of well (feet)	Cost of drilling well and installing pump and powerplant
1937	140	$2,000	1952	168	$4,200
1940	160	3,800	1952	200	5,000
1942	180	4,000	1953	165	4,200
1943	140	3,000	1953	172	5,500
1944	175	3,200	1953	175	4,000
1946	170	3,420	1954	122	5,000
1949	175	4,200	1954	168	4,800
1950	150	3,750	1954	172	4,500
1950	174	3,000	1954	200	6,000
1951	158	4,100	1954	200	6,400
1952	150	4,500			

About 70 percent of the irrigated acreage is planted to corn, and the remaining 30 percent is planted to alfalfa, grain sorghum, soybeans, potatoes, sugar beets, and miscellaneous crops. A total of 21,248 acres is reported to have been irrigated with water pumped from wells in 1954, an apparent average of 83 acres per well. However, the amount of land irrigated by each well was somewhat more than 83 acres because some wells were installed in late summer and were not used during the 1954 irrigation season. A total of about 26,000 acre-feet of water is reported to have been pumped for irrigation in 1954, an average of 1.23 acre-feet per acre irrigated. (See table 3.) The amount of water pumped for supplemental irrigation varies considerably from year to year because of variations in the amount and distribution of precipitation received during the growing season; in general, however, the quantity pumped each year has been increasing.

The water pumped from irrigation wells is distributed by gravity in ditches or pipes or under pressure through pipes and sprinklers. The most common distribution method is by gravity in unlined ditches. By this method, a canvas dam in the ditch raises the water level above the level of the field, and curved plastic or metal tubes siphon the water from the ditch. The water then flows by gravity through small furrows down the length of the crop rows. Distribution of water by gated pipe is becoming popular, and it may soon be the most common type of distribution because less labor is required by its use than by the open-ditch siphon-tube method. This pipe has openings that are spaced about 40 inches apart and which may be regulated in size by

TABLE 3.—*Summary of acreage irrigated with water from wells and acre-feet of water pumped in Clay County in 1954*

Location		Irrigated acres of—							Reported quantity pumped (acre-feet)	Acre-feet per acre
Township north	Range west	Corn	Alfalfa	Grain sorghum	Soybeans	Pasture	Other	Total		
5	5	1,200	155	--------	22	15	--------	1,392	1,870	1.34
5	6	930	93	28	--------	--------	--------	1,051	1,875	1.78
5	7	1,529	50	58	--------	--------	131	1,768	2,841	1.61
5	8	517	35	43	--------	--------	250	845	1,240	1.47
6	5	404	118	--------	--------	15	--------	537	517	.96
6	6	523	5	100	--------	--------	--------	628	684	1.09
6	7	1,005	45	105	--------	40	110	1,305	1,607	1.23
6	8	1,163	137	165	--------	7	90	1,562	1,765	1.13
7	5	448	65	12	--------	--------	5	530	618	1.16
7	6	537	30	27	--------	20	200	814	1,008	1.24
7	7	1,627	1,530	220	--------	10	197	3,584	2,313	.65
7	8	757	10	122	--------	--------	--------	889	997	1.12
8	5	455	26	--------	--------	--------	18	499	932	1.87
8	6	1,759	168	242	110	21	433	2,733	3,485	1.27
8	7	1,195	32	92	--------	27	15	1,361	2,162	1.59
8	8	1,202	98	265	19	--------	166	1,750	2,318	1.32
Total or average		15,251	2,597	1,479	151	155	1,615	21,248	26,232	1.23

small sliding gates; the openings allow water to flow from the pipe to the crop rows. Sprinklers are coming into common use to irrigate rolling land; they are particularly adapted for irrigating alfalfa and pasture, but their use for row crops, especially corn, is difficult because much labor is necessary to move the sprinklers in tall-growing crops.

The rate of ground-water development in the county during the past few years (see fig. 11) is related to the agricultural economy and technical advances, such as more efficient pumps and wells, the availability of diesel engines and of propane and butane fuels, and more effective methods of water distribution. The availability, in parts of the county, of natural gas for engine fuel also has had an accelerating effect on ground-water development in those areas.

The number of irrigation wells installed during any year is, in part, related to the amount and distribution of annual precipitation. In drought years, especially if the year is preceded by a dry year or fall, the interest in irrigation is at a high level and many more wells are constructed than during wet or near-normal years. The adverse effect of subnormal precipitation on the economy of a nonirrigated farm may be partly reduced by tilling practices that conserve moisture in the soil, but irrigation is the only means by which high yields can be maintained throughout a prolonged drought.

The low level of farm-crop prices during the drought years of 1930–39 probably retarded the expansion of irrigation by ground water during that period. However, when farm income became higher, farmers began to install irrigation systems as insurance against another drought.

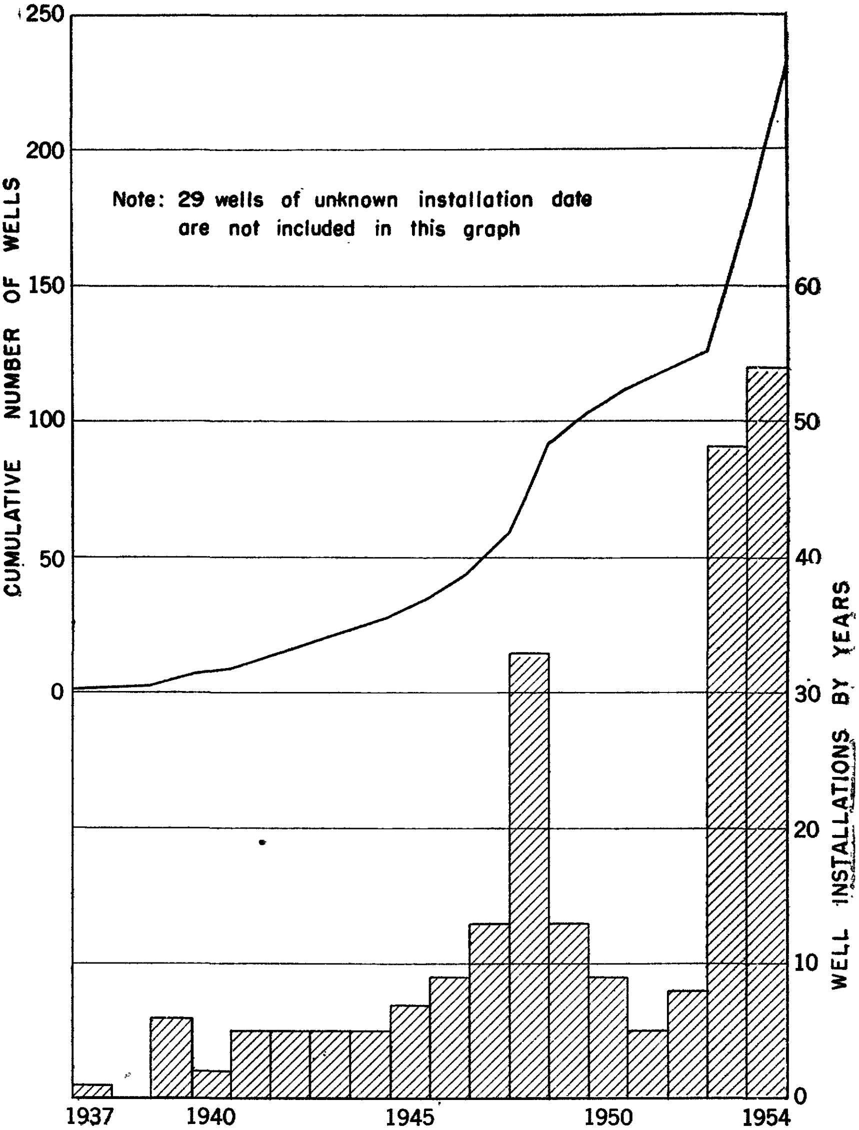

FIGURE 11.—Rate of installation of irrigation wells in Clay County.

Prior to 1953, the greatest number of wells installed in any one year was that during 1948, which was characterized by being the second consecutive year of subnormal precipitation and one in which crop prices were high. The years of 1953 and 1954 were again years of subnormal precipitation, and during them the greatest expansion of well development to date was made. More than 100 wells, or about a third of all the irrigation wells in the county, were drilled during that

2-year period. The attitude of farmers whose recent interest in irrigation stems from the abnormally dry fall and winter of 1954–55 indicates that the drilling of new wells probably will continue at a rapid rate during the next few years. Well drillers also report increased interest in irrigation with ground water.

Most irrigators report that irrigation produces greater crop yields in years of above-normal precipitation as well as in dry years. Only a few farmers expressed dissatisfaction in the results obtained from irrigation; thus, the amount and distribution of future rainfall probably will not have as important an effect on the development of ground water for irrigation as it has had in the past. The use of ground water for irrigation may be expected to increase at a relatively steady rate regardless of future climatic conditions.

CHEMICAL QUALITY OF THE GROUND WATER

By F. H. Rainwater

Improved farming methods and development of ground-water irrigation have accentuated the importance of water quality in Clay County, Nebr., and also have raised problems of maintaining the suitability of both water and land resources for present and future beneficial use. Good-quality water and highly productive soils are great natural resources that have constantly increasing value. The extent to which water can be effectively utilized is closely associated with its chemical quality. Water users are many, and water that meets the quality requirements of one user may be unsatisfactory for another. Water consumption in Clay County can be roughly divided into two classes, domestic and agricultural. Hardness, iron and manganese, fluoride, sulfate, chloride, and nitrate contents are of primary concern to the domestic consumer. The total mineral content, the ratio of sodium to calcium and magnesium, and the bicarbonate and boron content largely determine the suitability of the water for irrigation.

As rain descends through the atmosphere, it dissolves small quantities of gases, which increase its solvent power. After reaching the land surface, some of the precipitation runs off the surface swiftly and dissolves little material, and some infiltrates the soil. In Clay County, much of the infiltrated water is returned to the atmosphere by evaporation or plant transpiration; the remainder travels through and dissolves minerals from the soil and parent material. The addition of carbon dioxide to the water by decaying organic matter in the topsoil makes the water acidic and greatly enhances its ability to dissolve minerals. Therefore, water reaching the ground-water reservoir is more mineralized than rainwater or snowmelt. The amount and chemical nature of the dissolved solids in ground water are dependent on the chemical and physical type of rock materials through which the water passes and the duration of contact with them. The chemical quality of water in any area is the resultant of the overall geologic and hydrologic environment.

Chemical analyses of ground-water samples collected in Clay County are given in table 4. The dissolved mineral content as measured by specific conductance ranged from 317 to 691 micromhos. This concentration range is approximately equivalent to 210 to 450 ppm of dissolved solids, which is low when compared with many other ground and surface waters of the Great Plains area. Calcium bicarbonate is the principal dissolved mineral in solution and makes up about half of the total dissolved material in 12 samples for which dissolved solids were determined. The presence of calcium and bicarbonate in about equal chemical concentrations (in equivalents per million) shows that limestone ($CaCO_3$) or other limy material is the major parent material that has been dissolved. Sulfate, an ion generally associated with gypsum deposits or shale, was present in variable amounts.

DEFINITION OF TERMS

Most of the terms used in the field of water chemistry are common ones. Although some have a limited use, others may convey a variety of meanings. Therefore, as an aid to clarity, some of the terms used in this report are defined as follows:

Parts per million (*ppm*) is a unit that expresses concentration of chemical constituents by weight, usually as grams of constituent per million grams of solution.

Equivalents per million (*epm*) is a unit that expresses concentration of chemical constituents in terms of the reacting values of the electrically charged particles, or ions, in solution. One equivalent per million of a positively charged ion (cation) will react with one equivalent per million of a negatively charged ion (anion). Parts per million are converted to equivalents per million by multiplying by the reciprocal of the combining weight of the ion. The following factors are used:

Cation	*Factor*	*Anion*	*Factor*
Calcium (Ca^{++})	0.04990	Carbonate (CO_3^{--})	0.03333
Magnesium (Mg^{++})	.08224	Bicarbonate (HCO_3^-)	.01639
Sodium (Na^+)	.04350	Sulfate (SO_4^{--})	.02082
Potassium (K^+)	.02558	Chloride (Cl^-)	.02820
		Fluoride (F^-)	.05263
		Nitrate (NO_3^-)	.01613

Specific conductance is a measure of the ability of a water to conduct an electrical current and is expressed in terms of micromhos at 25 ° C.

TABLE 4.—*Chemical analyses of ground water in Clay County*

[Use: Dom, domestic; Irr, irrigation; PS, public supply; S, livestock. SAR, sodium-adsorption ratio. Results are in parts per million except as indicated]

Well	Depth (feet)	Use	Date of collection	Temperature (° F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
5-5-12ad	160	Irr	8- 5-54						21		183	0
5-5-18ab	159	Irr	8- 5-54						18		188	0
5-5-35bb	150	Irr	8- 5-54						18		196	0
5-6-10bb	175	Irr	8- 5-54						16		193	0
5-6-32dc	161	Irr	8- 5-54						16		163	0
5-6-36ca	180	Irr	8- 5-54	55	28	0.08	57	9.5	21	5.8	196	0
5-7-2cc	185	Irr	8- 5-54						18		206	0
5-7-8bb	174	Irr	4-29-54	54	25	.06	45	6.9	14	5.5	182	0
			8- 5-54						17		201	0
5-7-28bb	185	Irr	8- 5-54						14		204	0
5-8-2aa	158	Irr	8- 5-54						12		199	0
5-8-6db	178	Irr	8- 5-54						11		182	0
5-8-26dd	130	Irr	8- 5-54						22		308	0
6-5-18aa	140	Irr	8- 4-54						26		237	0
6-5-22da	141	Irr	8- 4-54						22		207	0
6-5-32cd	100	Dom	4-29-54	53	30	1.2	50	8.5	23	9.0	180	0
6-6-9bd	163	Irr	8- 4-54						25		244	0
6-6-30cd	167	Irr	8- 4-54						17		182	0
6-6-36aa	135	Irr	8- 4-54						28		210	0
6-7-1bd	183	Irr	4-29-54	54	23	.07	86	11	24	7.8	241	0
			8- 4-54						24		256	0
6-7-11cc	180	Irr	8- 4-54						26		258	0
6-7-27ca	200	Irr	8- 4-54						17		187	0
6-8-7bd	160	Irr	8- 5-54						13		173	0
6-8-8cb2	135	Dom	4-29-54	54	32		43	6.9	13	7.3	171	0
7-5-5cb	141	Irr	8- 4-54						19		234	0
7-5-11bb	170	Irr	8- 4-54						28		183	0
7-5-15ca	210	Irr	4-30-54	53	31	1.6	66	9.8	30	4.8	259	0
7-5-26bb2	160	S	8- 4-54	59	28	4.41	60	12	25	4.2	233	0
7-5-34bb	100	Irr	8- 4-54	59	29	.01	39	7.4	22	3.8	152	0
7-6-4bd	163	Irr	8- 4-54						21		228	0
7-7-9cc	180	PS	4-29-54	55	30	.08	85	12	30	10	280	0
7-7-15ac	163	Irr	8- 4-54						25		248	4
7-8-7dd	200	Irr	8- 4-54						24		211	0
8-5-18ca	165	Irr	6-27-54	48	33	.22	64	11	18	5.5	230	0
			8- 3-54						18		230	0
8-5-22bb	143	Irr	8- 3-54						20		233	4
8-5-26cb	190	Irr	8- 3-54						28		331	0
8-6-2bb	149	Irr	8- 3-54						22		248	0
8-6-20ba	178	Irr	8- 3-54						16		180	0
8-6-27db	182	Irr	8- 3-54						19		200	0
8-7-17cd	165	Irr	8- 3-54						15		144	0
8-7-26ac	156	Irr	8- 3-54						24		216	0
8-7-34ac [1]	200	PS	9-25-52	58	28	.03	91	14	26	6.3	222	0
			8- 3-54						26		223	0
8-8-1ca	165	Irr	8- 3-54						21		225	6
8-8-18ac	180	Irr	4-29-54	55	26	.70	98	14	30	8.3	282	0
			8- 3-54						29		274	0
8-8-31dc	175	Irr	8- 3-54						23		251	0
8-8-36bb	168	Irr	8- 3-54						28		238	0

[1] Composite sample from three wells.

TABLE 4.—*Chemical analyses of ground water in Clay County*—Continued

Well	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	SAR	Specific conductance (micromhos at 25° C)	pH
5-5-12ad							160	10	22	0.7	410	7.8
5-5-18ab							180	26	18	.6	432	8.1
5-5-35bb							160	0	20	.6	390	7.7
5-6-10bb							179	21	16	.5	425	7.8
5-6-32dc							152	18	19	.6	378	7.8
5-6-36ca	33	17	0.2	19	0.06	297	181	20	19	.7	455	7.3
5-7-2cc							173	4	18	.6	414	7.9
5-7-8bb	17	6.5	.3	2.4	.05	215	141	0	17	.5	343	7.5
							152	0	20	.6	366	7.9
5-7-28bb							171	4	15	.5	396	8.1
5-8-2aa							160	0	14	.4	361	7.8
5-8-6db							146	0	14	.4	336	7.9
5-8-26dd							249	0	16	.6	560	8.0
6-5-18aa							249	55	18	.7	597	7.9
6-5-22da							177	7	21	.7	444	7.8
6-5-32cd	32	19	.2	14	.04	278	160	12	23	.8	435	7.0
6-6-9bd							261	61	17	.7	609	7.9
6-6-30cd							164	15	18	.6	408	8.0
6-6-36aa							198	26	24	.9	520	8.0
6-7-1bd	93	17	.3	.2	.02	392	260	62	16	.6	601	7.5
							255	45	17	.7	591	8.0
6-7-11cc							232	20	20	.7	563	8.1
6-7-27ca							156	3	19	.6	380	8.0
6-8-7bd							130	0	18	.5	317	7.9
6-8-8cb2	11	8.0	.1	6.1	.04	216	136	0	16	.5	334	7.1
7-5-5cb							212	20	16	.6	495	7.8
7-5-11bb							128	0	32	1.1	378	8.1
7-5-15ca	25	19	.2	12	.04	333	205	0	24	.9	519	7.6
7-5-26bb2	39	20	.2	.0	.08	309	199	8	21	.8	490	7.5
7-5-34bb	16	20	.2	11	.06	227	128	3	27	.8	358	7.2
7-6-4bd							222	35	17	.6	521	7.9
7-7-9cc	70	13	.3	15	.05	410	261	31	19	.8	628	7.3
7-7-15ac							292	82	16	.6	657	8.3
7-8-7dd							163	0	24	.8	419	8.0
8-5-18ca	32	16	.1	2.7	.04	302	203	14	16	.5	473	7.3
							201	12	16	.6	461	8.1
8-5-22bb							209	11	17	.6	478	8.3
8-5-26cb							245	0	20	.8	566	8.0
8-6-2bb							279	76	15	.6	626	8.0
8-6-20ba							158	10	18	.6	384	8.0
8-6-27db							179	15	19	.6	436	8.0
8-7-17cd							147	29	18	.5	361	7.7
8-7-26ac							248	71	17	.7	583	8.1
8-7-34ac [1]	147	16	.1	1.7	.05	462	285	103	16	.7	646	7.2
							287	104	16	.7	651	8.2
8-8-1ca							213	19	18	.6	493	8.3
8-8-18ac	124	12	.3	.6	.04	459	302	71	17	.8	687	7.4
							302	77	17	.7	685	8.2
8-8-31dc							226	20	18	.7	530	7.9
8-8-36bb							308	113	17	.7	691	8.0

[1] Composite sample from three wells.

Because the specific conductance is dependent on the amount of ions in solution, it can be used as a measure of the mineralization of the water. The following approximate relations are generally applicable:

$$\text{Specific conductance} \times (0.65 \pm 0.05) = \text{ppm dissolved solids}$$

$$\frac{\text{Specific conductance}}{100} = \text{total epm cations} = \text{total epm anions}$$

Percent sodium is the ratio, expressed as a percentage, of the concentration of sodium to the sum of the concentrations of the principal positively charged ions (calcium, magnesium, sodium, and potassium)—all concentrations are expressed in equivalents per million.

Sodium-adsorption-ratio is related to the adsorption of sodium by soil and is an index of the sodium, or alkali, hazard of the water. (See section on "Criteria for rating irrigation water.")

Leaching percentage is the ratio, expressed as a percentage, of the amount of water that passes downward through the root zone to the amount of water that is applied to the land surface.

"*Residual sodium carbonate*" is the amount of carbonate plus bicarbonate, expressed in equivalents per million, that would remain in solution if all the calcium and magnesium were precipitated as carbonates.

Salt is a comprehensive term embracing all ionizable material in solution from such minerals as gypsum ($CaSO_4 \cdot 2H_2O$), calcite ($CaCO_3$), and epsom salts ($MgSO_4 \cdot 7H_2O$), and others. The term does not refer to common table salt ($NaCl$) alone.

Salinity is the dissolved mineral content of a water or the soluble salt content of a soil.

Saline soil refers to a soil that contains sufficient soluble salts to impair its productivity.

FACTORS AFFECTING THE CHEMICAL QUALITY OF THE WATER

The difference in quality of the ground water from place to place in Clay County is the combined result of several factors, none of which alone is completely responsible for the chemical characteristics at any location. The most important factors are (1) the direction of ground-water movement and the source and amount of recharge and (2) the chemical and physical composition of the saturated material in the vicinity of the wells. Although general relationships, or water-quality patterns, are apparent, each well is a separate entity; the quality of the pumped water is dependent more on local than regional conditions. Nevertheless, an understanding of the general relationships is important to efficient countywide development of the ground-water resources.

As in the discussion of the quantity and movement of the ground water, Clay County must be considered in quality-of-water discussions as a small segment of a large ground- and surface-water drainage basin. The quality of the water is influenced by the environment in adjacent areas as well as in the county.

CHEMICAL QUALITY IN RELATION TO DIRECTION OF GROUND-WATER MOVEMENT AND RECHARGE

The location of the sampling points and the specific conductance of the water are shown on figure 12. The general movement of ground

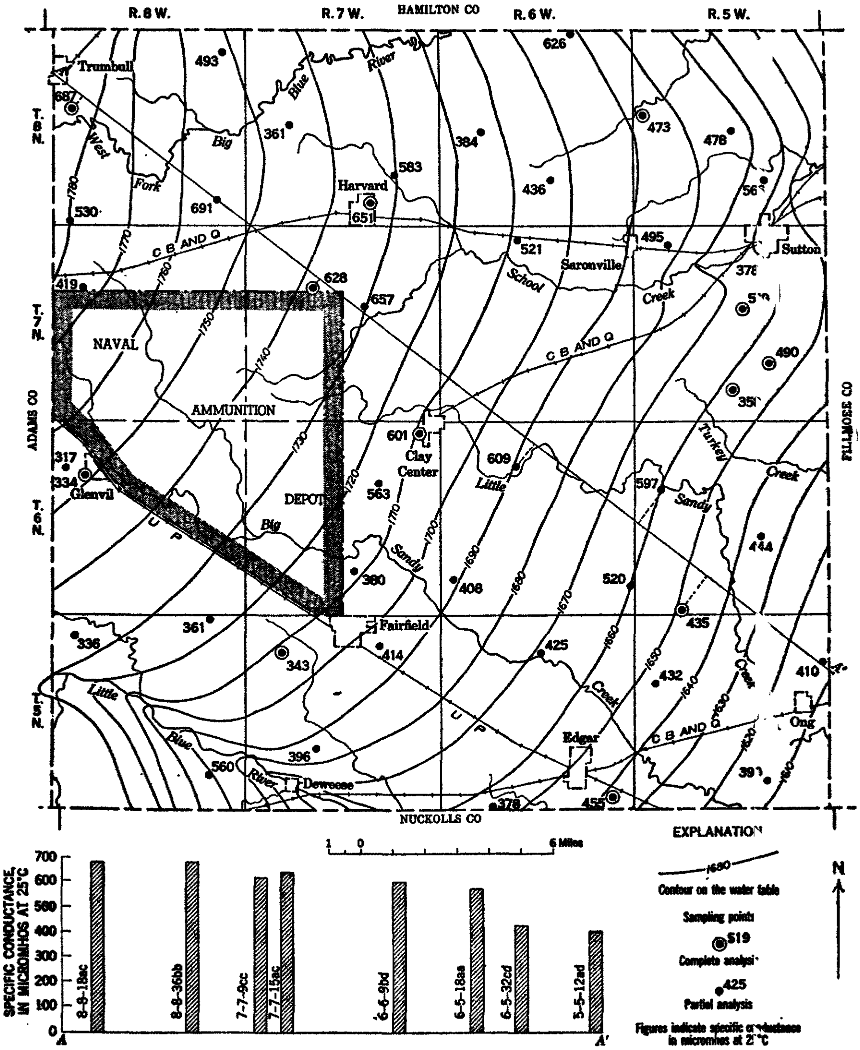

FIGURE 12.—Map of Clay County showing relation of specific conductance to direction of ground-water movement.

water through Clay County is in a southeasterly direction, and the specific conductance of the water in a section from Trumbull to Ong (line *A–A′*, fig. 12) decreased from 687 to 410 micromhos as the water moved through the aquifer. A similar decrease was noted from Harvard toward the northeast corner of the county. However, the concentration increased from Glenvil to Edgar. The water near Glenvil had the lowest concentration of dissolved solids in the county; therefore, water in any direction from Glenvil had a higher degree of mineralization. Although there are several local exceptions, the decrease in concentration in the direction of ground-water movement is generally applicable to the entire county and has been observed in adjacent counties downgradient.

Local changes in the chemical quality of the ground water often are significant in relation to ground-water recharge. The pattern of mineralization of the water in Clay County provides additional evidence that substantial ground-water recharge occurs within the county. If underflow were the major source of recharge, the mineral content of the water would be expected to increase in the direction of ground-water movement, for the material through which the water moved would contribute additional dissolved substances to the water. No known "demineralizers" are present in the rocks of the aquifer to account for a decrease in mineralization. Dilution of the ground water by local recharge is the most probable cause of the decrease; consequently, local precipitation must be an important source of recharge to the water table.

CHEMICAL QUALITY IN RELATION TO GEOLOGY

The chemical quality of the ground water is influenced also by the chemical and physical nature of the water-bearing deposits. Erosion of the pre-Pleistocene bedrock, as described in the section on "Geology," incised valleys and left uplands and disconnected ridges that were later filled and covered during glacial periods with clay, silt, sand, and gravel. The north-south geologic sections (pl. 2) show that the buried valleys contain thick deposits of sand and gravel, whereas the ridges and uplands are covered principally by silt and clay. The low permeability of the slit and clay in the Pleistocene deposits and the Ogallala formation, and of the shale in the Niobrara and Carlile formations, creates greater internal friction to fluid flow than the sand and gravel deposits and decreases the rate of movement of ground water. As the water moves slowly through these fine-grained materials, more time and more surface area are available for solution than when the water is moving through the sand and gravel.

Bedrock fragments incorporated into the Pleistocene material close to the outcrop areas of the different formations during the process of deposition, erosion, and reworking may account for some of the observed variations in water quality.

Isolation of the chemical and physical characteristics of the water-bearing material is very difficult, and illustration of the influence of each by water-quality data is inconclusive. However, the aggregate effect of geology on water quality is shown by the relation of pre-Pleistocene topography to water mineralization. (See fig. 13.) The water samples having the higher dissolved-mineral concentration generally were from wells near the higher elevations of the bedrock. For example, in the region from Trumbull to Clay Center, specific con-

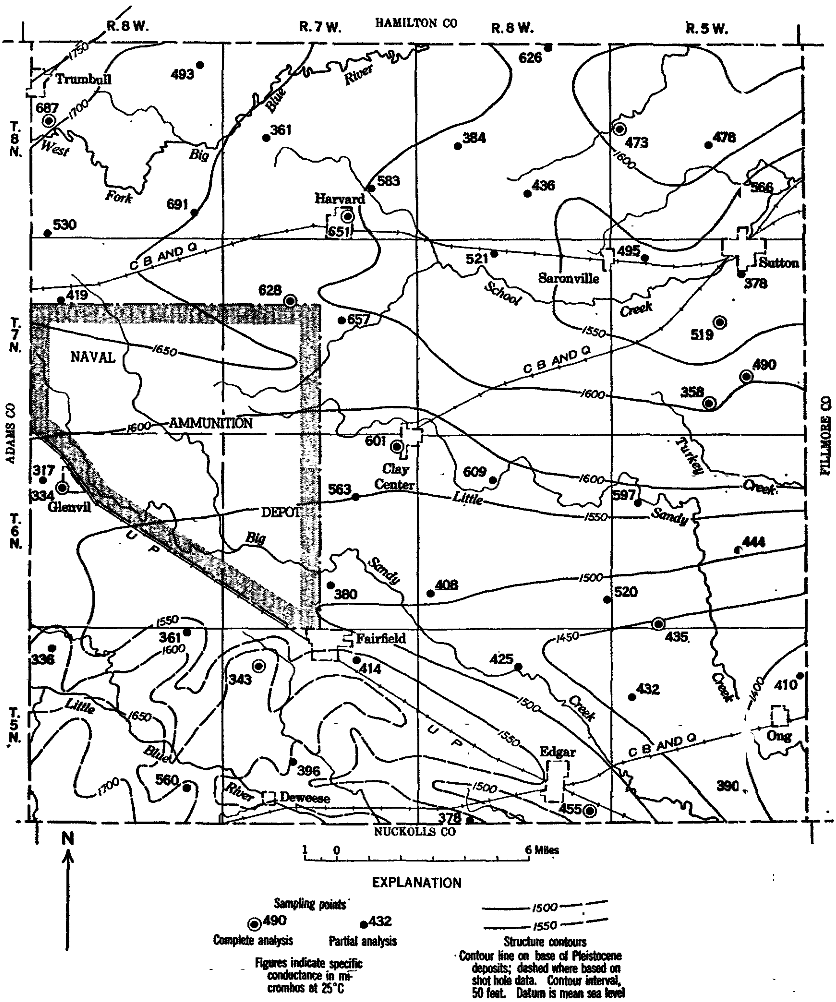

FIGURE 13.—Map of Clay County showing relation of specific conductance to bedrock elevation.

ductances of 500 to 700 micromhos are prevalent; whereas along the buried valleys from Glenvil to Ong, the conductances generally range from 300 to 500 micromhos.

The percentage of sulfate by weight in the residue on evaporation increases as the total salt content increases. (See fig. 14.) The Ogallala formation, which constituted the surficial material immediately prior to glacial time, contains very little sulfate. However, a part of the Niobrara formation, which cropped out or was very near

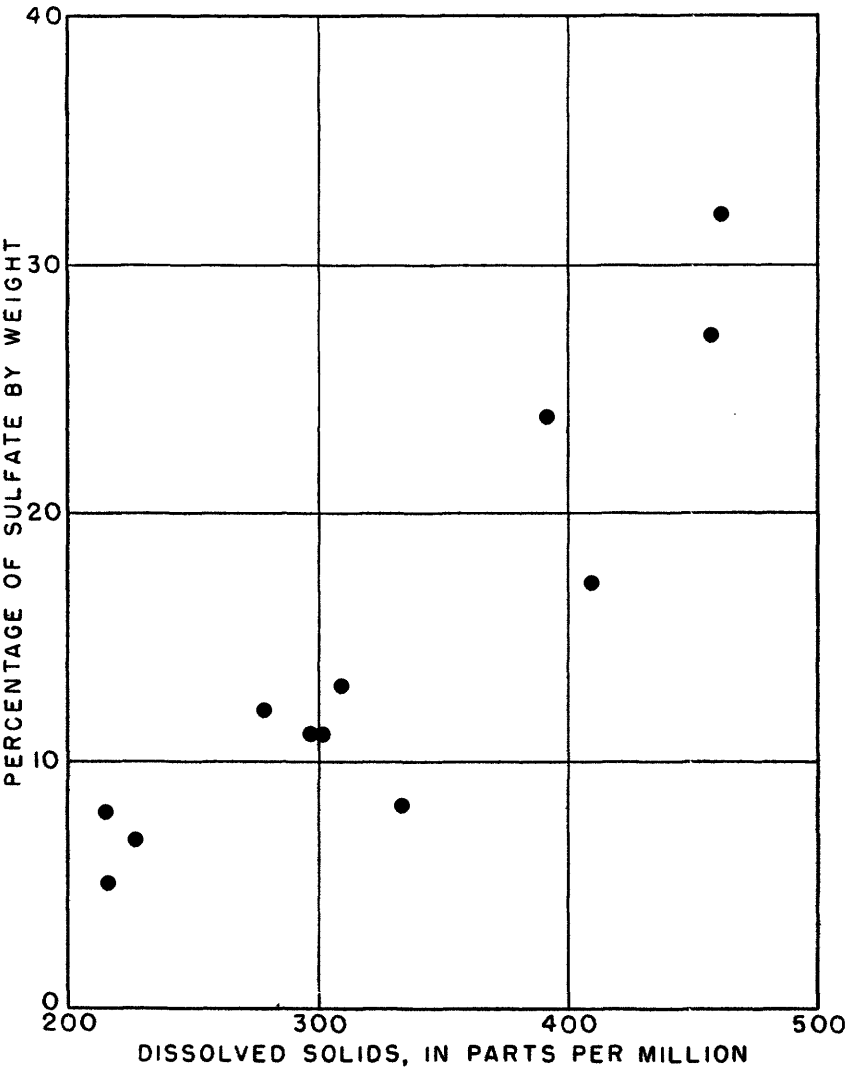

FIGURE 14.—Percentage of sulfate in anhydrous residue.

the surface along the ridges and uplands, yields calcium sulfate water to wells in other areas. Part of the sulfate, however, may be derived from clay deposits within the Pleistocene material.

CHEMICAL QUALITY IN RELATION TO PUMPING

Four irrigation wells were sampled prior to the 1954 irrigation season and were resampled in August near the close of the season to ascertain changes in water quality attributable to prolonged pumping. Abridged analyses in table 5 show no appreciable change in either total concentration or percentage composition. The fact that these results are similar is not proof that there will be no fluctuation in quality during wet and dry cycles or in local areas when irrigation development decreases the ground-water supply. Some changes may occur, particularly in places where the water table is near the land surface or where the water-yielding material is thin, but the changes probably will not significantly affect the usability of the water. This conclusion is based primarily on the relatively homogeneous chemical makeup

TABLE 5.—*Analyses of water from resampled wells, showing constancy of composition*

Date	Specific conductance (micromhos at 25° C)	Hardness as $CaCO_3$ (Parts per million)	Alkalinity (HCO_3) (Parts per million)	Percent sodium
Well 5-7-8bb				
Apr. 29, 1954	343	141	182	17
Aug. 5	366	152	201	20
Well 6-7-1bd				
Apr. 29, 1954	601	260	241	16
Aug. 4	591	255	256	17
Well 8-5-18ca				
June 27, 1954	473	203	230	16
Aug. 3	461	201	230	16
Well 8-7-34ac				
Sept. 25, 1952	646	285	222	16
Aug. 3, 1954	651	287	223	16
Well 8-8-18ac				
Apr. 29, 1954	687	302	282	17
Aug. 3	685	302	274	17

of the water-bearing material and on the absence of water of truly poor quality from existing wells in the county.

WATER QUALITY AND USE

The ground water in Clay County is of generally good quality for many uses, although chemical additives or treatment may be recommended if the water is to be used for certain specific purposes. Water-quality criteria for the major water uses in the report area are included in the following discussion.

DOMESTIC USE

Water for domestic use should be clear, pleasant to the taste, of reasonable temperature, and free from organisms that are capable of producing intestinal infections. Departments of health from time to time have established standards that govern the quality of water used under their jurisdiction. The only nationwide standards pertaining to the quality of potable water supplies are those described by the U. S. Public Health Service (1946). These standards were first enacted in 1914 under the provisions of the Interstate Quarantine Regulations and have since been revised in 1925, 1942, and 1946. Specifically, these standards apply only to the waters that are used for drinking and culinary purposes on railroad cars, aircraft, and vessels in interstate traffic. However, they have been adopted by the American Water Works Association as recommended limitations for public water supplies. Those standards that pertain to chemical constituents are shown, in part, in the following table:

Allowable limits, in parts per million, for potable water

Constituents	*Limiting concentrations*
Iron and manganese together	0.3
Magnesium	125
Chloride	250
Fluoride	1.5
Sulfate	250
Dissolved solids	[1]500

[1] 1,000 ppm permitted if no other water is available.

Excessive concentrations of certain chemical constituents may be very undesirable. Iron and manganese in high concentrations are objectionable for domestic uses because they may stain porcelain, enamel, and fabrics. Water containing large quantities of magnesium in conjunction with sulfate (epsom salt) has saline cathartic properties. Chloride in concentrations of more than a few hundred parts per million imparts a characteristic salty taste. High fluoride concentration in water is associated with the dental defect known as mottled enamel if the water is used for drinking by children during calcification, or formation, of the permanent teeth (Dean, 1936).

However, the consumption during the same period of water that contains small quantities of fluoride has been shown to build stronger and healthier teeth. The American Dental Association and numerous State and local health agencies recommend about 1.0 ppm of fluoride in drinking water for children during the calcification period. Nitrate in water may indicate previous contamination by sewage or other organic matter because it represents the final stage of oxidation in the nitrogen cycle. Cyanosis in infants, owing to methemoglobinemia, has resulted from drinking water of high nitrate content.

With the exception of some undesirably high quantities of iron, the recommended maximum concentration limits for chemical constituents were not exceeded in the samples from Clay County.

Hardness is the characteristic of water usually recognized by the increased quantity of soap required to produce a lather or by the deposits of insoluble salts formed when the water is heated or evaporated. Calcium and magnesium cause most of the hardness of water. Other constituents, such as iron, aluminum, strontium, barium, zinc, or free acid, also cause hardness; however, they are not present in sufficient quantities, as a rule, to have any appreciable effect. Specific limits cannot be set for hardness, but the following gradations generally are recognized:

Hardness (ppm)	*Rating and usability*
<60	Soft—suitable for many uses without further softening.
61–120	Moderately hard—usable except in some industrial applications.
121–200	Hard—softening required by laundries and some other industries.
>200	Very hard—requires softening for most purposes.

All the ground water sampled in Clay County is rated as either hard or very hard. The areal distribution of water hardness is shown by figure 15.

IRRIGATION

Irrigation with ground water is an integral part of the agrarian economy of Clay County; in 1954, 257 irrigation wells pumped about 26,000 acre-feet of water to supplement the rainfall on a reported 21,248 acres of farmland.

CRITERIA FOR RATING IRRIGATION WATER

Irrigationists have long recognized that the success or economic feasibility of irrigation is dependent on water quality, and a better understanding of the subject is developing rapidly. The interpretation of the analysis of an irrigation water has been described as empirical in the sense that an explanation of the analysis is based

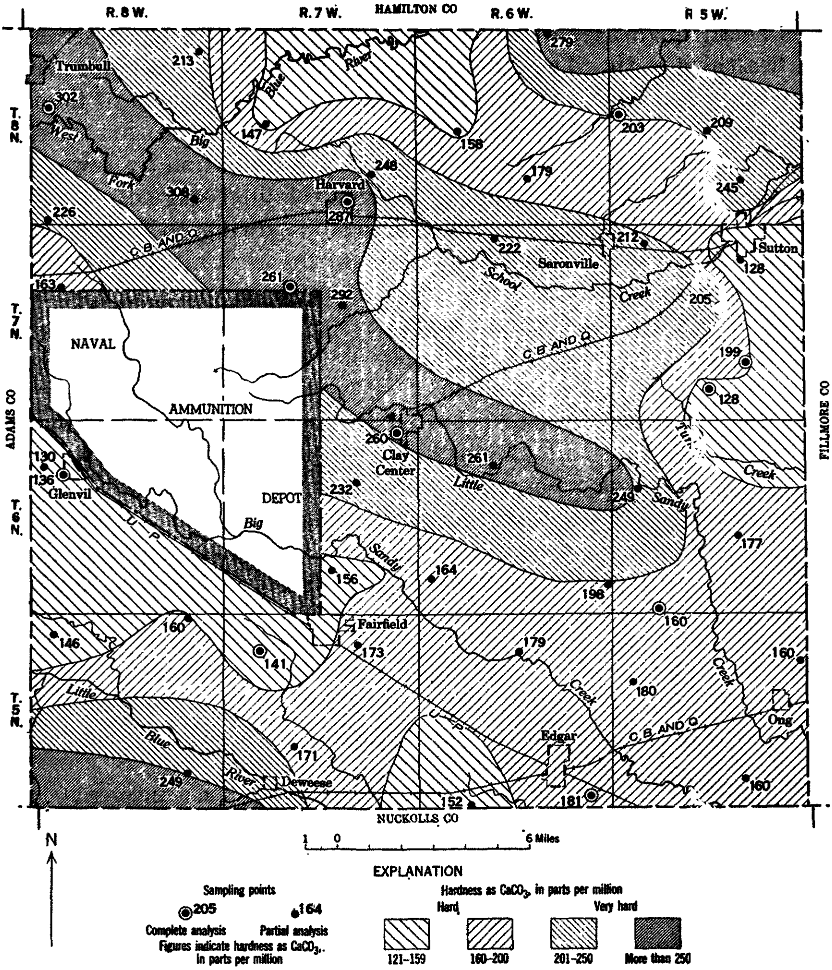

FIGURE 15.—Map of Clay County showing areal distribution of ground-water hardness.

on field observations, experience, and plant-tolerance research. Thus, the rating and classification of an irrigation water appear to be wholly arbitrary; but, although different approaches are often used, the agreement among workers in this field is good. The following statements have been drawn largely from publications in the field of irrigation, particularly the subject of quality of water for irrigation (Chem. and Eng. News, 1951; Eaton, 1950, 1954; Israelsen, 1950; Scofield, 1936; Thorne and Thorne, 1951; U. S. Bur. Reclamation, 1953; U. S. Salinity Lab. Staff, 1954; Wilcox, 1948; and Wilcox, Blair, and Bower, 1954).

Chemical-quality factors that determine the suitability of water for irrigation are (1) the total salt content and the amount of some constituents of the applied water, (2) the relative proportions of some of the ions in the applied water, and (3) the increase in concentration of salts and the chemical changes that take place because of evapotranspiration after the water is applied. Poor irrigation practice or application of water of unsuitable quality may decrease the productivity of the land. Experience has proved that without adequate drainage and (or) application of excess water to leach the soil, the use of water classified as excellent for irrigation has caused some soils to become saline and relatively impervious. Conversely, relatively saline water, when applied in excess of normal requirements to permeable, well-drained soil, has been used successfully. The net effect of applying water of seemingly unsuitable quality has often been adjusted or controlled by improving the drainage, by applying sufficient water in excess of crop needs to maintain a soil structure and environment favorable for crop production, or by applying chemicals.

Investigations have shown that a high concentration of dissolved salts in the soil or root zone generally is undesirable. However, plant varieties differ, not only in tolerance of total salts but also in tolerances of the various ions that compose the salt mixture. Too high a concentration of dissolved salts in the soil solution may decrease the rate of water intake by the plant.

Boron in small amounts is essential for the normal growth of all plants; however, it is toxic to certain plants in concentrations that are required for the optimum growth of others. Water that contains less than 0.33 ppm boron is classed as "excellent" for irrigating even the most boron-sensitive crops (Wilcox, 1948, p. 27).

The nature and concentration of the cations (positively charged ions) are significant in determining the suitability of water for irrigation because the reactions of the cations with the soil affect the soil texture. Calcium and magnesium tend to keep a soil permeable and in good tilth; unfavorable physical conditions can result if sodium is the predominant cation. Water that has a high ratio of sodium to calcium and magnesium may adversely affect the soil through the chemical process of cation exchange, in which sodium replaces calcium and magnesium in the soil complex. Continued application of water that contains a high sodium ratio may cause the soil to become relatively impermeable to the downward movement of water and may ultimately bring about serious drainage problems, saline-alkali or alkali soils, and crop damage. The phrase "Hard water makes soft land and soft water makes hard land" is an accurate summation of cationic relations.

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The U. S. Salinity Laboratory Staff (1954) has developed a rating diagram that shows salinity hazard and sodium hazard independently. The sodium-adsorption-ratio(SAR) is used to predict the sodium, or alkali, hazard involved in the use of irrigation waters. The formula for calculating SAR, in which concentrations are expressed in equivalents per million, is as follows:

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

Figure 16 shows the diagram recommended by the U. S. Salinity Laboratory Staff (1954) for the classification of irrigation water. The curves have a negative slope to compensate for the dependence of sodium hazard on total concentration. Interpretation of the diagram by the laboratory staff is as follows:

Salinity Hazard

Low-salinity water (*C*1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (*C*2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (*C*3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (*C*4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium Hazard

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable-sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (*S*1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-sodium water (*S*2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (*S*3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high

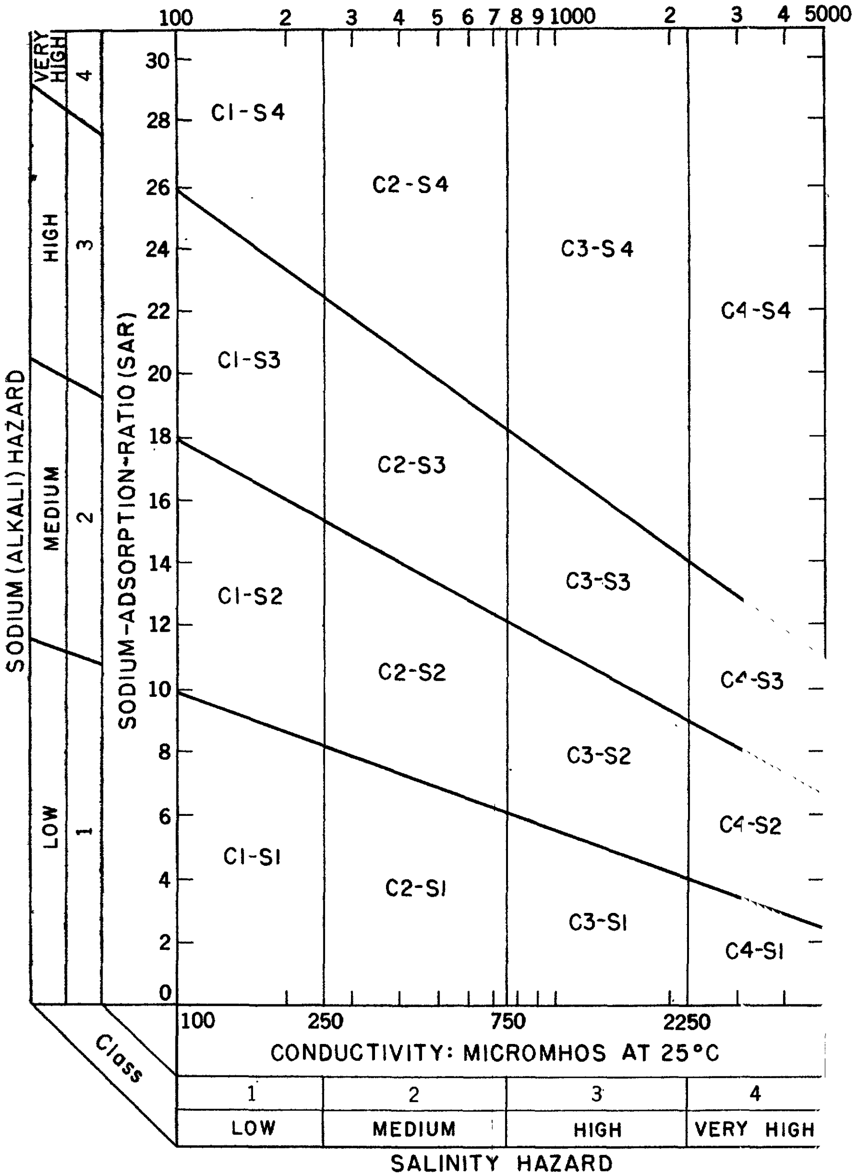

FIGURE 16.—Diagram by U. S. Salinity Laboratory Staff for classification of irrigation water.

leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (*S4*) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

The designers of the diagram point out that—

In the classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of crop. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality.

In studies of water quality for irrigation, the concentrating action of evaporation and transpiration, the chemical changes that take place in the water through precipitation of some salts, and selective plant uptake also must be considered. Surface evaporation and plant extraction of water, (H_2O), which are almost always in excess of plant uptake of salt, increase the concentration of salts in the soil solution. The concentration usually increases with depth through the root zone. Carbonates and bicarbonates, because of their tendency to form relatively insoluble salts with calcium and magnesium, are the principal constitutents influencing changes in percentage composition. If the amount (in equivalents per million) of carbonate plus bicarbonate in the original water exceeds that of calcium plus magnesium, the soil solution will contain sodium carbonate. This residual sodium carbonate, being the salt of a strong base (sodium) and a weak acid (carbonic), has strong alkaline properties. The organic material of the soil is dissolved by strong alkaline solutions (pH 8.4 or higher), and the soil takes on a grayish or blackish color caused by a colloidal coating of organic matter on the individual soil particles or aggregates; such a soil condition is referred to as "black alkali." Wilcox (1952), from experiments with Rhodes grass and drainage percentages ("leaching percentages"; see p. 79) of 25 and 6.25, reports:

The importance of bicarbonate in irrigation waters has been under investigation at the laboratory for several years. It has been found that bicarbonate waters are less desirable for irrigation purposes than chloride or sulfate waters. Eaton [1950] defined the term "residual sodium carbonate" as the excess of bicarbonate over calcium plus magnesium expressed in milliequivalents per liter. Based on the findings of this experiment, it is thought that waters with more than 2.5 meq./l. "residual sodium carbonate" are not suitable for irrigation purposes. Waters with from 1.25–2.5 meq./l. are marginal and those with less than 1.25 meq./l. "residual sodium carbonate" are probably safe. In connection with the marginal group of waters, good management practices and proper use of amendments might make it possible to use some of these waters successfully for irrigation. These conclusions are based on limited data and are, therefore, tentative.

"Residual sodium carbonate" tolerances recommended by Wilcox probably are somewhat higher than would be permissible in Clay County, because the average drainage percentage, or percentage of applied water that passed below the root zone, used in his study is higher than would be expected in Clay County.

SUITABILITY OF GROUND WATER FOR IRRIGATION

A classification of the ground waters of Clay County with respect to their suitability for irrigation is given in table 6. Under the U. S. Salinity Laboratory classification, all the ground-water samples have medium salinity hazard and low sodium hazard. The water is satisfactory if a moderate amount of leaching occurs (*C*2), and there is little danger of the development of harmful levels of exchangeable sodium (*S*1). Few of the samples contained residual sodium carbonate, and none analyzed for boron contained excessive quantities of boron.

LEACHING AND CALCIUM REQUIREMENTS

Eaton (1954) used another approach to the irrigation-water subject. Rather than rate a water as good or unsuitable, he developed formulas that, when applied to any water, define the "leaching percentage" and amount of chemical additives required. The formulas estimate (1) the "leaching percentage," or percentage of applied water that should be leached downward beyond the root zone to maintain salt concentrations in the soil sufficiently low for reasonable yields, and (2) the quantity of calcium required to prevent unfavorable sodium ratios. The required calcium is the amount that must be added to limit the percent sodium of the soil solution to 70, to replace carbonate precipitation of calcium and magnesium, and to replace calcium and magnesium taken up by crops. The term "reasonable yields" designates, for crops of intermediate salt tolerances, a production level of 70 to 80 percent of yields obtained in a semiarid climate on nonsaline land; "good yields," between 85 and 90 percent. (See table 7.) A summary of Eaton's formulas, in the order of use and the designations used, are as follows:

Sw—Salinity of irrigation waters expressed as milliequivalents per liter (or equivalents per million) of Cl plus half the SO_4.

d% and *D%*—Tentative (*d*) and final (*D*) percentage of applied irrigation water passed through the root zone as drainage (leaching percentage).

Mss—Salinity of mean soil solution measured as Cl plus half the SO_4, in milliequivalents per liter. The value 40 is taken as an *Mss* concentration that is expected to produce reasonable yields and 20

TABLE 6.—*Suitability of ground water for irrigation*

Well	Specific conductance (micromhos at 25°C)	Percent sodium	Sodium-adsorption-ratio	Classification [1]	Residual sodium carbonate (epm)	Boron (ppm)
5–5–12ad	410	22	0.7	*C*2–*S*1	0.00	------
5–5–18ab	432	18	.6	*C*2–*S*1	.00	------
5–5–35bb	390	20	.6	*C*2–*S*1	.01	------
5–6–10bb	425	16	.5	*C*2–*S*1	.00	------
5–6–32dc	378	19	.6	*C*2–*S*1	.00	------
5–6–36ca	455	19	.7	*C*2–*S*1	.00	0.06
5–7–2cc	414	18	.6	*C*2–*S*1	.00	------
5–7–8bb	343	17	.5	*C*2–*S*1	.16	.05
5–7–28bb	396	15	.5	*C*2–*S*1	.00	------
5–8–2aa	361	14	.4	*C*2–*S*1	.06	------
5–8–6db	336	14	.4	*C*2–*S*1	.06	------
5–8–26dd	560	16	.6	*C*2–*S*1	.07	------
6–5–18aa	597	18	.7	*C*2–*S*1	.00	------
6–5–22da	444	21	.7	*C*2–*S*1	.00	------
6–5–32cd	435	23	.8	*C*2–*S*1	.00	.04
6–6–9bd	609	17	.7	*C*2–*S*1	.00	------
6–6–30cd	408	18	.6	*C*2–*S*1	.00	------
6–6–36aa	520	24	.9	*C*2–*S*1	.00	------
6–7–1bd	601	16	.6	*C*2–*S*1	.00	.02
6–7–11cc	563	20	.7	*C*2–*S*1	.00	------
6–7–27ca	380	19	.6	*C*2–*S*1	.00	------
6–8–7bd	317	18	.5	*C*2–*S*1	.24	------
6–8–8cb2	334	16	.5	*C*2–*S*1	.08	.04
7–5–5cb	495	16	.6	*C*2–*S*1	.00	------
7–5–11bb	378	32	1.1	*C*2–*S*1	.46	------
7–5–15ca	519	24	.9	*C*2–*S*1	.14	.04
7–5–26bb2	490	21	.8	*C*2–*S*1	.00	.08
7–5–34bb	358	27	.8	*C*2–*S*1	.00	.06
7–6–4bd	521	17	.6	*C*2–*S*1	.30	------
7–7–9cc	628	19	.8	*C*2–*S*1	.00	.05
7–7–15ac	657	16	.6	*C*2–*S*1	.00	------
7–8–7dd	419	24	.8	*C*2–*S*1	.20	------
8–5–18ca	473	16	.5	*C*2–*S*1	.00	.04
8–5–22bb	478	17	.6	*C*2–*S*1	.00	------
8–5–26cb	566	20	.8	*C*2–*S*1	.52	------
8–6–2bb	626	15	.6	*C*2–*S*1	.00	------
8–6–20ba	384	18	.6	*C*2–*S*1	.00	------
8–6–27db	436	19	.6	*C*2–*S*1	.00	------
8–7–17cd	361	18	.5	*C*2–*S*1	.00	------
8–7–26ac	583	17	.7	*C*2–*S*1	.00	------
8–7–34ac [2]	651	16	.7	*C*2–*S*1	.00	------
8–8–1ca	493	18	.6	*C*2–*S*1	.00	------
8–8–18ac	687	17	.8	*C*2–*S*1	.00	.04
8–8–31dc	530	18	.7	*C*2–*S*1	.00	------
8–8–36bb	691	17	.7	*C*2–*S*1	.00	------

[1] After U. S. Salinity Laboratory Staff, 1954.
[2] Composite sample from 3 wells.

to produce good yields, of crops of intermediate salt tolerance grown in a semiarid climate, such as that at Riverside, Calif.

Required leaching percentage—tentative

$$\frac{Sw \times 100}{2 \times Mss - Sw} = d\%$$

$$\text{or } \frac{Sw \times 100}{2 \times 40 - Sw} = d\%$$

Calcium requirements—Ca in milliequivalents per liter

Ca *a*: To adjust water to 70 percent sodium:

$$\text{Na} \times 0.429 - (\text{Ca} + \text{Mg}) = \text{Ca} \text{ (retain plus or minus sign)}$$

Ca *b*: To offset HCO_3 precipitation:

$$\frac{\text{HCO}_3 \times (100 - d\%)}{100} = \text{Ca}$$

Ca *c*: To supply Ca plus Mg taken by plants in excess of Na:

$$\frac{0.30 \times (100 - d\%)}{100} = \text{Ca}$$

Total Ca: $a+b+c$. Multiply total Ca by 234 to get pounds of gypsum per acre-foot of irrigation water.

Required leaching percentage—final

$$\frac{(Sw + \frac{1}{2} \text{ total Ca}) \times 100}{2 \times Mss - (Sw + \frac{1}{2} \text{ total Ca})} = D\%$$

The calcium and magnesium lost by leaching and by plant uptake in soils watered by precipitation are replaced by hydrogen ions, with a consequent increase in soil acidity; ground limestone or marl (calcium carbonate) is commonly added to serve the twofold purpose of correcting acidity and supplying calcium for plant growth. Conversely, under irrigation, the calcium uptake of plants and the calcium carbonate precipitation from the soil solution increase the soil alkalinity; sodium ions, rather than hydrogen ions, are involved. As plants probably do not take up bicarbonate and take up little sodium from the soil or irrigation water, these ions may accumulate with the consequent development of residual sodium carbonate and of pH values in the black-alkali range. Therefore, Eaton expresses calcium requirements for irrigation water in terms of gypsum (calcium sulfate) because gypsum is a relatively soluble mineral and is effective in preventing alkali-soil conditions.

Rainfall is not included in the drainage estimates. Eaton (1954, p. 6) justifies the omission as follows:

> It might seem necessary to consider rainfall; rainfall, in effect, serves as a diluent for the irrigation water. But actually a formula for summarizing the salts of irrigation waters in terms of their leaching requirements should characterize the irrigation water rather than conditions of its use. This is not to say that abundant rainfall does not promote leaching * * * Suppose that during the process of reducing the volume of the water by evaporation, a few hundred milliliters of distilled water is added. This addition does not change the concentration of the final volume nor would it change the percentage of the original *irrigation* water which must be wasted from the rootzone; the addition only serves to lengthen the period of volume reduction. From the standpoint of salinity, rain water falling on the land requires no leaching.

Leaching and calcium requirements for reasonable yields are given in table 7. For good yields these requirements would be a little higher.

Although the required leaching percentages are small, the flushing of the dissolved salts of the irrigation water through the root zone may be difficult in some areas of Clay County. In lieu of actual leaching data, the average countywide leaching percentage can be approximated roughly from the following equation:

$$\text{Leaching percentage} = \frac{\text{Ground-water recharge by precipitation}}{\text{Precipitation} - \text{overland runoff}}$$

The mean annual precipitation is 24.76 inches, the average annual overland runoff is about 1 inch (Colby and Oltman, 1948), and the ground-water recharge by precipitation has been computed as approximately 1.6 inches. The countywide leaching percentage thus is about 6 percent when the values are substituted in the equation. Although the countywide leaching percentage is greater than the required leaching percentages shown in table 7, the actual leaching percentage in part of the farmable area may be less than the required percentage because the figure of 1.6 inches is affected by the high rate of recharge through the permeable soils of the stream valleys; the recharge through the less permeable soils of the irrigated uplands is correspondingly less.

A soil survey of Clay County was reported by Roberts and Gemmell (1927). This survey shows that, with the exception of the generally unfarmable stream flood plains, only about 25 to 30 percent of the land is well drained vertically. Hastings silt loam constitutes about one-fourth of the soil in the county and is the best upland soil in the county; its principal difference from the other soils is that it

TABLE 7.—*Leaching and chemical-additive requirements for reasonable yields*

[Calcium required: *a*, to adjust water to 70 percent sodium; *b*, to offset bicarbonate precipitation; and *c*, to supply calcium plus magnesium taken by plants in excess of sodium]

Well	Tentative required leaching percentage	Calcium required				Gypsum required (pounds per acre-foot)[1]	Final required leaching percentage
		a	*b*	*c*	Total		
		Milliequivalents per liter					
5-5-12ad	1.0	−2.81	2.97	0.30	0.46	108	1.3
5-5-18ab	1.1	−3.27	3.05	.30	.08	19	1.2
5-5-35bb	.8	−2.87	3.18	.30	.61	143	1.2
5-6-10bb	1.0	−3.28	3.13	.30	.15	35	1.1
5-6-32dc	1.0	−2.74	2.64	.30	.20	47	1.1
5-6-36ca	1.1	−3.23	3.17	.30	.24	56	1.2
5-7-2cc	.8	−3.13	3.35	.30	.52	122	1.2
5-7-8bb	.5	−2.56	2.97	.30	.71	166	.9
5-7-28bb	.7	−3.16	3.32	.30	.46	108	1.0
5-8-2aa	.6	−2.98	3.24	.30	.56	131	.9
5-8-6db	.5	−2.71	2.97	.30	.56	131	.9
5-8-26dd	.8	−4.57	5.01	.30	.74	173	1.3
6-5-18aa	1.7	−4.50	3.81	.29	−.40	−94	1.7
6-5-22da	1.0	−3.13	3.36	.30	.53	124	1.3
6-5-32cd	1.1	−2.77	2.92	.30	.45	105	1.4
6-6-9bd	1.7	−4.75	3.93	.29	−.53	−124	1.7
6-6-30cd	.9	−2.96	2.95	.30	.29	68	1.1
6-6-36aa	1.4	−3.44	3.39	.30	.25	59	1.5
6-7-1bd	1.9	−4.75	3.87	.29	−.59	−138	1.8
6-7-11cc	1.3	−4.16	4.18	.30	.32	75	1.5
6-7-27ca	.8	−2.80	3.04	.30	.54	126	1.1
6-8-7bd	.5	−2.36	2.83	.30	.77	180	1.0
6-8-8cb2	.4	−2.48	2.79	.30	.61	143	.8
7-5-5cb	1.1	−3.88	3.79	.30	.21	49	1.2
7-5-11bb	.8	−2.04	2.98	.30	1.24	290	1.6
7-5-15ca	1.0	−3.54	4.20	.30	.96	225	1.6
7-5-26bb2	1.2	−3.51	3.77	.30	.56	131	1.6
7-5-34bb	.9	−2.15	2.47	.30	.62	145	1.3
7-6-4bd	1.3	−4.05	3.69	.30	−.06	−14	1.3
7-7-9cc	1.4	−4.66	4.53	.30	.17	40	1.5
7-7-15ac	2.1	−5.37	4.10	.29	−.98	−229	2.0
7-8-7dd	.8	−2.81	3.43	.30	.92	215	1.4
8-5-18ca	1.0	−3.73	3.73	.30	.30	70	1.2
8-5-22bb	1.0	−3.81	3.91	.30	.40	94	1.2
8-5-26cb	.7	−4.38	5.38	.30	1.30	304	1.5
8-6-2bb	1.9	−5.17	3.98	.29	−.90	−211	1.9
8-6-20ba	.9	−2.86	2.92	.30	.36	84	1.1
8-6-27db	1.0	−3.22	3.25	.30	.33	75	1.2
8-7-17cd	1.1	−2.66	2.33	.30	−.03	−7	1.0
8-7-26ac	1.9	−4.51	3.47	.29	−.75	−176	1.8
8-7-34ac[2]	2.4	−5.26	3.56	.29	−1.41	−330	2.3
8-8-1ca	1.1	−3.87	3.85	.30	.28	66	1.3
8-8-18ac	2.1	−5.48	4.52	.29	−.67	−157	2.2
8-8-31dc	1.2	−4.09	4.06	.30	.27	63	1.3
8-8-36bb	2.6	−5.64	3.80	.29	−1.55	−363	2.5

[1] Negative figures indicate the extent to which calcium in the water is already in excess of that needed to maintain satisfactory conditions, without addition of gypsum.
[2] Composite sample from 3 wells.

NOTE.—Data calculated with Eaton's formulas (Eaton, 1954).

has no claypan. Crete silt loam is the most prevalent soil (about half the county); however, it contains a tight claypan, locally called "brown gumbo layer," beginning 14 to 20 inches below the surface. Butler silt loam occurs in basinlike areas; the upper subsoil layer is a true claypan, extremely compact and almost impervious. The Fillmore silt loam is known as "black gumbo soil" and also has a claypan layer in the upper part of the subsoil. Drainage is especially poor through the Scott silt loam; rainwater that drains into the depressions remains on the surface for a period of time ranging from a few days to several months. The Butler, Fillmore, and Scott silt loams cover about 15 percent of the county.

Periodic checks of soil salinity are recommended for land under ground-water irrigation. Salinization of soils above a claypan can

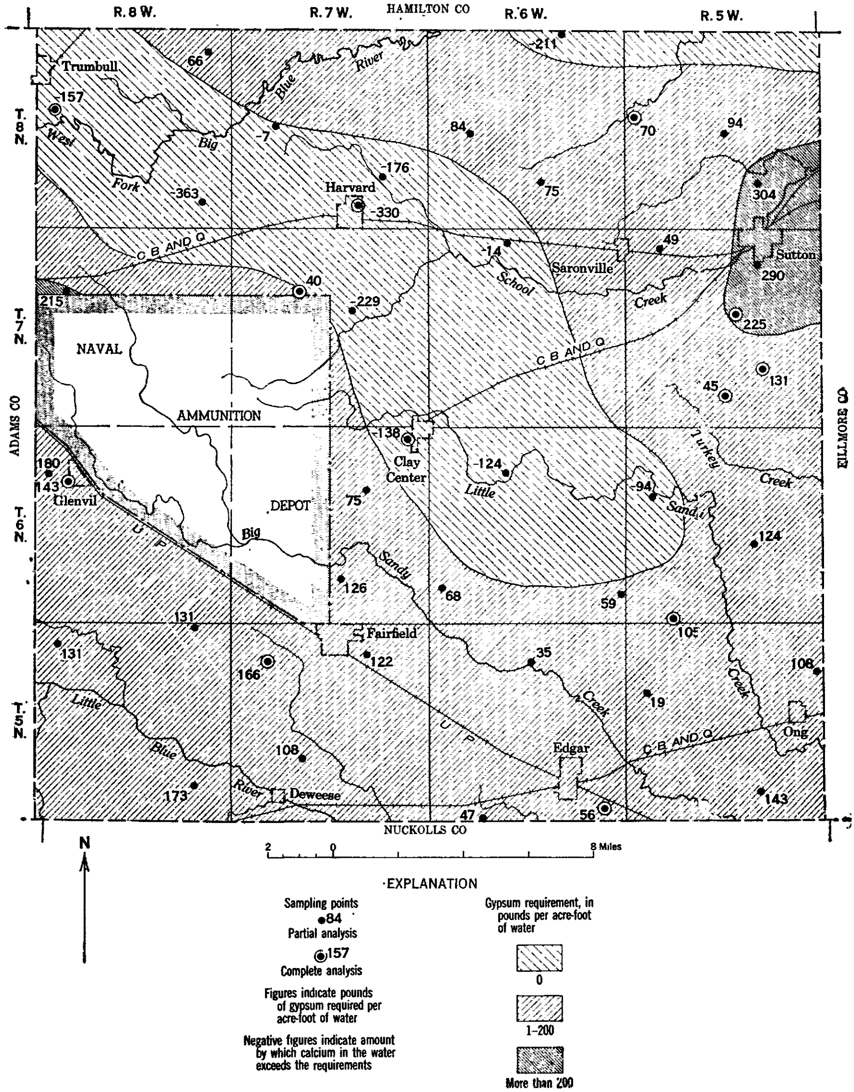

FIGURE 17.—Map of Clay County showing areas requiring added calcium as indicated by Eaton's formulas (Eaton, 1954, p. 3–16).

be prevented by careful management, but "desalinization," or reclamation, may be very difficult.

Figure 17 is a map based on the column for "Gypsum required" in table 7. The areal distribution of calcium requirements follows, in general, the pattern of mineralization. The more concentrated ground water contains calcium in excess of requirements, whereas additional calcium is recommended where irrigation is to be done with the more dilute waters. The difference in requirements for water from wells close together emphasizes the local variation in water quality. The preferred method of gypsum application may be dependent on the amount required and on local irrigation practices. In Clay County, however, direct application to the soil of finely divided gypsum in amounts proportional to the need and to the quantity of water applied will probably produce the desired results.

Eaton's formulas include calcium to replace the calcium and magnesium removed by the plants. The 0.30 milliequivalents per liter (70 pounds of gypsum) used in the formula is an average quantity and is generally applicable under crop-rotation practices. Nevertheless, the irrigator should be cognizant of the relative calcium and magnesium uptake by specific plants. The following table, which includes data extracted from a report by Eaton (1954, table 2), shows that the common forage hays remove large quantities of calcium and magnesium; the fodders and straws, less; and the grains, very little.

Estimates of calcium plus magnesium removed from the soil per acre-foot of water (rain plus irrigation)

Crop	Produce (pounds per acre-foot of water)	Calcium plus magnesium removed per acre-foot of water	
		Milliequivalents per liter	Gypsum equivalent, in pounds
Alfalfa hay	2, 930	0. 84	197
Brome grass hay	2, 530	. 11	26
Clover hay	3, 260	1. 09	255
Sudan grass hay	6, 510	1. 00	234
Corn fodder	7, 080	. 61	143
Barley hay	5, 250	. 33	77
Oat hay	4, 240	. 33	77
Wheat hay	4, 880	. 26	61
Corn grain	1, 760	. 08	19
Barley grain	1, 990	. 09	21
Oat grain	1, 520	. 08	19
Wheat grain	1, 560	. 02	5

The leaching and gypsum requirements calculated by Eaton's formulas provide for only the maintenance of the "status quo" of the soil without irrigation and are not intended to correct any soil-mineral deficiencies or textural abnormalities. If the required calcium is applied and the final leaching percentage is maintained, the soil will become neither better nor worse as the result of irrigation. If the water contains calcium in excess of the required amount, the land will benefit; conversely, if the water is deficient in calcium and none is added, the land will be depleted gradually of its calcium, and adverse soil-texture and crop-nutrient conditions may develop.

RECORDS

Data from logs of seismic-survey shot holes, including the inferred base of the Pleistocene series and the top of the Cretaceous system, are listed in the table below.

Logs of 127 test holes and wells are given in table 9, page 88.

Daily measurements of depth to water in well 5-6-26bd, 1948-50, are listed in table 10, page 135. Measurements were taken from recording-gage charts at lowest daily stage.

Measurements of depth to water in 90 selected wells in Clay County, 1952-55, are given in table 11, page 137.

Records of wells in Clay County, including depths, methods of lift, static water levels, yields, drawdowns, and uses, are given in table 12, page 145.

TABLE 8.—*Data from logs of seismic-survey shot holes*

[Logs of seismic shot holes drilled by National Geophysical Co., Inc., for Northern Natural Gas Producing Co. On file in office of Conservation and Survey Division, University of Nebraska. Altitudes of shot holes established by National Geophysical Co., Inc. All altitudes are in feet above mean sea level]

Shot hole	Altitude (feet)	Inferred base of Pleistocene series		Top of Cretaceous System	
		Depth below land surface (feet)	Altitude (feet)	Depth below land surface (feet)	Altitude (feet)
5-6-30cc	1,735	230	1,505	335	1,400
7-2cd	1,768	200	1,568		
2dd	1,765	240	1,525	315	1,450
4dd	1,781	210	1,571	255	1,526
5aa	1,792	250	1,542		
5dd	1,783	225+	1,558−		
6aa	1,796	275	1,521	275+	1,521−
6dd	1,791	160	1,631	200	1,591
8dd	1,781	200+	1,581−		
9dd	1,778	160	1,618		
11cc	1,766	150	1,616	225	1,541
12cc	1,758	170	1,588	210	1,548
13dd	1,746	160	1,586	220	1,526
14dd	1,742	160	1,582	235	1,507
15cc	1,765	170	1,595	245	1,520
15dd	1,758	200	1,558	235	1,523
17dd	1,776	170	1,606	270	1,506
18aa	1,784	160	1,624	265	1,519
19dd	1,785	180	1,605	210	1,575
20bb	1,782	180	1,602	270	1,512

TABLE 8.—*Data from logs of seismic-survey shot holes*—Continued

Shot hole	Altitude (feet)	Inferred base of Pleistocene series		Top of Cretaceous System	
		Depth below land surface (feet)	Altitude (feet)	Depth below land surface (feet)	Altitude (feet)
5-7-20dd	1,772	160	1,612	220	1,552
21dd	1,730	130	1,600	200	1,530
23dd	1,748	180	1,568	285	1,463
24dd	1,745	200	1,545	285	1,460
26bb	1,752	200	1,552	200	1,552
26dc	1,741	170	1,571	280	1,461
27bd	1,751	170	1,581	285	1,466
28bd	1,765	200−	1,565−	------	------
28cc	1,763	(?)	(?)	250	1,513
28dc	1,756	240?	1,516?	240+	1,516−
30ba	1,714	80	1,634	100	1,614
30cc	1,726	(?)	(?)	220	1,506
30dd	1,673	100	1,573	150	1,523
31cc	1,706	40	1,666	200	1,541
31dd	1,738	100	1,638	190	1,548
32cc	1,703	(?)	(?)	160	1,543
33cc	1,690	(?)	(?)	120	1,570
34cb	1,674	80	1,594	200	1,474
34cc	1,662	(?)	(?)	140	1,522
34dd	1,670	(?)	(?)	100	1,570
35ad	1,706	120	1,586	120	1,586
36dd	1,745	170	1,575	210	1,535
8- 1bb	1,810	245	1,565	------	------
3aa	1,816	250	1,566	295	1,521
3dd	1,809	200	1,609	270	1,539
4aa	1,819	280	1,539	300	1,519
5aa	1,785	245+	1,540−	------	------
5bb	1,796	190	1,606	------	------
7bb	1,823	190	1,633	------	------
7dd	1,722	120	1,602	135	1,587
8bb	1,796	175	1,621	------	------
9bb	1,809	235	1,574	235	1,574
10bb	1,811	235	1,576	235	1,576
12aa	1,796	200	1,596	210	1,586
12bb	1,787	190	1,597	210	1,577
13aa	1,789	200	1,589	275	1,514
13dd	1,787	155+	1,627−	------	------
14cc	1,740	80	1,660	160	1,580
14dd	1,731	160	1,571	160	1,571
15aa	1,810	250	1,560	250	1,560
15bb	1,730	100	1,630	130	1,600
16bb	1,714	65	1,649	120	1,594
16cd	1,743	60	1,683	------	------
17cc	1,816	(?)	(?)	170	1,646
17cd	1,794	55?	1,739?	125	1,669
18bb	1,731	100	1,631	120	1,611
19cc	1,816	125	1,691	150	1,666
19dd	1,820	(?)	(?)	150	1,670
20aa	1,748	40	1,718	135	1,613
20ab	1,752	25?	1,740?	105	1,647
21dd	1,741	60	1,681	100	1,641
22bb	1,705	20	1,685	55	1,650
23cc	1,726	70	1,656	100?	1,626?
24cc	1,706	(?)	(?)	170	1,536
25cc	1,776	(?)	(?)	200	1,576
25da	1,715	130	1,585	220?	1,495?
27dd	1,798	180	1,618	205	1,593
28dd	1,812	100	1,712	210	1,602
29aa	1,829	140	1,689	170	1,659
29cc	1,796	80	1,716	135	1,661
29dd	1,836	160	1,676	200	1,636
31dd	1,848	(?)	(?)	190	1,658
32dd	1,840	(?)	(?)	195	1,645
33dd	1,813	90	1,723	200	1,613
34dd	1,795	(?)	(?)	225	1,570
36cc	1,732	100	1,632	205	1,527
6-7-35cd	1,774	285−	1,489−	------	------
36dd	1,769	295−	1,474−	------	------

TABLE 9.—*Logs of test holes and wells*

[Logs marked with an asterisk (*) are drillers' logs; all others are test holes drilled by the Conservation and Survey Division, University of Nebraska, in cooperation with the U. S. Geological Survey. Altitude of land surface, in feet above mean sea level, was determined by altimeter (a), spirit level (i), or estimation from the topographic map (t). Depth to water is given in feet below land surface]

	Thickness (feet)	Depth (feet)
4-5-12aa		
Nuckolls County. Altitude (a), 1,619 ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
Fill: silt and clay, light-brown	3	3
Soil: silt, clayey, to silty clay, dark-brown to black	5	8
Silt, clayey, light grayish-brown to pink	2	10
Silt, sandy, gravelly in lower part, light-gray to brownish-yellow	2.5	12.5
Sand, fine, to coarse gravel, light pinkish-gray to brown; contains a few pebbles	16	28.5
Clay, sandy, light-gray to green	.5	29
Sand, fine, to coarse gravel, light pinkish-brown to gray; contains a few pebbles and is finer textured in lower part	61	90
Clay, silty, to clayey silt, light brownish-tan	5	95
Silt, sandy, to fine silty sand, light brownish-tan, greenish-gray to yellow in lower part	11	106
Sand, fine, to some medium gravel, light brownish-gray to pink	30	136
Silt, clayey to sandy, fine, light brownish-tan to pink, granular-textured in lower part	11	147
Sand, fine, to some fine gravel, light brownish-gray to pink	13	160
Sand, fine, to fine gravel, reddish-brown to gray; contains some medium gravel	13	173
Silt, clayey, light brownish-tan	5	178
Sand, fine, to medium gravel, reddish-brown to gray	18	196
Clay, silty, light grayish-tan to pink	2	198
Sand, fine, to fine gravel, brownish-red to gray	2	200
Silt, clayey, to fine sand, brown to light-gray	10	210
Sand, fine to medium, light brownish-gray	11	221
Tertiary—Pliocene:		
Clay, silty, medium-gray	4	225
Clay, silty to sandy, fine sand, medium to dark-gray and green	5	230
Clay, silty, and some interbedded fine to medium sand, medium-blue to greenish-gray; contains a few shell fragments	15.5	245.5
Silt, clayey, medium-gray to bluish-green; contains a few shell fragments	2.5	248
Sand, fine to medium, light brownish-gray	2	250
Silt, clayey, to silty clay, medium-gray to blue	20	270
4-9-1aa		
Webster County. Altitude (i), 1,854 ft. Depth to water, 80 ft, November 17, 1947.		
Quaternary—Recent and Pleistocene:		
Soil: silt, slightly clayey, dark brownish-gray	0.5	0.5
Silt, clayey, medium brownish-gray	2	2.5
Silt, slightly clayey, buff-gray; contains a few calcareous nodules and limonitic flecks	14.5	17
Soil: silt, slightly clayey, medium reddish-brown	3	20
Silt, slightly clayey, tannish-gray with a slight pink tint	2	22
Silt, clayey, tannish-gray with a red tint	3.5	25.5
Silt, clayey, in part slightly clayey, light tannish-gray with a buff tint; light-gray with a tan tint and contains a few limonitic flecks below 38 ft	14.5	40
Silt, slightly to moderately calcareous, very light tannish-gray; contains a few rootlets and calcareous nodules; some very fine sandy silt below 65 ft	30	70
Silt, to sandy silt, very fine sand, slightly calcareous to moderately to very calcareous below 86.5 ft, tannish-gray with buff tint	20	90
Silt, sandy, very fine sand, very calcareous, light-gray	3	93
Sand, fine to coarse, silty, brownish-tan; contains a trace of fine gravel below 100 ft	10	103
Tertiary—Pliocene:		
Silt, slightly to moderately calcareous, brownish tan-gray; contains many calcareous fragments and rootlets	12	115
Silt, slightly calcareous, intermittent calcareous zones, tannish-gray with a slight red tint	15	130
Marl, light-gray	1	131
Silt, slightly clayey, slightly to moderately calcareous, thin calcareous zones, noncalcareous below 150 ft, light brownish-gray; light reddish-brown below 145 ft	20	151
Silt, very slightly calcareous, buff-brown	5	160
Silt, slightly clayey, slightly calcareous, brownish-buff with a gray tint	8	168
Marl, light-gray	1	169
Silt, clayey, slightly to moderately calcareous, brownish-gray with a tan tint	7	176
Marl, white to gray	2	178
Silt, clayey, slightly to moderately calcareous, brownish-gray with a tan tint	4.5	182.5
Gravel, principally chalk grains	5	187.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Chalk, shaly, yellow and white	4.5	192
Shale, chalky, medium and dark-gray	8	200

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
5-4-30bb		
Fillmore County. Altitude (a), 1,663 ft. Depth to water, 52.7 ft, October 2, 1946.		
Quaternary—Recent and Pleistocene:		
Soil: silt, clayey, dark-brown	1.5	1.5
Clay, silty, dark brownish-gray	1	2.5
Silt, clayey, light brownish-buff	10	12.5
Silt, clayey, soillike, dark-brown	2.5	15
Clay, silty, dark-gray to brown	2	17
Silt, sandy, medium to light-gray	3	20
Silt, sandy to clayey, fine sand, light-gray	5	25
Sand, fine to coarse, light-gray	3	28
Sand, medium, to coarse gravel, brownish-gray to pink; contains a few pebbles	87	115
Sand, fine, to gravel, light brownish-gray to pink	55	170
Sand, medium, to fine and some medium gravel, brownish-gray to pink	15.5	185.5
Clay, sandy, light brownish-gray	2	187.5
Sand, medium, to fine and some medium gravel, red-brown to gray	8.5	196
Clay, sandy, and silt, light-brown to gray; contains some white calcareous material	2.5	199.5
Sand, very fine to coarse, light brownish-gray; contains some fine gravel in the lower part	23	222.5
Silt, clayey to sandy, fine sand, light-brown to gray	7.5	230
Sand, fine, to fine gravel, light brownish-gray to pink	12.5	242.5
Silt, sandy, light-gray	1.5	244
Sand, fine to coarse, some silt seams, light-gray	8.5	252.5
Silt, sandy, medium grayish-tan	10.5	263
Sand, fine to coarse, light-gray	11.5	274.5
Tertiary—Pliocene:		
Silt, light-brown to gray	1.5	276
Clay, silty, medium-gray to blue	4.5	280.5
Clay, silty, moderately calcareous, gray	19.5	300
Clay, moderately calcareous, dark-gray	20	320
Clay, silty, gray; contains a few shell fragments	45	365
Clay, silty, dark-gray to brown	15	370
Clay, silty, light brownish-gray; contains a few reworked chalk and shale fragments	12.5	382.5
Sand, fine, to medium gravel, principally reworked chalk fragments and shells; brown to gray	7.5	390
Cretaceous—Upper Cretaceous—Graneros shale:		
Shale, very calcareous, dark-gray to blue; contains some bentonite	1	391
Shale, black to brown; contains many shell fragments and has a strong petroliferous odor	19	410
5-5-1dd		
Clay County. Altitude (a), 1,693 ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
Soil: Clay, silty, dark-brown	1.5	1.5
Silt, clayey, medium brownish-gray to buff; contains a few calcareous concretions below 2.5 ft	14.5	16
Soil: silt, clayey, dark-brown	2.5	18.5
Clay, silty, dark reddish-brown to 20 ft, light reddish-brown from 20 to 24 ft, medium-brown to red below 24 ft	9.5	28
Silt, sandy to clayey, medium-brown to red	2	30
Silt, clayey, light-brown to gray	2	32
Clay, silty, to clayey silt, light-brown to pink; medium grayish-brown with some black carbonaceous streaks from 36 to 40 ft	10	42
Silt, clayey, slightly calcareous, pinkish-brown to grayish-green; contains a few concretions	3	45
Silt, clayey to sandy, fine sand, some white silt, light-gray to green	3	48
Silt, sandy, to fine sand, sandier in lower part, light greenish-gray; contains a few yellow streaks	5	53
Sand, fine, to some fine gravel, brownish-gray to pink	2	55
Sand, medium, to fine and some medium to coarse gravel, pinkish-brown to gray	6	61
Silt, clayey to sandy, fine sand, medium light-gray and light brownish-tan; light pinkish-tan below 64 ft	9	70
Silt, sandy, to silty sand, light grayish-brown	4.5	74.5
Sand, fine, to fine and some medium gravel, coarser texture with depth and some pebbles below 110 ft, light brownish-gray to pink	85.5	160
Sand, fine, to medium gravel, principally sand from 180 to 200 ft, brownish-gray to pink; green tint below 220 ft	70	230
Sand, fine, to some fine gravel, light brownish-gray to pink	16	246
Clay, silty, slightly calcareous, pinkish- to grayish-tan, medium bluish-gray in lower part	4	250
Silt, clayey, slightly calcareous, medium bluish-gray; contains a pelecypod shell	14	264
Silt, sandy, to fine sand, medium-gray; contains a few shell fragments in lower part	19	283
Sand, fine, to fine gravel, silt layers from 288 to 291 ft and 294.5 to 296 ft, greenish-gray to pink	16.5	299.5

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
5-5-1dd—Continued		
Tertiary—Pliocene:		
Clay, silty, moderately calcareous, medium-gray; dark-gray below 315 ft	21.5	321
Sand, gravel, and shale fragments, dark-gray to light brownish-gray	2	323
Cretaceous—Upper Cretaceous—Carlile shale:		
Clay, silty, dark-gray	6.5	329.5
Clay, shale, moderately calcareous, yellow	10.5	340
***5-5-5ad**		
Clay County. Owner, George Plautz. Driller, Don Barney. Altitude (a), 1,736 ft. Depth to water, 90.6 ft, September 9, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	22.5	24
Clay, sandy	16	40
Clay, gray	27	67
Sand, some gravel	6	73
Clay	5	82
Sand and gravel	11	93
Clay	2	95
Sand and gravel	16	111
Sand and a little gravel	4	115
Sand and gravel	43	158
Gravel	0	158
***5-5-11ba**		
Clay County. Owner, Dale Friedline. Driller, Don Barney. Altitude (a), 1,699 ft. Depth to water, 77.8 ft, June 24, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	20
Clay, yellow and brown	35	37
Clay, sandy	12	49
Sand and clay, dirty	6	55
Sand and some gravel	10	65
Clay, white	12	77
Sand and some gravel	13	90
Sand and gravel	28	118
Sand	3	121
Sand and gravel	37	158
***5-5-33db**		
Clay County. Owner, Emil Hartnett. Driller, Don Barney. Depth to water, 34.1 ft, September 8, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	15.5	17
Sand and gravel	28	45
Sand and rice gravel	20	65
Sand and gravel	30	95
Sand and a little wheat gravel	15	110
Fine sand	2	112
Sugar sand, trace of gravel	13	125
Sand and a little wheat gravel	13	138

TABLE 9.—*Logs of test holes and wells*—Continued

***5–6–4ac**

Clay County. Owner, Edgar Organ. Driller, Don Barney. Depth to water, 76 ft, August 20, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	16	18
Clay, brown	7	25
Clay, yellow	29	54
Sand	11	65
Sand and some gravel	6	71
Sand and gravel	60	131
Clay, sandy	3	134
Sand, fine, trace of gravel	6	140
Sand, medium-fine, and some gravel	18	158
Gravel	0	158

***5–6–4ba**

Clay County. Owner, Glen Peterson. Driller, John Alfs. Altitude (a), 1,753 ft. Depth to water, 81 ft, August 20, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil	3	3
Clay	37	40
Clay, sand, and lime-rock mixture	13	53
Sand	9	62
Clay and gravel	4	66
Sand and gravel	42	108
Trace of clay	1	109
Gravel	9	118
Gravel and clay	5	123
Fine sand	4	127
Sand and gravel	12	139
Sand, good	8	147
Gravel	16	163
Sand and gravel	2	165
Sand	8	173

***5–6–7aa**

Clay County. Owner, Kenneth Westering. Driller, Don Barney. Altitude (a), 1,759 ft. Depth to water, 75.4 ft, August 20, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow and brown	51.5	53
Sand, dirty	8	61
Sand, some gravel	12	73
Sand, fine	6	79
Sand and gravel	33	112
Clay, sandy	18	130
Sand and some gravel	6	136
Sand and gravel	19	155
Sand and some gravel	3	158

***5–6–16db**

Clay County. Owner, Mrs. Guy Green. Driller, Don Barney. Altitude (a), 1,741 ft. Depth to water, 76.1 ft, August 20, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	26	28
Sand, fine, dirty, and clay	7	35
Clay	19	54
Sand, some clay	10	64
Clay	12	76
Sand and gravel	5	81
Sand	2	83
Sand and gravel	35	118
Sand, some gravel	42	160

TABLE 9.—*Logs of test holes and wells*—Continued

5-6-19bb

Clay County. Altitude (a), 1,750 ft. Depth to water, 71.0 ft, August 1, 1949.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil and road fill: silt, clayey, dark brownish-gray; slightly lighter color and slightly calcareous below 2.5 ft	3.5	3.5
Soil: clay, silty, medium-brown to gray	.5	4
Clay, silty, medium-gray with brown tint; less clayey and light brownish-gray below 5 ft	3	7
Silt, slightly clayey; contains a few limonitic flecks, buff-gray; slightly lighter in color below 12 ft	8	15
Silt, very slightly clayey, light buff-gray; contains many limonitic flecks	5	20
Silt, slightly clayey to very slightly sandy, brownish-tan; contains many angular dark-brown iron-clay fragments	3	23
Silt, moderately clayey, light-gray; contains a few embedded very fine to fine sand grains	3	26
Silt, moderately clayey to very slightly sandy, fine to coarse sand, sandier below 30 ft, tannish-gray with a pink tint	8	34
Sand, fine to very coarse, scattered gravel grains, tannish-gray	6	40
Sand, fine, to medium gravel, brownish-gray to pink	8	48
Silt, slightly clayey, light-gray	2	50
Sand, fine to very coarse, silty, dark-gray to very light brownish-gray	5	55
Sand, fine, to medium gravel, brown to tannish-gray to pink, some iron stain	48.5	103.5
Silt, slightly clayey to sandy, fine to medium sand, light brownish-tan with a gray tint	4.5	108
Sand, fine, to fine gravel, silty, some interbedded sandy silt layers, brownish-gray	7	115
Sand, fine, to medium gravel, brownish-gray to pink	18	133
Silt, clayey to very sandy, light-gray to brownish-tan	2	135
Sand, fine to coarse, slightly finer below 150 ft, light brownish-gray	18	153
Sand, fine to very coarse, silty, trace of fine gravel, light-gray with a green tint	7.5	160.5
Tertiary—Pliocene:		
Silt, sandy, very fine to fine sand, slightly calcareous, light brownish-tan with a gray tint	14.5	175
Sand, medium, slightly silty, slightly calcareous, light brownish-gray	5	180
Silt, sandy to slightly clayey, slightly calcareous, light brownish-tan; contains a few calcareous nodules	8	188
Silt, slightly to moderately calcareous, light-gray with a slightly brown tint; contains some siltstone layers below 190 ft	7	195
Silt, moderately calcareous, light-gray with a brown tint	5	200
Silt, moderately calcareous, light brownish-gray, slightly darker below 210 ft	28	228
Cretaceous—Upper Cretaceous—Carlile shale:		
Clay, slightly calcareous, light-gray to light brownish-gray; contains thin ironstone layers	2	230
Clay shale, very plastic, light-gray; contains some thin ironstone layers	20	250

***5-6-22da**

Clay County. Owner, Willard S. Avery. Driller, Don Barney. Altitude (a), 1,72[illegible] ft. Depth to water, 73.7 ft, August 19, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow to brown	36	38
Clay, sandy, and some lime rock	14	52
Sand, dirty	3	55
Sand and gravel	60	115
Clay	2	117
Sand and a little gravel	4	121
Sand and gravel	15	136
Clay	17	153
Clay, yellow, and hard lime rock	2	155

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***5-6-23cb**		
Clay County. Owner, Leland Hawley. Driller, Wendell Shuck. Altitude (a), 1,726 ft. Depth to water, 77 ft, August 19, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	16	18
Clay, yellow, and gumbo, mixed	9	27
Clay	18	45
Sand and gravel	29	74
Gravel, coarse	13	87
Sand and gravel	23	110
Gravel	30	140
Clay and fine sand	29	169
Sand and gravel	-------	-------
***5-6-28db**		
Clay County. Owner, Floyd Kollman. Driller, Don Barney. Altitude (a), 1,738 ft. Depth to water, 78.5 ft, November 16, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	47	49
Sand and gravel, dirty	31	80
Sand and gravel	65	145
Clay, sandy	4	149
Sand	4	153
Sand and some gravel	5	158
Sand	5	163
Sand, some gravel	15	178
***5-6-32cc**		
Clay County. Owner, William Hakanson. Driller, Don Barney. Altitude (a), 1,733 ft. Depth to water, 75.9 ft, December 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	26	29
Clay, sandy	13	42
Sand, dirty, and clay	3	45
Sand and gravel	14	59
Sand, trace of gravel	3	62
Sand and gravel, good	5	67
Sand and gravel	5	72
Sand, medium-fine, and gravel	13	85
Sand and gravel	19	104
Sand, fine, and clay	3	107
Sand, fine, and some gravel	2	109
Clay, white	16	125
Clay, sandy	4	129
Sand and clay, hard	3	132
Sand, trace of gravel, and clay	6	138
Sand and gravel	12	150
Sand, fine, and some clay	7	157
Sand, fine, and a little gravel	1	158
***5-6-32dc**		
Clay County. Owner, William R. Nichols. Driller, Wendell Shuck. Altitude (a), 1,730 ft. Depth to water, 73.1 ft, August 19, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	37	40
Sand and gravel	65	105
Sand, fine	5	110
Sand and gravel	53	163

TABLE 9.—*Logs of test holes and wells*—Continued

***5-7-4cd**

Clay County. Owner, Ed Schliep. Driller, John Alfs. Altitude (a), 1,793 ft. Depth to water, 89.1 ft, October 30, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	5	5
Clay	51	56
Sand and gravel	4	60
Gravel	8	68
Sand and gravel	12	80
Clay, sand	5	85
Sand	10	95
Sand and gravel	25	120
Gravel	16	136
Clay	1	137
Sand and gravel	40	177

***5-7-8bb**

Clay County. Owner, Carl Brodrick. Driller, John Alfs. Altitude (a), 1,786 ft. Depth to water, 81 ft, October 30, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay	42	45
Sand and clay	4	49
Sand and gravel	19	68
Gravel, coarse	2	70
Sand and clay	10	80
Sand and gravel	6	86
Clay	3	89
Sand	4	93
Sand, good, and gravel	27	120
Sand	3	123
Sand, good, and gravel	9	132
Clay	2	134
Sand and gravel	16	150
Sand	3	153
Sand and gravel	22	175

***5-7-17cb**

Clay County. Owner, Edith Lambie. Driller, Don Barney. Altitude (a), 1,788 ft. Depth to water, 84.4 ft, August 13, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow and brown	51	53
Sand	12	65
Sand and gravel	25	90
Sand and some gravel	4	94
Sand	4	98
Sand and gravel	7	105
Clay, sandy	12	117
Sand and gravel	18	135
Sand and some gravel	6	141
Sand and gravel	4	145
Sand	6	151
Sand and gravel	21	172
Sand	3	175
Tertiary—Pliocene:		
Clay, sandy	3	178

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***5-7-20dc**		
Clay County. Owner, Anton Skalka. Driller, Don Barney. Altitude (t), 1,774 ft. Depth to water, 95.4 ft, October 21, 1952.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	14	17
Clay, brown	20	37
Clay, sandy	9	46
Sand, dirty, and clay	8	54
Sand and gravel	20	74
Clay	4	78
Sand, fine, dirty, some clay	3	81
Sand and a little gravel	4	85
Sand and gravel	20	105
Sand, fine, dirty	9	114
Clay, gray	5	119
Sand, trace of gravel and clay	7	126
Sand, medium-fine, some gravel	3	129
Sand and gravel	10	139
Sand and rice gravel	6	145
Sand, medium-fine, and gravel	4	149
Sand, fine, some clay	6	155
Sand, fine	7	162
Sand and rice gravel	12	174
Tertiary—Pliocene:		
Sand, fine, and sandy clay	4	178
Sand, fine, very dirty	16	194
Clay	4	198
***5-7-21ca**		
Clay County. Owner, Joseph R. Skalka. Driller, Don Barney. Altitude (a), 1,773 ft. Depth to water, 80.5 ft, October 21, 1952.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	37	39
Sand and some gravel	6	45
Sand and gravel	24	69
Sand, fine	9	78
Sand and gravel	18	96
Clay	8	104
Clay, sandy	8	112
Sand and rice gravel	14	126
Clay, sandy	6	132
Sand, fine	23	155
Sand, medium-fine, and wheat gravel	24	179
Sand, fine, and gravel	6	185
Tertiary—Pliocene:		
Clay	10	195
***5-7-22db**		
Clay County. Owner, George J. Harms. Driller, Don Barney. Altitude (a), 1,764 ft. Depth to water, 80.3 ft, October 21, 1952.		
Quaternary—Recent and Pleistocene:		
Topsoil	2.5	2.5
Clay, yellow	16.5	19
Clay, brown	16	35
Clay, sandy	11	46
Sand and some gravel	4	50
Sand and gravel	32	82
Sand and some gravel	5	87
Sand and gravel	19	106
Clay	9	115
Sand and clay	5	120
Sand and trace of rice gravel	5	125
Sand, fine, and gravel	4	129
Sand and gravel	15	144
Sand, fine, and trace of gravel	7	151
Sand and trace of gravel	8	159
Sand and some gravel	6	165
Sand and gravel	6	171
Sand, medium-fine, and rice gravel	7	178

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
5-7-24ca		
Clay County. Owner Ed O. Schliep. Driller, John Alfs. Altitude (a), 1,759 ft. Depth to water, 84.6 ft, November 17, 1954.		
Quaternary—Recent and Pleistocene:		
Clay	50	50
Clay and gravel	5	55
Sand and gravel	58	113
Clay	5	118
Sand and gravel	15	128
Clay	2	130
Sand and gravel	16	146
Clay	4	150
Sand and gravel	40	190
Tertiary—Pliocene:		
Clay	30	220
Clay and a little fine sand	10	230
Clay	10	240
5-7-28bb		
Clay County. Owner, Albert J. Skalka. Driller, Don Barney. Altitude (t), 1,773 ft. Depth to water, 87.5 ft, October 21, 1952.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	41.5	43
Sand and gravel	19	62
Clay, white, soft	3	65
Sand and gravel	3	68
Sand, medium-fine, and some gravel	4	72
Sand and rice gravel	3	75
Sand and gravel	7	82
Clay	3	85
Sand and gravel	9	94
Clay	11	105
Sand and clay	7	112
Sand, medium-fine, and some gravel	8	120
Sand and wheat gravel	9	129
Sand and trace of wheat gravel	16	145
Clay, sandy, and quicksand	5	150
Sand, fine	7	157
Sand, fine, and rice and wheat gravel	17	174
Clay and fine sand, and sand, dirty	4	178
5-7-28cc		
Clay County. No well constructed. Owner, Albert Skalka. Driller, Don Barney. Depth to water, 90 ft, 1950.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	27	29
Clay, sandy	5	34
Sand and sandy clay	6	40
Clay, sandy	4	44
Sand and gravel	39	83
Sand and rice gravel	14	97
Clay, sticky, yellow	12	109
Clay, sandy	4	113
Sand and rice gravel	5	118
Sand and gravel	6	124
Clay, sandy	6	130
Sand, very fine	7	137
Sand, fine	6	143
Sand and some wheat gravel	16	159
Sand and gravel	3	162
Clay	16	178

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***5-7-29ad**		
Clay County. Owner, Leo Sykora. Driller, Don Barney. Altitude (a), 1,773 ft. Depth to water, 92.7 ft, October 21, 1952.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	15.5	17
Clay, dark-brown	3	20
Clay, light-brown	7	27
Clay, sandy	12	39
Sand and gravel	22	61
Gravel	6	67
Sand and gravel	18	85
Sand, medium-fine	2	87
Sand, fine, and gravel	7	94
Clay, sandy	5	99
Sand, fine, and clay, dirty	6	105
Clay, slightly sandy, gray	15	120
Sand, gravel, and clay balls	10	130
Sand, fine, and a trace of gravel	5	135
Sand, fine, and some rice gravel	1	136
Sand, very fine, and some clay balls	3	139
Sand, fine, and some gravel	3	142
Clay	6	148
Sand, rice gravel, and clay balls	4	152
Sand, gravel, and clay balls	3	155
Sand and gravel	13	168
Tertiary—Pliocene:		
Clay	22	190
***5-8-1bb**		
Clay County. Owner, Ralph Kissinger. Driller, Don Barney. Altitude (t), 1,810 ft. Depth to water, 91.8 ft, October 28, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	47	49
Clay, sandy	4	53
Sand and clay	2	55
Sand, some gravel and clay	10	65
Sand, some gravel	12	77
Clay, sandy	6	83
Sand, medium-fine, and gravel	15	98
Sand and gravel	22	120
Clay, sandy	8	128
Sand, fine, and some gravel	3	131
Sand and a little gravel	14	145
Clay, sandy	4	149
Sand and gravel	9	158
Sand	7	165
Sand and gravel	4	169
Sand, medium-fine	6	175
Sand, medium-fine, and gravel	9	184
Sand, fine, and a little gravel	5	189
Sand, fine	9	198

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***5-8-1dc**		
Clay County. Owner, Peter F. Muzik. Driller, Don Barney. Altitude (a), 1,810 ft. Depth to water, 94.8 ft, August 12, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	1	1
Clay, yellow	33	34
Clay, sandy	5	39
Clay, limy, white	17	56
Sand	4	60
Sand and gravel	18	78
Clay, sandy	5	83
Sand	3	86
Sand and gravel	28	114
Clay, sticky	7	121
Sand and a little gravel	4	125
Sand and gravel	13	138
Clay, sandy	4	142
Sand	6	148
Sand and gravel	7	155
Sand, like sugar	9	164
Sand and wheat gravel	8	172
Sand, like sugar	3	175
Sand and gravel	3	178
***5-8-2aa**		
Clay County. Owners, Ward and Herbert Fitzke. Driller, Don Barney. Altitude (a), 1,820 ft. Depth to water, 94 ft, October 30, 1952.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow, and clay, brown	50	52
Sand and gravel	28	80
Clay	3	83
Sand and gravel	35	118
Clay	9	127
Sand and gravel	16	143
Clay, sandy	4	147
Sand and gravel	31	178
***5-8-3bb**		
Clay County. Owner, Ida Onken. Driller, Don Barney. Altitude (a), 1,825 ft. Depth to water, 96.7 ft, October 21, 1952.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	17	19
Clay, brown	6	25
Clay, sandy	27	52
Sand, gravel and clay	40	92
Sand, medium-fine, and some gravel	3	95
Sand and rice gravel	6	101
Sand and gravel	38	139
Sand and rice gravel	6	145
Sand, medium-fine, gravel and clay balls	8	153
Sand, gravel, and a few clay balls	2	155
Sand and gravel, good	3	158

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
5-8-6bb		
Clay County. Altitude (i), 1,829 ft. Depth to water, 83.6 ft, November 19, 1947.		
Quaternary—Recent and Pleistocene:		
Soil: silt, very slightly clayey, very dark brownish-gray	1	1
Silt, slightly clayey, brownish buff-gray	1	2
Silt, clayey, buff-gray with a slight brown tint	1.5	3.5
Silt, slightly clayey, less clayey below 10 ft, buff-gray with slight yellowish tint; contains a few calcareous nodules	14.5	18
Soil: silt, very slightly clayey, dark reddish-brown	3	21
Soil: silt, clayey, medium brownish-gray	2	23
Silt, clayey, tannish-gray with a pink tint	4	27
Silt, in part slightly clayey, calcareous below 29.5 ft, brownish tan-gray	3	30
Silt, slightly clayey to slightly sandy, light tannish-gray; contains calcareous fragments	3	33
Silt, clayey, very calcareous, light-gray	3	36
Clay, slightly to moderately calcareous, light greenish-gray; contains very calcareous mottling in the upper part	5.5	41.5
Silt, clayey, medium-gray; contains sand below 42.5 ft	1.5	43
Sand and gravel, texture grades from sand to medium gravel with some coarse gravel and pebbles, slightly coarser texture below 50 ft, brownish-gray to pink with a slight yellowish tint; contains some soft greenish-gray clayey silt from 50 to 55 ft	20	63
Silt, sandy, light brownish-tan with a grayish tint	3	66
Silt, sandy to very slightly clayey to very sandy in lower part, grayish-green	3	69
Sand and gravel, light brownish-gray to pink; texture grades from sand to medium gravel with some coarse gravel in lower part	24.5	93.5
Silt, in part slightly clayey, limonitic-stained in upper part, light brownish-tan; contains a white calcareous zone from 97 to 97.5 ft	5.5	99
Silt, sandy, brownish-tan to gray	9	108
Sand and gravel, brownish-gray to pink; texture grades from sand to medium gravel with some coarse gravel	14	122
Silt, very slightly clayey to sandy below 125 ft, brownish-tan with a grayish tint	8	130
Sand and gravel, brownish-gray to pink, grades from sand to coarse gravel, principally sand below 230 ft; contains a light greenish-gray silty layer from 170 to 171 ft	112.5	242.5
Tertiary—Pliocene:		
Silt, medium-gray; light gray to medium gray below 248 ft	12.5	255
Silt, slightly calcareous, brownish-gray	5.5	260.5
Silt, granular, medium brownish-gray; contains a thin hard calcareous layer at 263 ft	2.5	263
Silt, in part very slightly clayey, slightly calcareous, light brownish-gray, with a slight tan tint below 275 ft; contains a few calcareous fragments from 285 to 290 ft	47.5	310.5
Sand and gravel, brownish-gray; contains many chalk fragments	11	321.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, light-gray to medium-gray, dark-gray below 325 ft; contains a hard zone at 321.5 ft	8.5	330
5-8-19bb		
Clay County. Altitude (i), 1,772 ft. Depth to water, 44.4 ft, November 17, 1947.		
Quaternary—Recent and Pleistocene:		
Soil: silt, very slightly clayey, dark brown, nearly black	0.7	0.7
Soil: silt, slightly clayey, medium brownish-gray	.8	1.5
Silt, slightly clayey, light-brown to buff-gray	.5	2
Silt, in part slightly clayey, very slightly calcareous, buff-gray with slight brown tint; contains some embedded gravel	16	18
Soil: silt, very slightly clayey to very slightly sandy, medium-brown with a gray tint	5.5	24.5
Sand and gravel, slightly coarser texture with depth, brownish-gray to pink; contains some dark iron staining and many pebbles below 50 ft	45.5	70
Sand to medium gravel with trace of coarse gravel, brownish-gray to pink	17.5	87.5
Tertiary—Pliocene:		
Silt, slightly clayey, moderately to very calcareous, brownish-tan with a gray tint; contains reworked chalk fragments below 92.5 ft	5.5	93
Silt, slightly clayey to sandy, slightly to moderately calcareous, very light-brown; contains very fine to fine sand	4	97
Cretaceous—Upper Cretaceous—Niobrara formation:		
Chalk to limestone, soft, light-yellow to light yellowish-white below 100 ft; contains a hard limonite zone at 104.5 ft	8	105
Chalk, soft, yellowish-white	5	110
No sample, drilled like chalk	5	115

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
6-4-6cc		
Fillmore County. Altitude (a), 1,706 ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
Soil: silt, clayey, to silty clay, dark-brown	1	1
Clay, silty, medium-brown with grayish tint	1.5	2.5
Silt, clayey, medium brownish-buff to gray; contains a few calcareous concretions and limonitic streaks	3.5	6
Silt, clayey, light grayish-buff; contains a few limonitic nodules	12	18
Silt, clayey, soillike, dark-brown	1.5	19.5
Silt, clayey to sandy, light red-brown; contains fine sand	20.5	40
Silt, sandy, light-gray to brown; contains fine sand	8.5	48.5
Sand and gravel, grading from fine sand to fine gravel, brownish-gray to pink	11.5	60
Sand and gravel, grading from medium sand to medium gravel with some coarse gravel, pinkish-brown to gray	8	68
Silt, clayey, light-brown to white; contains much calcareous concretionary material below 70 ft	13.5	81.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Chalk and shale, chalky, white to light-yellow	18.5	100
Shale, chalky, light-yellow	25.5	125.5
Chalk, medium to bright yellow	8	133.5
Shale, chalky, light-yellow to white; contains some limonitic stain in the lower part	4.5	138
Cretaceous—Upper Cretaceous—Carlile Shale:		
Clay shale, dark-gray to black	12	150
6-5-24dd		
Clay County. Altitude (a), 1,707 ft. Depth to water, 91.1 ft, September 27, 1946.		
Quaternary—Recent and Pleistocene:		
Silt, clayey, dark brownish-gray	1	1
Clay, silty, dark-gray to brown	4	5
Silt, clayey, light-gray with buff tint; contains some limonitic stain	13.5	18.5
Soil: clay, silty, to clayey silt, medium dark-brown	1.5	20
Clay, silty, medium-light brownish-gray	2	22
Clay, silty to slightly sandy, light pinkish-brown to gray	4	26
Clay, silty, medium light-gray with pink tint; contains some limonitic stain	4	30
Clay, silty to fine sand, light-gray to pink; contains some limonitic stain	5	35
Clay, sandy, light-gray to pink; contains many brown limonitic areas	5	40
Clay, very sandy, light pinkish-brown	2	42
Sand, grading from fine to coarse, light pinkish-gray	8	50
Sand, silty, light brownish-gray	10	60
Sand, fine, light-gray to brown	2.5	62.5
Sand and gravel, grading from fine sand to medium gravel, brown to pink; contains much limonitic stain	7.5	70
Sand and gravel, grading from medium sand to coarse gravel with some pebbles, brownish-gray to pink; contains a thin light-gray clayey silt layer below 85 ft	20	90
Sand and gravel, grading from medium sand to fine gravel with some medium gravel and some fine sand below 93 ft, light brownish-gray to pink	10	100
Sand and gravel, texture grading from medium sand to coarse gravel, slightly finer texture with depth, brownish-gray to pink	100	200
Sand and gravel, grading from medium sand to fine gravel with some medium gravel, greenish-gray to pink; contains some dark-green shale fragments in lower part	31.5	231.5
Tertiary—Pliocene:		
Silt, clayey, gray to light brownish-tan; contains some calcareous concretionary material in lower part	8.5	240
Silt, clayey, to silty clay, light brownish-tan to brown; contains a white calcareous zone from 253 to 253.5 ft	15	255
Silt, clayey, to silty clay, light grayish-tan; contains reworked chalk fragments and some limonitic fragments	15	270
Clay, silty, medium light-gray; contains many reworked yellow shale and limonitic fragments	6	276
Cretaceous—Upper Cretaceous—Carlile shale:		
Clay shale, dark-gray to black	14	290

TABLE 9.—*Logs of test holes and wells*—Continued

***6-5-27ca**

Clay County. Owner, Clem Gowen. Driller, John Alfs. Altitude (a), 1,731 ft. Depth to water, 93.8 ft, October 22, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay	48	51
Sand	17	68
Clay	4	72
Sand, good	2	74
Sand and gravel	25	99
Sand	10	109
Clay, sandy	5	114
Sand, good	12	126
Sand and gravel	3	129
Sand	13	142
Sand and gravel	25	167

***6-6-5bb**

Clay County. Owner, Arnold L. Livgren. Driller, Don Barney. Altitude (a), 1,768 ft. Depth to water, 66 ft, October 27, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	25	27
Sand, dirty, and some clay	10	37
Sand and some gravel	21	58
Clay, pinkish-gray	16	74
Sand and some rice gravel	31	105
Clay, sandy	14	119
Sand	8	127
Sand and gravel	19	146
Clay, sandy	2	148
Sand, medium-fine	12	160
Sand	14	174
Cretaceous—Upper Cretaceous—Niobrara formation:		
Lime rock, white	4	178

***6-6-6db**

Clay County. Owner, Carl Dahlsten. Driller, Don Barney. Altitude (a), 1,768 ft. Depth to water, 64.4 ft, October 27, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Hardpan and clay, yellow	23	25
Sand and clay, blue	14	39
Sand	15	54
Sand and gravel, dry	5	59
Clay, very sandy	9	68
Sand, fine, and some gravel	11	79
Sand and gravel	24	103
Clay, blue	12	115
Sand, rice and wheat gravel, blue	63	178
Cretaceous—Upper Cretaceous—Niobrara formation:		
Lime rock and silt	16	194

***6-6-7cd**

Clay County. Owner, Agnes Williamson. Driller, Don Barney. Altitude (a), 1,771 ft. Depth to water, 73.2 ft, October 27, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	38	40
Sand, dirty, and clay	12	52
Sand and gravel, dry	13	65
Clay	14	79
Sand and gravel	53	132
Clay	4	136
Sand and wheat gravel	9	145
Sand and gravel	11	156
Sand and some wheat gravel	22	178

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***6-6-9bd**		
Clay County. Owner, T. R. Nelson. Driller, Don Barney. Altitude (a), 1,773 ft. Depth to water, 82.4 ft, October 27, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	19	21
Sand, fine, dirty, and some clay	23	44
Clay	6	50
Sand, dirty	19	69
Sand and some gravel	10	79
Clay	7	86
Sand	5	91
Sand and some gravel	13	104
Sand and gravel	16	120
Clay, blue	12	132
Sand, fine, blue	4	136
Sand and gravel	29	165
Sand, blue	13	178
6-6-18bb		
Clay County. Altitude (a), 1,792 ft. Depth to water, 89.4 ft, August 5, 1949.		
Quaternary—Recent and Pleistocene:		
Soil: silt, very dark brownish-gray	1	1
Soil: silt, slightly clayey, moderately clayey and granular below 2 ft, medium brownish-gray	3	4
Silt, slightly clayey, buff-gray with a brown tint	1	5
Silt, moderately to slightly clayey, buff-gray	3	8
Silt, slightly calcareous, buff-gray with slight yellow tint; contains a few limonitic flecks	7	15
Silt, fine to coarse, slightly coarser texture below 17.5 ft, light buff-gray	6	21
Silt, slightly sandy with very fine to fine sand, light tannish-gray	1.5	22.5
Soil: silt, moderately sandy with very fine to fine sand, brown to tan with a gray tint	3	25.5
Silt, moderately clayey to slightly sandy, light-brown to tan with a gray tint	1.5	27
Sand, silty, to silt, very sandy with very fine to medium sand, light tannish-gray	4.5	31.5
Silt, slightly clayey to moderately sandy, tannish-gray	6	37.5
Silt, very sandy with fine to medium sand, some coarse sand, tannish-gray	3.5	41
Silt, clayey to moderately sandy with very fine to medium sand, light-gray with brown tint	4	45
Silt, moderately to very sandy, tannish-gray	5	50
Sand, fine to coarse, silty, tannish to brownish-gray	13.5	63.5
Sand, fine to coarse with some very coarse and trace of fine gravel, brownish-gray, lighter below 70 ft	11.5	75
Sand and gravel, grading from fine sand to fine gravel with some medium gravel, coarse to very coarse sand below 80 ft, light brownish-gray	8.5	83.5
Sand, very fine to medium to very coarse below 90 ft, silty, light-gray; contains some limonitic staining at top	12	95.5
Silt, sand and gravel grading from medium sand to fine gravel, interbedded, light-gray to light tannish-gray	3	98.5
Sand, fine, and some fine gravel, brownish-gray	6.5	105
Sand, fine, to medium gravel, brownish-gray with pink grains	32	137
Sand, fine to coarse, light brownish-gray	10	147
Silt, slightly clayey to sandy, light brownish-gray; contains calcareous spots and nodules below 148.5 ft	4	151
Sand, fine, to fine gravel, coarser with depth, brownish-gray	97.5	248.5
Tertiary—Pliocene:		
Silt, slightly clayey to very fine sandy, slightly to moderately calcareous, light brownish-tan; contains a few calcareous nodules	11.5	260
Siltstone, containing very fine sand, tannish-brown, light-gray with brown tint below 276 ft	24.5	284.5
Sand and gravel, consisting entirely of chalk fragments, yellowish-gray	5.5	290
Sand and gravel, chalk fragments, silty, brownish-tan	10	300
Sand, medium, to fine gravel, consists entirely of chalk fragments	7	307
Cretaceous—Upper Cretaceous—Carlile shale:		
Clay shale, slightly pyritic below 315 ft, light-gray to medium-gray	14	321

TABLE 9.—*Logs of test holes and wells*—Continued

***6-6-30cd**

Clay County. Owner, Woods Bros. and Ells. Driller, Thieszen Irrigation Co. Altitude (a), 1,790 ft. Depth to water, 99.6 ft, October 22, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	52	52
Sand	14	66
Sand, gravel, and clay	5	71
Sand and gravel	23	94
Sand	8	102
Gravel	10	112
Sand	6	118
Gravel	18	136
Clay	12	148
Sand and gravel	4	152
Gravel and sand	24	176

6-6-31bb

Clay County. Altitude (a), 1,779 ft. Depth to water, 86.7 ft, August 4, 1949.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil: silt, very slightly clayey, moderately clayey from 1 to 2.5 ft, dark brownish-gray; medium grayish-brown from 2 to 2.5 ft	2.5	2.5
Silt, very clayey, light brownish-gray with a yellow tint	1	3.5
Silt, moderately clayey, light buff-gray	1	4.5
Silt, very slightly calcareous, light buff-gray with a slight yellow tint; contains a few dense limy nodules from 10 to 15 ft	13.5	18
Soil: silt, moderately clayey to clayey, dark grayish-brown to brown below 21.5 ft; contains embedded very fine to medium sand	4.5	22.5
Silt, moderately clayey to very slightly sandy, very fine to medium sand; moderately sandy below 26.5 ft, light-brown with a slight red tint	9	31.5
Soil: silt, moderately clayey to slightly sandy, dark grayish-brown; contains very fine to fine sand	.2	31.7
Silt, very clayey, light-brown with a slight red tint; contains embedded very fine to fine sand	2.3	34
Silt, very clayey, light-brown; contains embedded very fine to coarse sand	1	35
Silt, moderately clayey to slightly sandy to moderately sandy from 37 to 41 ft, light-brown, slightly pink below 41 ft; contains very fine to fine sand with a trace of medium to coarse sand	7.5	42.5
Silt, slightly clayey to moderately sandy with very fine to medium sand and a trace of coarse sand, very sandy below 47 ft, light-brown with a pink tint	7.5	50
Sand, silty, with some interbedded sandy silt, very fine to very coarse, predominantly frosted grains, light-brown with a pink tint; light-brown below 57 ft	10	60
Sand, very fine, to fine gravel; principally quartz; rounded, frosted, and polished; 10 percent gravel from 63.5 to 65 ft; 25 percent gravel from 65 to 67 ft	7	67
Clay, very light-gray	.5	67.5
Sand, very fine to coarse with a trace of very coarse, and fine gravel, principally quartz, polished	5	72.5
Sand, fine, to fine gravel with some medium gravel; contains much quartz and some light-colored feldspar; moderately polished; 45 percent gravel, 72.5 to 75 ft; medium sand to medium gravel, 60 percent gravel, some dark iron stain from 75 to 81 ft	8.5	81
Silt, moderately clayey to moderately sandy, very light brownish-gray, mottled yellow with limonite to very light-gray with a slight green tint below 83 ft; contains very fine to medium sand with embedded coarser grains	5.5	86.5
Sand, fine, to fine gravel, 25 percent gravel; principally quartz with a trace of feldspar; moderately polished; contains some medium gravel and rounded light-gray clay granules below 90 ft	8	94.5
Sand, fine, to medium gravel, 50 percent gravel; principally quartz and some light-colored feldspar; moderate iron stain below 115 ft	29	123.5
Silt, moderately to very sandy, light yellow-brown; contains very fine to medium sand; light-brown and contains white limy nodules below 125 ft; in part moderately clayey below 130 ft; very sandy below 134 ft	11	135
Sand, very fine to very coarse with a trace of fine gravel, very silty, light brownish-gray	5	140
Sand, very fine to very coarse, principally quartz, moderately rounded and frosted, some polished, slightly silty; no silt and a trace of fine gravel below 145 ft	10	150
Sand, fine, to fine gravel, principally quartz with some light-colored feldspar, some rounded, many frosted and polished grains	6.5	156.5
Sand, fine to coarse, some very coarse, principally quartz with some light-colored feldspar; some rounded, many frosted and polished grains; contains more very coarse sand below 159 ft; contains a trace of fine gravel from 175 to 180 ft; contains some fine to medium gravel from 190 to 200 ft; texture grades from fine to very coarse sand below 200 ft	53.5	210

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
6-6-31bb—Continued		
Quaternary—Recent and Pleistocene—Continued		
Sand, fine, to fine gravel, principally quartz and some light-colored feldspar; contains some medium gravel, grading coarser with depth, and increasing feldspar content below 200 ft	35	245
Sand, fine to coarse with some very coarse, principally quartz; contains occasional light-brown rounded silt granules below 260 ft and many silt granules below 270 ft	28.5	273.5
Silt, very fine, sandy, moderately to slightly calcareous, light brownish-tan; medium-gray below 286 ft; contains occasional limy nodular fragments below 290 ft	26.5	300
Tertiary—Pliocene:		
Silt, slightly calcareous, light medium-gray; contains small pelecypod fragments; contains a few rootlets below 305 ft	10	310
Silt with fine sand, slightly calcareous, light brownish-gray	16	316
Silt, slightly consolidated, slightly calcareous, light brownish-gray to green	4	320
Silt, very sandy with very fine sand, slightly to moderately calcareous, light-gray; contains a shell fragment	24	324
Siltstone, granular, sandy with very fine sand, moderately calcareous, brownish-gray	6	330
Sand, very fine to fine to medium, silty, slightly calcareous, brownish-gray	8.5	338.5
Silt, sandy with very fine sand, moderately to very calcareous, light-gray; contains a thin hard limy layer at the top	1.5	340
Siltstone, granular, slightly calcareous, medium-gray	4	344
Silt, slightly clayey to sandy, light-gray with a brown tint; contains a very fine sand	17.5	361.5
Sand, very fine, silty, slightly calcareous, light-gray with a brown tint	18.5	380
Silt, very sandy with very fine sand, moderately calcareous, medium-gray	4	384
Sand, very fine to medium, slightly silty, slightly calcareous, light-gray	6	390
Silt, slightly clayey, very calcareous, medium-gray; light-gray and more calcareous from 395 to 400 ft; very light brownish-gray below 400 ft	20	410
Silt, sandy with very fine sand, moderately calcareous, light brownish-gray; light-gray below 420 ft	20	430
Sand, very fine to coarse, light greenish-gray; contains many calcareous fragments	8.5	438.5
Silt, clayey, very calcareous, medium greenish-gray	6.5	445
Silt, sandy, slightly to moderately calcareous, medium-gray; contains a trace of carbonaceous material	9.5	454.5
Sand, medium to very coarse, slightly calcareous, dark-gray with some green grains	11.5	466
Cretaceous—Upper Cretaceous—Carlile shale:		
Clay shale, silty, moderately to very calcareous, dark-gray; very calcareous below 475 ft; very silty and contains several thin hard layers below 480 ft	24	490

***6-6-32cb**

Clay County. Owner, Carlos Bascom. Driller, Don Barney. Altitude (a), 1,761 ft. Depth to water 75.2 ft, October 23, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	17	19
Clay, brown	16	35
Clay, yellow	18	53
Clay, sandy	5	58
Sand, fine, dirty	4	62
Sand and gravel	11	73
Clay, sandy	4	77
Sand and gravel	42	119
Clay	13	132
Sand and some gravel	4	136
Sand and gravel	29	165
Sand and some gravel	5	170

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***6-7-1bd**		
Clay County. Owner, James Styck. Driller, Don Barney. Altitude (a), 1,789 ft. Deptl to water, 81.1 ft, October 27, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	42.5	44
Sand, dirty, and clay	21	65
Sand and some gravel	4	69
Sand and gravel	10	79
Clay	7	86
Sand	6	92
Sand and some gravel	5	97
Sand and gravel	15	112
Clay, black	7	119
Clay, sandy	12	131
Sand, dirty	2	133
Sand and gravel	6	139
Clay	2	141
Sand and gravel	20	161
Clay	6	167
Sand, good	25	192
Sand and gravel	6	198
***6-7-1db**		
Clay County. Owner, William P. Hertel, Jr. Driller, Don Barney. Altitude (a), 1,777 ft. Depth to water, 69.8 ft, October 27, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	39	42
Sand and clay	9	51
Sand, gravel, and clay	10	61
Sand and gravel	8	69
Clay	8	77
Sand and some gravel	8	85
Sand and gravel	22	107
Clay	13	120
Sand and gravel	29	149
Clay	2	151
Sand and wheat gravel	9	160
Sand, fine, and clay	9	169
Sand	9	178
***6-7-14bc1**		
Clay County. Owner, John Knox. Driller, John Alfs. Altitude (t), 1,810 ft. Depth to water, 96.9 ft, July 29, 1954.		
Quaternary—Recent and Pleistocene:		
Soil	3	3
Clay	48	51
Sand	3	54
Gravel, loose	14	68
Clay, sandy	6	74
Sand	2	76
Sand, good	8	84
Gravel, good	4	88
Sand	5	93
Gravel with a trace of clay at 93 ft	8	101
Sand and gravel, good	17	118
Sand	9	127
Gravel	10	137
Sand, fine	7	144
Sand, good	6	150
Sand	16	166
Sand, good	10	176
Sand, fine	16	192
Sand	8	200
Gravel	8	208
Sand, good	7	215

TABLE 9.—*Logs of test holes and wells*—Continued

***6-7-22bb**

Clay County. Owner, Warren Wilson. Driller, Wendell Shuck. Altitude (a), 1,798 ft. Depth to water, 84.0 ft, October 27, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	42	45
Gravel and clay	5	50
Clay, sandy	10	60
Gravel	3	63
Gravel, good	11	74
Clay and gravel	11	85
Gravel, good	15	100
Sand and gravel	5	105
Gravel	15	120
Sand and gravel	8	128
Gravel	7	135
Sand and gravel	5	140
Sand, fine	2	142
Gravel	22	164

***6-7-26cc**

Clay County. Owner, Roy E. Squires. Driller, John Alfs. Altitude (a), 1,790 ft. Depth to water, 86.8 ft, October 22, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Clay	64	64
Sand and gravel	22	86
Clay and fine sand	5	91
No sample, probably fine sand	39	130
Clay	13	143
Sand and gravel	15	158
Clay	2	160
Sand and gravel	20	180

***6-7-31bb**

Clay County. Owner, Carl A. Fitzke. Driller, Don Barney. Altitude (a), 1,812 ft. Depth to water, 89.0 ft, August 12, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	52.5	54
Sand	68	122
Clay, sandy	7	129
Sand and some gravel	5	134
Sand and gravel	8	142
Clay, sandy	3	145
Sand	4	149
Sand and gravel	9	158

***6-8-7bd**

Clay County. Owner, Ray J. Kissinger. Driller, Don Barney. Altitude (a), 1,868 ft. Depth to water, 110.4 ft, October 21, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	21	23
Clay, brown	12	35
Clay, hard	3	38
Clay, sandy	32	70
Sand and gravel, dirty, some clay	2	72
Sand and gravel, a little dirty	8	80
Sand and gravel	9	89
Clay	4	93
Sand, dirty, and some clay	5	98
Sand and gravel, a little hard	14	112
Sand and some gravel	1	113
Sand, medium-fine, and gravel	1	114
Sand and gravel	31	145

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***6-8-7bd—Continued**		
Quaternary—Recent and Pleistocene—Continued		
Sand and gravel, good	13	158
Sand	2	160
Sand and some gravel	3	163
Clay, sandy	7	170
Sand and rice gravel	8	178

***6-8-8cc**

Clay County. Owner, Ray J. Kissinger. Driller, John Alfs. Depth to water, 103.0 ft, October 21, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil, black	4	4
Clay	18	22
Clay, black	2	24
Clay	44	68
Gravel	10	78
Clay and sand	6	84
Gravel	50	134
Clay	3	137
Gravel and sand	21	158
Clay	5	163
Gravel and sand	11	174

***6-8-16cb**

Clay County. Owner, Henry R. Hinrichs. Driller, Don Barney. Altitude (a), 1,836 ft. Depth to water, 90 ft, October 21, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	52	55
Sand and gravel, some clay	18	73
Clay, sandy	7	80
Sand, some gravel	7	87
Sand and gravel	41	128
Clay	4	132
Sand and gravel	9	141
Sand and some gravel	7	148
Sand, sugar	4	152
Sand, fine, dirty	8	160
Sand, rice and wheat gravel	15	175

***6-8-17bb**

Clay County. Owner, Willard W. Kissinger. Driller, Don Barney. Altitude (a), 1,846 ft. Depth to water, 97.8 ft, October 21, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	19.5	21
Clay, brown	14	35
Clay, sandy	11	46
Sand to sandy clay	19	65
Sand and gravel, hard	14	79
Clay	6	85
Sand, dirty, some gravel and clay	4	89
Sand and good gravel	6	95
Sand, medium-fine, and gravel	3	98
Sand and gravel, good	11	109
Sand, medium-fine, and gravel	3	112
Sand and good gravel	21	133
Sand, medium-fine, and gravel	11	144
Sand, good, and rice gravel	2	146
Sand and gravel with a trace of clay at 155 ft	12	158

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
6-8-19bc		
Clay County. Altitude (i), 1,847 ft. Depth to water, 96.9 ft, November 18, 1947.		
Quaternary—Recent and Pleistocene:		
Soil and road fill: silt, dark brownish-gray	0.5	0.5
Soil: silt, in part slightly clayey, very dark brownish-gray	.7	1.2
Silt, clayey, medium brownish-gray with a buff tint	1.3	2.5
Silt, slightly clayey, buff-gray	2	4.5
Silt, buff-gray with slight yellow tint, lighter with a few limonitic flecks below 7 ft; contains a few calcareous nodules	14.5	19
Soil: silt, slightly clayey, dark reddish-brown	3	22
Silt, clayey, brownish tan-gray with a very slight pink tint below 23 ft	3.5	25.5
Silt, in part slightly clayey, tan-gray with a pink tint	9	34.5
Silt, sandy with very fine to fine sand, tan-gray with pink tint	1.5	36
Silt, in part slightly clayey, tan-gray	1.5	37.5
Silt, slightly clayey, light-gray with tan tint	2	39.5
Clay, silty, slightly to moderately calcareous, light-gray in part, tan below 43 ft; contains some very calcareous zones in upper part	6.5	46
Silt, sandy with very fine to fine sand, pinkish-tan with a slight gray tint	4	50
Silt, very sandy, tannish-gray; contains very fine sand to fine gravel	4.5	54.5
Sand to medium gravel, brownish-gray with pink grains	5	59.5
Sand, fine to coarse, brownish-gray	3.5	63
Sand to medium gravel with silt and clay pebbles, brownish-gray with pink grains	3	66
Sand to coarse gravel, light brownish-gray with pink and green grains; some yellow iron stain	14	80
Sand and some gravel, light brownish-gray; contains a buff-gray sandy silt layer from 80 to 81 ft	5	85
Sand to medium gravel, light brownish-gray with pink and green grains; contains considerable coarse gravel below 90 ft	19	104
Sand to fine gravel with some medium gravel, brownish-gray with some pink grains	9.5	113.5
Silt, slightly clayey, light greenish-gray; some yellow staining in upper part; yellowish-brown below 115 ft	3.5	117
Silt, clayey, light brownish-gray; contains a calcareous nodular zone from 117.5 to 118.5 ft	2.5	120
Silt, slightly clayey, becoming slightly sandy with depth, brownish-gray; contains a calcareous nodular zone from 120 to 121 ft	7	127
Sand to medium gravel, brownish-gray with pink grains	3	130
Sand to medium gravel with some coarse gravel, brownish-gray with pink grains	12.5	142.5
Silt, sandy, in part very sandy, brownish-gray	7	149.5
Sand to medium gravel, brownish-gray to pink; contains a thin light-gray silt layer at 165 ft	15.5	165
Sand to fine gravel, brownish-gray to pink; contains a light brownish-gray silt to clayey-silt layer from 169 to 169.5 ft	4.5	169.5
Sand to coarse gravel, brownish-gray to pink	50.5	220
Sand to medium gravel with some coarse gravel, brownish-gray to pink; contains some calcareous fragments and tan silt pebbles below 265 ft	68	288
Tertiary—Pliocene:		
Silt, in part sandy, slightly to very calcareous, very light brownish-gray	13	301
Silt, medium-gray with brown to green tint	3	304
Silt, slightly clayey, slightly to moderately calcareous, very light brownish-gray to light gray	6	310
Silt to siltstone, slightly to moderately calcareous, brownish-gray	17	327
Silt, in part slightly clayey, slightly to moderately calcareous, in part very fine sand below 335 ft, buff-gray	22	349
Silt, slightly calcareous, medium brownish-gray to medium-gray with brown tint	11	360
Silt, light-gray	3	363
Sand, fine to medium with some coarse, brownish-gray	7	370
Silt, light-gray	3	373
Sand, fine to medium with some coarse, brownish-gray	5	378
Silt, slightly to moderately calcareous, buff-gray with yellow tint	3	381
Sand, very fine to medium, brownish-gray	6	387
Silt, slightly calcareous and clayey with depth, light to medium-gray to dark-gray	14	401
Sand, fine to coarse, in part silty, medium-gray; contains many gastropod and pelecypod shells	9	410
Cretaceous—Upper Cretaceous—Niobrara formation:		
Limestone, chalky, light-gray with yellow stain	10	420
Cretaceous—Upper Cretaceous—Carlile shale:		
Clay shale, silty to slightly sandy, dark-gray to black	10	430

TABLE 9.—*Logs of test holes and wells*—Continued

***6-8-26cc**

Clay County. Owner, Henry Hinrichs, Jr. Driller, Don Barney. Altitude (a), 1,836 ft. Depth to water, 108.4 ft, June 25, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	66.5	68
Sand, dirty	7	75
Clay	4	79
Sand and gravel	20	99
Sand and some gravel	15	114
Sand and gravel	27	141
Clay	7	148
Sand and some gravel	7	155
Sand and gravel	5	160
Clay	8	168
Sand	5	173
Sand and some gravel	5	178

***6-8-29ba**

Clay County. Owner, Esther Bienhoff. Driller, John Alfs. Altitude (a), 1,837 ft. Depth to water, 96.8 ft, October 20, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Clay	57	57
Sand and gravel	61	118
Clay	19	137
Sand and clay	5	142
Clay	4	146
Sand and gravel	49	195

***6-8-30ab**

Clay County. Owner, Ira Hunnicutt. Driller, John Alfs. Depth to water, 97.0 ft, October 20, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Clay	56	56
Sand and gravel	34	90
Sand	6	96
Sand and gravel	19	115
Clay	17	132
Sand and gravel	13	145
Clay	6	151
Sand and gravel	25	176

***6-8-32bb**

Clay County. Owner, Irene E. Dahlgren. Driller, Don Barney. Altitude (a), 1,832 ft. Depth to water, 92.6 ft, October 20, 1952.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	17	19
Clay, brown	2	21
Clay, light-brown	9	30
Lime rock	9	39
Clay, sandy	12	51
Sand and some gravel	2	53
Sand and gravel	21	74
Clay	5	79
Sand, fine, and clay	4	83
Sand and some gravel	11	94
Sand and gravel	4	98
Sand, fine	1	99
Sand, medium-fine, and gravel	4	101
Clay, sandy	16	119
Sand, gravel, and clay	18	137
Sand, fine, gravel, and clay	6	143
Sand and gravel	14	157
Sand, rice and wheat gravel	16	173
Sand and gravel	5	178

467829—59——9

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***6-8-36bc**		
Clay County. Owner, Joe Peshek. Driller, Don Barney. Depth to water, 94.9 ft, August 12, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	16	18
Clay, dark	8	26
Clay, yellow	27	53
Clay, very sandy	4	57
Sand	4	61
Sand and gravel	8	69
Sand and some gravel	6	85
Sand and gravel	62	147
Clay, sandy	2	149
Sand and gravel	5	154
Sand and some rice and wheat gravel	16	170
6-9-1dd		
Adams County. Altitude (i), 1,832 ft. Depth to water, 69.9 ft, May 24, 1946.		
Quaternary—Recent and Pleistocene:		
Road fill: clay, dark-gray	1	1
Clay, dark-gray to black	3	4
Clay, dark brownish-gray	1	5
Clay, silty, medium brownish-gray	1	6
Silt, clayey, medium-brown	2	8
Clay, silty, medium brownish-gray to brown	2	10
Clay, medium brownish-gray	2	12
Clay, silty, light-gray with a brown tint; contains a few limonitic flecks	8	20
Silt, clayey, light-gray; contains limonitic flecks; brown tint in lower part	17	37
Sand, medium, to coarse gravel with some pebbles, light brownish-gray to pink	13	50
Gravel, fine to coarse with many pebbles, reddish-brown; contains some sand	5	55
Sand, silty, light yellowish-brown	6.5	61.5
Sand and gravel, medium, to coarse gravel with some pebbles, brownish-gray to red	38	99.5
Clay, silty, yellow; some light-gray	1	100.5
Sand, medium, to coarse gravel, reddish-brown to gray	29.5	130
Sand, medium, to fine gravel, brownish-gray to pink	10	140
Sand, medium, to medium gravel with some coarse gravel, reddish-brown	30	170
Sand, medium, to fine gravel, light brownish-gray to pink	10	180
Sand, medium, to medium gravel with some coarse gravel, reddish-brown to gray	63.5	243.5
Tertiary—Pliocene:		
Silt, sandy, with fine sand, light-brown to tan	6.5	250
Silt, clayey, dark brownish-gray	10	260
Silt, clayey, slightly to moderately calcareous, light-gray	10	270
Silt, clayey, moderately calcareous, light-gray	10	280
Silt, clayey, slightly calcareous, light grayish-brown; contains many reworked chalk fragments in lower part	29	309
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, light-yellow and grayish-white	11	320
Shale, chalky, light-yellow and white; more chalky in lower part	20	340
Shale, chalky, medium-gray	10	350
7-4-19cc		
Fillmore County. Altitude (a), 1,714 ft. Depth to water, 65.7 ft, September 24, 1946.		
Quaternary—Recent and Pleistocene:		
Soil and road fill: silt, clayey, dark-brown	5	5
Clay, silty, to clayey silt, medium grayish-brown	4.5	9.5
Silt, clayey, medium-gray; contains a few limonitic stains	13.5	23
Silt, clayey, to silty clay, soillike, dark-brown to gray	1.5	24.5
Silt, clayey to sandy, light-gray; light-brown below 28.5 ft; contains fine to coarse sand	10.5	35
Silt, sandy, light reddish-brown	3	38
Sand, fine to coarse, pinkish-brown to gray	2	40
Sand, fine to coarse, and silt, interbedded, reddish-brown silt to pinkish-brown and gray sand	5	45
Sand, fine to coarse, light brownish-gray with pink grains	2	47
Silt, sandy to clayey; light pinkish-brown; contains some limonitic stain in upper part	6	53
Silt, sandy, light-gray to green	2	55
Silt, slightly sandy, pinkish-brown to gray	2	57
Silt, clayey, to silty clay, light pinkish-brown to gray	3	80

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
7-4-19cc—Continued		
Quaternary—Recent and Pleistocene—Continued		
Silt, sandy to clayey, light-gray to green; contains some calcareous concretionary material in upper part	5	85
Silt, sandy, to silty sand, light-gray to green	5	90
Sand, fine to coarse, light-gray	20	110
Sand, fine, to medium gravel, brownish-gray with pink and green grains	26.5	136.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, to shaly chalk, light yellowish-gray	10	146.5
Chalk, light-yellow	3.5	150
Chalk, shaly, bright-yellow	8	158
Cretaceous—Upper Cretaceous—Carlile shale:		
Clay shale, dark-gray	12	170

***7-5-1cb**

Clay County. Owner, Warren Krause. Driller, Don Barney. Altitude (t), 1,732 ft. Depth to water, 78.2 ft, November 17, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	37	39
Sand, dirty, and sandy clay layers	23	62
Sand	8	70
Sand and some gravel	7	77
Sand and gravel	9	86
Clay, sandy	11	97
Sand	15	112
Sand, good, and some gravel	20	132
Sand and gravel	9	141
Sand, rice and wheat gravel	14	155
Sand and gravel	9	164
Sand, good, some rice and wheat gravel	14	178
Sand and gravel	20	198

7-5-3da

Clay County. Altitude (a), 1,683 ft. Depth to water unknown.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil: silt, dark-brown	3	3
Clay, buff to brownish-buff	7	10
Clay, silty, gray-buff to red	7	17
Sand, medium, to coarse gravel, red	13	30
Clay, sandy, gray to pink; contains calcareous streaks	20	50
Clay, sandy, gray to brownish-gray	7	57
Sand and gravel, silty	6	63
Clay, sandy, gray; slight yellow tint below 70 ft	12	75
Sand, fine, to medium gravel, coarser below 85 ft, white, yellow and pink	20	95
Gravel, fine to coarse, red, brown, yellow, pink and green	67	162
Tertiary—Pliocene:		
Clay, sandy, tan to pink	14	176
Clay, gray	4	180
Clay, gray-buff; contains calcareous streaks	17	197
Gravel, fine to medium, white, red and green	3	200
Clay, gray-brown to pink	29	229
Clay, sandy, brown; calcareous pebbles or concretions	4	233
Clay, silty, brownish-gray	7	240
Clay, sandy, greenish-gray	5	245
Clay, sandy, calcareous, gray; contains large calcareous pebbles	5	250
Clay, sandy, brown; contains coarse sand and calcareous pebbles	4	254
Gravel, fine to coarse, yellow, white and green; contains calcareous pebbles	9	263
Cretaceous—Upper Cretaceous—Carlile shale:		
Shale, dark-gray to black	27	290

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***7-5-8dd**		
Clay County. Owner, Martin Mau. Driller, Gustav Thieszen. Altitude (a), 1,752 ft. Depth to water, 81.5 ft, April 23, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	59	59
Sand, fine, and clay	10	69
Sand, fine	2	71
Sand and some gravel, good	4	75
Sand and gravel, good	18	93
Sand, good, and little clay	2	95
Sand, fine, and clay	8	103
Clay	14	117
Sand and clay	2	119
Sand, coarse	2	121
Sand and gravel, good	8	129
Sand, gravel, and little clay	2	131
Clay	14	145
Sand, gravel, and clay	2	147
Sand and gravel, good	16	163
Sand, gravel, and little clay	2	165
Clay, sandy	2	167
Sand and gravel	12	179
Sand, gravel, and little clay	2	181
Sand, coarse, and some gravel	16	197
Sand, gravel, and some clay	2	199
Sand, packed	3	202
***7-5-9dc**		
Clay County. Owner, Charles Beal. Driller, Rain Chief Irrigation Co. Altitude (a), 1,758 ft. Depth to water, 84.7 ft, June 7, 1954.		
Quaternary—Recent and Pleistocene:		
Clay	15	15
Gravel and sand	12	27
Clay and sand	3	30
Clay	30	60
Gravel and coarse sand	40	100
Clay	20	120
Sand and gravel	12	132
Clay	16	148
Gravel and clay	2	150
Gravel	28	178
Gravel and clay	2	180
Gravel	15	195
Clay and gravel	3	198
Gravel	10	208
Clay	1	209
Gravel	1	210
Clay and sand	6	216
Gravel	22	238
Tertiary—Pliocene:		
Clay	2	240
***7-5-15ca**		
Clay County. Owner, Albert Boom. Driller, Thieszen Drilling Co. Altitude (a), 1,745 ft. Depth to water, 77.8 ft, July 10, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	76	76
Clay	26	102
Sand, fine	14	116
Sand, medium	4	120
Clay and medium sand	4	124
Clay	12	136
Sand and gravel	25	161
Clay	15	176
Sand, medium-fine	4	180
Sand and gravel	20	200
Sand, fine	7	207
Sand, medium	4	211
Gravel	9	220

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***7-5-26bc**		
Clay County. No well installed (Irrigation test well); Harold Schmen, owner of land. Altitude (a), 1,746 ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
(no log)		
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, light-gray	146	147
***7-5-34bb**		
Clay County. Owner, Raymond Schwab. Driller, Don Barney. Altitude (t), 1,741 ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	25	27
Clay, sandy	26	53
Sand, fine, dirty, and clay	36	89
Clay, sticky	53	142
Sand and some gravel	12	154
Tertiary—Pliocene:		
Clay, sandy	26	180
Lime rock, white	3	183
Shale, very hard	-------	-------
***7-6-4bd**		
Clay County. Owner, Ivan L. Johnson. Driller, Don Barney. Altitude (a), 1,766 ft. Depth to water, 59.8 ft, November 11, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	60.5	62
Clay, sandy	8	70
Sand	18	88
Clay, sandy	6	94
Sand and some gravel	9	103
Sand and gravel	7	110
Sand	3	113
Sand and some gravel	5	118
Sand and gravel	60	178
7-6-18bb		
Clay County. Altitude (a), 1,789 ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
Soil: silt, dark-brown to black	3	3
Silt, to silty clay, buff	17	20
Silt, dark reddish-brown	4	24
Clay, blocky, reddish-brown	11	35
Clay, silty, reddish-buff; sandy in lower part	15	50
Sand to fine gravel, red	10	60
Gravel, fine to coarse, light-red and white	30	90
Sand, with a trace of gravel, silty, gray	10	100
Clay, silty, gray; contains some red sandy clay below 125 ft	31	131
Gravel, fine to coarse, yellow, red and white	14	145
Clay, reddish-brown	4.5	149.5
Gravel, fine to coarse; contains some brownish-gray clay below 184 ft	37.5	187
Gravel, fine to medium with some coarse, red and yellow	24	211
Tertiary—Pliocene:		
Clay, silty, pinkish-brown; calcareous with some sand and gravel below 238 ft	39	250
Cretaceous—Upper Cretaceous—Niobrara formation:		
Clay, very calcareous, white	5	255
Clay, white to brown	7.5	262.5
Shale, dark-gray with slight green tint; contains some white specks; calcareous and light-gray below 270 ft	27.5	290

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***7-6-24dd**		
Clay County. Owner, L. C. Schneller. Driller, Don Barney. Altitude (a), 1,75[illegible] ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	23.5	25
Clay, sandy	3	28
Sand, fine, and clay	13	41
Clay, sandy	5	46
Sand and clay	9	55
Sand, fine, and some clay	15	70
Sand, fine, and some wheat gravel	4	74
Sand, fine, and rice gravel	4	78
Sand and gravel	9	87
Clay, sandy	6	93
Sand, fine, and some clay	4	97
Sand, very fine	20	117
Sand, very fine, and trace of gravel	6	123
Sand, medium-fine, and rice gravel	7	130
Sand, medium-fine, and some gravel	9	139
Sand, medium-fine, and gravel	6	145
Sand and gravel	8	153
Sand, very fine, and a trace of gravel	25	178
Clay, yellow	30	198
***7-6-30cc**		
Clay County. Owner, Robert E. Kinyoun. Driller, Thieszen Drilling Co. Altitude (a), 1,787 ft. Depth to water, 75.0 ft, date unknown.		
Quaternary—Recent and Pleistocene:		
Topsoil	46	46
Sand, fine	18	64
Sand and gravel	14	78
Clay	18	96
Sand, medium	4	100
Gravel	4	104
Clay	12	116
Sand and gravel	16	132
Clay	4	136
Sand	4	140
Sand and gravel, blue	20	160
Clay, blue	6	166
***7-6-32bb**		
Clay County. Owner, Fred Schwindt, Jr. Driller, Don Barney. Altitude (a), 1,783 ft. Depth to water, 75.3 ft, November 9, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow and brown	28	31
Sand, dirty	7	38
Sand and Clay, dirty	16	54
Clay, yellow	5	59
Clay, gray	26	85
Sand, dirty, some gravel and clay	13	98
Sand, some wheat gravel, dirty and hard	7	105
Sand and some gravel, dirty and hard	7	112
Clay	3	115
Sand and gravel, hard formation	9	124
Clay	12	136
Sand, fine, dirty	4	140
Sand and trace of gravel	6	146
Sand and gravel	4	150
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale	5	155

TABLE 9.—*Logs of test holes and wells*—Continued

***7-6-32ca**

Clay County. Owner, Al F. Erthum. Driller, Don Barney. Altitude (t), 1,774 ft. Depth to water, 69.8 ft, November 9, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	25	27
Sand, dirty	32	59
Sand and gravel	5	64
Clay, limy, white	21	85
Sand	6	91
Sand and some gravel	5	96
Sand and gravel, blue-green	36	132
Clay, blue	1	133
Sand, blue	5	138
Sand, blue, and rice gravel	22	150
Shale, blue	2	152

***7-7-2db**

Clay County. Owner, George Pauley. Driller, Don Barney. Depth to water, 66.4 ft, October 28, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	43.5	45
Sand, dirty	15	60
Sand, medium-fine, and gravel	5	65
Clay	11	76
Sand and clay, some gravel	2	78
Sand, gravel, and a few clay balls	6	84
Sand and gravel	11	95
Sand, medium-fine, some gravel	5	100
Clay, sandy	14	114
Sand, fine, and some clay	4	118
Sand, fine	1	119
Clay, sandy	5	124
Sand and gravel	26	150
Clay	7	157
Sand, medium-fine, and some gravel	3	160
Sand and gravel	15	175

***7-7-3cd**

Clay County. Owners, Carl E. North and W. S. Moger. Driller, Thieszen Drilling Co. Depth to water, 57.4 ft, April 30, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	43	43
Sand and some gravel	8	51
Sand and gravel	30	81
Sand, coarse	2	83
Sand, gravel, and clay balls	2	85
Sand	2	87
Sand, fine	8	95
Sand	6	101
Sand and clay	2	103
Clay	4	107
Sand and clay	2	109
Sand, coarse	2	111
Sand and gravel	28	139
Sand, gravel, and clay balls	2	141
Clay, sandy	2	143
Sand, gravel, and clay	2	145
Sand and gravel	10	155
Sand and clay	4	159
Sand and gravel	5	164

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***7-7-3da**		
Clay County. Owner, Walter Yost. Driller, Morris Merryman. Depth to water, 69.0 ft, April 30, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	38	41
Clay, dark	6	47
Clay, yellow	3	50
Clay, sandy	7	57
Sand, fine	2	59
Sand and some gravel	6	65
Sand and gravel	4	69
Clay, yellow	8	77
Sand and wheat gravel	14	91
Sharp sand and some rice to wheat gravel	5	96
Clay, sandy, yellow	4	100
Sand, fine, and clay	9	109
Sand, very fine	7	116
Sand, very fine, and yellow clay	3	119
Sand and some gravel	18	137
Sand, fine	3	140
Sand and gravel	14	154
Clay, blue	3	157
Sand, fine, and clay	3	160
Sand and some gravel and clay balls	6	166
Sand and some gravel	6	172
Sand, gravel, and some clay balls	4	176
***7-7-6dc**		
Clay County. Owner, Ernest Erickson. Driller, Don Barney. Altitude (a), 1,842 ft. Depth to water, 96.9 ft, July 23, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, hard, brown	39	41
Sand and clay strips	29	70
Clay, gray	6	76
Sand	15	91
Sand and gravel	3	94
Clay	3	97
Sand and some gravel	8	105
Sand and gravel	6	111
Sand and little gravel	14	125
Sand, fine	9	134
Clay	6	140
Sand and gravel	14	154
Sand, fine, and some clay	16	170
Sand, coarse	4	174
Sand and gravel	21	195
Sand and some gravel	3	198
7-7-7cc		
Clay County. Altitude (t), 1,820 ft. Depth to water unknown.		
Quaternary—Recent and Pleistocene:		
Soil	2	2
Clay, silty, yellow	20	22
Clay, tan	3	25
Sand, fine, clayey, tan	4	29
Clay, tan	3	32
Clay, in part silty, gray to tan	8	40
Clay, silty, tan	10	50
Clay, very fine sand, light-brown	10	60
Sand and some gravel, limonitic stain	4	64
Sand, fine	9	73
Clay, silty, in part sandy, gray; tan below 81 ft	10	83
Sand, medium to coarse	2	85
Sand and gravel	21	106
Sand, very fine	14	120
Sand and gravel	78	198

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***7-7-17ac**		
Clay County. Owners, Morrison and Quirk. Driller, Petterson Bros. Altitude (t), 1,82[illegible] ft. Depth to water, 81.9 ft, May 1, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	2.5	2.5
Clay, yellow	18.5	21
Clay, dark-brown	4	25
Clay, brown	19	44
Clay, sandy	11	55
Clay, sandy, light	9	64
Sand, fine, dry	15	79
Sand, medium, and gravel	9	88
Sand, very fine	4	92
Clay, sandy, light	6	98
Sand, very fine, and clay	6	104
Sand, fine, and some gravel	4	108
Sand, very fine	2	110
Sand, fine, and clay balls	10	120
Clay, sandy, light	6	126
Sand, gravel, and clay balls	4	130
Sand, medium-fine, and gravel	14	144
Sand, medium, and gravel	2	146
Sand, fine	5	151
Sand and rice gravel	3	154
Clay, sandy, and clay balls	8	162
Sand, gravel, and clay balls	13	175
Sand, medium-fine, and few clay balls	3	178
Sand to rice gravel	12	190
Sand and gravel	12	202
Clay, brown, soft	13	215
***7-7-23ac**		
Clay County. Owner, Robert Kinyoun. Driller, Thieszen Drilling Co. Altitude (t), 1,789 ft. Depth to water, 68.5 ft, July 10, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay	40	42
Sand	24	66
Sand and gravel	10	76
Clay	10	86
Sand	8	94
Sand and gravel	8	102
Clay	10	112
Sand and gravel	12	134
Clay	4	138
Sand and gravel	18	156
Clay	4	160
***7-7-23bd**		
Clay County. Owner, Glen F. Slater. Driller, Don Barney. Altitude (a), 1,794 ft. Depth to water, 68.0 ft, date unknown.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, black gumbo	17.5	19
Clay, gray	26	45
Sand, fine	16	61
Sand and some gravel	11	72
Clay, sandy	15	87
Sand, fine	6	93
Sand and some rice and wheat gravel	6	99
Clay, sandy	9	108
Sand and trace of gravel	6	114
Sand and gravel	16	130
Clay, sandy	9	139
Sand and some gravel	11	150
Sand and little gravel	7	157
Cretaceous—Upper Cretaceous—Niobrara formation:		
Lime rock, hard	5	162

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
7-7-25dd		
Clay County. Altitude (a), 1,788 ft. Depth to water, 71.3 ft, August 5, 1949.		
Quaternary—Recent and Pleistocene:		
Soil: silt, very slightly clayey, very dark brownish-gray	1.5	1.5
Silt, moderately clayey, brown-buff with gray tint; slightly more clayey and lighter below 2.5 ft	2.5	4
Silt, slightly clayey, light buff-gray; contains a few limonitic flecks	1	5
Silt, moderately calcareous, noncalcareous in lower part, buff-gray with yellow tint to light-gray with buff tint; contains snail shells	17	22
Silt, clayey, very light tannish-gray; contains a few limonitic flecks and an occasional embedded sand grain	5	27
Silt, moderately clayey, tannish-gray; less clayey and slightly calcareous below 29 ft	3.5	30.5
Silt, moderately clayey to slightly sandy, more sandy below 35 ft, slightly calcareous, tannish-gray with pink tint; contains very fine sand, a few limonitic flecks, and yellow calcareous nodules	11	41.5
Silt, sandy, to silty sand, tannish-gray with pink tint; contains very fine to coarse sand with some coarser sand and gravel grains	3	44.5
Silt, very sandy, light-gray; contains very fine to coarse sand	5.5	50
Sand, fine to coarse, brownish-gray	10	60
Sand, fine to very coarse with some fine gravel and a thin silt zone at 64.9 ft, light brownish-gray	15	75
Silt, clayey to slightly sandy, light brownish-gray; very sandy and light-gray with blue-green tint below 77.5 ft	9.5	84.5
Sand, very fine, silty, moderately calcareous, light brownish-gray; contains some calcareous mottling and large calcareous nodules	5.5	90
Silt, sandy, in part very sandy, moderately calcareous, very light brownish-gray to light-gray with much calcareous mottling	7.5	97.5
Sand, medium, to fine gravel with some medium gravel, brownish-gray with pink grains	5.5	103
Clay, silty, moderately calcareous, brownish-gray; contains a few snail shells	3	106
Silt, clayey, very calcareous, with a thin gravelly seam at about 116 ft, medium-gray; lighter and slightly calcareous below 112 ft; contains many snail shells	11	117
Silt, very sandy, yellowish-brown to light brownish-gray; contains fine to coarse sand with scattered coarser grains	3	120
Silt, very sandy, slightly calcareous, light-gray with green tint; contains very fine to medium sand and a few rootlets	5	125
Silt, sandy, slightly calcareous, light-gray; contains very fine to fine sand	3.5	128.5
Silt, very sandy, in part very fine to coarse silty sand, moderately calcareous, light-gray with slight brown tint; contains large calcareous nodules	5	133.5
Sand, medium, to medium gravel, brownish-gray to pink	6.5	140
Sand, fine to some fine gravel, brownish-gray with pink and green grains	18	162
Silt, sandy, light brownish-gray; contains very fine to medium sand	1.5	163.5
Sand, fine to coarse, light brownish-gray	9.5	173
Silt, sandy, slightly calcareous, light brownish-gray; contains very fine to medium sand and a few calcareous nodules	2.5	175.5
Sand, fine to very coarse, light brownish-gray; contains a few chalk fragments below 180 ft	11.5	186
Cretaceous—Upper Cretaceous—Niobrara formation:		
Chalk, silty texture, light-yellow to yellowish-gray to white	14	200
***7-7-34cc**		
Clay County. Owner, H. F. Gerdes. Driller, Thieszen Drilling Co. Depth to water, 75.0 ft, date unknown.		
Quaternary—Recent and Pleistocene:		
Topsoil and clay	54	54
Sand, fine	8	62
Sand	6	68
Sand and gravel	4	72
Clay	6	78
Sand, very fine	4	82
Sand	4	86
Sand and gravel	18	104
Sand and good gravel	20	124
Clay	4	128
Sand, medium	2	130
Sand and some gravel	8	138
Gravel	18	156

TABLE 9.—*Logs of test holes and wells*—Continued

***7-7-35ba**

Clay County. Owner, Agnes Williamson. Driller, G. W. Grosch. Altitude (a), 1,800 ft. Depth to water, 88.6 ft, July 28, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	85	85
Very good sand and gravel	27	112
Sand and clay layers	10	122
Sand and gravel, good	43	165

***7-8-4db**

Clay County. Owner, Robert Donahue. Driller, Burt Lichti. Altitude (a), 1,860 ft. Depth to water, 95.7 ft, April 21, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Clay	75	75
Sand and gravel	11	86
Clay, sandy	9	95
Sand, gravel and some clay	15	110
Clay	8	118
Sand, fine	6	124
Sand and clay	6	130
Clay	34	164
Sand and gravel with a trace of clay	4	168
Clay, sandy	20	188
Gravel and sand with a trace of clay	12	200

***7-8-5db**

Clay County. Owner, Herman Knudson. Driller, Morris Merryman. Altitude (a), 1,877 ft. Depth to water, 102.8 ft, April 21, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	18	20
Clay, brown	9	29
Clay, sandy	4	33
Clay, blue	8	41
Clay, yellow	19	60
Sand and some clay	14	74
Sand and some gravel	13	87
Clay, blue	12	99
Sand	6	105
Sand and gravel	9	114
Sand, fine	3	117
Sand and gravel	3	120
Gravel	8	128
Sand, fine	4	132
Clay	6	138
Sand and gravel with a trace of clay	11	149
Sand, fine, and gravel	14	168
Sand and gravel	11	179
Clay	4	183

***7-8-10ab**

Clay County. Owner, Charles W. Roback. Driller, Don Barney. Altitude (a), 1,852 ft. Depth to water, 91.0 ft, April 21, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	21	23
Clay, brown	8	31
Clay, sandy	13	44
Sand, fine, and clay	21	65
Clay, sandy	6	71
Sand and clay balls	7	78
Sand and some gravel	2	80
Sand, medium-fine, and gravel	5	85
Clay, sandy	5	90
Sand, gravel, and a few clay balls	8	98

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***7-8-10ab—Continued**		
Quaternary—Recent and Pleistocene—Continued		
Sand, fine, dirty, and clay	5	103
Sand, fine, and some gravel	2	105
Sand and gravel, dirty, some clay	17	122
Clay	6	128
Sand and gravel	19	147
Clay	11	158
Sand, fine, hard, some clay	7	165
Sand, medium-fine, and rice gravel	5	170
Sand, medium-fine, and gravel	4	174
Sand and gravel	11	185
Sand, medium-fine, and gravel	13	198
7-9-12aa		
Adams County. Altitude (i), 1,868 ft. Depth to water, 90.1 ft, May 20, 1946.		
Quaternary—Recent and Pleistocene:		
Soil: silt, dark-brown	2	2
Clay, silty, dark brownish-gray	1	3
Silt, clayey, light brownish-buff	15	18
Silt, clayey, dark-brown	3	21
Silt, sandy in lower part, light-brown	6	27
Sand, fine to coarse, light brownish-gray to pink	3	30
Silt, sandy to clayey, light reddish-brown with darker zones	10	40
Silt, sandy, light-gray	6	46
Sand, fine to coarse, light brownish-gray; contains a silt zone from 56 to 57 ft	14	60
Sand and some fine gravel, light brownish-gray to pink	5	65
Sand to medium gravel with some coarse gravel below 70 ft, light brownish-gray to pink	7.5	72.5
Silt, light-gray	2.5	75
Sand, medium, to medium gravel, light brownish-gray to pink	1	76
Silt, light-gray	6	82
Sand, medium, to coarse gravel, finer below 105 ft, light pinkish-gray	36.5	118.5
Silt, in part sandy, light-gray to yellow	4.5	122
Sand, medium, to medium gravel with some coarse gravel, light pinkish-gray	24	146
Silt, sandy, to silty sand, light- to yellowish-gray	6	152
Sand, medium, to coarse gravel with a silty sand layer from 177.5 to 178 ft, light pinkish gray; reddish-brown below 170 ft	28	180
Sand, medium, to medium gravel with some coarse gravel, brownish-gray to pink	17.5	197.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, bright- to yellowish-orange; dark-gray below 217.5 ft; contains some white chalk from 200 to 217.5 ft	32.5	230
7-9-24dd		
Adams County. Altitnde (i), 1,863 ft. Depth to water, 91.9 ft, November 26, 1947.		
Quaternary—Recent and Pleistocene:		
Soil: silt, very slightly clayey to sandy, very dark brownish-gray; contains very fine sand	0.5	0.5
Silt, slightly clayey, granular, dark brownish-gray	.5	1
Silt, clayey, to slightly clayey, brownish buff-gray; buff-gray from 2.2 to 3 ft; contains a few limonitic flecks and has a slight yellow tint below 3 ft	3	4
Silt, very slightly clayey to sandy, buff-gray with yellow tint; slightly lighter below 6.5 ft	11	15
Silt, slightly clayey, very light buff-gray with very few limonitic flecks	5.5	20.5
Soil: silt, slightly clayey, dark reddish-brown	2	22.5
Silt, clayey, tan-gray with a slight brownish tint; pink to red tint 25 to 29 ft; less clayey and light tan-gray with a pink tint below 29 ft	10	32.5
Silt, sandy to very sandy to less sandy below 35 ft, light tan-gray; contains very fine to medium sand	7.5	40
Silt, very slightly clayey to (in part) slightly sandy, tan-gray with brown tint; in part very sandy and gravelly below 45 ft, tan to brownish-gray	8.5	48.5
Silt, clayey to slightly sandy, light-gray	1.5	50
Silt, slightly sandy, brownish-gray with tan tint; contains some limy fragments	2.5	52.5
Silt, sandy to very sandy with very fine sand, light greenish-gray	3	55.5
Sand to fine gravel with trace of medium gravel, brownish-gray with a few pink grains	7	62.5
Silt, very sandy with fine to medium sand, greenish-gray	2	64.5
Sand to medium gravel with some coarse gravel, brownish-gray with pink and some light-green grains	6.5	70

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
7-9-24dd—Continued		
Quaternary—Recent and Pleistocene—Continued		
Sand to medium gravel with trace of coarse gravel, in part iron-stained, brownish-gray with pink grains	8.5	78.5
Silt, sandy, grayish-green; contains very fine sand	1.5	80
Silt, sandy to very sandy with very fine sand, brownish tan-gray	5	85
Sand to coarse gravel, finer below 90 ft, light brownish-gray with pink and light and dark-green grains	9	94
Sand to fine gravel with some medium gravel, light brownish-gray to pink	9.5	103.5
Silt, sandy, grayish-green; contains very fine sand	1.5	105
Sand, fine to coarse, principally medium, brownish-gray	5	110
Silt, very sandy to gravelly, greenish-gray	4	114
Sand to medium gravel with some coarse gravel, brownish-gray with pink grains	21	135
Gravel, fine to coarse, principally coarse, brownish-gray to pink	5	140
Sand to medium gravel, more sandy below 145 ft, brownish-gray with pink grains	10	150
Sand to fine gravel with some medium gravel and some coarse gravel, coarser below 160 ft, light brownish-gray with pink grains	12	162
Silt, slightly clayey to sandy, buff-gray with yellowish limonitic tint	1	163
Sand, fine to medium with some coarse; some fine gravel below 170 ft, light-gray to brown	18	181
Sand to medium gravel with some coarse gravel, brownish-gray to pink	9	190
Sand to medium gravel, light brownish-gray with pink grains; contains coarse gravel and pebble zone from 196.5 to 197 ft and silty zone from 197 to 197.5 ft	10	200
Sand to medium gravel with a sandy zone from 206.5 to 207.5 ft, light brownish-gray with pink grains	10	210
Sand to medium gravel, slightly more gravel below 215 ft, light brownish-gray with a few pink and light-green grains	10	220
Sand to medium gravel with trace of coarse gravel, light brownish-gray with pink grains	13	233
Silt, very slightly clayey to sandy, brownish-tan with a gray tint; contains very fine sand	2	235
Tertiary—Pliocene:		
Silt, slightly clayey, tan-brown with a gray tint; contains some calcareous fragments and moderately calcareous light brownish-gray zones below 240 ft	15	250
Silt, slightly to very clayey, moderately calcareous, brownish buff-gray; contains some chalk fragments and limy layers or nodules from 254 to 254.9 ft	10.5	260.5
Sand to fine gravel, principally reworked chalk fragments, yellow	2	262.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Chalk, yellowish-white with some interbedded yellow and white layers from 280 to 290 ft, grading to light-gray below 290 ft	30.5	293
Chalk, shaly, light- to medium-gray	7	300

8-5-1dd

Clay County. Altitude (a), 1,717 ft. Depth to water unknown.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil: silt, medium-brown	1	1
Clay, silty, to clayey silt, medium-brown	1.5	2.5
Clay, silty, medium-brown with gray tint	1.5	4
Silt, light brownish-buff; grayish-brown in lower part	15	19
Clay, silty, medium brownish-gray	1	20
Soil: clay, silty, dark-brown	2	22
Clay, silty, medium to light reddish-brown	6	28
Silt, clayey, light brownish-tan to pink; contains a few calcareous nodules	6	34
Silt, clayey, calcareous, light-gray to pinkish-tan and brown	11	45
Silt, clayey, to silty clay, light-gray to brown	5	50
Silt, clayey, to silty clay with much white calcareous material, medium brownish-gray and white	4	54
Silt, clayey to sandy, light-gray with green tint; contains fine sand	13	67
Sand, medium, to fine gravel with some medium gravel, light brownish-gray to pink	19	86
Sand, fine to medium, light brownish-gray	2.5	88.5
Silt, light-gray	3.5	92
Sand, medium, to fine gravel, some medium gravel, coarser texture in lower part, light brownish-gray to pink	17.5	109.5
Tertiary—Pliocene:		
Silt, sandy, light-gray	1	110.5
Silt, clayey, light brownish-tan to grayish-brown; contains a calcareous zone at 134.5 ft and many reworked chalk fragments below 140 ft	38	148.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, light-yellow and white	37.5	186
Shale, chalky, medium-gray; white specks; yellowish- to grayish-white below 195 ft	21	207
Limestone, chalky, light-yellow to grayish-white	8	215
Cretaceous—Upper Cretaceous—Carlile shale:		
Shale, dark-gray (bit sample)	5	220

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***8-5-6cc**		
Clay County. Owner, Ephraim K. Nuss. Driller, Morris Merryman. Altitude (a), 1,761 ft. Depth to water, 79.4 ft, April 28, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	21	24
Clay, dark	6	30
Clay, yellow	24	54
Clay, blue	31	85
Sand, fine, and clay	4	89
Sand and rice gravel	6	95
Sand	3	98
Sand, good, some gravel	16	114
Sand, fine, with trace of clay	3	117
Sand and gravel	11	128
Tertiary—Pliocene:		
Clay, yellow, with a trace of lime rock at 160 ft	63	191
Cretaceous—Upper Cretaceous—Niobrara formation:		
Clay, chalky, white	5	196
Clay, yellow and white, mixed	13	209
Chalk rock, white	6	215
Clay, light-yellow	21	236
Clay, hard, blue	4	240
Shale, blue	14	254
***8-5-11ba**		
Clay County. Owner, Art Hoffman. Driller, Merle Packard. Altitude (a), 1,736 ft. Depth to water, 87.4 ft, November 12, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	10	10
Clay	71	81
Sand, medium, and gravel, good	9	90
Sand, fine to medium, good	20	110
Sand, fine to medium, good, with a thin layer of clay	10	120
Sand, fine to medium	10	130
Sand, fine to medium, with clay layer	10	140
Sand, medium	3	143
Clay	7	150
Tertiary—Pliocene:		
Clay with some gravel	10	160
Cretaceous—Upper Cretaceous—Niobrara formation:		
Clay and limestone	10	170
Clay and black soil	10	180
8-5-24dd		
Clay County. Altitude (a), 1,655 ft. Depth to water, 9.6 ft, September 25, 1946.		
Quaternary—Recent and Pleistocene:		
Soil: silt, clayey, dark-brown	1	1
Silt, clayey, medium brownish-buff, light grayish-buff with some limonitic stain below 13 ft	17.5	18.5
Silt, medium-gray to green	4.5	23
Sand, fine to coarse, dark-gray to green, dark-gray silt layer at base	1	24
Sand, medium, to coarse gravel and pebbles, brownish-gray to pink	4.5	28.5
Silt, light brownish-buff	1.5	30
Clay, silty, light bluish- to greenish-gray	1	31
Sand, fine to coarse with many rounded clay particles; coarser texture in lower part, light-gray	9	40
Sand, medium, to coarse gravel with a few pebbles, brownish-gray to pink	10	50
Gravel, fine to coarse, with many pebbles and some sand, brownish-gray to pink	10	60
Sand and gravel, medium to coarse gravel with some pebbles, brownish-gray to pink	65	125
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, to shaly chalk, white to light-yellow	5	130

TABLE 9.—*Logs of test holes and wells*—Continued

***8-6-14ca**

Clay County. Owner, Dr. H. Ochsner. Driller, Thieszen Drilling Co. Altitude (t), 1,760 ft. Depth to water, 66.7 ft, October 19, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil and clay	80	80
Sand and gravel	22	102
Sand, coarse	16	118
Clay	6	124
Sand and gravel	14	138
Clay	10	148
Sand, coarse, good	12	160
Sand and gravel	22	182
Tertiary—Pliocene:		
Clay	2	184

8-6-15cd

Clay County. Altitude (t), 1,760 ft. Depth to water unknown.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil	2.5	2.5
Clay, silty, yellowish-tan	18.5	21
Soil: clay, silty, brown	2	23
Clay, pink; contains some limy nodules below 45 ft	27	50
Clay, sandy, calcareous, light greenish-gray	11	61
Sand, fine	4	65
Sand, clay and some gravel, light-gray	13	78
Sand and gravel	20	98
Clay, sandy with fine sand, gray, yellow below 103 ft	16	114
Sand and gravel	8	122
Clay, sandy to gravelly, gray	5	127
Sand and gravel	14	141
Clay, sandy, light greenish-gray	10	151
Clay, sandy, brown	5	156
Sand and gravel	27	183
Tertiary—Pliocene:		
Clay, pink; contains some limy material below 200 ft	32	215
Clay, light-tan	7	222

***8-6-15cd1**

Clay County. Owner, Clayton England. Driller, Don Barney. Altitude (a), 1,762 ft. Depth to water, 61.8 ft, April 27, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, yellow	17	20
Clay, brown	18	38
Clay, sandy	2	40
Clay, gray	33	73
Clay, sandy	6	79
Sand and some clay	4	83
Sand, fine, and a trace of gravel	2	85
Sand and gravel	14	99
Sand, medium-fine, and gravel	2	101
Sand, fine, and clay	24	125
Sand, fine, clay, and gravel	8	133
Sand and gravel	12	145
Clay, sandy	15	160
Sand and clay	5	165
Sand and a trace of gravel	3	168
Sand and gravel	17	185
Sand, medium-fine, and little gravel	5	190
Tertiary—Pliocene:		
Clay	8	198

TABLE 9.—*Logs of test holes and wells*—Continued

***8-6-18db**

Clay County. Owner, Earl England. Driller, Don Barney. Altitude (a), 1,789 ft. Depth to water, 70.2 ft, October 20, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow and brown	44	46
Sand and yellow clay	12	58
Sand, dirty	3	61
Clay, yellow	12	73
Clay, sandy	9	82
Sand and some gravel	5	87
Sand and gravel	50	137
Sand, fine	15	152
Clay, sandy	7	159
Sand and little gravel	13	172
Sand and gravel	4	176

***8-6-21ac**

Clay County. Owner, Frank G. Keasling. Driller, Don Barney. Altitude (a), 1,769 ft. Depth to water, 65.3 ft, October 20, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	69	71
Clay, sandy	11	82
Sand	4	86
Sand and gravel	9	95
Sand	6	101
Sand and gravel	6	107
Sand	5	112
Sand and gravel	4	116
Sand and a trace of gravel	5	121
Clay	2	123
Sand and gravel	12	135
Clay	12	147
Sand and gravel	3	150
Clay	2	152
Sand and some gravel	8	160
Sand and gravel	18	178

***8-6-26bd**

Clay County. Owner, Kenneth Kauk. Driller, Thieszen Drilling Co. Altitude (a), 1,762 ft. Depth to water, 64.9 ft, October 10, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	78	78
Sand and gravel	14	92
Sand, medium-fine	10	102
Sand and gravel	20	122
Clay, fine sand	6	128
Sand	16	144
Gravel and some sand	30	174

***8-6-27db**

Clay County. Owner, Lloyd Hultine. Driller, Thieszen Drilling Co. Altitude (a), 1,768 ft. Depth to water, 69.2 ft, April 27, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	70	70
Clay	10	80
Sand	14	94
Sand, fine	10	104
Sand, medium	4	108
Gravel	16	124
Sand and clay	5	129
Sand and gravel	17	146
Clay	8	154
Sand and gravel	28	182

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***8-6-29ab**		
Clay County. Owner, Raymond M. Hiatt. Driller, Don Barney. Altitude (t), 1,784 ft. Depth to water, 68.1 ft, October 20, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, hard	67	69
Clay, sandy	14	83
Sand	2	85
Sand and gravel	11	96
Clay, sandy	7	103
Sand	7	110
Sand and some gravel	4	114
Clay, sandy	5	119
Sand and gravel	22	141
Clay, sandy	8	149
Sand	9	158
Sand and gravel	15	173
Sand	2	175
Sand, some gravel	3	178
***8-6-36ca**		
Clay County. Owner, Edward C. Walther. Driller, Morris Merryman. Altitude (t), 1,763 ft. Depth to water, 75.3 ft, July 10, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	17.5	19
Clay, dark	11	30
Clay, yellow (lost water circulation at 40 ft)	16	46
Clay, white, sticky	30	76
Sand, very fine, greenish-gray	16	92
Clay	6	98
Sand, very fine	5	103
Sand	3	106
Sand, some gravel	5	111
Sand, fine	4	115
Sand, some gravel	3	118
Sand and gravel	14	132
Sand, medium-fine	2	134
Sand and rice gravel	4	138
Sand and gravel	7	145
Clay	2	147
Sand and rice gravel	4	151
Sand, medium, and gravel	10	161
Quicksand	3	164
***8-6-36cb**		
Clay County. Owner, Edward C. Walther. Driller, Morris Merryman. Altitude (a), 1,768 ft. Depth to water, 72.4 ft, April 27, 1953.		
Quaternary—Recent and Pleistocene:		
Clay	70	70
Sand, fine, hard	8	78
Sand, fine	37	115
Sand, good	7	122
Sand and gravel	11	133
Sand balls	5	138
Sand and gravel, good	32	170

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***8-7-19dc**		
Clay County. Owner, Lawrence Burmond. Driller, Thieszen Drilling Co. Altitude (i), 1,847.6 ft. Depth to water, 99.5 ft, October 21, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay	53	55
Sand	4	59
Clay	12	71
Sand, medium	4	75
Sand	14	89
Clay	14	103
Sand and gravel	60	163
***8-7-20cc**		
Clay County. Owner, Harold Smith. Driller, Don Barney. Altitude (i), 1,822.5 ft. Depth to water, 78.4 ft, April 21, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay, hard, brown	11	14
Clay, yellow	23	37
Clay, sandy	6	43
Sand, white	20	63
Sand and some gravel	11	74
Clay, white	6	80
Clay, very sandy	4	84
Sand and gravel	19	103
Clay, sandy, soft, white	4	107
Sand and gravel	21	128
Sand, blue	21	149
Sand, blue, and some gravel	9	158
***8-7-21ba**		
Clay County. Owner, Harold Schultz. Driller, John Alfs. Altitude (a), 1,821 ft. Depth to water, 79.5 ft, October 21, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay	50	52
Sand and gravel	18	70
Clay	22	92
Gravel	15	107
Sand	9	116
Gravel	11	127
Clay	1	128
Sand	38	166
Clay	--------	--------
***8-7-22bb**		
Clay County. Owner, Harry Frank. Driller, John Alfs. Altitude (a), 1,813 ft. Depth to water, 76.1 ft, April 20, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay	56	58
Sand	9	67
Clay	19	86
Sand	4	90
Gravel	12	102
Sand	14	116
Sand and gravel	30	146
Gravel	7	153
Sand and gravel	4	157
Clay	9	166
Sand and gravel	14	180

TABLE 9.—*Logs of test holes and wells*—Continued

8-7-24aa

Clay County. Altitude (a), 1,812 ft. Depth to water unknown.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Soil	2.5	2.5
Clay, silty, yellow-brown	13.5	16
Soil: clay, dark-brown	2.5	18.5
Clay, yellowish-red to light-brown	11.5	30
Clay, yellow-brown	10	40
Clay, red, yellow, and brown; contains limy concretions below 50 ft	20	60
Clay, red-brown	22	82
Clay, sandy, light tannish-gray; contains fine sand	16	98
Sand, fine, clayey, light tan-gray	5	103
Sand and gravel	14	117
Clay, gravelly, yellow	1	118
Sand and gravel	3	121
Clay, gravelly	4	125
Sand and gravel	34	159
Sand, fine, clayey in part, light-green	16	175
Sand and gravel, limonitic-stained	34	209
Tertiary—Pliocene:		
Clay, sandy, buff-tan	21	230
Cretaceous—Upper Cretaceous—Niobrara formation:		
Chalk, yellowish-tan	15	245

***8-7-26ba**

Clay County. Owner, Everett England. Driller, Don Barney. Altitude (a), 1,806 ft. Depth to water, 75.0 ft, October 21, 1954.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Sand and some clay	54	56
Sand and some clay and gravel	10	66
Clay	18	84
Sand and gravel	58	142
Sand and some gravel	3	145
Sand	5	150
Clay	2	152
Sand and gravel	6	158

***8-7-28ac**

Clay County. Owner, H. V. Brenneman. Driller, Morris Merryman. Altitude (i), 1,822 ft. Depth to water, 80.9 ft, April 21, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	18	20
Clay, dark	15	35
Clay, tough, light-colored	4	39
Clay, yellow	22	61
Clay, sandy, yellow	7	68
Sand, packed	3	71
Sand and gravel, packed	5	76
Clay, yellow	5	81
Clay, sticky, light-colored	13	94
Sand, some gravel	11	105
Sand and gravel	6	111
Sand, packed	3	114
Sand and rice gravel	5	119
Sand and gravel	16	135
Sand, fine, and clay	6	141
Sand and gravel, good	10	151
Sand	4	155
Quicksand	2	157

467829—59——10

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***8-7-29bc**		
Clay County. Owner, William F. Wendt. Driller, John Alfs. Altitude (i), 1,831 ft. Depth to water, 81.2 ft, April 21, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay	44	46
Clay, sandy	19	65
Gravel	11	76
Clay	13	89
Sand and gravel	29	118
Gravel	31	149
Clay	1	150
Sand, fine	15	165
***8-7-30ca**		
Clay County. Owner, Fred Schliep. Driller, Morris Merryman. Depth to water, 102.7 ft, April 12, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay	20	22
Clay, sandy	8	30
Sand, fine, and some clay	6	36
Clay, dark, with some sand	7	43
Sand and clay	14	57
Clay, sandy	16	73
Sand	15	88
Sand and gravel	8	96
Clay	18	114
Sand and some gravel	6	120
Sand and gravel	3	123
Clay, trace	2	125
Sand and gravel	12	137
Sand, medium-fine	2	139
Sand, medium-fine, and some gravel	3	142
Sand and gravel	12	154
Sand and clay	5	159
Sand and gravel, good	7	166
Clay, sandy	4	170
Sand, fine, some clay	10	180
Clay, sandy, blue	4	184
Quicksand	9	193
***8-7-32bc**		
Clay County. Owner, Edward Yost. Driller, Don Barney. Altitude (i), 1,836 ft. Depth to water, 90.2 ft, October 20, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	51	53
Sand	21	74
Sand and little gravel	2	76
Sand and gravel	6	82
Clay, sandy	9	91
Sand and gravel	14	105
Sand and rice gravel, good	5	110
Clay, sandy, blue	6	116
Sand, blue	2	118
Sand and gravel, blue	16	134
Clay and sand, blue	4	138
Sand and gravel	11	149
Clay, blue, very sandy	11	160
Sand and gravel	18	178

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
8-7-36dd		
Clay County. Altitude (a), 1,795 ft. Depth to water, 69.0 ft, August 8, 1949.		
Quaternary—Recent and Pleistocene:		
Soil and road fill: silt, clayey, medium brownish-gray	1	1
Silt, slightly clayey, buff-gray	.5	1.5
Silt, coarse, buff-gray with yellow tint; slightly clayey with brownish tint below 16.5 ft	16.5	18
Silt, very slightly clayey to very slightly sandy, tannish-brown with gray tint; contains very fine to fine sand	2	20
Clay, silty, brownish-tan with gray tint	5	25
Silt, clayey, light brownish-tan; contains less clay and is buff tan with gray tint below 27 ft	6	31
Silt, slightly sandy with very fine to fine sand, tannish-gray with red tint	4	35
Silt, slightly clayey to slightly sandy, brownish-gray	3.5	38.5
Sand, very fine to medium with some coarse, very silty, slightly calcareous, light brownish-gray	3	41.5
Silt, sandy, moderately calcareous, brownish-tan with gray tint; contains very fine to fine sand and some calcareous nodules	3	44.5
Silt, clayey, very calcareous, white	6	50.5
Silt, sandy to slightly clayey, moderately calcareous, light tannish-gray; contains very fine sand	5	55.5
Sand, medium to very coarse, brownish-gray	4.5	60
Sand, fine, to medium gravel, light brownish-gray with pink grains	2.5	62.5
Silt, sandy, to silty sand, brown; contains very fine sand	12.5	75
Sand, fine, to fine gravel, grayish-brown	6	81
Sand, medium, to medium gravel, very light brownish-gray	15	96
Sand, fine to very coarse, brownish-gray	11.5	107.5
Silt, sandy, to fine to coarse sand, very silty, light-gray	9.5	116
Sand, fine, to fine gravel, brownish-gray	4	120
Sand, fine, to fine gravel with some medium gravel, brownish-gray	84.5	204.5
Tertiary—Pliocene:		
Silt, slightly clayey to sandy, moderately calcareous, tan with a gray tint; contains very fine sand	14	218.5
Siltstone, sandy, moderately calcareous, noncalcareous below 222 ft, tan with a gray tint; contains very fine sand	8.5	227
Silt, sandy, moderately calcareous, slightly clayey below 230 ft, light buff-gray; contains very fine sand	9	236
Silt, very calcareous, nodular, light-gray	4	240
Silt, slightly clayey to sandy, moderately calcareous, light-gray with brown tint; contains very fine sand and calcareous nodules	15	255
Silt, sandy, to very fine sand, moderately calcareous, light-gray; contains few calcareous nodules; light brownish-gray and very sandy below 260 ft	10	265
Sand, very fine to fine, silty, moderately calcareous, less calcareous below 270 ft, brownish-gray	9	274
Sand, very fine to medium to coarse, brownish-gray; light-gray below 283.5 ft	13	287
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, silty, slightly pyritic from 292 to 298.5 ft, light- to dark-gray	27	314
Shale, chalky, light- to medium-gray	56	370
Chalk, light-gray	13.5	383.5
Cretaceous—Upper Cretaceous—Carlile shale:		
Shale, sandy, to shaly sandstone, black, fine-grained	.5	384
Clay shale, dark-gray	6	390

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***8-8-2bd**		
Clay County. Owner, Earl L. Strong. Driller, Morris Merryman. Altitude (a), 1,844 ft. Depth to water, 87.3 ft, April 20, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay	50.5	52
Clay, sandy	8	60
Sand and gravel, solid	7	67
Sand, fine, some clay	8	75
Sand, fine	6	81
Clay	16	97
Sand and gravel, with clay balls	6	103
Sand and gravel	2	105
Clay	1	106
Rice gravel	2	108
Sand and gravel	6	114
Clay	6	120
Sand and a little gravel, solid	6	126
Sand and gravel	7	133
Sand	10	143
Sand and some gravel	11	154
Cretaceous—Upper Cretaceous—Niobrara formation:		
Lime rock, yellow	2	156
Lime rock, yellow-ocher	21	177
***8-8-3bd**		
Clay County. Owner, Blake Mankin. Driller, Don Barney. Depth to water, 96.7 ft, April 20, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	20.5	22
Clay, brown	45	67
Sand and gravel, dirty and hard	8	75
Clay, very sandy	8	83
Sand, fine, dirty	4	87
Clay, white	17	104
Sand	2	106
Sand and gravel	19	125
Sand and gravel, good	33	158
***8-8-4ad**		
Clay County. Owner, Raymond Oschner. Driller, Don Barney. Altitude (a), 1,867 ft. Depth to water 96.5 ft, April 20, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	1	1
Clay, yellow	20	21
Clay, brown	18	39
Clay, little sandy, light	54	93
Sand, some gravel	2	95
Sand and gravel	2	97
Sand, medium-fine, rice gravel	4	101
Clay, sandy	2	103
Sand, fine, dirty	2	105
Sand, medium-fine, some rice gravel	2	107
Sand, fine, dirty	3	110
Sand, gravel, and some clay balls	8	118
Sand and gravel	8	126
Sand, medium-fine, rice gravel	13	139
Sand and gravel, blue	6	145
Clay, blue	5	150
Sand, medium-fine, and rice gravel	8	158
Sand and rice gravel	17	175
Sand, blue	2	177
Cretaceous—Upper Cretaceous—Niobrara formation:		
Lime rock, soft	1	178

TABLE 9.—*Logs of test holes and wells*—Continued

***8-8-5ad1**

Clay County. Owner, H. L. Haberman. Driller, John Alfs. Altitude (t), 1,890 ft. Depth to water, 106.9 ft, April 20, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay	27	30
Clay, sandy	9	39
Clay	29	68
Sand	10	78
Sand and gravel	20	98
Sand, fine	7	105
Clay, sandy	8	113
Sand	3	116
Sand and gravel	6	122
Sand, good	16	138
Sand and gravel	9	147
Tertiary—Pliocene:		
Clay, sandy	20	167
Lime rock	2	169
Sand, fine	2	171
Clay	15	186
Cretaceous—Upper Cretaceous—Niobrara formation:		
Clay, sticky, yellow	9	195

***8-8-5ad2**

Clay County. No well installed; H. L. Haberman, owner of land. Driller, John Alfs. Altitude (t), 1,890 ft. Depth to water, 106.9 ft, April 20, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	3	3
Clay	28	31
Clay, sandy	5	36
Clay	29	65
Clay, sandy	12	77
Sand	2	79
Sand and gravel	16	95
Sand, fine	5	100
Clay, sandy	21	121
Sand and gravel	11	132
Sand, fine, and gravel	6	138
Sand and gravel	8	146
Tertiary—Pliocene:		
Clay	40	186
Cretaceous—Upper Cretaceous—Niobrara formation:		
Lime rock	5	191
Clay, sticky, yellow; hard black sticky clay at 229 ft	38	229
Clay, hard, blue	5	234

TABLE 9.—*Logs of test holes and wells*—Continued

*8-8-7ca

Clay County. Owner, Ernest Ormsby. Driller, Morris Merryman. Altitude (a), 1,886 ft. Depth to water, 102.9 ft, April 22, 1953.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene:		
Topsoil	1.5	1.5
Clay, yellow	21.5	23
Clay, black	8	31
Clay, yellow	25	56
Clay, silty, dark	16	72
Sand	3	75
Sand and gravel	16	91
Sand, fine	8	99
Clay, sandy	15	114
Sand	2	116
Sand, rice gravel	4	120
Sand and gravel	6	126
Sand and some rice gravel	8	134
Gravel	3	137
Sand and gravel	6	143
Clay, trace	1	144
Sand, fine, some gravel	4	148
Sand, some gravel	7	155
Sand and rice gravel	4	159
Clay, blue	2	161
Tertiary—Pliocene:		
Clay, dark	19	180

8-8-19cc

Clay County. Altitude (i), 1,889 ft. Depth to water unknown.

	Thickness (feet)	Depth (feet)
Quaternary—Recent and Pleistocene—Continued		
Soil: silt, slightly clayey, dark brownish-gray	0.7	0.7
Silt, clayey, brownish-gray with a buff tint	1.3	2
Silt, slightly clayey, very slightly clayey below 5 ft, buff-gray with a yellow tint	8	10
Silt, buff-gray with yellow tint, slightly darker with depth	14.5	24.5
Soil: silt, very slightly clayey to very slightly sandy, dark reddish-brown	3	27.5
Sand, fine to coarse, silty, to very sandy silt, tannish-gray with a pink tint	3.5	31
Silt, sandy, tannish-gray with a pink tint; contains very fine to fine sand	9	40
Soil: silt, very slightly clayey, dark-brown with red tint	3.5	43.5
Silt, slightly clayey, tannish-gray with a pink tint	6.5	50
Silt, slightly to very sandy with some fine gravel below 65.5 ft, tannish-gray with pink tint	18	68
Sand, medium to coarse, tan-gray	2	70
Sand to medium gravel with considerable coarse gravel and some pebbles below 84 ft, brown to tan-gray with pink grains; contains some iron stain	22.5	92.5
Silt, very sandy, grayish-green; contains very fine to fine sand, much iron stain, and is slightly clayey below 98.5 ft	7.5	100
Silt, slightly clayey, greenish-gray	1	101
Sand to coarse gravel with a slightly clayey silt layer below 134 ft, light brownish-gray with pink grains	34	135
Sand to coarse gravel, light brownish-gray with pink grains; some iron stain	65.5	200.5
Silt, slightly clayey, yellowish-brown; limonitic stain	4.5	205
Tertiary—Pliocene:		
Siltstone, sandy, granular, tannish-brown; contains very fine sand; some rootlets	11.5	216.5
Silt, slightly clayey, brownish-buff with gray tint; buff to brownish-buff below 220 ft	9.5	226
Silt, clayey, buff-brown with gray tint; some calcareous material	4	230
Silt, slightly clayey, tannish-brown with gray tint, more gray below 236 ft; contains a few small calcareous nodules	10	240
Silt, brown-gray	16	256
Silt, in part sandy, greenish-gray; contains many rounded chalk fragments	9.5	265.5
Silt, in part slightly calcareous, sandy below 271 ft, medium-gray with brown tint becoming green with depth	8	273.5
Sand to medium gravel with some coarse gravel, green; contains many chalk fragments	8.5	282
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, silty, dark-gray; slightly more silty from 285 to 295 ft; has a slight petroliferous odor below 290 ft	18	300

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
***8-8-26cb**		
Clay County. Owner, Mike Glantz. Driller, Don Barney. Altitude (i), 1,852.8 ft. Depth to water, 92.5 ft, April 21, 1953.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay	31	33
Clay and sand	7	40
Clay, sandy	18	58
Sand, dirty, and clay	7	65
Sand, dirty	9	74
Sand and gravel, dirty	5	79
Sand and gravel	10	89
Clay, yellow	9	98
Sand, medium-fine, and gravel	5	103
Sand, medium, and dirty gravel	12	115
Clay, gray	4	119
Sand, gravel, and clay balls	10	129
Sand and gravel	40	169
Sand, very fine, and clay	9	178
***8-8-31dc**		
Clay County. Owner, Willis Hall. Driller, Don Barney. Altitude (a), 1,857 ft. Depth to water, 79.9 ft, October 21, 1954.		
Quaternary—Recent and Pleistocene:		
Topsoil	2	2
Clay, yellow	21	23
Clay, sandy	26	49
Sand, dirty, some gravel	6	55
Sand and gravel	8	63
Clay	15	78
Sand, some gravel	15	93
Sand and gravel	32	125
Sand	13	138
Sand and some gravel	7	145
Sand and gravel	33	178
8-9-12aa		
Adams County. Altitude (i), 1,878 ft. Depth to water, 87.1 ft, May 23. 1946.		
Quaternary—Recent and Pleistocene:		
Clay, silty, dark-brown	1.5	1.5
Silt, clayey, light-brown to buff; dark-brown from 20 to 25 ft; medium-brown from 25 to 27 ft; light reddish-brown from 27 to 34 ft	32.5	34
Silt, clayey to sandy, light-gray to brown; contains fine sand	6	40
Silt, light brownish-buff to gray	8	48
Clay, silty, medium brownish-gray	2	50
Clay, medium-gray to brown; contains calcareous nodules	5	55
Clay, silty, light-gray	2	57
Sand, fine, to fine gravel, light brownish-gray to pink	8	65
Sand, medium, to coarse gravel, light brownish-gray to pink; reddish-brown in lower part	15	80
Silt, light-gray to yellow	10	90
Silt, sandy with interbedded sand and some gravel below 100 ft, light-gray	20	110
Sand, medium, to medium gravel, light brownish-gray to pink with much limonitic stain	15	125

TABLE 9.—*Logs of test holes and wells*—Continued

	Thickness (feet)	Depth (feet)
8-9-12aa—Continued		
Tertiary—Pliocene:		
Silt, clayey, light greenish-gray	5	130
Clay, silty, light-gray to bluish-green	6	136
Clay, silty, more silty from 145 to 150 ft, light-gray to light brownish-gray to brown	20	156
Siltstone, sandy, light-brown; contains a few rootlets and some white limy material in lower part	9	165
Clay, silty, calcareous, light-brown; contains much hard limy nodular material and a hard limy zone at 176 ft	11	176
Siltstone with some limy layers, light-brown	14	190
Clay, silty, light-brown; contains some grayish-white limy material and intermittent hard limy zones	15	205
Clay, sandy, calcareous, light brownish-gray; contains many reworked chalk fragments	6	211
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, chalky, light-yellow to white; contains some limonitic fragments	31	242
Shale, chalky, medium-gray, speckled light-gray in lower part	8	250
9-7-36dd		
Hamilton County. Altitude (a), 1,790 ft. Depth to water, 69.4 ft, August 8, 1949.		
Quaternary—Recent and Pleistocene:		
Soil: silt, very dark brownish-gray	1	1
Silt, slightly to moderately clayey, brown to buff with gray tint; slightly to moderately calcareous and buff-gray with a yellowish tint below 2 ft; contains very fine sand from 10 to 14 ft	17.5	18.5
Soil: silt, slightly clayey to slightly sandy, dark brownish-gray with tan tint	3.5	22
Silt, clayey, brownish-tan with gray tint	2	24
Silt, moderately clayey, tannish-gray with red tint; contains very fine sand below 35 ft	14	38
Silt, clayey to slightly sandy, moderately calcareous, tannish-gray; contains many calcareous nodules	9	47
Silt, moderately clayey, slightly calcareous, light-gray; contains many calcareous nodules below 49 ft	8	55
Silt, moderately sandy to slightly clayey, light-gray; contains very fine to fine sand with some medium sand	5	60
Silt, sandy, to silty sand, slightly calcareous, light-gray; contains very fine to fine sand	10	70
Silt, sandy to slightly clayey, light-gray with slight brown tint; contains very fine sand	3	73
Sand, fine, to fine silty gravel with some cementation, brownish-tan	7	80
Siltstone, sandy, dark-gray	.4	80.4
Silt, sandy to slightly clayey, light-gray	.6	81
Sand, medium, to medium gravel, light brownish-gray to pink and green	24	105
Silt, clayey, sandy with depth, light-gray with yellowish-brown stain	4	109
Sand, fine, to medium gravel, brownish-gray	61	170
Tertiary—Pliocene:		
Silt, slightly sandy to very slightly clayey, slightly calcareous to moderately calcareous with many calcareous nodular fragments below 175 ft, brownish-tan to gray	10	180
Silt, slightly to moderately clayey, slightly calcareous to moderately calcareous, light brownish-tan with gray tint; contains many calcareous nodular fragments	16.5	196.5
Cretaceous—Upper Cretaceous—Niobrara formation:		
Shale, clayey, very calcareous, light yellowish-gray	3.5	200
Shale, chalky to slightly clayey, light yellowish-gray	13	213
Shale, very calcareous, medium-gray	7	220

TABLE 10.—*Daily measurements of depth to water in well 5–6–26bd,*[1] *1948–50*

[Measurements were taken from recording-gage charts, lowest daily stage, and are given in feet below land-surface datum

Day	1948							1949					
	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1		77.03	77.07	77.03	77.01	76.99	77.00	76.96	76.89	76.98	76.88	76.85	76.76
2		77.03	77.08	77.04	77.01	76.99	76.99	76.94	76.88	76.98	76.90	76.85	76.75
3		77.03	77.08	77.03	77.01	76.99	76.99	76.94	76.87	76.97	76.89	76.85	76.75
4		77.04	77.07	77.05	77.01	76.98	76.98	76.94		76.96	76.89	76.85	76.75
5	77.03	77.04	77.07	77.05	77.00	76.99	76.99	76.94	76.95	76.96	76.88	76.85	76.75
6	77.04	77.04	77.06	77.06	76.99	76.99	76.91	76.94	76.97	76.95	76.88	76.86	76.74
7	77.05	77.04	77.05	77.08	76.99	76.98	76.88	76.94	77.02	76.96	76.87	76.85	76.74
8	77.04	77.05	77.05	77.08	76.99	76.98	76.88	76.96	77.04	76.96	76.87	76.85	76.74
9	77.03	77.08	77.03	77.07	76.98	76.99	76.89	76.97	77.05	76.96	76.85	76.85	76.74
10	77.03	77.07	77.03	77.06	76.97	76.99	76.91	76.96	77.05	76.96	76.84	76.85	76.73
11	77.03	77.05	77.02	77.04	76.97	76.99	76.96	76.96	77.04	76.96	76.83	76.85	76.73
12	77.03	77.04	77.02	77.03	76.97	77.00	76.97	76.96	77.04	76.95	76.82	76.84	
13	77.03		77.01	77.03	76.97	77.00	76.97	76.95	77.04	76.95	76.84	76.84	
14	77.03		77.01	77.03	76.97	76.99	76.97	76.95	77.04	76.95	76.84	76.84	
15	77.04		77.01	77.03	76.97	76.99	76.97	76.96	77.02	76.95	76.84	76.83	
16	77.05		77.01	77.02	76.98	76.99	76.98	76.96	77.03		76.83	76.83	
17	77.06	77.08	77.00	77.02	76.98	76.98	76.98	76.95	77.03		76.94	76.82	76.70
18		77.09	77.00	77.02	76.98	76.97	76.97	76.95	77.03		76.94	76.81	76.70
19	77.07	77.07	77.00	77.02	76.98	76.97	76.97	76.95	77.03	76.92	76.94	76.82	76.70
20	77.07	77.07	76.99	77.03	76.98	76.81	76.96	76.95	76.99	76.91	76.94	76.81	76.68
21	77.06	77.06	77.01	77.03	76.97		76.96	76.94	77.00	76.90	76.93	76.81	76.67
22	77.05	77.06	77.01	77.02	76.97	76.96	76.96	76.94	76.99	76.90	76.93	76.80	76.66
23	77.05	77.06	77.01	77.02	76.97	76.97	76.96	76.95	76.99	76.89	76.93		76.64
24	77.05	77.06	77.01	77.01		76.98	76.96	76.95	76.98	76.90	76.88		76.63
25	77.05	77.05	77.01	77.02	77.01	76.98	76.97	76.94	76.99	76.89	76.88		76.65
26	77.04	77.05	77.01	77.02		76.98	76.97	76.94	76.98	76.88	76.87		76.64
27	77.04	77.05	77.02	77.02		76.98	76.96	76.93	76.98	76.88	76.87		76.63
28	77.04	77.05	77.03	77.01		76.99	76.96		76.98	76.88	76.87		76.63
29	77.04	77.06	77.03	77.01		76.99	76.97	76.94		76.88	76.87	76.77	76.62
30	77.04	77.06	77.02	77.01		77.00	76.97	76.92		76.87	76.86	76.76	76.61
31		77.06	77.03		77.00		76.97	76.90		76.88		76.76	

See footnote on next page.

TABLE 10.—*Daily measurements of depth to water in well 5-6-26bd,*[1] *1948-50*—Continued

Day	1949						1950					
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1	76.60	76.41	76.36	76.30	76.30	76.27	76.12	76.12	76.14	76.10	76.11	76.09
2	76.60	76.41	76.35	76.28	76.30	76.27	76.11	76.12	76.14	76.09	76.10	76.09
3	76.59	76.41	76.35	76.28	76.30	76.26	76.11	76.12	76.13	76.11	76.09	76.08
4	76.58	76.40	76.33	76.28	76.29	-----	76.11	76.12	76.12	76.11	76.09	76.07
5	76.58	76.40	76.34	76.28	76.30	-----	76.11	76.12	76.11	76.12	76.10	76.06
6	76.57	76.40	76.34	76.27	76.30	-----	76.11	76.13	76.10	76.12	76.10	76.06
7	76.56	76.40	76.34	76.27	76.30	-----	76.13	76.13	76.13	76.09	76.12	76.05
8	76.55	76.40	76.34	76.28	76.29	-----	76.12	76.14	76.13	76.09	76.11	76.05
9	76.54	76.40	76.34	76.28	76.28	-----	76.13	76.14	76.13	76.08	76.10	76.07
10	76.53	76.40	76.33	76.26	76.28	76.25	76.13	76.15	76.13	76.10	76.10	76.15
11	76.52	76.39	76.32	-----	77.28	76.26	76.13	76.15	76.12	76.10	76.10	76.15
12	76.52	76.39	76.32	-----	76.29	76.27	76.11	76.14	76.12	76.10	76.09	76.15
13	76.51	76.39	76.32	-----	76.29	76.27	76.12	76.14	76.12	76.10	76.08	76.16
14	76.50	76.38	76.32	-----	76.28	76.27	76.11	76.14	76.12	76.09	76.07	76.16
15	76.50	76.39	76.31	76.31	76.27	76.27	76.13	76.14	76.11	76.10	76.07	76.17
16	76.49	76.38	76.30	76.32	76.27	76.25	76.13	76.14	76.11	76.10	76.07	76.18
17	76.48	76.39	76.31	76.32	76.27	76.24	76.13	76.14	76.10	76.11	76.07	76.17
18	76.47	76.38	76.30	76.32	76.27	-----	76.14	76.14	76.09	76.10	76.10	-----
19	76.46	76.37	76.29	76.33	76.26	-----	76.13	76.15	76.08	76.10	76.09	-----
20	76.46	76.37	76.29	76.34	76.26	-----	76.12	76.14	76.08	76.09	76.10	-----
21	76.46	-----	76.30	76.34	76.27	-----	76.13	76.14	76.07	76.08	76.10	-----
22	76.46	-----	76.30	76.35	76.27	-----	76.12	76.13	76.08	76.08	76.09	-----
23	76.45	-----	76.30	76.36	76.27	-----	76.12	76.13	76.07	76.08	76.08	-----
24	76.45	-----	76.29	76.35	76.26	76.12	76.12	76.13	76.07	76.09	76.10	-----
25	76.44	-----	76.28	76.35	76.26	76.13	76.12	76.14	76.10	76.09	76.11	-----
26	76.44	-----	76.28	76.34	76.26	76.13	76.12	76.14	76.10	76.09	76.10	-----
27	76.43	76.37	76.28	76.33	76.26	76.13	76.12	76.13	76.11	76.09	76.09	-----
28	76.43	76.37	-----	76.32	76.27	76.13	76.12	76.14	76.12	76.09	76.08	-----
29	76.43	76.36	-----	76.30	76.27	76.13	76.12		76.13	76.10	76.10	-----
30	76.42	76.36	-----	76.31	76.27	76.12	76.12		76.13	76.11	76.09	-----
31	76.41	76.36		76.31		76.12	76.12		76.11		76.09	

[1] See table 11 for measurements made in this well in 1952, 1954, and 1955.

TABLE 11.—*Measurements of depth to water in wells in Clay County*

[Measurements are given in feet below land-surface datum]

Date	Water level	Date	Water level	Date	Water level
5-5-11ba					
June 24, 1954	77.83	Jan. 25, 1955	78.37	Apr. 15, 1955	78.06
Aug. 19	78.45	Feb. 14	78.25	Nov. 1	79.28
Dec. 10	78.18	Mar. 15	78.36	Dec. 12	78.90
5-5-17ac					
Sept. 8, 1954	70.30	Jan. 25, 1955	70.27		
5-6-23cb					
Aug. 19, 1954	73.08	Dec. 14, 1954	72.30		
5-6-26bd [1]					
Sept. 25, 1952	74.73	Dec. 10, 1954	75.07	Apr. 15, 1955	78.08
June 24, 1954	74.17	Jan. 25, 1955	75.05	Nov. 1	76.40
Aug. 19	74.91	Feb. 14	75.05	Dec. 22	76.32
Oct. 22	75.00	Mar. 15	75.07		
5-7-4cd					
Oct. 30, 1952	89.14	Oct. 28, 1954	89.45		
5-7-21ca					
Oct. 21, 1952	80.49	Nov. 16, 1954	81.02		
5-7-22db					
Oct. 21, 1952	79.80	Nov. 16, 1954	79.30		
5-7-29ad					
Oct. 21, 1952	91.67	Nov. 16, 1954	88.47		
5-7-32ac					
Apr. 13, 1937	12.45	Nov. 14, 1940	14.14	Dec. 10, 1954	13.01
June 28	12.80	Oct. 31, 1941	12.39	Jan. 25, 1955	12.94
Oct. 23	12.84	Dec. 31, 1946	13.29	Feb. 14	12.71
July 1, 1938	12.30	Mar. 1, 1954	13.06	Mar. 15	12.74
Oct. 18	12.16	June 24	13.41	Apr. 15	12.67
Apr. 11, 1940	13.19	Aug. 19	11.51	Nov. 1	12,54
Aug. 2	13.68	Oct. 19	13.28	Dec. 23	12.31
5-8-2aa					
Oct. 30, 1952	94.03	Nov. 17, 1954	94.86		
5-8-3bb					
Oct. 21, 1952	96.20	Oct. 28, 1954	96.91		

[1] See table 10 for daily measurements, 1948-50.

TABLE 11.—*Measurements of depth to water in wells in Clay County*—Continued

Date	Water level	Date	Water level	Date	Water level
6-5-27ac					
Aug. 11, 1954	99.78	Oct. 22, 1954	99.65		
6-7-22bb					
Oct. 27, 1954	84.00	Nov. 11, 1954	84.02		
6-7-27ca					
Oct. 22, 1954	85.37	Jan. 25, 1955	85.19		
6-7-27da					
Oct. 22, 1954	93.31	Jan. 25, 1955	93.02		
6-8-8cc					
Oct. 21, 1952	102.54	Oct. 28, 1954	102.90		
6-8-17bb					
Oct. 21, 1952	97.74	Dec. 10, 1954	95.86	Apr. 15, 1955	95.64
June 24, 1954	95.53	Jan. 25, 1955	95.81	Nov. 1	97.11
Aug. 20	97.12	Feb. 14	95.76	Dec. 23	96.52
Oct. 28	100.31	Mar. 15	95.76		
6-8-32bb					
Oct. 20, 1952	92.55	Oct. 28, 1954	93.12		
6-8-36bc					
Aug. 12, 1954	94.39	Oct. 28, 1954	93.77		
7-5-5cb					
Apr. 23, 1953	51.48	Oct. 20, 1954	54.05		
7-5-8dd					
Apr. 23, 1953	80.47	Nov. 12, 1954	81.20		
7-5-9dc					
July 7, 1954	85.50	Nov. 12, 1954	84.40		
7-5-15ca					
July 10, 1953	76.80	Nov. 12, 1954	77.10		

TABLE 11.—*Measurements of depth to water in wells in Clay County*—Continued

Date	Water level	Date	Water level	Date	Water level
7-5-35cd					
June 24, 1954	63.00	Jan. 25, 1955	63.54	Apr. 15, 1955	63.63
Aug. 19	63.25	Feb. 14	63.55	Nov. 1	63.87
Oct. 27	63.30	Mar. 15	63.65	Dec. 23	63.10
Dec. 10	63.32				
7-6-1ab					
Apr. 27, 1953	66.38	Oct. 20, 1954	69.17		
7-6-2cd					
Oct. 20, 1954	79.64	Nov. 12, 1954	79.50		
7-6-3ab					
Apr. 27, 1953	58.70	Nov. 12, 1954	61.98		
7-6-4bd					
July 22, 1954	63.06	Oct. 20, 1954	59.86	Nov. 11, 1954	59.84
7-6-23aa					
July 22, 1954	54.33	Nov. 12, 1954	53.15		
7-6-24dd					
Apr. 27, 1953	72.52	Nov. 12, 1954	72.56		
7-7-3ba					
July 10, 1953	67.70	Oct. 20, 1954	68.08	Nov. 10, 1954	67.93
7-7-4dc					
Apr. 30, 1953	67.00	Nov. 10, 1954	68.95		
7-7-6dc					
July 23, 1954	96.88	Nov. 10, 1954	94.55		
7-7-14ba					
Apr. 30, 1953	65.83	Nov. 10, 1954	64.73		
7-7-15ac					
Apr. 30, 1953	65.74	Oct. 28, 1954	67.26		
7-7-15da					
Apr. 30, 1953	64.87	Oct. 28, 1954	66.40		

TABLE 11.—*Measurements of depth to water in wells in Clay County*—Continued

Date	Water level	Date	Water level	Date	Water level
7-7-23ac					
July 10, 1953	68.50	Nov. 9, 1954	69.09		
7-7-27da					
May 1, 1953	75.03	Nov. 11, 1954	75.87		
7-8-4db					
Apr. 21, 1953	95.22	Nov. 10, 1954	96.95		
7-8-5db					
Apr. 21, 1953	102.27	Nov. 10, 1954	103.40		
7-8-7cb					
July 8, 1954	101.48	Nov. 10, 1954	100.90		
7-8-7dd					
Apr. 21, 1953	100.60	Oct. 21, 1954	101.69		
7-8-8db					
Apr. 21, 1953	96.62	Nov. 10, 1954	98.27		
7-8-10ab					
Apr. 21, 1953	90.53	Oct. 28, 1954	92.00	Nov. 10, 1954	92.26
7-8-16aa					
Apr. 1, 1954	99.00	Jan. 5, 1955	95.62		
8-5-6cc					
Apr. 28, 1953	78.86	Oct. 19, 1954	81.39		
8-5-22bb					
July 2, 1954	72.40	Oct. 19, 1954	72.51		
8-5-26cb					
July 2, 1954	71.52	Oct. 19, 1954	71.87		
8-5-33cc					
July 10, 1953	66.59	Oct. 19, 1954	67.80	Nov. 12, 1954	67.82

TABLE 11.—*Measurements of depth to water in wells in Clay County*—Continued

Date	Water level	Date	Water level	Date	Water level
		8-5-33dc			
Apr. 27, 1953	71.70	Oct. 19, 1954	72.87		
		8-5-33dd			
July 10, 1953	64.29	Oct. 19, 1954	65.28		
		8-5-34cd			
July 2, 1954	69.30	Oct. 19, 1954	69.31		
		8-6-2cd			
Apr. 28, 1953	70.24	Nov. 11, 1954	72.36		
		8-6-3ad			
Apr. 28, 1953	75.10	Nov. 11, 1954	76.86		
		8-6-9ad			
Apr. 28, 1953	64.55	Nov. 11, 1954	66.77		
		8-6-10ca			
Apr. 28, 1953	64.16	Nov. 11, 1954	66.84		
		8-6-12bb			
Apr. 28, 1953	76.80	Dec. 9, 1954	78.98	Apr. 15,1955	79.32
July 1, 1954	81.50	Jan. 25, 1955	78.87	Nov. 1	84.57
Aug. 19	83.61	Feb. 14	78.71	Dec. 23	81.26
Oct. 19	79.45	Mar. 15	78.56		
		8-6-13bc			
July 16, 1954	65.74	Oct. 19, 1954	66.83		
		8-6-14bc			
July 10, 1953	64.91	Nov. 12, 1954	65.21		
		8-6-14cb			
July 10, 1953	64.50	Oct. 20, 1954	65.11		
		8-6-14db			
Apr. 27, 1953	61.25	Aug. 19, 1954	66.89	Oct. 19, 1954	64.65

TABLE 11.—*Measurements of depth to water in wells in Clay County*—Continued

Date	Water level	Date	Water level	Date	Water level
		8-6-15cd			
Apr. 27, 1953	61.32	Nov. 12, 1954	64.49		
		8-6-20ba			
Apr. 28, 1953	62.79	Nov. 11, 1954	65.90		
		8-6-20dc			
Apr. 28, 1953	69.55	Oct. 20, 1954	72.96		
		8-6-22cb			
July 16, 1954	54.74	Oct. 20, 1954	53.49		
		8-6-24bc			
July 10, 1953	67.30	Nov. 11, 1954	69.77		
		8-6-35ba			
Apr. 27, 1953	73.46	Oct. 20, 1954	76.89		
		8-6-36ca			
July 10, 1953	74.77	Nov. 12, 1954	76.84		
		8-7-15db			
Apr. 28, 1953	85.65	Nov. 9, 1954	88.37		
		8-7-17cd			
Apr. 20, 1953	83.28	Oct. 22, 1954	85.80		
		8-7-19dc			
Oct. 21, 1954	99.52	Nov. 10, 1954	99.29	Jan. 25, 1955	98.65
		8-7-20cc			
Apr. 21, 1953	77.90	Oct. 21, 1954	80.99	Jan. 25, 1955	80.15
		8-7-20dc			
Apr. 21, 1953	75.85	Nov. 10, 1954	78.54	Jan. 25, 1955	77.99

TABLE 11.—*Measurments of depth to water in wells in Clay County*—Continued

Date	Water level	Date	Water level	Date	Water level
8-7-22bb					
Apr. 20, 1953	76.10	Nov. 9, 1954	78.51		
8-7-28ac					
Apr. 21, 1953	80.38	Nov. 10, 1954	82.86	Jan. 25, 1955	82.36
8-7-31da					
Apr. 21, 1953	77.39	Oct. 20, 1954	80.00	Nov. 10, 1954	79.88
8-7-33ac					
Apr. 30, 1953	80.47	Nov. 10, 1954	84.00		
8-7-36db					
Apr. 30, 1953	67.00	Nov. 11, 1954	69.86		
8-8-1ca					
Apr. 20, 1953	86.85	Oct. 28, 1954	88.90		
8-8-2bd					
Apr. 20, 1953	86.76	Nov. 10, 1954	88.98		
8-8-4ad					
Apr. 20, 1953	96.00	Nov. 10, 1954	98.41		
8-8-5ad					
Apr. 20, 1953	106.35	Oct. 28, 1954	108.63		
8-8-5cd					
Apr. 20, 1953	100.37	Oct. 28, 1954	102.57		
8-8-7ca					
Apr. 22, 1953	102.42	Nov. 10, 1954	104.90		
8-8-16dc					
July 8, 1954	97.22	Nov. 10, 1954	95.74		

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TABLE 11.—*Measurements of depth to water in wells in Clay County*—Continued

Date	Water level	Date	Water level	Date	Water level
		8-8-17ab			
Apr. 22, 1953	103.57	Oct. 28, 1954	106.16	Mar. 15, 1955	105.29
June 24, 1954	105.56	Dec. 9	105.78	Apr. 15	104.80
Aug. 19	109.79	Jan. 25, 1955	105.53	Nov. 1	109.94
Oct. 21	106.39	Feb. 14	105.31	Dec. 23	107.79
		8-8-26cb			
Apr. 21, 1953	92.00	Nov. 10, 1954	94.59		
		8-8-30ac			
Apr. 22, 1953	108.57	Nov. 10, 1954	110.25		
		8-8-36bb			
Oct. 21, 1954	70.51	Nov. 10, 1954	70.39		

TABLE 12.—*Records of wells in Clay County*

Well: See text for explanation of well-numbering system.
Method of lift: C, centrifugal pump; D, diesel engine; E, electricity; G, gasoline or tractor fuel; N, no lift; NG, natural gas; P, propane; T, turbine; W, windmill.
Type of casing: C, concrete; GI, galvanized iron; I, iron; M, other metal.
Measuring-point, description: EDP, end of discharge pipe; HIB, hole in pump base; TOC, top of casing.
Static water level: Reported distance below measuring point given in feet; measured distance below measuring point given in feet and tenths and hundredths of a foot.
Use of well: D, domestic; I, irrigation; Ind, industry; O, observation; PS, public supply; S, stock.
Remarks: Ca, complete chemical analysis (see table 4); Pa, partial chemical analysis (see table 4); L, log of well available (see table 9).

Well	Owner or tenant	Year drilled	Depth of well	Method of lift	Diameter of casing (inches)	Type of casing	Measuring point: Description	Measuring point: Height above or below (−) land surface (feet)	Measuring point: Altitude above mean sea level (feet)	Static water level: Distance below measuring point (feet)	Static water level: Date of measurement	Drawdown (feet)	Yield (gpm)	Use of well	Remarks
5-5- 2bb	W. C. Hansen	1947	160	T, P	18	M	HIB	1.0	1,720	94.11	6-24-54		600	I	
3bd	Dr. H. T. Patterson	1949		T, G			HIB	0		85.35	11-17-54		1,000	I	
5ad	George Plautz		160	T, P	18	M	HIB	0		90.55	9- 9-54		1,000	I	L
6ab	Roger Overturf	1939	120	T, NG	10	M				75			450	I	
6ac	do	1954	130	T, NG	12	M	HIB	1.0	1,735	78.15	9- 9-54		500	I	
6bc	Ivan George	1943	122	T, NG	8	M				86			480	I	
11ba	Dale Friedline	1953	163	T, P	18	M	HIB	0	1,699	77.83	6-24-54		800	I, O	L
12ac	Harold Roush		155	T, P	18	M	HIB	.5		86.27	9- 8-54		900	I	
12ad	do	1954	160	T, P	18	C	HIB	.5	1,697	83.98	10-22-54		650	I	Pa
14dc	John and Carrie Dennis		192	T, G	18	M	EDP	2.5	1,691	79.71	9- 8-54		1,500	I	
17ac	Ralph Wilson	1947	154	T, NG	18	M	HIB	0	1,713	70.30	9- 8-54	6	1,000	I	
18ab	Elmer Shuck	1947	159	T, P	18	M	HIB	.5	1,738	93.44	9- 8-54		950	I	Pa
20aa		1954		T	18	C								I	
20bb	Harold Beck	1953	153	T, NG	18	M	HIB	.5		71.98	9- 8-54		900	I	
21bb	George H. Nicely	1940	160	T, NG	18	M	HIB	0	1,698	69.53	9- 8-54	10	1,000	I	
28cd	Herbert Johnson	1954	152	T, P	18	C	HIB	.5	1,696	69.69	9- 8-54	12	1,000	I	
33ab	do	1946	155	T, NG	18	M	HIB	0		65.34	9- 8-54		1,000	I	
33ca	Marvin Mosier	1953	135	T, P	18	M	HIB	0	1,660	36.80	9- 8-54	7	500	I	
33db	Emil Hartnett	1954	130	T, P	18	M	HIB	0		34.05	9- 8-54		700	I	L
34bb	Herman C. Johnson	1944	150	T, NG	18	M	HIB	.5	1,685	67.15	9- 8-54	15	1,000	I	
35bb	Grace Cartney	1939	150	T, P	18	M	HIB	0	1,687	73.06	9- 8-54		1,000	I	Pa
5-6- 4ac	Edgar Organ	1951	165	T, P	18	M	HIB	0		75.97	8-20-54		1,000	I	L
4ba	Glen Peterson	1946	180	T, G	18	M	HIB	0	1,753	81.00	8-20-54	13	1,000	I	L
7aa	Kenneth Westering	1953	165	T, G	18	M	HIB	0		75.44	8-20-54	15	1,000	I	L
9cb	Caroline Johnson and Blanche Vaughn	1951	160	T, P	18	M	HIB	0	1,749	79.31	8-20-54	9	900	I	

TABLE 12.—*Records of wells in Clay County*—Continued

Well	Owner or tenant	Year drilled	Depth of well	Method of lift	Diameter of casing (inches)	Type of casing	Measuring point: Description	Measuring point: Height above or below (−) land surface (feet)	Measuring point: Altitude above mean sea level (feet)	Static water level: Distance below measuring point (feet)	Static water level: Date of measurement	Drawdown (feet)	Yield (gpm)	Use of well	Remarks
5-6-10bb	Rudolph Spousta	1946	175	T, G	18	M			1,742	75.49	8-20-54		900	I	Pa
12ab	Will Wenske	1954	150	T, P	18	M	HIB	0	1,727	70.61	8-20-54		750	I	
15bc	Edward Wenske	1954	150	T, P	18	M	HIB	.5		76.97	10-22-54	11	1,000	I	
16db	Mrs. Guy Green	1953	154	T, P	18	M	HIB	0	1,741	76.08	8-20-54		750	I	L
21dd	Guy Green	1946	157	T, P	18	M	HIB	0	1,741	78.41	8-20-54	17	1,000	I	
22bb	Logan Lee	1948	155	T, P	18	M	HIB	.5	1,738	77.68	8-19-54	11	900	I	
22da	Willard S. Avery	1954	140	T, P	18	M	HIB	0		73.66	8-19-54		900	I	L
23cb	Leland Hawley	1950	167	T, P	12	M	EDP	3.9	1,726	76.98	8-19-54		750	I	L
26bd	B. W. Merrill	1900	86		4	M	TOC	1.0	1,724	78.00	6- 1-48			O	
26ca1	City of Edgar	1880		T, NG	12	M				75			200	PS	
26ca2	do		150	T, E	12	M				75			200	PS	
28db	Floyd Kohllman	1954	160	T, E	18	M	HIB	.5	1,738	78.53	11-16-54	16	1,000	I	L
32cc	Wm. Hakanson	1950	150	T, P	18	M	HIB	0		75.90	12-13-54		900	I	L
32dc	William R. Nichols	1950	161	T, P	18	M	HIB	0	1,730	73.10	8-19-54		650	I	Pa, L
34cd	John Bennett	1948	150	T, P	18	C	HIB	.5	1,711	65.75	11-16-54		500	I	
35ca	Carl L. Gass	1954	150	T, NG	18	M	TOC	0	1,719	75.25	12-13-54		1,000	I	
36ca	Clema Archer	1948	180	T, P	18	M	HIB	.5		76.62	8-19-54	21	1,000	I	Ca
36dd	Wendell Lee	1946		T, P	18	M	HIB	0	1,716	77.85	8-19-54	11	1,000	I	
5-7- 2bb		1954			18	M								I	
2cc	Jess Selby	1949	185	T, P	18	M	HIB	0	1,773	78.25	8-18-54	18	800	I	Pa
3cb1	City of Fairfield		138	T, E	10	M				87			300	PS	
3cb2	do		138	T, E	10	M				87			250	PS	
3cc	M. E. Kriutzfield	1954	160	T, NG	18		HIB	0	1,778	79.30	10-28-54		900	I	
4cd	Ed Schliep	1946	180	T, G	18	M	HIB	0	1,793	89.14	10-30-52		1,000	I	L
4dc	John Brodrick			T			HIB	1.0	1,792	89.71	10-30-52			I	
4dd	J. L. Hagemeyer	1954												I	
5cb	Ed Schliep	1942	180	T, P	18	M	HIB	0	1,802	89.12	10-12-52		1,200	I	
6ca	Frank Gerdes		160	T, NG	18	M	HIB	.5	1,797	84.07	8-13-54		1,000	I	
8bb	Carl Brodrick	1946	174	T, P	18	M	HIB	0	1,786	81.04	10-30-52		900	I	Ca, L
9ab	C. J. Hubbel	1942	160	T, G	18	C	HIB	1.0		88.70	10-30-52		1,000	I	
11bb	Burt Payzant	1945	185	T	18	M	HIB	.5		76.09	10-22-54		1,000	I	
11cb	Warren Wilson	1945	160	T, G	18	M	HIB	1.0	1,768	75.76	10-31-52			I	

17cb	Edith Lambie	1954	180	T, P	18	M	HIB	0	1,788	86.40	8-13-54			I	L
20ba	James Lipousky	1954			18	C	TOC	1.0	1,773	100				I	
20cc	do	1949	180	T, P	18	M	HIB	0	1,794	101.10	10-22-54			I	
20dc	Anton Skalka	1948	175	T, P	17	M	HIB	.5		95.44	10-21-52	23	1,000	I	L
21ca	Joseph R. Skalka	1949	180	T, P	18	M	HIB	0	1,773	80.49	10-21-52	25	1,000	I	L
22db	George J. Harms	1946	180	T, P	18	M	HIB	.5	1,764	80.30	10-21-52	25	1,000	I	L
24ca	Ed C. Schliep	1954	190	T, E	18	M	HIB	0	1,759	84.55	11-17-54		1,000	I	L
28bb	Albert J. Skalka	1950	185	T, E	18	M	HIB	.5		87.48	10-21-52	43	1,000	I	Pa, L
28dc	do	1953	176	T, D	18	M	HIB	0	1,761	86.87	10-22-54		950	I	
29ad	Leo Sykora	1948	168	T, G	18	M	HIB	1.0	1,773	92.67	10-21-52	30	1,000	I	L
32ac	Univ. of Nebraska	1936	23	N	1	M	TOC	3.3	1,671	15.89	12-15-36			O	
33bb	B. W. Merrill	1940	41	C, E	14	M				15	12—54			I	
5-8- 1ac	L. L. Dana		195	T	18	M	HIB	0	1,806	87.06	10-22-53		1,500	I	
1bb	Ralph Kissinger	1948	165	T, E	18	M				91.84	10-28-54		1,000	I	L
1dc	Peter Muzik	1954	176	T, G	18	M	HIB	0	1,810	94.82	8-12-54		1,000	I	L
2aa	H. and Ward Fitzke	1951	158	T, P	18	M	HIB	0	1,820	94.03	10-30-52	16	900	I	Pa, L
3bb	Ida Onken	1948	175	T, E	18	M	TOC	.5	1,825	96.70	10-21-52	12	850	I	L
6db	Albert Davis	1952	178	T, P	18	M	HIB	.5	1,828	96.25	10-21-52		1,000	I	Pa
11bb	Harm Lindemann	1954	173	T, G	16	M	HIB	0	1,809	91.77	8-12-54	13	1,000	I	
13ba	Joseph F. Svoboda	1953	180	T	18	M	HIB	0	1,797	90.85	8-13-54	15	960	I	
14cb	Albert Nejezchleb		167	T, P	14	M				87			1,000	I	
14db	Ralph Fike	1954	170	T	14				1,804	90			900	I	
26dd	Alex Bednar	1953	130	T, G	18	M	HIB	0	1,788	93.80	8-13-54		300	I	Pa
6-5-18aa	Max Overturf	1945	140	T	12	M			1,742	90			700	I	Pa
22da	Forest Overturf	1943	141	T, P	12					101			700	I	Pa
27ac	Herschel Gowan	1954	180	T, G	18	M	HIB	0	1,736	99.78	8-11-54	13	700	I	
27ca	Clem Gowan	1945	172	T	18	M	HIB	0	1,731	93.76	10-22-54	13	1,000	I	L
32ab	Milford Sundling	1954	163	T, P	12	M	TOC	0		86.10	11-17-54			I	
32cd	E. Anderson		100	W						80.00	4-29-54			D	Ca
32dd	Gracia Anderson	1939	133	T, P	14	M			1,736	90			500	I	
33ba	Harry Overturf	1939	160	T, D	18	M	HIB		1,732	85.08	12-14-54		750	I	
6-6- 5bb	Arnold L. Livgren	1953	168	T, NG	18	M	HIB	0	1,768	65.96	10-27-54	20	900	I	L
6db	Carl H. Dahlsten	1950	168	T, NG	18	M	HIB	0	1,768	64.37	10-27-54	18	900	I	L
7cd	Agnes Williamson	1951	170	T, P	18	M	HIB	0	1,771	73.15	10-27-54		900	I	L
9bd	T. R. Nelson	1953	163	T, P	18	M	HIB		1,773	82.38	10-27-54	18	750	I	Pa, L
30cd	Woods brothers and Ells	1953	167	T, NG	18	M	HIB	.5	1,790	99.57	10-22-54	20	1,000	I	Pa, L
32cb	Carlos Bascom	1953	163	T, P	18	M	HIB		1,761	75.19	10-23-54	11	1,000	I	L
36aa	Melvin Overturf	1941	135	T, NG	10	M	HIB	1.0	1,751	91.48	8-20-54	20	450	I	Pa
6-7- 1aa1	City of Clay Center	1908	164	T, E, NG	10	M				85			500	PS	
1aa2	do	1920	165	T	16	M				85			500	PS	
1bd	James Styck	1954	183	T, NG	18	M	HIB	0	1,789	81.10	10-27-54	15	1,000	I	Ca, L
1db	William P. Hertel, Jr.	1951	174	T, NG	18	M	HIB	0	1,777	69.83	10-27-54		750	I	L
10cc	Othella McKelvie	1944	180	T, G	18	C	HIB	0	1,809	87.78	7-28-54	10	1,000	I	

TABLE 12.—*Records of wells in Clay County*—Continued

Well	Owner or tenant	Year drilled	Depth of well	Method of lift	Diameter of casing (inches)	Type of casing	Measuring point: Description	Measuring point: Height above or below (−) land surface (feet)	Measuring point: Altitude above mean sea level (feet)	Static water level: Distance below measuring point (feet)	Static water level: Date of measurement	Drawdown (feet)	Yield (gpm)	Use of well	Remarks
6-7-11cc	Alice McKelvie	1953	180	T, NG	18	M	HIB	0.0	1,790	73.62	7-28-53		1,000	I	Pa
14bc1	John Knox	1944	175	T, NG	18	M	HIB	.5		96.87	7-29-54		1,000	I	L
14bc2	do		175	T, NG	18	M	HIB	.5		87.62	7-29-54		1,000	I	
14da	Roland Knox	1949	175	T, G	18	M	HIB	0	1,803	93.84	10-27-54		1,000	I	
22bb	Warren Wilson	1950	175	T, G	18	M	HIB	0	1,798	84.00	10-27-54	11	1,000	I	L
25bd	Ada Woods	1953	173	T, NG	18	C	HIB	0	1,782	84.32	10-22-54	20	1,000	I	
26cc	Roy E. Squires	1948	160	T, NG	18	M	HIB	0	1,790	86.76	10-22-54		1,000	I	L
27ca	Ralph Kissinger	1952	200	T, NG	18	M	HIB	0	1,800	85.37	10-22-54	10	2,000	I	Pa
27da	do	1937	140	T, NG	18	M	HIB	1.0	1,798	94.31	10-22-54	25	900	I	
31bb	Carl A. Fitzke	1954	160	T, P	18	M	HIB	0	1,812	88.98	8-12-54	10	1,000	I	L
6-8-4ac	U. S. Naval Ammunition Depot.	1942	200	T, E	18	M	HIB	1.5	1,837	89.11	1-5-55	14	1,070	Ind	
4db	do	1942	180	T, E	18	M	HIB	1.5	1,834	89.80	1-5-55	20	1,212	Ind	
7bd	Ray J. Kissinger	1949	160	T, G	18	M	HIB	0	1,868	110.44	10-21-52			I	Pa, L
7da	Albert Ellermeier	1942	180	T, P	18	M	TOC	0		104.39	10-21-52		1,150	I	
8cb1	City of Glenvil	1929	165	T, E	8	M				115				PS	
8cb2	Ralph J. Kissinger		135											D	Ca
8cc	do	1943	160	T, D	18	M	HIB	.5		103.04	10-21-52			I	L
10cd	U. S. Naval Ammunition Depot.	1943	171	T, E	18	M	HIB	2.0	1,829	93.77	1-5-55	20	1,070	Ind	
12ca	do	1942	185	T, E	18	M	HIB	1.5	1,827	97.37	1-5-55	15	1,100	Ind	
16cb	Henry R. Hinrichs	1951	169	T, P	18	M	HIB	0	1,836	89.98	10-21-52	15	1,000	I	L
17bb	Willard W. Kissinger	1948	151	T, P	18	M	HIB	0	1,846	97.74	10-21-52	19	1,000	I, O	L
19ba	Henry C. Hinrichs, Sr	1954		T	18	C			1,842					I	
19cb	Albert Davis	1953	165	T, G	18	M	HIB	0	1,847	98.11	8-12-54	11	1,000	I	
25bc	Luther Uden	1954	122	T, P	18	M	HIB	0	1,824	91.98	6-25-54		900	I	
26cc	Henry Hinrichs, Jr	1954	179	T, P	18	M	HIB	0	1,836	108.43	6-25-54		1,000	I	L
29ba	Esther Bienhoff	1948	170	T, G	18	M	HIB	0	1,837	96.82	10-20-52		1,000	I	L
30ab	Ira Hunnicutt	1947	170	T, G	18	M				97			1,000	I	L
30bc	Albert Davis	1953	165	T, P	18	M	HIB	0	1,846	98.14	8-12-54	11	1,000	I	
32bb	Irene E. Dahlgren	1949	179	T, G	18	M	TOC	0	1,832	92.55	10-20-52	18	1,000	I	L
34db	Leslie Fagan	1954	179	T, P	18	M	HIB	.5	1,828	98.99	10-28-54	8	900	I	

36aa	B. Chas. Johnson	1953	168	T, G	18	M	HIB	.0		90.60	10-28-54		900	I	
36bc	Joe Peshek	1953	160	T, P	18	M	HIB	.5		94.89	8-12-54		1,000	I	L
7-5- 1cb	Warren Krause	1954	190	T, P	18	M	HIB	.5		78.15	11-17-54			I	L
2ab	City of Sutton	1954	210	T, E	16	M				80			600	PS	
2cc	do	1949	220	T, E	12					80			1,300	PS	
5cb	Clarence Carlson	1942	141	T, E	18	M	HIB	.5	1,738	51.98	4-23-53	18	1,000	I	Pa
8dd	Martin Mau	1949	202	T, P	18	C	HIB	1.0	1,752	81.47	4-23-53	24	1,000	I	L
9dc	Charles Beal	1954	240	T, E	18	C	HIB	.5	1,758	86.00	7- 7-54	11	1,000	I	L
11bb	William Sheridan and Sons	1953	170	T, NG	18	M	HIB		1,746	86.54	11- 9-54			I	Pa
15ca	Albert Boom	1953	210	T, P	18	C	HIB	1.0	1,745	77.80	7-10-53		1,000	I	Ca, L
26bb1	Jarold Schmer	1952	150	T, P	18	C	HIB	0	1,734	76.54	10-28-54	50	476	I	
26bb2	do		160	C, E	2					85			3	S	Ca
34bb	Raymond Schwab	1949	100		18	M			1,731	76.40	11-12-54	25	25	I	Ca, L
35cd	School land		76	N	6		TOC	0	1,710	63.30	10-27-54			O	
7-6- 1ab	Edward C. Walther	1947	161	T, P	18	M	HIB	.5	1,758	66.88	4-27-53	7	900	I	
2cd	Ernest Ham	1953	220	T, NG	18	M	HIB	0	1,775	79.64	10-20-54	26	1,000	I	
3ab	Roland Johnson	1947	164	T, P	18	C	HIB	.5	1,761	59.20	4-27-53	4	600	I	
3db	Herman Allen		185	T, G	18	M	HIB	0		66.33	10-20-54	25	1,000	I	
4bd	Ivan L. Johnson	1954	163	T, G	18	M	HIB	0	1,766	63.06	7-22-54	13	1,000	I	Pa, L
23aa	Kenneth Beattie		174	T, NG	18	M	HIB	0	1,744	54.33	7-22-54	16	1,100	I	
24dd	L. C. Schneller	1948	149	T, NG	18		HIB	0	1,755	72.52	4-27-53	14	1,000	I	L
30cc	Robert E. Kinyoun	1953	165	T, P	18	C	HIB	0	1,787	78.80	11- 7-54		600	I	L
32bb	Fred Schwindt	1950	150	T, NG	18	M	HIB	0	1,783	75.26	11- 9-54	55	650	I	L
32ca	Al F. Erthum	1954	150	T,	18	M	HIB	0		69.75	11-19-54	14	850	I	L
7-7- 2ad	Ernest M. Yost	1953	172	T, NG	18	C	HIB	0	1,788	64.17	10-20-54		930	I	
2ca	Walter H. Yost	1954	168	T, P	18	M	HIB	0		66.95	7- 1-54		1,000	I	
2db	George Pauley	1948	174	T, NG	18	GI	HIB	0		66.41	10-28-54		1,300	I	L
3ba	Floyd Keasling	1953		T, NG	18	C	HIB	.5	1,800.0	68.20	7-10-53			I	
3cd	Carl E. North and W. S. Moger.	1948	163	T, NG	18	C	HIB	0		57.40	4-30-53	23	1,000	I	L
3da	Walter Yost	1948	162	T, NG	18	C	HIB	.5	1,802.3	69.00	4-30-53	41	1,250	I	L
4dc	Walter C. Fitzke			T, NG	12	I	HIB	2.0	1,805	69.00	4-30-53			I	
5ac	Donald Keasling	1953	173	T, D	18	M	HIB	0	1,831	82.95	11-10-54	20	900	I	
5bc	Wayne Glantz	1953	173	T, P	18	C	HIB	1.0		83.06	10-20-54		500	I	
6dc	Ernest Erickson	1954	183	T, G	18	M	HIB	0	1,842	96.88	7-23-54		850	I	L
9cc	Morrison & Quirk	1954	180	T	12		HIB	0	1,809	70.38	11- 9-54			PS	Ca
14ba	Arthur Anderson	1948	165	T, NG	18	M	HIB	0	1,790	65.83	4-30-53			I	
15ac	do	1947	163	T, NG	18	M	HIB	.5		66.24	4-30-53			I	Pa
15ca	do	1948	164	T, NG	18	M	HIB	.5		69.90	4-30-53			I	
15da	do	1953	164	T, NG	18	I	HIB	.5	1,792	65.37	4-30-53			I	
16bd	Morrison & Quirk	1948		T, NG	18	M	HIB	.5		74.80	5- 1-53		1,600	I	

TABLE 12.—*Records of wells in Clay County*—Continued

Well	Owner or tenant	Year drilled	Depth of well	Method of lift	Diameter of casing (inches)	Type of casing	Measuring point: Description	Measuring point: Height above or below (−) land surface (feet)	Measuring point: Altitude above mean sea level (feet)	Static water level: Distance below measuring point (feet)	Static water level: Date of measurement	Drawdown (feet)	Yield (gpm)	Use of well	Remarks
7-7-17ac	Morrison & Quirk	1948	198	T, NG	18	M	HIB	0.0		81.90	5-1-53	10	1,600	I	L
23ac	Robert Kinyoun	1953		T	18	C	HIB	0		68.50	7-10-53			I	L
23bd	Glen F. Slader	1954	162	T	18	M	HIB	0	1,794	68.79	11-11-54	22	1,000	I	L
24dd	Gene Mundorff	1953	152	T, D	18	M	HIB	0	1,796	80.44	11-9-54		900	I	
27da	L. S. Yost	1948	189	T, P	18	C	HIB	0	1,798	75.03	5-1-53		1,000	I	
34cc	H. F. Gerdes	1953	156	T, P	18	C	HIB	0	1,799	74.90	11-9-54		1,000	I	L
35ba	Agnes Williamson	1952	168	T, P	18	M	HIB	0	1,800	77.05	10-27-54	17	800	I	L
7-8-4db	Robert Donahue	1953	200	T	18	GI	HIB	.5	1,860	95.72	4-21-53	16		I	L
5db	Herman Knudson	1947	179	T, P	18	M	TOC	.5	1,877	102.77	4-21-53			I	L
7cb	Eugene Halloran	1954	200	T, P	18	C	HIB	0	1,883	101.48	7-8-54	11	1,500	I	
7dd	C. J. Hargleroad	1947	200	T, P	18	M	HIB	.5		101.10	4-21-53		1,000	I	Pa
8cc	do	1954	189	T, D	18	M	HIB	.5		105.41	10-21-54	10	1,000	I	
8db	George Rinder	1947	180	T, D	18	C	HIB	.5	1,873	97.12	4-21-53		1,000	I	
10ab	Chas. W. Roback	1948	200	T, G	18	GI	HIB	.5	1,852	91.03	4-21-53	7½	1,000	I	L
10db	George Ablott	1953	170	T, P	18	M	HIB	0	1,853	93.93	10-28-54			I	
16aa	U. S. Naval Ammunition Depot.		183	T, E	18	M	HIB	1.0	1,856	100.00	4-1-54	9	1,150	Ind	
28cc	do	1942	200	T, E	18	M	HIB	.5	1,826	94.97	1-5-55	11		Ind	
8-5-6cc	Ephraim K. Nuss	1948	130	T	18	C	HIB	.5	1,761	79.36	4-28-53	50	600	I	L
11ba	Art Hofmann	1954	144	T, P	18	C	HIB	.5	1,736	87.35	11-12-54	22	600	I	L
18ca	H. V. Nuss	1948	165	T, P	18	C	HIB	.5	1,756	69.35	4-27-53	7-10	850	I	Ca
22bb	Edmond Griess	1954	143	T, P	18	C	HIB	1.5	1,749	73.90	7-2-54			I	Pa
26ab	John Sheridan	1954	185	T, P	18	C	HIB	1.0	1,732	70.41	10-19-54		1,000	I	
26cb	Lloyd Reutzel	1954	190	T, P	18	C	HIB	.5	1,734	72.02	7-2-54		800	I	Pa
33cc	Earl Vauck	1953		T, NG	18	M	HIB	.5	1,741	67.09	7-10-53			I	
33db	Leonard Johnson	1954	172		18	C								I	
33dc	Earl Vauck	1952	168	T, G	18	M	HIB	.5		72.20	4-27-53	16	1,000	I	
33dd	do	1953		T, NG	18	M	HIB	.5		64.79	7-10-53			I	
34cd	Roger Sheridan	1953	169	T, NG	18	M	HIB	0	1,733	69.30	7-2-54			I	
8-6-2bb	Dayton Bouder	1952	149	T, P	18	C	HIB	.5		71.74	4-28-53	15		I	Pa
2cd	C. J. Helzer	1948	168	T, G	18	C	HIB	.5	1,762	70.74	4-28-53	20	1,000	I	

3ad	Adam Ross	1949	156	T			HIB	1.0	1,770	76.10	4-28-53			I	
9ad	Dale Nelson	1952	167	T, G	18	M	HIB	0	1,763	64.55	4-28-53	18	600	I	
10ca	Glen Nelson	1952	167	T, G	18	M	HIB	0	1,762	64.16	4-28-53	18	600	I	
12bb	Paul Helzer	1950	135	T, P	18	C	HIB	.5	1,766	77.30	4-28-53	55	925	I, O	
12cd	William Ochsner	1954	150	T, P	18	M	HIB	.5		69.25	10-19-54		1,000	I	
13bc	George Anderson	1954	180	T, G	18	M	HIB	0		65.74	7-16-54		1,200	I	
14bc	Herbert Spielman	1953	160	T, P	18	M	HIB	.5	1,762	65.41	7-10-53			I	
14ca	Dr. H. V. Ochsner	1954	181	T, P	18	M	HIB	0		66.72	10-19-54		1,000	I	L
14cb	Lester Rath	1953		T, P	18		HIB	1.0		65.50	7-10-53			I	
14db	Herbert J. Ochsner	1948		T, G	18	I	HIB	0	1,760	61.25	4-27-53			I	
15cd	Clayton England	1948	187	T, P	18	M	HIB	.5	1,762	61.82	4-27-53	12	1,000	I	L
16ad	Will Rath	1954	185	T, D	18	C	HIB	2.0	1,769	66.49	10-20-54		1,000	I	
18db	Earl England	1954	175	T, P	18	M	HIB	0	1,789	70.18	10-20-54	17	1,000	I	L
20ba	do	1948	178	T, P	18	M	HIB	.5	1,781	63.29	4-28-53	20	1,000	I	Pa
20dc	Roger G. Anderson	1942	140	T, G	18	C	HIB	1.0	1,786	70.55	4-28-53	34	600	I	
21ac	Frank G. Keasling	1954	178	T, D	18	M	HIB	0	1,769	65.26	10-20-54	14	1,000	I	L
22ab	J. T. Rempel	1954	200	T, P	18	C				62			1,400	I	
22cb	Nels Nelson	1954	175	T, P	18	C	HIB	.5	1,756	55.24	7-16-54		1,000	I	
23dd	Herbert and Morris Kauk	1954	172	T, P	18	C	HIB	0	1,756	63.17	10-20-54	12	1,000	I	
24bc	Harold G. Traudt	1953	176	T, P	18	C	HIB	.5	1,759	67.80	7-10-53			I	
25ca	Marvin L. Schultz	1953		T, P	18	M	HIB	.5	1,765	73.34	7-10-53			I	
26bd	Kenneth Kauk	1953	172	T, P	18	C	HIB	0	1,762	64.92	10-10-54	14	1,100	I	L
26ca	Lloyd Hultine	1948	179	T, G	18	C	HIB	1.0		69.22	4-27-53	20	1,000	I	
27ac	Vic Englehardt	1948	150	T, P	18	C	EDP	6.5		59.47	4-27-53		1,000	I	
27db	Lloyd Hultine	1953	182	T, P	18	C	HIB	0	1,768	68.11	10-10-54	14	1,100	I	Pa, L
28ac	Roger G. Anderson	1954	168	T, G	18	M	HIB	0	1,776	69.74	10-20-54	22	700	I	
28dd	Ernest F. Johnson	1954	160	T, P	18	C	HIB	1.0		65.89	10-20-54	10	850	I	
29ab	Raymond M. Hiatt	1953	170	T, P	18	M	HIB	0		68.11	10-20-54		700	I	L
35ba	Albert Hultine	1948	179	T, G	18	C	HIB	.5	1,768	73.96	4-27-53	19	1,000	I	
36ca	Edward C. Walther	1953	165	T, P	18		HIB	.5	1,763	75.27	7-10-53			I	L
36cb	do	1943	163	T, P	18	C	HIB	.5	1,763	72.36	4-27-53	13		I	L
8-7-13dc	Kenneth Keasling	1954	175	T, P	18	C	HIB	1.0	1,810	87.72	10-20-54		1,000	I	
15db	Raymond Keller	1949	173	T, P	18	C	HIB	.5	1,820	86.15	4-28-53			I	
16dd	Joseph Frank	1945	158	T, NG	18	M	HIB	0		80.87	4-20-53			I	
17cd	Daniel H. Schultz	1947	165	T, G	18	GI	HIB	0	1,832	83.28	4-20-53	18	900	I	Pa
19dc	Lawrence Burmond	1953	160	T, P	18	C	HIB	0	1,847.6	99.52	10-21-54		900	I	L
20cc	Harold Smith	1939	160	T, G	18	M	HIB	.5	1,827.2	78.40	4-21-53	30	800	I	L
20dc	Forrest A. Pense	1939	140	T, D	18	M	HIB	1.0	1,822.8	76.85	4-21-53			I	
21ba	Harold Schultz	1953	163	T, P	18	M	HIB	.5	1,819	79.49	10-21-54		750	I	L
22bb	Harry Frank	1946		T, NG	18	M	HIB	0	1,813	76.10	4-20-53		1,000	I	L
22cc	Silas Gerlach		167	T, P	18	M	HIB	0	1,812.5	76.20	7-1-54		1,000	I	
23ca	State airbase	1940	167	N	18	C	TOC	0		87				N	
26ac	Mike Glantz	1954	156	T, NG	18	C	HIB	0		70.56	10-21-54		750	I	Pa
26ba	Everett England	1954	140	T, NG	18	M	HIB	0	1,806	74.95	10-21-54	15	1,000	I	L
28ac	H. V. Brenneman	1948	156	T, P	18	M	HIB	.5	1,822.0	80.88	4-21-53	10	900	I	L

TABLE 12.—*Records of wells in Clay County*—Continued

Well	Owner or tenant	Year drilled	Depth of well	Method of lift	Diameter of casing (inches)	Type of casing	Measuring point: Description	Measuring point: Height above or below (—) land surface (feet)	Measuring point: Altitude above mean sea level (feet)	Static water level: Distance below measuring point (feet)	Static water level: Date of measurement	Drawdown (feet)	Yield (gpm)	Use of well	Remarks
8-7-29ac	Vance and Clarence Anderson.	1941	154	T, G	18	M	HIB	0.5	1,822.0	76.05	4-21-53	20	800	I	
29bc	William F. Wendt	1948	160	T, P	18	M	HIB	.5	1,831.0	81.17	4-21-53		1,000	I	L
30ca	Fred Schliep	1946	168	T, G	18	M	HIB	.5		102.70	4-21-53	8	1,000	I	L
31da	Harold Smith	1949	161	T, P	18	C	HIB	.5	1,824.7	77.89	4-21-53	17	800	I	
32bc	Edward Yost	1954	170	T, P	18	M	HIB	.5	1,836.0	90.20	10-20-54		900	I	L
33ac	Ralph Keller	1941	153	T, P	18	M	HIB	.5	1,824	80.97	4-30-53	17	900	I	Ca
34ac1	City of Harvard	1924		T, E	6	M				67			150	PS	Ca
34ac2	do	1924	200	T, E	6					67			150	PS	
34ac3	do	1942	200	T, E, NG	8					67			400	PS	
34db	do	1954	200	T, E	8	M				67			400	PS	
36db	C. G. Yost	1941	150	T, NG	18	M	HIB	.5	1,793	67.50	4-30-53	19	1,000	I	
8-8-1ca	Prissler Bros	1950	165	T, P	18	C	HIB	.5	1,843	87.35	4-20-53			I	Pa
2bd	Earl Strong	1946	154	T, NG	18	M	HIB	.5	1,844	87.26	4-20-53			I	L
3bd	Blake Mankin	1950	157	T, NG	18	GI	HIB	.5		96.65	4-20-53	13	1,000	I	L
4ad	Ray Ochsner	1948	151	T, NG	18	GI	HIB	.5	1,867	96.50	4-20-53	13½	950	I	L
4dd	Russell Brown	1953	155	T, NG	18	C	HIB	0		96.00	7-1-54		1,000	I	
5ad1	H. L. Haberman	1949	148	T, NG	18		HIB	.5		106.85	4-20-53			I	L
5cd	Walter Knicely	1944	154	T, NG	18	M	HIB	0		100.37	4-20-53			I	
7ac	George Murray	1953	158	T, NG	18		HIB	.5		96.13	4-22-53		1,000	I	
7bd	Village of Trumbull	1936	125	T, E	8	M							200	PS	
7ca	Ernest Ormsby	1948	160	T, NG	18		HIB	.5	1,886	102.92	4-22-53			I	L
7db	Roy Andrews	1946	162	T, NG	18	M	HIB	.5		101.80	4-22-53		1,000	I	
8ac	Glen Rader	1953	150	T, NG	18	C	HIB	0		97.00	7-1-54	14	1,000	I	
8db	Lillian Holm	1940	155	T, NG	18	M	HIB	.5		98.97	4-22-53		1,000	I	
16cc	Ellen Wilson	1946	160	T, G	18	M	HIB	.5		93.91	4-22-53		1,[illegible]	I	
16dc	Ralph Wilson	1953	160	T, D	18	M	HIB	0	1,861	97.22	7-8-54		1,000	I	
17ab	Ray O'Donnell	1946	155	T, NG	18	M	HIB	.5	1,884	104.07	4-22-53		1,000	I, O	
18ac	Kenneth Turner	1954	180	T, NG	18	C	HIB	0	1,889	108.18	10-21-54			I	Ca
26cb	Mike Glantz	1948	169	T, P	18		HIB	.5	1,852.1	92.50	4-21-53			I	L
30ac	W. F. Golgert	1944		T, G	18	M	HIB	.5	1,899	109.07	4-22-53			I	
31dc	Willis Hall	1953	175	T, P	18	M	HIB	.5	1,857	79.91	10-21-54		600	I	Pa, L
36bb	Art Haack	1954	168	T, D	18	C	HIB	0	1,823.8	70.51	10-21-54	26	1,300	I	Pa

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