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BULLETIN 40

GEOLOGY AND GROUND-WATER RESOURCES OF MORTON COUNTY, KANSAS

By THAD G. MCLAUGHLIN

with analyses by

ROBERT H. HESS

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

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GEOLOGY AND GROUND-WATER RESOURCES OF MORTON COUNTY, KANSAS

By THAD G. McLAUGHLIN

ABSTRACT

Morton county is in the southwestern corner of Kansas and is a part of the southern High Plains section of the Great Plains province. It is relatively flat and is drained by Cimarron river and its tributaries. The county has a semiarid climate, the average annual precipitation being about 18 inches. Wheat farming is the principal occupation, but row crops are cultivated extensively in the areas of dune sand south of Cimarron river.

The depth to the ground-water table ranges from about 30 feet in the northwestern part of the county to about 225 feet in the southeastern part. The water table slopes eastward at an average rate of about 19 feet to the mile. The maximum slope, which is in the northwestern part of the county, is about 40 feet to the mile. The minimum slope is 7 feet to the mile, in the northeastern corner of the county.

The ground-water reservoir is recharged by flood waters in the ephemeral streams north of Cimarron river, by direct precipitation on the areas of dune sand south of the river, and by precipitation in the county or on the outcrops of water-bearing beds in near-by areas.

Water is discharged from the ground-water reservoir by wells, by seepage into Cimarron river, and by transpiration and evaporation in the Cimarron river valley. There is also a gradual subsurface movement of ground water eastward out of the county.

Most of the wells in this area are drilled, but a few are bored or dug. The water is principally for domestic and stock use but some is used for public, railroad, or irrigation supplies.

The ground water in this area is hard, but it is suitable for most ordinary uses. The waters from the Cockrum sandstone, the Ogallala formation, and the Cheyenne sandstone are similar in composition and hardness. Waters from the alluvium and from the Triassic(?) and Permian redbeds are very hard and are not suitable for domestic use. Much of the water contains fluoride in amounts that may be harmful, particularly the water from the Cockrum sandstone.

There are six divisions of the stratified rocks in Morton county that contain water supplies useful to man. These water-bearing rocks range in age from Permian to Recent. The Permian redbeds yield mineralized water to flowing artesian wells at depths of 550 to 700 feet near Richfield. The water contains considerable calcium and sulphate derived from gypsum associated with the redbeds.

The Triassic(?) redbeds yield water from beds at two horizons. The upper zone of buff sandstone yields moderately hard water to wells in the vicinity of Point Rock on Cimarron river. Flowing artesian wells are obtainable in the

lower zone of red sandstone and siltstone near Point Rock, and the water is reported to be highly mineralized. The Triassic(?) redbeds are in places overlain by the clays and marls of the Morrison(?) formation, which probably yield little or no water to wells in this county.

The next younger formation, the Cheyenne sandstone, yields water to wells in the northwestern part of the county at depths of 172 to 215 feet. The Kiowa shale has a low permeability and probably yields little or no water to wells.

The Cockrum sandstone overlies the Kiowa shale and yields water to most of the wells in the northwestern quarter of the county at depths of 30 to 125 feet.

Most of the county is underlain by undifferentiated silt, sand, and gravel of Pliocene and Pleistocene age. The Ogallala formation (Pliocene), consisting of silt, sand, and gravel, is the principal water bearer in the county and yields water to wells in all but the northwestern part of the county. The depth to water level in the Ogallala ranges from 60 feet in the northern part of the county to 225 feet in the southeastern part of the county. The Ogallala formation lies unconformably on rocks of Permian to Cretaceous age. The Ogallala formation and the overlying undifferentiated Pleistocene deposits are overlain, north of the river, by a thin blanket of loess. South of the river they are covered by dune sand.

In the Cimarron river valley are deposits of alluvium that yield very hard water to shallow stock wells.

Logs of test holes, water wells, and gas wells are given in the report. The data on water wells, on chemical analyses of waters, and on water-table fluctuations are listed in tables. The surface geology of the county, the depths to the water table, and the shape of the water table are shown on maps.

INTRODUCTION

Purpose and Scope of the Investigation

In July, 1939, an investigation of the geology and ground-water resources of Morton county, Kansas, was undertaken by the United States Geological Survey and the State Geological Survey of Kansas, with the coöperation of the Division of Sanitation, Kansas State Board of Health, and the Division of Water Resources, Kansas State Board of Agriculture. This work was done under the general administration of R. C. Moore and K. K. Landes, state geologists, and O. E. Meinzer, geologist in charge of the Division of Ground Water of the Federal Survey, and under the direct supervision of S. W. Lohman, Federal geologist in charge of ground-water investigations in Kansas.

Since 1931 an extended drought, accompanied by severe dust storms, has caused repeated crop failures in western Kansas. These conditions have resulted in a lower farm income and an increased interest in the possibilities of irrigation in this area.

During the last nine years Morton county has had an average annual precipitation far below normal, resulting in a cumulative deficiency in rainfall for the nine years of more than 61 inches.

The investigation upon which this report is based was made in order to determine as nearly as possible the quantity, quality, movement and availability of the ground water, and the location and extent of areas in which ground water may be developed for irrigation. The present use of water for domestic, stock, public, and irrigation supplies does not seem to be depleting the supply of ground water in this county, but it is possible that future overdeveloping of water for irrigation in shallow-water areas might seriously endanger this supply. It is hoped that the data given herein will facilitate the safe development of the ground-water resources of the county.

Location and Size of the Area

Morton county is in the southwestern corner of Kansas (fig. 1). It is bordered on the south by Oklahoma and on the west by Colorado. Most of the county lies between parallels 37° and 37°24′ north latitude and meridians 101°33′ and 102°3′ west longtitude. It includes 20 townships and has an area of 733 square miles.

Previous Work

The first studies of the ground-water resources of western Kansas were made in 1895 by Haworth (1897, pp. 49-114), who discussed the occurrence of ground water in the Cockrum sandstone and younger formations of western Kansas. A few years later Johnson (1900, pp. 601-741, 1901, pp. 631-669) made a study of the southern High Plains with special reference to ground water, its source, its availability, and its use. At about the same time Darton (1905) studied the geology and ground-water resources of eastern Colorado and western Kansas, including Morton county. In 1911 Parker

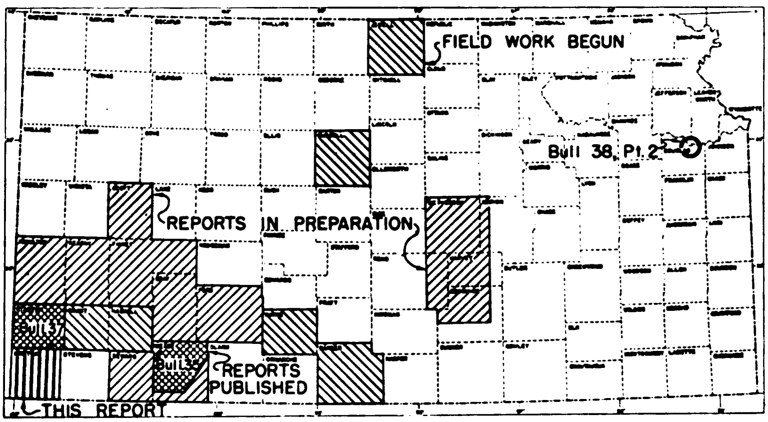

Fig. 1. Index map of Kansas showing area covered by this report and areas for which coöperative ground-water reports have been published or are in preparation.

(1911) reported on the chemical characters of the water supplies of Kansas and described briefly the geology and ground-water conditions of each county.

Theis, Burleigh, and Waite (1935) made a two-year reconnaissance of the ground-water resources of the southern High Plains and released a mimeographed summary of their findings. Later, Schoff (1939) made a detailed study of the ground water in Texas county, Oklahoma, including a section on the uplands in adjacent parts of Oklahoma and Kansas. Texas county borders Morton county on the south and has many similar hydrologic problems. Smith (1941) made a reconnaissance of the Tertiary and Quaternary geology of southwestern Kansas.

Methods of Study

The field work in Morton county was done during July, August, and part of September, 1939. Measurements were made with a steel tape in about 120 wells to determine the depth of the well and the the depth to the water level below some arbitrary measuring point (generally the top of the casing). Periodic water-level measurements were made in 19 representative wells in the county in order to obtain information on the fluctuations of the ground-water table. Thirty-six samples of water from representative wells were collected, and were analyzed by Robert H. Hess, chemist, Kansas State Board of Health.

Eleven test holes were drilled at strategic points in the county by the portable hydraulic-rotary drilling machine of the State and Federal Surveys, operated by Ellis D. Gordon and Perry McNally. The

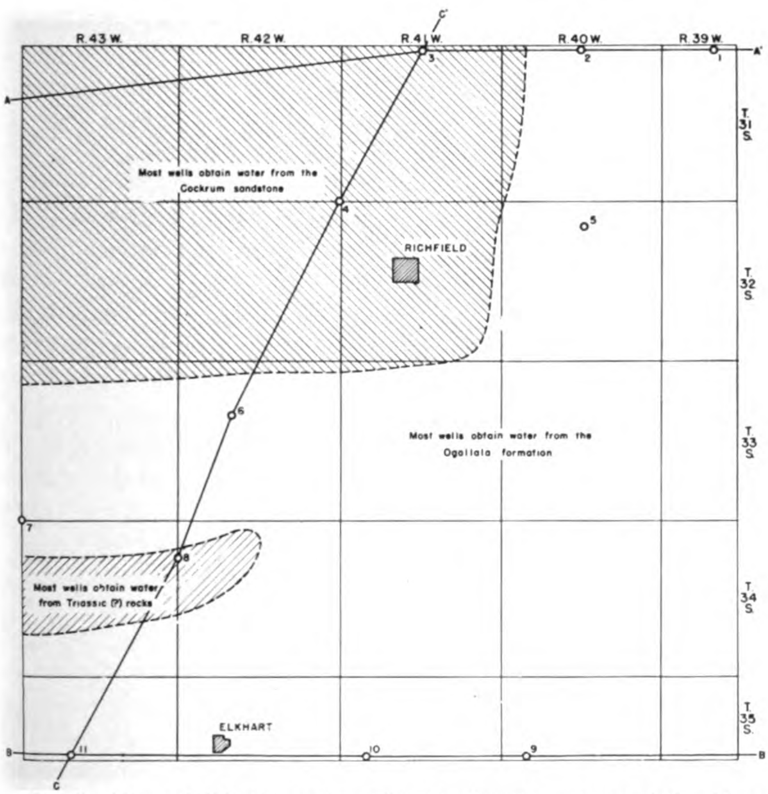

Fig. 2. Map of Morton county showing location of test holes, lines along which cross sections are drawn (plate 6 A-C), and areas in which the principal water-bearing formations supply water to wells.

locations of the test holes are shown in figure 2. The depths of the test holes ranged from 90 to 430 feet (see well logs). Five of the test holes were drilled to the Cockrum sandstone and seven penetrated Triassic(?) or Permian redbeds. The drill cuttings were collected and studied in the field by Perry McNally and were later examined with a microscope in the office. Considerable information was obtained from landowners, tenants, and drillers concerning the nature and thickness of the water-bearing beds, the quantity and quality of water available, and the use to which it is put. Well logs were obtained from water-well drillers and from companies that have drilled gas wells in the Morton county section of the Hugoton gas field. The altitudes of the measuring points of some of the water wells and of a few test holes were determined with a plane table and alidade by a level party of the Topographic Branch of the Federal Geological Survey, headed by J. B. LaDuex. This level work was done as a part of the regular coöperative topographic mapping program of the Federal and State Geological Surveys. The altitudes at the rest of the test holes were determined by the well-drilling crew—Gordon and McNally.

The field data were recorded on land-ownership maps, and were transferred in the office to a highway map of the county prepared for the Kansas Highway Planning Board by the Kansas Highway Department (pls. 1 and 2). The roads and drainage were corrected from field observations and from aerial photographs taken by the United States Department of Agriculture. A geologic map (pl. 1) was made mainly from field observations of the rock outcrops but in part from the soil map of Morton county prepared by Joel (1937). A study was made of the various kinds of soil and the rock types from which they were developed. The soil is so closely related to the parent rock from which it is derived that much of the geology, particularly the areal extent of the loess, is revealed by the soil maps. The map showing the depths to water level (pl. 2) is based mainly upon measured water levels in many wells in the county (table 6).

The wells shown on plate 2 were located within the sections by use of the speedometer, and the locations are accurate to about 0.1 mile. The wells are numbered by townships from north to south and by ranges from east to west, and within a township the wells are numbered in the same order as the sections. For each well shown on plate 2 the number above the line corresponds to the number of the well in the well tables and the number below the line is the depth to the ground-water table below a fixed measuring point.

Acknowledgments

Residents of the area were very coöperative in giving permission to measure their wells and in giving information on water supplies. Thomas Harford, of the Kansas City Power and Light Company, supplied well logs and other data on the municipal wells at Elkhart; Perry Williams gave similar information on the municipal well at Rolla; and Jake Kilbourne provided data on wells drilled by him in Morton county. The county engineer, E. C. Dean, supplied maps, well logs, and other data.

The manuscript for this report has been reviewed critically by S. W. Lohman, O. E. Meinzer, and W. D. Collins, of the Federal Geological Survey; R. C. Moore, state geologist; Ralph H. King, State Geological Survey editor; Earnest Boyce, director of the Division of Sanitation of the Kansas State Board of Health; and George S. Knapp, chief engineer of the Division of Water Resources of the Kansas State Board of Agriculture. The maps and cross sections were prepared by G. W. Reimer, draftsman of the State Survey.

GEOGRAPHY

Topography and Drainage

Morton county is in the High Plains section of the Great Plains physiographic province. It comprises a comparatively flat, nearly featureless plain interrupted by the valleys of Cimarron river and its tributaries and by an extensive area of sand dunes south of Cimarron river. About 60 percent of the area of the county is upland that is predominantly flat, but locally has broad mounds and depressions. More than 30 percent of the area is covered by dune sand, of which about 60 percent has a typical sand-dune topography. In some places the sand dunes form relatively steep, irregular hills, and in other places broad rises and depressions that locally give the area a hummocky topography. Slopes along the stream valleys make up the other 10 percent of the area. These slopes are gentle along parts of North Fork of the Cimarron but are abrupt along the north side of the main channel of the Cimarron.

The highest points in the county are in the northwestern and southwestern parts where the altitude slightly exceeds 3,700 feet. The lowest point is along North Fork of the Cimarron in the northeastern part of the county, and has an altitude of about 3,150 feet. The total relief, therefore, is about 550 feet.

The land surface in Morton county slopes toward the northeast at the rate of about 15 feet to the mile. The slope from south to north in the western part of the county is about 10 feet to the mile and in the eastern part of the county it is about 7 feet to the mile.

Morton county is drained by Cimarron river and its tributaries, all of which are intermittent streams. Cimarron river enters the county from the west at a point about 5.5 miles north of the Kansas-Oklahoma line, flows east-northeast across the county, and enters Stevens county at a point about 10.5 miles south of the Stanton-Morton county line. The valley of Cimarron river is about half a mile wide throughout the county and is 100 to 225 feet deep. It is marked on the north side by rounded bluffs and on the south side by sand dunes. The tributaries of the Cimarron are all north of the river and flow northeastward in a direction roughly parallel to the direction of flow of the Cimarron. The tributary valleys are 50 to 100 feet deep and about one mile wide.

Cimarron river rises in northeastern Colfax county, New Mexico, near the city of Raton, and flows eastward through northern Union county, New Mexico, into Cimarron county, Oklahoma, and across the southeastern corner of Baca county, Colorado, into Kansas. In dry weather it obtains its water from springs and seeps in the Mesozoic and Tertiary rocks that crop out in its drainage basin. Generally there is no visible flow in the Cimarron except after heavy rains, but the water level along much of its course is only a few feet below the stream bed.

It is interesting to note the great changes that have taken place in Cimarron river and its valley within a comparatively short time. At the present time the Cimarron usually is dry throughout most of its course in Kansas, but it may contain some water in the eastern counties even in dry weather, owing to the addition of water by tributary streams in those counties. In contrast to this, Haworth, in 1897 (p. 21) stated that

> In Kansas it [Cimarron river] has water in it throughout the greater part of the year in most of its course.

According to Johnson (1901, p. 664), in 1901 the flow near Arkalon, Seward county, was about 82 second feet and the flow at a point south of Englewood, Clark county, was large enough so that a diversion ditch, using only about one-third of the perennial flow, supplied enough water to irrigate 1,200 acres of bottom land. According to the office of the U. S. Geological Survey in Topeka, the average daily discharge of Cimarron river near Arkalon in 1938-'39 was 42.3 second feet.

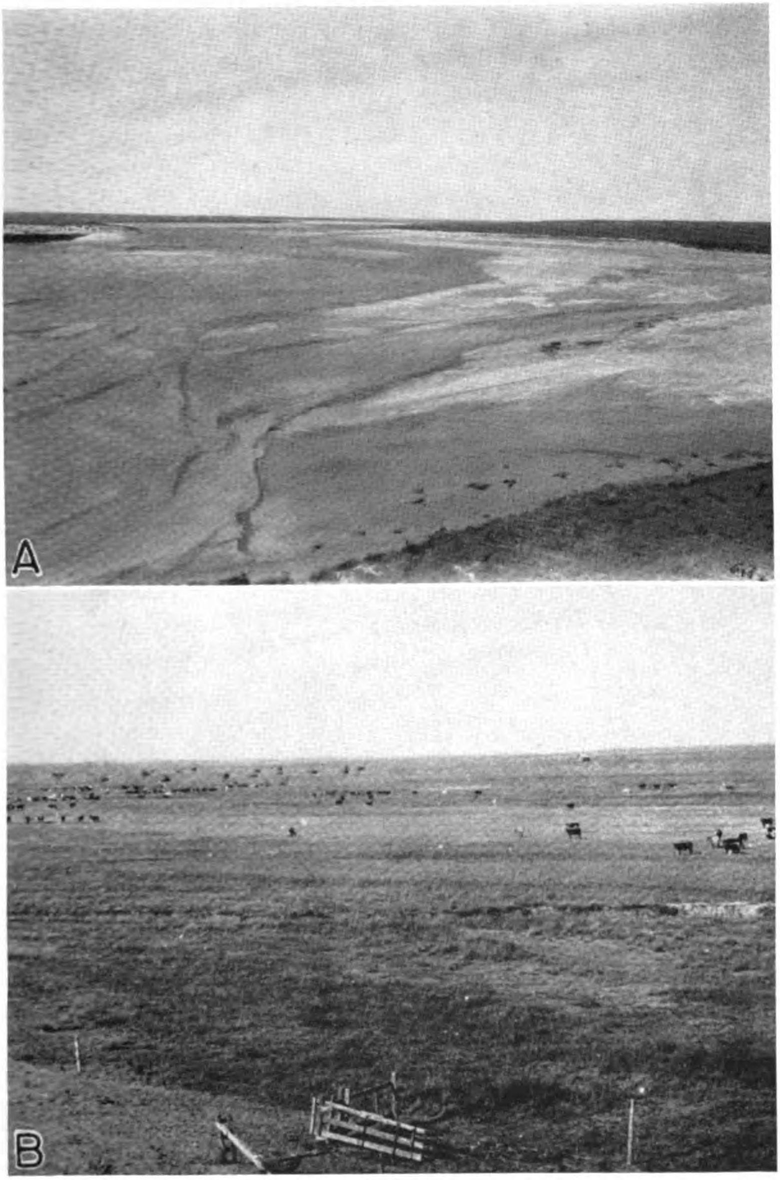

Plate 3. A, Cimarron river valley in 1939 (photo by H. A. Waite). B, Cimarron river valley in Morton county in 1899 (photo by W. D. Johnson).

In 1911 Parker (pp. 143, 144, 305-311) wrote that—

> At irregular intervals the river sinks into the sand and flows beneath the surface for a number of miles. For instance, from the old post office of Metcalf, Okla., to Point of Rocks, Kan., a distance of 25 miles, the channel of the Cimarron is often dry, but at Point of Rocks, Kan., the water comes to the surface at Wagon Bed Springs, a famous camp on the old Santa Fe trail, and the channel is usually full from that point on for a number of miles. . . .
>
> William Easton Hutchison states that the Cimarron river is a constantly running stream throughout the entire width of Morton county, where it has a valley on one side or the other of the channel from one-half mile to three miles in width, on which an abundant crop of natural hay is raised.

Prior to about 1900, the Cimarron river valley was a broad, shallow grass-covered depression, and the water table beneath the valley was near the land surface, but successive floods, particularly that of 1914, have destroyed the grass cover and left a barren area of alluvium between the bluffs on the north side and the sand hills on the south side. The marked change in the appearance of the Cimarron valley from 1899 to 1939 is shown in plate 3.

The area of sand dunes south of Cimarron river has many undrained basins in which rainfall collects, sinks into the porous material, and finds its way to the ground-water reservoir.

Climate

Morton county, like other parts of the High Plains section, has a climate characterized by low precipitation, rapid evaporation, a wide range of temperature variations, hot summers and moderate winters, and occasional blizzards. The winds are strong throughout the year, especially in late winter and early summer, the prevailing winds being from the south and southwest. These strong winds, to-

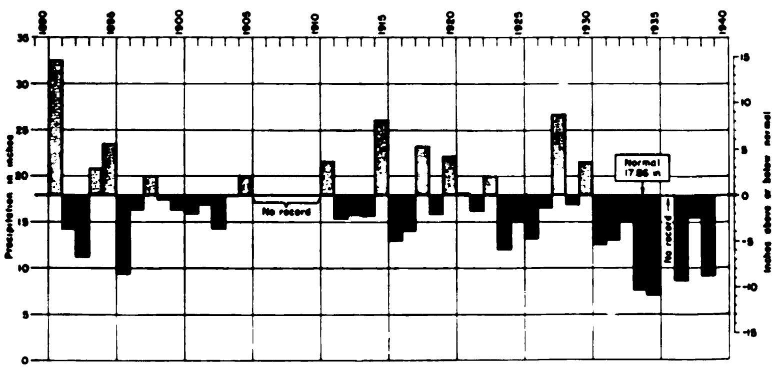

Fig. 3. Graph showing the annual precipitation at Richfield, Kan. (from records of the U. S. Weather Bureau).

gether with the extended dry periods and overcultivation of the land, have added another feature to the climate of the High Plains—the dust storm.

The annual precipitation in the southern High Plains section is extremely variable. According to the U. S. Weather Bureau the greatest annual precipitation on record in Morton county was 32.58 inches in 1891 and the least was 7.09 inches in 1935. (All climatic data, unless otherwise stated, are based on the records of the U. S. Weather Bureau's station at Richfield, Kan.) The mean annual precipitation is 17.86 inches. The graphs show the annual precipitation at Richfield (fig. 3), and the annual precipitation and departure from the normal precipitation at Elkhart (fig. 4).

The data shown in figures 3 and 4 indicate that by the end of 1939 Morton county had experienced the longest period of subnormal precipitation since the weather records were begun. The accumulated deficiency in precipitation at Elkhart by the end of 1939 exceeded 60 inches.

Many of the rains are very localized and torrential. In a single rainstorm in the summer of 1939 more than 4 inches of rain fell on a small area about 5 miles south of Elkhart, while only a trace was recorded at Elkhart. In 1925 the total precipitation recorded at Richfield was 9.8 inches less than that recorded at Elkhart, which is only 20 miles away. July is usually the wettest month of the year and January is generally the driest month. In July, 1895, the precipitation was 12.31 inches, which was more than half of the total precipitation for that year and nearly twice as great as the total precipitation in 1935. The average annual snowfall is 19.9 inches, of which the greater part falls in December and February.

The mean annual temperature in Morton county is 55.3° F. The highest temperature ever recorded in the county was 111° F., in June, and the lowest was —19° F., in January. The average date of the last killing frost in the spring is April 23, but killing frosts have occurred as late as May 22. The first killing frost in the fall has occurred as early as September 23 and as late as November 8, but it generally takes place about October 18. The average length of the growing season is about 178 days; however, the season has ranged from a minimum of 135 days in 1895 to a maximum of 204 days in 1900.

Generally more than 300 days of each year are clear or only partly cloudy, and this high percentage of clear days, together with the high summer temperatures and low humidity, results in a total yearly evaporation of about 60 to 70 inches.

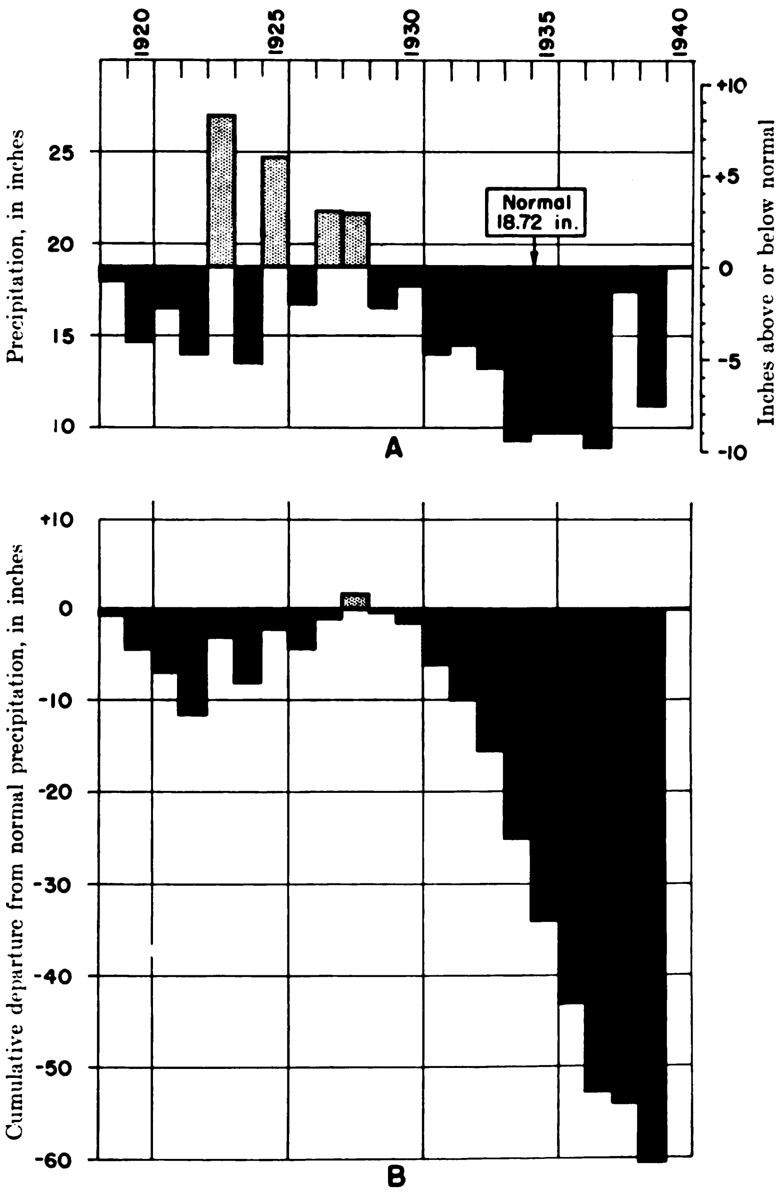

Fig. 4. Graphs showing (A) the annual precipitation at Elkhart, Kan., and (B) the cumulative departure from normal precipitation at Elkhart (from records of the U. S. Weather Bureau).

Mineral Resources

Eastern Morton county is a part of the Hugoton gas field, which is potentially one of the largest in the world. The first successful test well for gas was completed on the Boles farm, in sec. 3, T. 35 S., R. 34 W., in the summer of 1920. It had an initial production of 5,000,000 cubic feet a day. Since then more than 35 gas test wells have been drilled in Morton county. Two test wells in the western part of the county were unsuccessful, but all others in the county have had large initial production. The gas is produced from Permian rocks at depths ranging from 2,716 to 3,450 feet.

In the following table are listed the gas test wells drilled in Morton county as of 1938, and the total depth and initial production of each well. Data were supplied principally by the Argus Production Company at Hugoton.

The initial production of the wells ranges from about 1,000,000 to 14,000,000 cubic feet of gas a day, and the bottom-hole pressure is about 450 pounds to the square inch. Part of the gas is used locally by small communities and by farmers, but most of it is piped to Hugoton where it enters the main pipe lines to Kansas City and Chicago. The ready availability of large quantities of cheap natural gas may be instrumental in the development of the shallow-water irrigation area north of Rolla, which lies within the gas field.

Other than gas, the mineral resources of Morton county are scarce, so far as now known. Gravels along Cimarron river have been used to a very slight extent as road metal and as building stone, but caliche found at many places in the county is used extensively as road metal on state and county highways.

Agriculture

The settlement of Morton county began in the latter part of the 19th century. A great boom in the cattle industry began in 1880, and as a result the entire Great Plains province became fully stocked.* This era was followed by a period of severe drought from about 1886 to 1895, which caused many farmers to abandon the area and forced those who remained to begin breaking the sod to plant wheat. The Homestead Act, which granted only 160 acres of land to each family, encouraged the growth of wheat farming because 160 acres of land was scarcely sufficient to support a family if they depended entirely upon stock raising. The development of the tractor and other modern farming equipment, together with the unusually

* The future of the Great Plains: Report of the Great Plains Committee, pp. 1-112, 1936.

locations of the test holes are shown in figure 2. The depths of the test holes ranged from 90 to 430 feet (see well logs). Five of the test holes were drilled to the Cockrum sandstone and seven penetrated Triassic(?) or Permian redbeds. The drill cuttings were collected and studied in the field by Perry McNally and were later examined with a microscope in the office. Considerable information was obtained from landowners, tenants, and drillers concerning the nature and thickness of the water-bearing beds, the quantity and quality of water available, and the use to which it is put. Well logs were obtained from water-well drillers and from companies that have drilled gas wells in the Morton county section of the Hugoton gas field. The altitudes of the measuring points of some of the water wells and of a few test holes were determined with a plane table and alidade by a level party of the Topographic Branch of the Federal Geological Survey, headed by J. B. LaDuex. This level work was done as a part of the regular coöperative topographic mapping program of the Federal and State Geological Surveys. The altitudes at the rest of the test holes were determined by the well-drilling crew—Gordon and McNally.

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Acknowledgments

Residents of the area were very coöperative in giving permission to measure their wells and in giving information on water supplies. Thomas Harford, of the Kansas City Power and Light Company, supplied well logs and other data on the municipal wells at Elkhart; Perry Williams gave similar information on the municipal well at Rolla; and Jake Kilbourne provided data on wells drilled by him in Morton county. The county engineer, E. C. Dean, supplied maps, well logs, and other data.

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GEOGRAPHY

Topography and Drainage

Morton county is in the High Plains section of the Great Plains physiographic province. It comprises a comparatively flat, nearly featureless plain interrupted by the valleys of Cimarron river and its tributaries and by an extensive area of sand dunes south of Cimarron river. About 60 percent of the area of the county is upland that is predominantly flat, but locally has broad mounds and depressions. More than 30 percent of the area is covered by dune sand, of which about 60 percent has a typical sand-dune topography. In some places the sand dunes form relatively steep, irregular hills, and in other places broad rises and depressions that locally give the area a hummocky topography. Slopes along the stream valleys make up the other 10 percent of the area. These slopes are gentle along parts of North Fork of the Cimarron but are abrupt along the north side of the main channel of the Cimarron.

The highest points in the county are in the northwestern and southwestern parts where the altitude slightly exceeds 3,700 feet. The lowest point is along North Fork of the Cimarron in the northeastern part of the county, and has an altitude of about 3,150 feet. The total relief, therefore, is about 550 feet.

The land surface in Morton county slopes toward the northeast at the rate of about 15 feet to the mile. The slope from south to north in the western part of the county is about 10 feet to the mile and in the eastern part of the county it is about 7 feet to the mile.

Morton county is drained by Cimarron river and its tributaries, all of which are intermittent streams. Cimarron river enters the county from the west at a point about 5.5 miles north of the Kansas-Oklahoma line, flows east-northeast across the county, and enters Stevens county at a point about 10.5 miles south of the Stanton-Morton county line. The valley of Cimarron river is about half a mile wide throughout the county and is 100 to 225 feet deep. It is marked on the north side by rounded bluffs and on the south side by sand dunes. The tributaries of the Cimarron are all north of the river and flow northeastward in a direction roughly parallel to the direction of flow of the Cimarron. The tributary valleys are 50 to 100 feet deep and about one mile wide.

Cimarron river rises in northeastern Colfax county, New Mexico, near the city of Raton, and flows eastward through northern Union county, New Mexico, into Cimarron county, Oklahoma, and across the southeastern corner of Baca county, Colorado, into Kansas. In dry weather it obtains its water from springs and seeps in the Mesozoic and Tertiary rocks that crop out in its drainage basin. Generally there is no visible flow in the Cimarron except after heavy rains, but the water level along much of its course is only a few feet below the stream bed.

It is interesting to note the great changes that have taken place in Cimarron river and its valley within a comparatively short time. At the present time the Cimarron usually is dry throughout most of its course in Kansas, but it may contain some water in the eastern counties even in dry weather, owing to the addition of water by tributary streams in those counties. In contrast to this, Haworth, in 1897 (p. 21) stated that

> In Kansas it [Cimarron river] has water in it throughout the greater part of the year in most of its course.

According to Johnson (1901, p. 664), in 1901 the flow near Arkalon, Seward county, was about 82 second feet and the flow at a point south of Englewood, Clark county, was large enough so that a diversion ditch, using only about one-third of the perennial flow, supplied enough water to irrigate 1,200 acres of bottom land. According to the office of the U. S. Geological Survey in Topeka, the average daily discharge of Cimarron river near Arkalon in 1938-'39 was 42.3 second feet.

PLATE 3. A, Cimarron river valley in 1939 (photo by H. A. Waite). B, Cimarron river valley in Morton county in 1899 (photo by W. D. Johnson).

In 1911 Parker (pp. 143, 144, 305-311) wrote that—

> At irregular intervals the river sinks into the sand and flows beneath the surface for a number of miles. For instance, from the old post office of Metcalf, Okla., to Point of Rocks, Kan., a distance of 25 miles, the channel of the Cimarron is often dry, but at Point of Rocks, Kan., the water comes to the surface at Wagon Bed Springs, a famous camp on the old Santa Fe trail, and the channel is usually full from that point on for a number of miles. . . .
>
> William Easton Hutchison states that the Cimarron river is a constantly running stream throughout the entire width of Morton county, where it has a valley on one side or the other of the channel from one-half mile to three miles in width, on which an abundant crop of natural hay is raised.

Prior to about 1900, the Cimarron river valley was a broad, shallow grass-covered depression, and the water table beneath the valley was near the land surface, but successive floods, particularly that of 1914, have destroyed the grass cover and left a barren area of alluvium between the bluffs on the north side and the sand hills on the south side. The marked change in the appearance of the Cimarron valley from 1899 to 1939 is shown in plate 3.

The area of sand dunes south of Cimarron river has many undrained basins in which rainfall collects, sinks into the porous material, and finds its way to the ground-water reservoir.

Climate

Morton county, like other parts of the High Plains section, has a climate characterized by low precipitation, rapid evaporation, a wide range of temperature variations, hot summers and moderate winters, and occasional blizzards. The winds are strong throughout the year, especially in late winter and early summer, the prevailing winds being from the south and southwest. These strong winds, to-

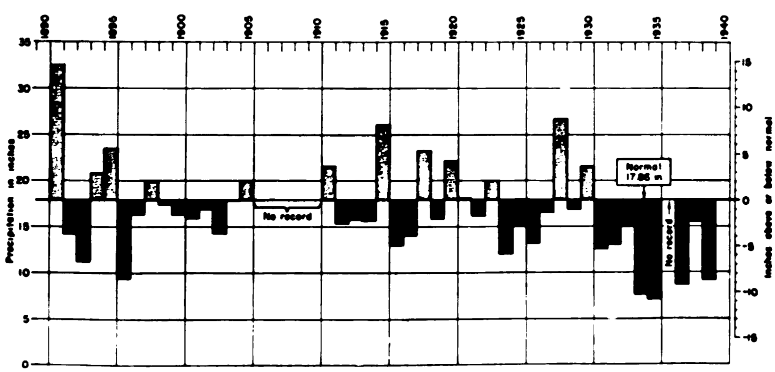


Fig. 3. Graph showing the annual precipitation at Richfield, Kan. (from records of the U. S. Weather Bureau).

gether with the extended dry periods and overcultivation of the land, have added another feature to the climate of the High Plains—the dust storm.

The annual precipitation in the southern High Plains section is extremely variable. According to the U. S. Weather Bureau the greatest annual precipitation on record in Morton county was 32.58 inches in 1891 and the least was 7.09 inches in 1935. (All climatic data, unless otherwise stated, are based on the records of the U. S. Weather Bureau's station at Richfield, Kan.) The mean annual precipitation is 17.86 inches. The graphs show the annual precipitation at Richfield (fig. 3), and the annual precipitation and departure from the normal precipitation at Elkhart (fig. 4).

The data shown in figures 3 and 4 indicate that by the end of 1939 Morton county had experienced the longest period of subnormal precipitation since the weather records were begun. The accumulated deficiency in precipitation at Elkhart by the end of 1939 exceeded 60 inches.

Many of the rains are very localized and torrential. In a single rainstorm in the summer of 1939 more than 4 inches of rain fell on a small area about 5 miles south of Elkhart, while only a trace was recorded at Elkhart. In 1925 the total precipitation recorded at Richfield was 9.8 inches less than that recorded at Elkhart, which is only 20 miles away. July is usually the wettest month of the year and January is generally the driest month. In July, 1895, the precipitation was 12.31 inches, which was more than half of the total precipitation for that year and nearly twice as great as the total precipitation in 1935. The average annual snowfall is 19.9 inches, of which the greater part falls in December and February.

The mean annual temperature in Morton county is 55.3° F. The highest temperature ever recorded in the county was 111° F., in June, and the lowest was —19° F., in January. The average date of the last killing frost in the spring is April 23, but killing frosts have occurred as late as May 22. The first killing frost in the fall has occurred as early as September 23 and as late as November 8, but it generally takes place about October 18. The average length of the growing season is about 178 days; however, the season has ranged from a minimum of 135 days in 1895 to a maximum of 204 days in 1900.

Generally more than 300 days of each year are clear or only partly cloudy, and this high percentage of clear days, together with the high summer temperatures and low humidity, results in a total yearly evaporation of about 60 to 70 inches.

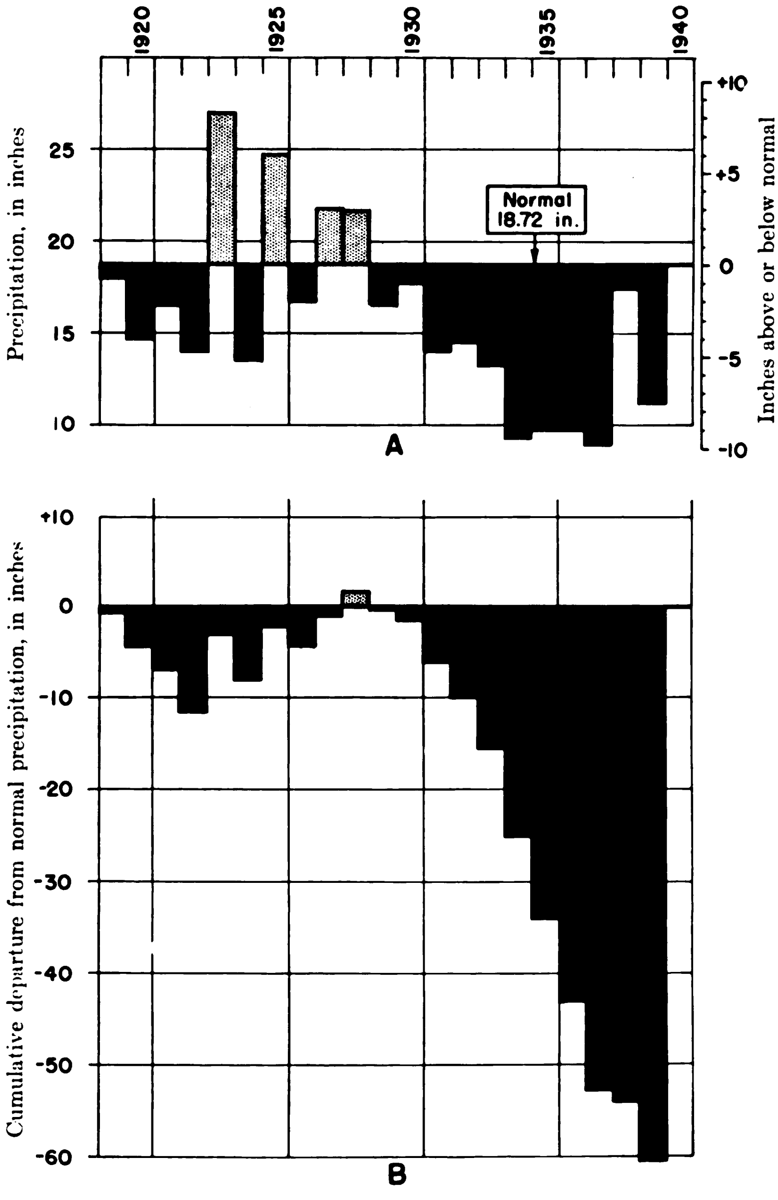


FIG. 4. Graphs showing (A) the annual precipitation at Elkhart, Kan., and (B) the cumulative departure from normal precipitation at Elkhart (from records of the U. S. Weather Bureau).

Mineral Resources

Eastern Morton county is a part of the Hugoton gas field, which is potentially one of the largest in the world. The first successful test well for gas was completed on the Boles farm, in sec. 3, T. 35 S., R. 34 W., in the summer of 1920. It had an initial production of 5,000,000 cubic feet a day. Since then more than 35 gas test wells have been drilled in Morton county. Two test wells in the western part of the county were unsuccessful, but all others in the county have had large initial production. The gas is produced from Permian rocks at depths ranging from 2,716 to 3,450 feet.

In the following table are listed the gas test wells drilled in Morton county as of 1938, and the total depth and initial production of each well. Data were supplied principally by the Argus Production Company at Hugoton.

The initial production of the wells ranges from about 1,000,000 to 14,000,000 cubic feet of gas a day, and the bottom-hole pressure is about 450 pounds to the square inch. Part of the gas is used locally by small communities and by farmers, but most of it is piped to Hugoton where it enters the main pipe lines to Kansas City and Chicago. The ready availability of large quantities of cheap natural gas may be instrumental in the development of the shallow-water irrigation area north of Rolla, which lies within the gas field.

Other than gas, the mineral resources of Morton county are scarce, so far as now known. Gravels along Cimarron river have been used to a very slight extent as road metal and as building stone, but caliche found at many places in the county is used extensively as road metal on state and county highways.

Agriculture

The settlement of Morton county began in the latter part of the 19th century. A great boom in the cattle industry began in 1880, and as a result the entire Great Plains province became fully stocked.* This era was followed by a period of severe drought from about 1886 to 1895, which caused many farmers to abandon the area and forced those who remained to begin breaking the sod to plant wheat. The Homestead Act, which granted only 160 acres of land to each family, encouraged the growth of wheat farming because 160 acres of land was scarcely sufficient to support a family if they depended entirely upon stock raising. The development of the tractor and other modern farming equipment, together with the unusually

* The future of the Great Plains: Report of the Great Plains Committee, pp. 1-112, 1936.

TABLE 1.—*Ownership, location, depth, and initial production of natural gas wells in Morton county.*

OWNER OF PROPERTY.	Name of company.	Location	Depth, feet.	Initial production, cubic feet a day.
E. M. Watkins	Watkins Land Co.	NE¼ sec. 11, T. 31 S., R. 43 W	1,130	Dry
J. F. Simmons	Texas Interstate Pipeline Co.	SE¼ sec. 16, T. 32 S., R. 39 W	2,880	3,000,000
L. C. Morgan	Argus Production Co.	SE¼ sec. 6, T. 33 S., R. 39 W	2,775	1,000,000
A. O. Mangels	do	SE¼ sec. 4, T. 33 S., R. 39W	3,314	1,500,000
Hy. Garner	do	SE¼ sec. 18, T. 33 S., R. 39 W	2,714	2,250,000
Wm. Mangels	do	SW¼ sec. 19, T. 33 S., R. 39 W	2,906	1,000,000
E. E. Mangels	do	NE¼ ec. 20, T. 33 S., R. 39 W	2,704	3,250,000
G. L. Hayward	do	NW¼ sec. 31, T. 33 S., R. 39 W	2,830	1,500,000
R. E. Burton	do	SE¼ sec. 11, T. 33 S., R. 40 W	2,761	1,500,000
E. F. Chambers	do	NW¼ sec. 25, T. 33 S., R. 40 W	2,853	1,500,000
Wm. Models	do	NW¼ sec. 4, T. 34 S., R. 39 W	2,851	13,500,000
R. Armstrong	do	SW¼ sec. 4, T. 34 S., R. 39 W	2,900	11,500,000
Minnie Mangels	do	SW¼ sec. 6, T. 34 S., R. 39 W	2,900	3,750,000
F. A. Thompson	do	SW¼ sec. 7, T. 34 S., R. 39 W	2,900	3,000,000
G. L. Hayward	do	NW¼ sec. 8, T. 34 S., R. 39W	2,852	4,500,000
S. M. Dreibelbis	do	NW¼ sec. 9, T. 34 S., R. 39 W	2,810	13,000,000
S. M. Dreibelbis	do	NE¼ sec. 9, T. 34 S., R. 39 W	2,900	6,000,000
G. L. Hayward	do	SW¼ sec. 9, T. 34 S., R. 39 W	2,871	14,000,000
L. Snare	do	SE¼ sec. 9, T. 34 S., R. 39 W	2,800	10,000,000
Ralph Armstrong	do	NW¼ sec. 16, T. 34 S., R. 39 W	2,933	8,500,000
F. A. Thompson	do	NW¼ sec. 18, T. 34 S., R. 39 W	2,810	6,500,000
M. S. Dixon	do	SE¼ sec. 18 T. 34 S., R. 39 W	2,900	4,500,000
Geo. Dorth	do	NE¼ sec. 20, T. 34 S., R. 39 W	2,850	6,500,000
L. M. Tillett	do	SW¼ sec. 21, T. 34 S., R. 39 W	2,840	8,500,000
Helen Ehrhard	do	NW¼ sec. 28, T. 34 S., R. 39 W	2,750	9,750,000
W. H. Sullivan	do	NW¼ sec. 29, T. 34 S., R. 39 W	2,795	3,000,000
W. R. Littell	do	SW¼ sec. 24, T. 34 S., R. 40 W	2,826	4,000,000
Mrs. J. W. Watson	do	NE¼ sec. 27, T. 34 S., R. 40 W	2,716	6,000,000
Butts	Hydraulic Oil Co.	Middle sec. 22, T. 34 S., R. 43 W	3,450	Dry
G. H. Rickarts	Missouri-Kansas Gas Co.	SE¼ sec. 5, T. 35 S., R. 39 W	2,805	6,000,000
Clara L. Greening	Texas Interstate Pipeline Co.	Middle sec. 6, T. 35 S., R. 39 W	....	2,000,000
C. H. Rickarts	do	SE¼ sec. 8, T. 35 S., R. 39 W	2,854	5,500,000
R. S. Phillips	do	SE¼ sec. 9, T. 35 S., R. 39 W	2,838	12,000,000
R. S. Phillips	do	SE¼ sec. 16, T. 35 S., R. 39 W	2,795	10,500,000

high prices that were paid for farm products during World War I, led to overcultivation of the area between 1910 and 1920, and left almost no grazing land after 1920. The results might have been disastrous had it not been for the period of above-normal precipitation that produced several large wheat crops in the decade between 1920 and 1930.

The largest crop on record was that of 1926, when many fields produced more than 50 bushels to the acre and some yielded nearly 65 bushels. After 1930 there followed a drought worse than any since the county was first settled. For the nine years from 1931 to 1939 the cumulative deficiency of rainfall exceeded 61 inches and the average annual rainfall for that period was nearly 7 inches below normal.

As a result of overcultivation and repeated dry seasons the soil in this area began to be blown, and since 1934 serious damage has been done both by depletion of the soil and by the accumulation of windblown material (pl. 4).

The soils of Morton county are predominantly of three types (soil types 1, 2, and 5 of Joel, 1937, pp. 8-14): Soil type 1 is a heavy, compact, dark soil consisting of clay loams and silty clay loams and is especially suited for growing wheat and other small grains. This type of soil is derived from the loess that covers the northern half of Morton county (pl. 1). Although this type of soil is very susceptible to wind erosion, it is very thick and is not easily depleted.

Soil type 2 is a moderately friable brown and light-colored soil consisting of silt loams and clay loams over a calcareous subsoil. This type of soil is derived from the Ogallala formation and possibly in part from a very thin blanket of loess.

Soil type 5 is a light-textured, sandy soil made up of sands and loamy sands. It is derived from old subdued sand dunes and is subject to severe wind erosion where cultivation has removed the vegetative cover. These soils are very favorable for the cultivation of row crops, especially sorghums.

Because of the predominance of soils that are susceptible to severe wind erosion, Morton county has been more seriously damaged by the wind than has any other county in the entire "dust-bowl" area. More than 78 percent of the county is affected by serious wind erosion (Joel, 1937, p. 44). In much of this area, however, the wind erosion is being checked, in part by the work of the Soil Conservation Service.

In 1935, a total of 339,818 acres of land was under cultivation in Morton county (Joel, 1937, pp. 16-21). There were 475 farms and

PLATE 4. A, Abandoned farm west of Richfield, showing accumulation of wind-blown dust around the barn (photo by S. W. Lohman). B, Flowing artesian well (pl. 2, well 43) at Richfield (photo by H. A. Waite).

the average farm comprised 715 acres. About 45 percent of these farms were operated by tenants and about 55 percent were operated by the landowners or their employees. In general about 30 to 50 percent of the crop is abandoned each year before harvest, according to the county farm agent. Much of the badly eroded land is being purchased by the Soil Conservation Service. By May 1, 1940, a total of 90,651 acres had been bought and 15,000 acres more was under option, according to Soil Conservation Service figures.

Wheat is the predominant crop in Morton county, as in other parts of southwestern Kansas. The wheat acreage increased from 19,999 acres in 1924 to 71,852 acres in 1930. The following list of crops grown in Morton county was compiled by the 1930 census.

TABLE 2. *Acreage of principal crops grown in Morton county in 1930.*

Wheat	71,852
Sorghums	34,321
Corn	18,334
Broomcorn	10,786
Barley	4,461
Others	402

POPULATION

According to the Census Bureau the population of Morton county in 1940 was 2,186, or about 3 persons to the square mile. This is about a 46 percent reduction in population during the decade.

The principal cities are Elkhart, Rolla, and Richfield. Richfield, the oldest city in the county, once had a population of about 1,500, but now has only 96 residents. Elkhart was organized after the building of the railroad through the county in 1912. Its population in 1930 was 1,435, but in 1940 it was only 902. Rolla, incorporated in 1921, had a population of 437 in 1930, but in 1940 it had only 284 inhabitants.

The fluctuations of the population in Morton county have been closely related to the fluctuations of climatic conditions and crop prices. The population of the county was 724 in 1890, but decreased to 304 in 1900, after the severe drought between 1886 and 1895. The development of the tractor and the rising war-time prices caused the population to increase rapidly to 3,177 by 1920. The population of the county continued to increase during the next decade because of a series of good crop years, but since 1930 it has decreased considerably as a result of the dust storms and drought.

TABLE 3.—*Generalized section of the geologic formations in Morton county.*

System.	Series.	Subdivision.	Thickness, feet.	Physical character.	Water supply.
Quaternary.	Pleistocene and Recent.	Alluvium.	0–75 (?)	Sand and gravel containing Some silt and clay.	Yields adequate supplies of hard water to stock wells in the Cimarron river valley.
		—unconformable on older formations—			
		Dune sand.	0–75 (?)	Medium-grained, well-rounded quartz sand.	Does not yield water to wells in Morton county, but serves as catchment area for rainfall.
		—unconformable on older formations—			
		Loess.	0–15	Silt and some sand and clay.	Does not yield water to wells in Morton county.
		—unconformable on older formations—			
Tertiary and Quaternary.	Pliocene and Pleistocene.	Pliocene (including the Ogallala formation) and Pleistocene undifferentiated.	30–600	Predominantly silt, but also sand, gravel, caliche, and some clay.	Principal water-bearing formation in Morton county. Yields adequate supplies of moderately hard water to domestic, stock, municipal, and irrigation wells.
		—unconformable on older formations—			
Cretaceous.	Dakota group.*	Cockrum sandstone.	40–160	Fine-grained, buff sandstone and buff to brown clay.	Yields adequate supplies of moderately hard water to domestic, stock, and irrigation wells in the northwestern part of the county.
		Kiowa shale.	30–85	Dark-gray and blue-gray shales and beds of sandstone.	Yields little or no water to wells in Morton county.
		—local disconformity—			
		Cheyenne sandstone.	0–125	Medium- to coarse-grained gray and white sandstone.	Yields adequate supplies of moderately hard water to wells in the northwestern part of the county.
Jurassic(?).		Morrison(?) formation.	0–50	Bluish-green marl containing thin beds of gray and buff sandstone.	Yields little or no water to wells in Morton county.
		—unconformity—			
Triassic(?).		Undifferentiated redbeds.	300 ±	Buff and red fine-grained sandstones and red siltstones.	The upper beds yield adequate supplies of moderately hard water to wells near Point Rock. The lower beds yield moderate quantities of very hard water to artesian wells near Point Rock.
		—unconformity (?)—			
Permian.	Leonard and Guadalupe.*	Undifferentiated redbeds.	1100 ±	Red sandstones and siltstones and some beds of gypsum, anhydrite, and dolomite.	Yields large quantities of strongly mineralized water to flowing wells in the vicinity of Richfield.

* Classification of the State Geological Survey of Kansas.

TRANSPORTATION

A branch line of the Atchison, Topeka, and Santa Fe Railway was built through the county in 1912. It extends from Dodge City, Kan., to Boise City, Okla., and serves the cities of Elkhart, Wilburton, and Rolla.

One hard-surfaced road, Kansas highway 45, crosses the county parallel to the railroad from Rolla to Elkhart. Kansas highway 27 is hard surfaced from Elkhart to Cimarron river and is topped with caliche from the river to Richfield and to Johnson. A caliche-surfaced road, Kansas highway 51, extends from the Colorado-Kansas boundary through Richfield, Rolla, and Hugoton.

The hard-surfaced roads are the only all-weather roads in the county. Because of the slight precipitation and great evaporation, however, the earth roads are passable during most of the year. Drifting sand in the area south of the river makes the roads impassable more often than do rain and snow. Very few roads have been built across the sand dunes south of the river.

GENERAL GEOLOGY

SUMMARY OF STRATIGRAPHY

The rocks that crop out in Morton county are all of sedimentary origin and their areal extent is shown on plate 1. The rocks that supply water to wells in this area range in age from Permian to Recent. The principal water-bearing beds are the unconsolidated silts, sands, and gravels of Tertiary and Quaternary age (including the Ogallala formation) that overlie the Mesozoic and Paleozoic rocks. For simplicity of treatment the Pliocene and undifferentiated Pleistocene deposits are referred to in this report under the name Ogallala formation.

The character and ground-water supply of the geologic formations in Morton county are described briefly in the following generalized section (table 3) and in more detail under "Water-bearing formations."

GEOLOGIC HISTORY

The geologic history of Morton county is similar to that of much of the High Plains section. Morton county is underlain by thick deposits of limestone, sandstone, shale, clay, sand, and gravel and lesser amounts of salt and gypsum. The character, appearance, and relationships of these rocks as studied in well cuttings and at outcrops reveal considerable of the geologic history of the region.

Paleozoic Era

Very little is known of the early Paleozoic sediments in this county for they do not crop out and have not been reached by deep test drilling. According to Darton (1920, p. 7) the seas covered a large part of western Kansas during most of the Paleozoic era except possibly during the Silurian and Devonian periods. Marine deposits of Cambrian and Ordovician age crop out along the Front Range in Colorado and have been penetrated by test wells in central and eastern Kansas. It is probable that these sediments also underlie southwestern Kansas.

The seeming absence of any deposits of Silurian or Devonian age in this area suggests a widespread land area at that time. If any sediments were laid down at that time they were removed by later erosion, probably during early Mississippian time.

In 1925 a well was drilled in southern Hamilton county to a depth of 5,486 feet. It encountered thick deposits of marine limestone and shale of Mississippian, Pennsylvanian, and early Permian age as well as deposits of salt, gypsum, and redbeds of late Permian age. The marine character of the limestone and shale indicates widespread invasions by the sea. These invasions probably were interrupted by many short periods of emergence.

In Late Permian time there was general emergence that produced shallow basins and broad mud flats in which the redbeds were deposited. The red color of these beds together with the presence of thick deposits of gypsum and salt indicate an arid climate in Late Permian time.

Mesozoic Era

TRIASSIC(?) PERIOD

The conditions during the Triassic(?) period were probably not much changed from those in Late Permian time, for the Triassic(?) deposits are very similar in character to the Upper Permian deposits. They consist of redbeds, buff to white sandstones, and a very small amount of gypsum.

Not all of the Triassic system is represented in Morton county. The absence of part of these rocks indicates either that they were never deposited or that they were deposited and subsequently removed by erosion.

JURASSIC PERIOD

Rocks of Jurassic age (Morrison formation) crop out at Two Buttes in southern Prowers county, Colorado, about 50 miles northwest of Richfield. Test hole 4, in the southeastern corner of sec. 36,

T. 31 S., R. 42 W., penetrated 40 feet of blue-green marl and buff sandstone that probably is equivalent to the Morrison formation. Other test holes drilled in the county by the State and Federal Geological Surveys failed to encounter these beds. Fossil remains of dinosaurs and other land animals have been collected from the Morrison beds in other areas. During the Jurassic period Morton county was part of a large land mass upon which the fluviatile Morrison beds were laid down. Subsequent erosion removed much of these beds.

CRETACEOUS PERIOD

The standstones of the Cheyenne formation were deposited in this area in Early Cretaceous time. According to Twenhofel (1924, p. 19) they were deposited in shallow seas or by streams. Then followed an invasion of the sea and the deposition of the dark, very fossiliferous Kiowa shale. At the beginning of Late Cretaceous time sandstones and clays were laid down probably under both fluviatile and near-shore marine conditions. These beds were formerly known as the Dakota sandstone, but for reasons given later, are called the Cockrum sandstone in this report. In certain areas the sandstone contains salt water and marine fossils and is well stratified, but fossil plants found in the Cockrum sandstone in other areas suggest a fresh-water origin. Moore (1933, p. 443) suggests that the Cockrum sandstone is a stream-laid and sea-worked deposit. Marine sediments of Late Cretaceous age probably were deposited in all or part of Morton county and removed by erosion during late Cretaceous and early Tertiary time.

Cenozoic Era

TERTIARY PERIOD

The Cretaceous period was followed by great uplifts that produced the Rocky Mountains and uplifted the High Plains section. This orogeny was followed by a long period of erosion that lasted until Late Tertiary (Pliocene) time. During Late Tertiary and Early Quaternary (Pleistocene) time sediments from the Rock Mountains were carried eastward by streams and deposited as the Ogallala formation and younger undifferentiated Pleistocene beds on the eroded surface of Permian and Mesozoic rocks. The nature of the vertebrate fossils found in these beds in southwestern Kansas suggests that the climate was cooler and more moist than at the present time.

QUATERNARY PERIOD

Conditions similar to those of Pliocene time existed in Morton county during the early part of the Quaternary period. Great dust storms during the Quaternary period deposited a blanket of loess over much of the county north of Cimarron river, and dune sand was laid down in the area south of the river. Erosion during the Quaternary period stripped the area of some of its cover of Tertiary sediments, exposing, in places, part of the underlying Mesozoic rocks. The Cimarron valley and other topographic features of the area were developed in Quaternary time, and alluvium was deposited by Cimarron river and some of its tributaries.

GROUND WATER

PRINCIPLES OF OCCURRENCE

The discussion of the principles governing the occurrence of ground water that is given here takes account of conditions in Morton county. Preparation of the discussion has been based chiefly on the authoritative and detailed treatment of the occurrence of ground water by Meinzer (1923), to which the reader is referred for more extended consideration. A general discussion of the principles of ground-water occurrence, with special reference to Kansas, has been published by Moore (1940).

The rocks that make up the outer crust of the earth are generally not entirely solid, but contain numerous openings, called voids or interstices, which may contain air, natural gas, oil, or water. The number, size, shape, and arrangement of the interstices in rocks depends upon the character of the rocks. The occurrence of water in any region is therefore determined by the geology.

The interstices or voids in rocks range in size from microscopic openings to the huge caverns found in some limestones. The open spaces are generally connected so that water may percolate from one to another, but in some rocks these open spaces are isolated and the water has little chance to percolate. In Morton county the rocks from which ground water is obtained are sandstones and poorly consolidated silts, sands, and gravels. Generally the sands and gravels of the Ogallala formation contain numerous interstices and water percolates freely through them, but locally these interstices may be filled with calcium carbonate or other material such as clay, which makes the rock almost impermeable. Much of the silt, sand, and gravel of the Ogallala formation is poorly sorted and the finer particles fill much of the space between the larger particles, thereby decreasing the amount of space available to ground water. The sandstones of the Permian, Triassic(?), and Dakota are cemented with iron oxide, calcium carbonate, or silicon dioxide. The cement occupies a part of the open spaces, but enough voids are left to carry some water.

The porosity of a rock is the percentage of the total volume of the rock that is occupied by the interstices. A rock is said to be saturated when all its interstices are filled with water or other liquid, and the porosity is then practically the percentage of the total volume of rock that is occupied by water.

The porosity of a rock determines only the amount of water a given rock can hold, not the amount it may yield to wells. Some rocks may be moderately porous and yet will not yield an appreciable amount of water to a well. The permeability of a rock is defined as its capacity for transmitting water under pressure and is measured by the rate at which it will transmit water through a given cross section under a given difference of pressure per unit of distance. A rock containing very small interstices may be very porous, but it would be difficult to force water through it, whereas a coarser-grained rock, although it may have less porosity, generally is much more permeable. Some water is held in rocks by the force of molecular attraction, which, in some fine-grained rocks, is sufficiently great to make the rock relatively impermeable.

Below a certain level in the earth's crust the permeable rocks generally are saturated with water and are said to be in the zone of saturation. The upper surface of the zone of saturation is called the ground-water table or simply the water table. All the rocks above the water table are in the zone of aeration, which ordinarily consists of three parts: the belt of soil water, the intermediate or vadose zone, and the capillary fringe.

The belt of soil water lies just below the land surface and contains a small amount of water held by molecular attraction. The soil zone must first be saturated with water before any water can percolate downward to the water table. The thickness of the zone is dependent upon the character and thickness of the soil and upon the precipitation.

The intermediate or vadose zone lies between the belt of soil water and the capillary fringe. The interstices in the rocks in this zone are generally filled with air but may contain water for a short time while it is moving downward from the belt of soil moisture to the ground-water table. The vadose zone may be absent in places, such as some river valleys where the water table is near the surface, or it may be several hundred feet thick, as in parts of Morton county.

The capillary fringe lies directly above the water table and is formed by water rising from the zone of saturation by capillary action. The water in the capillary fringe is not available to wells, which must be deepened to the zone of saturation before water will enter them. The capillary fringe may be absent in coarse sediments, where the capillary attraction is negligible, but may be as much as 8 feet thick in very fine-grained sediments.

Artesian Wells

The pressure head of water has been defined as the height that a column of water will rise in a tightly cased well that has no discharge. Ground water is said to have artesian, normal, or subnormal pressure head, according as its static level is above the upper surface of the zone of saturation, at this surface, or below this surface. Artesian water, therefore, may be defined as ground water that has artesian head.

In some of the rock formations of Morton county, strata of permeable rock, such as sandstone, alternate with less permeable beds, such as shale or siltstone. In this county the strata dip toward the east, so that water falling on the outcrop area of a permeable bed moves eastward down the dip between the confining layers of relatively impermeable material and saturates the permeable stratum. Under such conditions wells drilled to the water-bearing beds in Morton county may, and locally do, encounter water under artesian pressure, and in two areas this pressure is sufficient to cause them to flow.

About 50 years ago three flowing artesian wells were drilled in the vicinity of Richfield. Well 43 (pls. 4B, 5), on the E. C. Wilson farm in the SW¼ sec. 16, T. 32 S., R. 41 W., reported to be 710 feet deep, flows at the rate of 20 gallons a minute from a stratum encountered at a depth of 637 feet. The intial flow of the well was reported by the drillers and by Coffey and Rice (1912, p. 101) to have been about 1,200 gallons a minute.

Well 44, on the A. C. Dean farm in the SE¼ sec. 28, T. 32 S., R 41 W., is reported to be 610 feet deep and to have had an initial flow of about 350 gallons a minute, but the present flow is only 7.5 gallons a minute. Well 45, on the C. W. Orth farm in the NE¼ sec. 21, T. 32 S., R. 41 W., is reported to be 558 feet deep and it flows less than 1 gallon a minute. It is reported that its flow has always

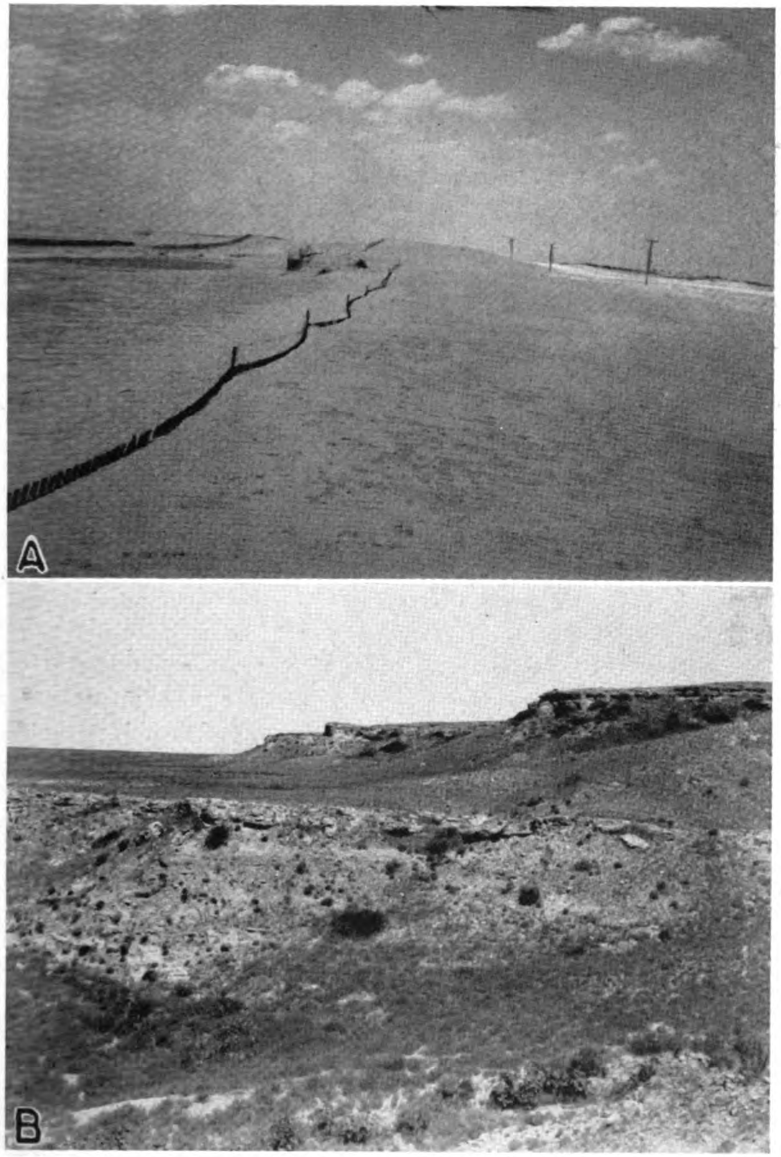


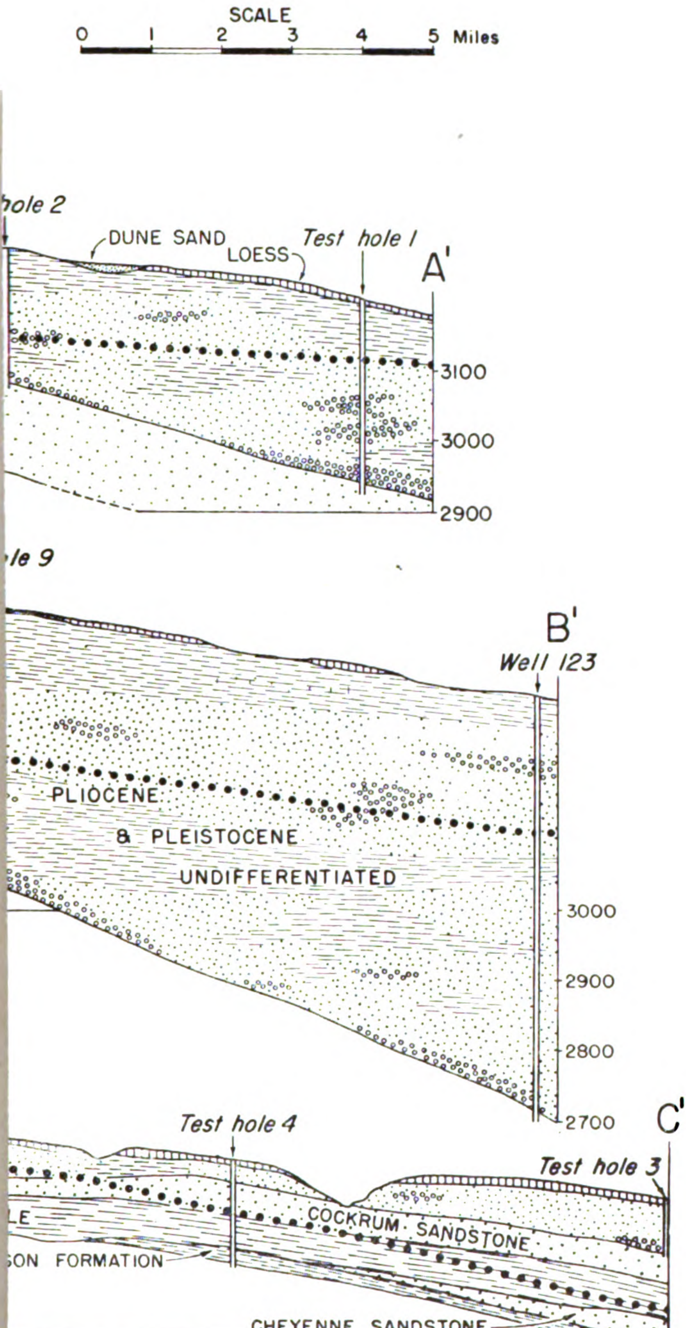
PLATE 5. A, Active sand dunes along Cimarron river near Rolla (photo by H. A. Waite). B, Point Rock, on the north side of the Cimarron valley near Elkhart; the lower beds are Triassic(?) redbeds and the upper beds are a part of the Ogallala formation (photo by H. A. Waite).

been small, even though the well stands at a lower altitude than wells 43 and 44.

The artesian water-bearing bed in the Richfield area is a red sandstone that lies nearly 350 feet below the base of the Cockrum sandstone and is probably Permian in age. Thick beds of red siltstone above and below the sandstone serve as the confining beds. The source area for the artesian water in Morton county is not definitely known. The nearest probable source is the outcrop area of redbeds along Purgatoire and Chaquaco rivers in the north-central part of Las Animas county, Colorado. The redbeds crop out near the crest of the Red Rocks dome and dip eastward into Morton county at the rate of about 20 feet to the mile. The redbeds exposed at Red Rocks dome are more than 375 feet thick and the part believed to be of Permian age (Parker, 1934, p. 44) is about 85 feet thick. The rocks consist predominantly of red sandstones and siltstones, but there are a few thin beds of limestone. The redbeds above Permian (the Dockum? and Exeter) are red sandstones and could readily serve as source rocks. Rainwater falling on sandstones of the Dockum(?) and Exeter may move downward into Permian beds before striking impermeable strata and moving eastward along the dip of the strata.

The extent of the Richfield artesian area is not known, but if the reported data on the pressure head of well 43 are correct, there may be a fairly large area in which flowing artesian wells could be obtained. The three flowing wells that have been drilled in this area are in the valley of North Fork of Cimarron river and it is likely that the area of artesian flow is limited to a part of this valley.

Flowing wells have been obtained also in the vicinity of Point Rock, particularly along Cimarron river (pl. 6B). A well drilled many years ago near Point Rock is reported to have had a small flow from a depth of 202 feet, and test well 7, drilled in 1939 at Point Rock about 80 feet north of the river in sec. 12, T. 34 S., R. 43 W., encountered a small artesian flow in redbeds at a depth of 200 feet. The Hydraulic Oil Company No. 1 Butts well, in the middle of sec. 22, T. 34 S., R. 43 W., found artesian water at a depth of 204 to 212 feet, but there are no data on the flow or the head of the well. A stock well beside Cimarron river in southeastern Baca county, Colorado, is reported to have had a moderate flow from a depth of about 100 feet, but no data are available as to the head of the water or the character of the water-bearing material. Parker (1911, pp. 143-144, 305-311) reported several artesian wells



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90 to 105 feet deep along the Cimarron river valley south and southwest of Richfield, and states that an artesian flow was encountered in a well at the old town of Point of Rock about 4 miles northwest of Point Rock and near the southwest corner of sec. 23, T. 33 S., R. 43 W. The well was reported to yield a moderate quantity of "strong alkali" water. This well (86, pl. 2) is 254 feet deep and the water level on August 10, 1939, was 103 feet below the land surface. These wells are probably in an artesian area that extends many miles along Cimarron river. The water-bearing beds are the Triassic(?) or Permian redbeds and the source area is probably along Purgatoire and Chacuaco rivers in Las Animas county, Colorado.

At several other places in Morton county, artesian water has been encountered by wells, but the pressure head was insufficient to produce flowing wells. Well 140 (pl. 2) at Elkhart was drilled initially to a depth of 460 feet where it encountered strongly mineralized water in redbeds about 170 feet below the base of the Ogallala formation. The water rose within about 60 feet of the land surface. Some wells have failed to find a sufficient supply of water in the Cockrum sandstone in the northwestern part of the county and have been deepened to depths of 190 to 220 feet to get a supply from the underlying Cheyenne sandstone. When the water is encountered in the Cheyenne sandstone it rises to a level 85 to 100 feet below the land surface. It is reported that a few wells in the Ogallala formation also have encountered water under artesian pressure. At a depth of 280 feet the municipal well at Rolla (92) found water that rose to a point about 200 feet below the land surface.

The artesian water at Richfield, Elkhart, and Point Rock is strongly mineralized. The water at Elkhart was found to be unfit for public use, so the well was plugged at a depth of 300 feet so that a supply of softer water could be obtained from the Ogallala formation. A sample of water from well 43 in the Richfield area contained 2,627 parts per million of total solids—mostly calcium and sulphate (table 5). The casing in well 43 is in poor condition and some of the mineralized water is escaping into and mixing with the softer water in the Cockrum sandstone.

THE WATER TABLE

Shape and Slope

The water table is defined as the upper surface of the zone of saturation. The water table is not a static, level surface, but rather it is generally a sloping surface that has many irregularities caused by differences in permeability of the water-bearing materials or by unequal additions of water to and withdrawals from the ground-water reservoir at different places.

The shape and slope of the water table in Morton county are shown on the map, plate 1, by means of contour lines drawn on the water table. Each point on the water table along a given contour line has the same altitude. These water-table contours show the configuration of the water surface just as topographic contour lines show the shape of the land surface. The direction of movement of the ground water is at right angles to the contour lines in the direction of the downward slope.

The map (pl. 1) shows that the general direction of movement of the ground water in Morton county is to the east, but that the direction of movement and the slope varies considerably from one part of the county to another. The maximum slope is in the northwestern part of the county and is about 40 feet to the mile. The minimum slope is in the northeastern part of the county and is about 7 feet to the mile.

Irregularities on the water table may be caused in several ways. In places where conditions are exceptionally good for recharge from precipitation or intermittent streams, the water table may be built up to form a mound or low ridge from which the water spreads out, but this spreading is very slow because of the frictional resistance offered by small interstices through which the water must move. In material of low permeability these mounds or ridges may be very sharp, but in very permeable material the slopes generaly are gentle. Depressions in the water table indicate places where ground water is being discharged and may occur along streams that have cut below the normal level of the water table or in places where considerable water is withdrawn by wells or plants. The contour map indicates that the water table slopes toward the Cimarron river valley from both sides and that ground water is discharging into the river. The permeability of the water-bearing materials also affects the slope of the water table. If the water is moving through very fine-grained sediments the frictional resistance to the movement of the water is great, causing comparatively steep slopes. Where the sediments are coarse and very permeable the resistance to movement is slight and the slopes are more gentle. In the northwestern quarter of the county, where the slopes of the water table are steepest, the water is passing through the fine-grained Cockrum sandstone. East of Richfield the water moves into the more permeable sands and gravels of the Ogallala formation, and the slopes become much more gentle. Similarly, in the southwestern and southeastern parts of the county the ground water moves through the Ogallala and the slopes of the water table are gentle. The steeper slope of the water table in the south-central part of the county is probably due to the less permeable character of the Ogallala sediments in that area.

The contour lines on the map indicate a broad arch or ridge on the water table in the northwestern part of the county. This may be due in part to recharge from the ephemeral streams in that area and from rainfall on the areas in which the Ogallala and younger formations crop out. It is possible, however, that the lines represent a general easterly movement of the waters, the flexure of the contours toward Cimarron river being caused by the discharge of ground water into the river.

The discharge of ground water from wells causes local depressions of the water table known as cones of depression and excessive pumping of many wells may depress the water table over a large area. As shown by the map, however, there are at present no widespread depressions in the water table caused by pumping in Morton county.

Relation to Topography

The general slope of the upland surface in Morton county is between 7 and 15 feet to the mile and the slope of the water table ranges from 7 to 40 feet to the mile, but the slope of the land surface along stream valleys in this county may exceed 200 feet to the mile. The map, plate 2, shows the depths to water level in Morton county. The lines separating the shaded areas are isobath lines that connect points of equal depth to water level. As shown on the map, the depths to water level in Morton county range from less than 30 feet in the northwestern corner of the county and along some of the stream valleys to about 225 feet along the southern boundary of the county. The shallowest ground water is found in the alluvium of the Cimarron river valley and in the Cockrum sandstone in the northwestern part of the county, and the deepest water is found in the Ogallala formation in the southern part of the county.

For the purpose of detailed description, Morton county may be divided into six areas based upon the depths to water level: (1) northwestern area, (2) northeastern area, (3) Cimarron valley area, (4) Richfield area, (5) area south of Cimarron river and (6) southern area.

Northwestern area.—The northwestern area comprises about 35 sections in the western part of T's. 31 and 32 S., R. 43 W. In this area the water table is 30 to 75 feet below the land surface and in the stream valleys the depth to water level generally is only 30 to 40 feet. In the northern part of this area the principal water-bearing beds are the Cockrum sandstone and the Cheyenne sandstone, but in the southern part the Ogallala formation supplies most of the wells. Wells in this area range in depth from about 31 to 215 feet, the deeper wells penetrating the Cheyenne sandstone.

Northeastern area.—The northeastern area includes about 12 sections along North Fork of Cimarron river in the northeastern corner of the county, in which the water table lies 80 to 100 feet below the land surface and the depth of the wells ranges from 100 to 125 feet. The water in this area is obtained from the sands and gravels of the Ogallala formation.

Cimarron valley area.—The Cimarron valley area comprises a belt about 2 miles wide that parallels the river across the county. The water in part of the Cimarron valley lies at very shallow depths. Stock wells in the alluvium of Cimarron river range in depth from 15 to 30 feet and the water level is 10 to 15 feet below the land surface. South of the river the alluvium probably extends for a considerable distance under the cover of dune sand, and the depth to water is also moderately shallow here. North of the river some wells penetrate redbeds and obtain water at depths of 75 to 100 feet. Other wells north of the river get water from the Ogallala formation at depths of 65 to 100 feet.

The Cimarron valley area is bordered on both sides by much larger areas in which the depth to water level ranges from 50 to 100 feet. The large area north of the river is described below as the "Richfield area," and the eastern part of the smaller area south of the river is described below as the "area south of Cimarron river."

Richfield area.—The Richfield area comprises a large area in the central, west-central, and north-central parts of the county, extending north to the Stanton county line, in which the depth to water level ranges from 50 to 100 feet. It also includes a small area in which the depth to water level is less than 50 feet. In the northern part of this area water is obtained from the Cockrum sandstone and in the southern part the Ogallala formation supplies the wells. In the northwestern corner of the area the Cockrum sandstone yields very little water to wells but farther south it is more permeable and yields large supplies.

In the southern part of the area the Cockrum sandstone is absent and the Ogallala is the principal water-bearing formation. The Ogallala lies on redbeds and consists of 75 to 125 feet of silt, sand, and gravel. The lowermost 30 to 60 feet of these beds is saturated with water.

Area south of Cimarron river.—This area includes about 60 sections of land just south of and parallel to Cimarron river. The depth to water level ranges from 50 to 115 feet and the depth of wells ranges from 75 to 400 feet. The Ogallala is the principal water-bearing formation in this area.

Southern area.—The southern area is in the southern part of the county and it includes all of the county south of the 150-foot isobath line, which roughly parallels Kansas highway 45. The depth to water level ranges from 150 to about 225 feet and the depth of wells ranges from about 160 to nearly 250 feet. The Ogallala formation supplies water to the wells in this area.

Fluctuations

The water table does not remain static but fluctuates similar to the surface of a lake. Whether the water table rises or declines depends upon the ratio of the amount of inflow into the ground-water reservoir to the amount of withdrawal. If the inflow exceeds the draft, the water table will rise; conversely, if the draft exceeds the inflow into the ground-water reservoir the water table will decline.

The ground-water reservoir may be replenished by rainfall that moves through the soil and descends to the zone of saturation, by recharge from flood waters in streams such as North Fork of the Cimarron, and by subsurface inflow from areas to the north and west. The factors that cause decline in the water table in Morton county are loss of water by subsurface flow into areas to the east and south, loss by evaporation and transpiration, loss by seeps and springs, and loss by pumpage from wells. The factors that cause a rise in the water table in a given area are all directly related to the precipitation on that area or on adjacent areas; therefore, the water table might be expected to fluctuate in direct response to precipitation. This is true in many areas, but in Morton county there are many factors which alter the effect that precipitation has upon the water table. After long dry periods the soil moisture may be depleted and must be completely replenished before any appreciable amount of moisture can percolate downward to the water table. North of Cimarron river where the soil is very thick several moderate rains might be necessary to replenish the soil moisture. Such rains, therefore, would have little or no effect on the water table. Similarly, it would require a great deal of time for moisture that falls as precipitation upon adjacent areas to move downward to the water table and then to move laterally into Morton county. Precipitation in areas to the west that produces flood waters in North Fork of the Cimarron have a more immediate local effect upon the water table in Morton county.

The ground-water supply in Morton county is depleted principally by pumpage and by underground movement into areas to the east and south. The loss of water through seeps and springs is relatively small and takes place only along Cimarron river. The loss by evaporation and transpiration is also small because in most parts of the county the water table lies too deep below the land surface to be affected by these processes.

The fluctuations of the water table may be determined by observing and recording the changes in the water levels in wells. In July, 1939, periodic water-level measurements were begun on 19 wells located at strategic points in Morton county. The depth to water level in each well is measured once a month in order to determine the fluctuations of the ground-water table. The measurements made to date are listed in the following table. All measurements before November 1, 1939, were made by me; those after that date were made by Richard B. Christy.

The water levels in 6 of the 19 wells declined during the period between July, 1939, and June, 1940. The water level in the other 13 wells showed a net rise during the same period. The net variation ranged from 0.01 foot to 1.92 feet and averaged about 0.25 foot. In some wells the water level rose steadily, in others it declined steadily, and in 4 wells it remained almost stationary. The water levels in many wells rose rapidly until October or November and then declined steadily during the winter and spring. Not enough measurements have been made to show any definite relation of the fluctuation of the ground-water table in this area to the precipitation. As the observation-well program continues more data will become available and a more definite relation to the precipitation may develop.

TABLE 4.—*Water levels in observation wells in Morton county,* in feet below the measuring point.*
(For location of wells refer to plate 2; for descriptions, refer to well tables).

Well No.	1939.						1940.						
	July 25.	Aug. 24.	Sept. 25.	Oct. 26-27.	Nov. 14-15.	Dec. 16.	Feb. 1.	Feb 21.	Mar. 23.	Apr. 22.	May 14.	June 18.	July 17-18.
8	152.31	152.32	152.22	152.52	152.19	152.22	†	152.14	152.09	152.16	152.11	152.09	152.07
12	111.58	111.54	111.47	111.53	111.56	111.34	111.76	111.34	111.21	111.19	†	110.88	111.06
23	70.11	70.11	70.12	70.18	70.07	70.05	70.07	70.10	70.13	70.09	70.11	70.12	70.06
24	74.75	74.71	74.85	75.24	74.67	74.67	74.87	74.88	74.97	74.77	74.88	74.68	74.50
31	138.97	138.95	138.91	139.04	138.94	138.90	†	138.91	138.89	138.91	138.88	138.89	138.89
48	68.87	68.81	68.80	68.86	68.80	68.80	68.82	68.79	68.79	68.76	68.76	68.76	68.77
62	76.90	76.84	76.78	76.72	76.68	76.60	†	76.41	76.36	76.35	76.33	76.40	76.27
75	53.59	53.55	53.60	53.73	53.71	53.79	53.80	53.89	53.88	53.94	54.04	53.96	53.96
84	88.01	87.96	87.96	†	87.87	87.88	87.88	87.83	87.79	87.78	87.79	87.74	87.70
88	147.42	147.65	147.52	147.87	147.69	147.63	†	147.63	147.57	147.70	‡	....	....
99	129.68	129.67	129.67	†	129.60	129.60	†	129.54	129.53	129.53	129.50	129.47	129.49
108	159.94	159.93	159.90	160.14	159.83	159.82	†	159.92	159.79	159.97	159.84	159.82	159.79
110	67.51	67.48	67.54	67.49	67.53	67.61	67.67	67.62	67.59	67.61	67.63	67.56	67.53
113	113.98	113.89	113.87	113.76	113.78	113.80	113.84	113.88	113.83	113.77	113.82	113.77	113.76
120	90.13	90.12	90.16	90.03	90.11	90.16	90.19	90.14	90.09	90.10	90.15	90.17	90.19
121	198.86	198.73	198.40	198.51	198.59	198.54	†	198.58	198.51	198.54	198.06	198.46	198.74
131	226.88	226.62	226.86	226.83	226.86	226.89	†	226.84	226.80	226.89	226.84	226.84	226.87
134	167.39	167.35	167.25	167.20	167.11	167.16	167.28	167.19	167.21	167.21	167.27	167.17	§
150	211.11	211.85	210.98	211.65	211.11	211.91	211.09	211.35	211.09	211.67	212.16	213.03	213.03

* The descriptions and 1939 water-level measurements are being published in "Water levels and artesian pressures in observation wells in the United States in 1939": U. S. Geol. Survey Water-Supply Paper 866. Subsequent water levels will be published in future papers of this series.
† Unable to reach well. ‡ Well destroyed. § Well pumping.

The water-level measurements made in 1939 are being published in the 1939 annual water-level report of the U. S. Geological Survey, Water-Supply Paper 886, and future measurements will be published in ensuing reports of this series. The well numbers used in this report and in Water-Supply Paper 886 are given in table 5.

TABLE 5. *Observation wells in Morton county.*

Well number in this report	Well number in water-supply paper 886	Well number in this report	Well number in water-supply paper 886
8	8	99	87
12	11	108	93
23	21	110	69
24	22	113	97
31	28	120	104
48	42	121	105
62	54	131	114
75	65	134	117
84	74	150	127
88	77		

GROUND-WATER RECHARGE

Recharge is the addition of water to the ground-water reservoir, and may be accomplished in several different ways. The underground reservoir beneath Morton county seems to be recharged by local rainfall within the county, by influent seepage from ephemeral streams, and by subsurface inflow from areas to the west of the county. The amount of annual ground-water recharge is approximately equal to the amount of annual natural ground-water discharge plus the amount of water that is withdrawn annually from wells without permanently lowering the water table.

RECHARGE FROM LOCAL RAINFALL

The average annual precipitation in Morton county is only 18 inches, but probably only a small percentage of this amount reaches the ground-water reservoir. Of the total precipitation, part is lost by evaporation into the air, part leaves the county as runoff in the streams, and part is used by growing plants (transpiration). The remainder may percolate downward to the zone of saturation and become ground water.

The amount of water lost by evaporation in any area depends upon the precipitation, temperature, humidity, vegetative cover, depth to the water table, and the length of time the processes of evaporation have access to the moisture. In Morton county most of the annual precipitation falls as rain in May, June, July, and August, and the climate during these months is characterized by high temperatures and low humidity. Therefore probably a large proportion of the annual precipitation in Morton county is lost by direct evaporation into the atmosphere.

The vegetation in this area consumes considerable soil water by transpiration, especially in May and June when it is most abundant.

A large part of the precipitation in this area falls as torrential rains. When such rains fall upon steep slopes, such as those along Cimarron river and some of its tributaries, the water runs off rapidly into the streams, allowing but little opportunity for absorption of water by the soil. Most of the land in the county is relatively flat or slopes very gently, however, hence the runoff over most of the county is relatively small. Vegetation also reduces runoff, but during much of the year the land in Morton county is relatively barren of vegetation. Modern methods of terracing and contouring of farm land tend to reduce the runoff, and, therefore, may increase the rate of recharge to the soil and to the ground-water reservoir.

Other things being equal, the percentage of water that is absorbed by the soil and becomes available as recharge depends upon the character of the soil and of the underlying material through which the water must pass en route to the zone of saturation.

The soils in the loess-covered areas north of the river are compact and transmit water very slowly, but the sandy soils in the dune-sand area are porous and absorb considerable water. The soils developed on the Ogallala formation are also porous and absorb water readily in places where the slopes are not great.

After passing through the soil zone the water percolates downward until it meets a relatively impervious bed of clay or caliche. It may then move laterally along the dip of the impervious bed until it reaches a pervious zone or fracture that permits it to continue its downward movement. In some places where such impermeable beds are widespread, some water may remain in a perched ground-water reservoir above the normal water table.

The effect of the surficial geology upon the recharge is discussed below under the principal formations that crop out over appreciable areas in Morton county.

Ogallala areas.—About one-fourth of the area north of Cimarron river and small areas south of the river are underlain by the silt, sand and gravel of the Ogallala formation and overlying undifferentiated Pleistocene deposits (pl. 1). The soils developed from these materials are mostly sandy and porous but locally they may be calcareous, compact, and relatively impervious. The slope on most of the outcrops ranges from 2 to 5 percent, but it exceeds 10 percent along the north side of the Cimarron valley. The broad ground-water ridge shown on plate 1 north of the river indicates that the Ogallala formation probably is recharged to some extent by rainfall, although there is another possible explanation for this ridge (p. 35).

Dune-sand areas.—Most of the area south of the river is underlain by dune sand and may be divided into two subareas based upon the type of soil and the topography. The first is the dune area just south of the river, which has a typical sand-dune topography and soil. The slope generally ranges from 2 to 5 percent but in some places may exceed 10 percent. Such steep slopes are very favorable to runoff. The sand-dune area, however, has many undrained basins in which water collects and percolates into the soil. The loose, porous, and permeable nature of the soil and the many undrained basins make the area favorable for recharge of the underlying Ogallala formation, and it is likely that considerable rainwater percolates downward to the zone of saturation.

The second sand dune area is south of the first, extending nearly to the Kansas-Oklahoma line, and is characterized by gentle slopes and a more compact soil. The slope averages less than 2 percent and the soils are comprised of loamy sands, fine sands, sandy loams, and fine sandy loams. The subsoils are heavier but are also sandy. This area has few if any undrained basins, but the permeable soils and gentle slopes favor the absorption of rainfall. This area probably contributes considerable water to the ground-water reservoir.

Loess areas.—Deposits of wind-blown loess cover about three-fourths of the area north of Cimarron river and a small area along the Morton-Texas county line in southeastern Morton county (pl. 1). The soils that develop from loess are heavy and dark and consist of top soils of loams, clay loams, and silty clay loams and heavy clay subsoils that in places are very calcareous. The loess soils hold moisture well, but they absorb water very slowly. According to the soil map by Joel (1937), more than 95 percent of the upland loess area in the north half of the county has a slope of less than 2 percent. In spite of the gentle slope, the torrential nature of the rainfall together with the nearly impermeable character of the soil causes much of the water to be lost by runoff. The loss of water by runoff in such flat areas can be greatly reduced by contour farming. The loess soils are so thick and become so dry after long dry periods that most of the water that is not lost by runoff or evaporation is absorbed by the soil. It is probable that very little moisture that falls on the loess areas ever reaches the ground-water reservoir.

Recharge from Streams

The ridge on the ground-water table north of Cimarron river (pl. 1) may be caused in part by recharge of the ground-water reservoir from streams. North Fork of Cimarron river and its tributaries are ephemeral streams that lie above the water table. The land adjacent to these streams is moderately steep, so that much of the precipitation runs off into the streams. In some places where the channel is sandy and is underlain by permeable material, water may percolate downward to the zone of saturation. The Cimarron river valley has been cut into the zone of saturation, and hence it receives water from the ground-water reservoir rather than contributes water to it.

Recharge from Adjacent Areas

Ogallala formation.—A large part of Baca county, Colorado, is underlain by the Ogallala formation (and associated Pleistocene deposits) and probably serves as a catchment area for part of the ground water that moves eastward into Morton county. The eastward slope of the water table in Morton county, as shown by the contour lines on plate 1, indicates that much of the water is coming from the direction of Baca county. The Ogallala formation and Pleistocene deposits in Baca county, unlike those in Morton county, are not covered by loess except in the eastern part of the county and in other small isolated areas. The soils in this county are more sandy and the slopes are almost as gentle as those in Morton county. Although the rainfall in Baca county is about the same as in Morton county the area of the Ogallala exposed is so large (several hundred square miles) that probably a large amount of water is taken up by the Ogallala formation and eventually finds its way into Morton county. In the southeastern part of Baca county, along Cimarron river, the sand dunes also serve as a catchment area for recharge of the Ogallala formation.

Cockrum sandstone.—The Cockrum sandstone crops out in Colorado in a large area in the eastern half of Las Animas county, in southwestern Baca county, and in eastern Baca county along Sand arroyo and Bear creek and its tributaries. The sandstone dips eastward toward Kansas at the rate of about 20 feet to the mile. Over much of this area the topography is fairly flat and the soil very pervious, so that a large amount of water may enter the sandstone and move eastward down the dip of the strata into Morton county, as illustrated in figure 5.

Near the middle of the county the ground water moves eastward from the Cockrum sandstone into the Ogallala formation, as shown on the water-table contour map (pl. 1) by the change from a steep to a gentle slope of the water table in the northeastern part of the county. Much of the recharge of the Cockrum sandstone from outside the county thus enters the Ogallala formation.

Cheyenne sandstone.—The Cheyenne sandstone, which yields water to wells in northwestern Morton county, probably derives its

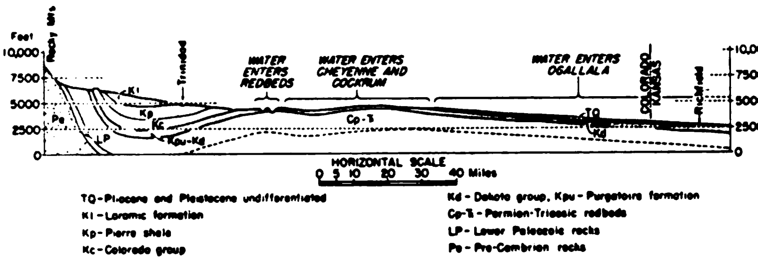

FIG. 5. Generalized east-west cross section from the Rocky Mountains, through Colorado, into Morton county, Kansas.

water in the same manner as the Cockrum sandstone. The Cheyenne sandstone is the lower part of the Dakota group, which crops out in many small areas along Purgatoire river, Rule creek, and their tributaries. These areas of outcrop are principally in northern Las Animas county, northwestern Baca county, southwestern Bent county and southeastern Otero county, Colorado. The overlying Kiowa shale is relatively impermeable and prevents recharge of the Cheyenne from the Cockrum sandstone or the Ogallala formation.

Redbeds.—The recharge of the redbeds is discussed in part in the section on artesian wells. The age of the redbeds in Morton county is uncertain and the redbeds in the valleys of Purgatoire, Chaquaco, and Rule creeks have been called variously Permian or Triassic. The rainfall in this area is scant and the area of outcrop is relatively small, so the recharge of the redbeds also is probably small. Moreover, the waters must move more than 100 miles to reach Morton county.

In summary it may be said that ground water in the Ogallala formation is probably recharged mostly from the dune-sand area south of Cimarron river, from the outcrop area of Ogallala in Baca county, Colorado, and from the ephemeral streams and Ogallala outcrops north of Cimarron river in Morton county. The recharge to the Cockrum comes principally from the outcrops of the Cockrum in southeastern Colorado.

DISCHARGE OF SUBSURFACE WATER

The discharge of subsurface water has been divided by Meinzer (1923a, pp. 48-56) into vadose-water discharge (discharge of soil water not derived from the zone of saturation) and ground-water discharge (discharge of water from the zone of saturation).

Vadose-water Discharge

The discharge of soil water not derived from the zone of saturation is called vadose-water discharge and includes the discharge of water directly from the soil by evaporation and through growing plants and crops by transpiration. In semiarid regions the consumption of soil water by crops may be large and is of vital importance to agriculture. This consumption of soil water generally reduces the recharge somewhat, for the deficiency of soil moisture must first be replenished before recharge can take place.

Ground-water Discharge

Ground-water discharge is the discharge of water directly from the zone of saturation or from the capillary fringe, and may take place through evaporation and transpiration or as hydraulic discharge through springs, seeps, wells, or infiltration galleries.

Transpiration and evaporation. — Water may be taken into the roots of plants directly from the zone of saturation or from the capillary fringe, and discharged from the plants by the process known as transpiration. The depths from which plants will lift the ground water varies with different plant species and different types of soil. The limit of lift by ordinary grasses and field crops is not more than a few feet; however, alfalfa and certain types of desert plants have been known to send their roots to depths of 60 or more feet to reach the water table (Meinzer, 1923, p. 82).

In Morton county, any significant discharge of water by evaporation and transpiration is limited to the areas in which the water table lies within 30 feet of the surface, although some discharge may take place through transpiration in some of the areas where the water table lies within 50 feet. As shown in plate 2, the shallow-water areas comprise a narrow belt along Cimarron river and small areas in the northeastern part of the county. Throughout the rest of the county the water table lies 50 to 250 feet below the surface so that little or no water is discharged in this way.

Considerable ground water probably is discharged by evaporation and transpiration along the Cimarron river valley, although the discharge must have been much greater in the past when the valley was grass covered. When the stream is dry the water table lies only a few inches beneath the sandy river channel, allowing direct evaporation to take place.

Springs and seeps.—Ground water is discharged from the ground-water reservoir through springs and seeps along Cimarron river. The valley of Cimarron river cuts into the ground-water body, causing water to seep out along the stream's course. Several of these seeps may be found in the bluffs along the north side of the Cimarron valley and are especially prominent near Spring creek on the east side of Point Rock. The water comes out near the contact of the Ogallala formation and the Triassic(?) redbeds. At one time there were several springs along Cimarron river in Morton and Stevens counties. It is probably that the discharge of ground water through seeps and springs into Cimarron river, together with the consumption of water along this valley by transpiration and evaporation, account for most of the natural ground-water discharge in Morton county.

Wells.—The above discussion treats of the natural discharge of ground water along the Cimarron valley, which seems to account for most of the discharge in the county. The rest of the ground water discharged within the county comes from wells, principally by pumping, but in small part by natural flow, and the recovery of ground water from wells is discussed below. Together the natural and artificial ground-water discharge seems to be small as compared with the total quantity of ground water stored in the county. Most of the ground water moves slowly out of the county (pl. 1) toward points of discharge farther east.

RECOVERY

Principles of Recovery

The discharge from a well is produced by a pump or some other lifting device or by artesian pressure (for a more detailed discussion of principles of recovery see Meinzer, 1923a, pp. 60-68). When water is standing in a well there is equilibrium between the pressure of the water inside the well and the pressure of the water outside the well. Whenever the pressure inside a well is reduced there is a resultant inward pressure and water moves into the well. The pressure on the inside of a well may be reduced in three ways: (1) by lowering the water level by a pump or other lifting device, (2) by removing the atmospheric pressure in a well pumped by suction, and (3) by relieving the pressure at the mouth of a well that discharges by artesian pressure. Whenever water is removed from a well there is a resulting draw-down or lowering of the water level, or, in a flowing artesian well, an equivalent reduction in artesian pressure.

When water is being discharged from a well at a given rate the water table is lowered in an area around the well to form a depression resembling somewhat an inverted cone. This depression of the water table is known as the cone of influence or cone of depression, and the surface area affected by it is known as the area of influence. The height of the cone of depression is equal to the draw-down. In any given well the greater the pumping rate the greater will be the draw-down, and the greater will be the diameter of the cone of influence and the area of influence.

The capacity of a well is the rate at which it will yield water after the water stored in the well has been removed. The capacity depends upon the quantity of water available, the thickness and permeability of the water-bearing bed, and the construction and condition of the well itself. The capacity of a well is generally expressed in gallons a minute. The known or tested capacity of a strong well is generally less than its total capacity, but some weak wells are pumped at their total capacity.

The specific capacity of a well is its rate of yield per unit of draw-down and is determined by dividing the tested capacity in gallons a minute by the draw-down in feet. Well 144 at Elkhart is reported to yield 120 gallons a minute with a draw-down of 30 feet. The specific capacity of that well, therefore, is 4 gallons a minute per foot of drawn-down, or simply 4.

When water is withdrawn from a well the water level drops rapidly at first and then more slowly, until it finally becomes nearly stationary. Conversely, when the withdrawal ceases the water level rises rapidly at first and then more slowly until it eventually resumes its original position, or approximately its original position.

Dug Wells

A dug well is one that is excavated with picks, shovels, spades, or by power machinery. They are generally between 2 and 10 feet in diameter and are comparatively shallow. They are most common in shallow-water areas such as river valleys, but may be found in the uplands where the water table is very deep. An old dug well on the upland east of Johnson, Stanton county, is reported to be 165 feet deep. Many of the earlier wells in Morton county were dug by hand, but almost all of them have been replaced by drilled wells. At present there are a few dug wells in the alluvium in the Cimarron river valley, in the Cockrum sandstone in the northwestern part of the county, and in the Ogallala formation in the northeastern part of the county. They range in depth from about 20 to 107 feet.

The dug wells in Morton county are curbed with stone, timber, barrels, or rims of tractor wheels. They are generally poorly sealed and hence may permit the entrance of surface waters. If such wells are situated near barnyards or privies, contamination of the water may result. Because of the difficulties of digging by hand below the water table, dug wells generally are excavated only a few feet below the water table. Therefore, dug wells are more likely to fail during a drought than are drilled wells, which generally extend many feet below the water table.

Bored Wells

Bored wells are made by augers or post-hole diggers in loose unconsolidated sediments. A few shallow wells in the alluvium of Cimarron river were made in this way.

Drilled Wells

A drilled well is one that is excavated by means of a percussion or rotary drill. Most of the wells in Morton county were drilled by the percussion method by means of portable cable-tool drilling rigs. They range in diameter from 4.5 to 12.5 inches.

Drilled wells in consolidated deposits.—About one-fourth of the wells in Morton county were drilled into consolidated deposits, chiefly sandstone and shale, after passing through the unconsolidated beds of the Ogallala formation. The wells are generally cased through the unconsolidated surface material and left open in the bedrock. Well 155, in the Cockrum sandstone, contains no casing and was drilled more than 30 years ago. In some of the wells casing is set in an upper sandstone to shut off hard water and the well is drilled down to a lower water-bearing bed that may contain softer water. If the well is cased its entire depth several reductions in the diameter of the casing may be necessary.

In Morton county the depth of the wells in consolidated sediments is generally less than 100 feet, but a few exceed 200 feet. More than 90 percent of the wells are cased with galvanized-iron casing and the wells range in diamter from 4.5 to 16 inches.

Drilled wells in unconsolidated deposits.—More than three-fourths of the wells in Morton county obtain water from the unconsolidated sediments of the Ogallala formation. Most of these wells are cased all the way to the bottom of the hole with 4.5-inch or 5.5-inch galvanized-iron casing. A few wells have steel casing, especially those six inches or more in diameter. In some of these wells water may enter only through the open end of the casing, but in many of the wells the casing is perforated below the water table to provide greater intake area. Samples of the water-bearing sand or gravel should be examined so that the proper size of perforation may be used. The capacity of a well and even the life of a well may be determined by the size of the perforation, for if the perforation is too coarse the fine material may filter through and clog the well, and if the perforations are too small the water will be held back by unnecessary friction.

Some wells in unconsolidated sediments are equipped with well screens or strainers. It is common practice to select a slot size that will pass 30 to 60 percent of the water-bearing material, depending upon the texture and degree of assortment. Retention of the coarser particles around the screen forms a natural gravel packing that greatly increases the effective diameter of the well, increases its area of intake, and hence increases its capacity.

Gravel-wall wells are very effective for obtaining large supplies of water from relatively fine-grained unconsolidated deposits, and are widely used for irrigation. In constructing a well of this type, a hole of large diameter, 30 to 60 inches, is first drilled by the rotary method or by means of an orange-peel bucket and is temporarily cased. A well screen or perforated casing of a smaller diameter than the hole, 12 to 25 inches, is then lowered into place and centered opposite the water-bearing beds. Blank casing extends from the screen to the surface. The annular space between the inner and outer casings is then filled with carefully sorted gravel, preferably of a grain size just a little larger than the openings in the screen or perforated casing, and also slightly larger than that of the water-bearing material. In most wells of this type a medium- or coarse-grained gravel is used, but in very fine-grained deposits a fine-grained gravel or coarse-grained sand should be used. The outer casing is then withdrawn part way to uncover the screen and allow the gravel packing to come in contact with the water-bearing material. The gravel increases the effective diameter of the well and decreases the velocity at which the water enters the well, thus preventing fine sand from choking the well and injuring the pumping equipment. The gravel envelope reduces the entrance friction and the draw-down and hence increases the capacity of the well.

In deciding whether or not to employ gravel-wall construction it is important to know the character of the water-bearing material. If the material is a coarse gravel (as it is in parts of Morton county) it would be unprofitable and unnecessary to construct a gravel-wall well. Some wells have been walled with a gravel that was finer and less permeable than the water-bearing material it replaced, to the detriment of production.

According to McCall and Davison (1939, p. 29) draw-down can be kept to a minimum in several ways.

> First, the well should be put down through all valuable water-bearing material. Secondly, the casing should be properly perforated so as to admit water to the well as rapidly as the surrounding gravel will yield the water. Third, the well should be completely developed so that the water will flow freely into the well. . . . Increasing the depth of a well will have a greater effect on reducing the draw-down than will increasing the diameter, so long as additional water-bearing formations are encountered.

A report (Davison, 1939) containing descriptions of different types of pumping plants, the conditions for which each is best suited, construction methods, and a discussion of construction costs is available from the Division of Water Resources, Kansas State Board of Agriculture, Topeka, Kan., and the reader is referred to this publication for additional details of well construction.

Methods of Lift and Types of Pumps

Almost all of the wells in Morton county, particularly those used for domestic and stock supplies, are equipped with lift or force pumps. The cylinders or working barrels in lift pumps and force pumps are similar and are placed at a level near that of the water table, but a lift pump is capable of discharging water only at the pump head, whereas a force pump can force water above this point—for example, to an elevated tank. Most of the pumps are operated by windmills, but a few are hand operated.

The pipe (1.5 to 3 inches in diameter) generally is clamped between two 4- by 4-inch boards that rest on the top of the casing. On some wells a circular piece of galvanized iron or steel is placed between the clamp and the casing to prevent small objects from falling into the well. In wells equipped with galvanized-iron casing the clamp may be supported by railroad ties in order to take the weight off the casing.

Most of the irrigation, public-supply, and railroad wells are equipped with power-operated centrifugal or turbine pumps, but in a few older wells power-operated force pumps are used. These pumps are driven by electric motors or by internal-combustion engines using gasoline, oil, or natural gas. Centrifugal pumps are mounted at the surface or in pits and can be used only where the depth to water plus the draw-down does not exceed the working suction limit. In wells in which the depth to water level or the draw-down is great deep-well turbine pumps generally are used. A turbine pump consists of a series of connected turbines called bowls or stages that are placed near or just below the water level and are connected by a vertical shaft to a vertical motor or pulley at the top. If there is a pulley at the top it is connected by a belt to a tractor motor, a combine engine, or an electric motor. Some turbines have gear heads for direct connection to the source of power.

UTILIZATION OF WATER

Early settlers in this county obtained water mainly from dug wells or cisterns, but these have been almost entirely replaced by drilled wells. At the peak of the development in the county there was a drilled well on nearly every quarter section of land. At present more than 90 percent of the wells provide water for domestic and stock use, about five percent for irrigation, and less than 5 percent for public water supply. One well is used by the Atchison, Topeka, and Santa Fe Railway.

Domestic and Stock Supplies

The domestic wells supply water in the homes for drinking, cooking, and washing, and in schools other than those supplied by municipal wells, and provide water for the irrigation of small garden plots. The stock wells supply drinking water for livestock. Domestic and stock supplies are obtained almost entirely from drilled wells, most of which are more than 100 feet deep. Most of the water from these wells is moderately hard, but is satisfactory for domestic and stock use. Much of the domestic and stock water, however, contains sufficient fluoride to be injurious to children's teeth during the period of their formation (see Quality of water).

Public Water Supplies

Only two cities in Morton county have municipal water supplies, Elkhart and Rolla, and both are supplied from wells.

Elkhart is served by the Kansas City Power and Light Company from 5 drilled wells (138-140, 143, 144) in and near the city. Two other wells (141, 142) were formerly used but have been abandoned. The five used wells range in depth from 260 to 300 feet and in static water level from 200 to 205 feet. Wells 138-140 are 8 inches in diameter, are equipped with electrically driven plunger pumps, and yield 28 to 42 gallons a minute. Wells 143 and 144, drilled more recently, are 12 inches in diameter, are equipped with electrically driven turbine pumps, and yield 80 to 120 gallons a minute, respectively, with a reported draw-down of 30 feet. All the wells obtain water from coarse sand and gravel in the lower part of the Ogallala formation. Well 140 was originally 460 feet deep and yielded mineralized water from the Triassic(?) redbeds, so it was plugged at a depth of 300 feet and now draws from the Ogallala.

The well pumps deliver the water directly into the mains, and the excess water is stored in two elevated steel tanks holding an aggregate of 200,000 gallons. The pressure in the mains ranges from 30 to 45 pounds to the square inch. The total capacity of the five wells is about 425,000 gallons a day, but the maximum daily consumption has not exceeded 218,000 gallons. The analysis of water from well 138 given in the table indicates that it has a total hardness of 300 parts per million and a fluoride content of 0.7 part. The water is softened somewhat by the addition of 50 pounds of lime to each 400,000 gallons of water. The fluoride content is well within the safe limit discussed under quality of water.

Rolla is supplied by a city-owned 8-inch drilled well (92), which is reported to be 280 feet deep. The well is equipped with an electrically driven turbine pump that forces the water into the mains at the rate of about 200 gallons a minute. The excess water is stored in an elevated steel tank holding 55,000 gallons, and the water is distributed at a pressure of 55 pounds to the square inch. Analysis 92 indicates that the water has a total hardness of 291 parts per million and a fluoride content of only 0.2 part. Although the water is hard it is not treated.

The water level in the city well at Rolla (92) stands 200 feet below the land surface and is much lower than in other wells in the vicinity. The depth to water level in wells north of Rolla is only about 100 feet and in wells just south of the city is about 165 feet. The municipal well at Rolla struck the first water at a depth of 160 feet, but because the supply was inadequate for public use the well was deepened and cased to a depth of 280 feet, where a more productive water-bearing bed was encountered. The water then rose to a point 200 feet below the land surface.

Railroad Supplies

In 1913 the Atchison, Topeka and Santa Fe Railway Company drilled a well at Elkhart to a depth of 218 feet. It encountered water in a coarse sand of the Ogallala formation at a depth of 194 to 218 feet (see log 18). The well was deepened to 277 feet in 1927 and additional water was encountered in sands of the Ogallala at a depth of 255 to 271 feet. In 1928 the well was again deepened to a depth of 370 feet, and ended in the Triassic(?) redbeds. The static water level is 208 feet below the land surface. The water is used in locomotive boilers and can be pumped into the city mains in case of an emergency.

Irrigation Supplies

The prolonged drought that began in 1930 and has resulted in many crop failures has called to the attention of the farmers the need for irrigation. The large quantity of ground water available and the nearby source of cheap natural gas for fuel are ideal for irrigation, but the cost of drilling wells and the excessive pumping lift would almost prohibit profitable irrigation in most parts of the county.

The artesian wells near Richfield were used for irrigation nearly 50 years ago, but these are no longer used. More recently dug wells in both the northeastern and northwestern parts of the county have been pumped to a small extent for irrigation.

Since April, 1930, more than 35 gas wells have been drilled in Morton county and for each of these wells a water well was first drilled to supply water for drilling. Most of these water wells were 6 inches in diameter and had a reported capacity of as much as 1,000 gallons a minute. After the gas wells were completed the water wells were abandoned and the casing pulled unless the landowners bought the casing. Several landowners in Morton county have bought the casing and saved the wells, and one of these (58) is now used for irrigation. The drilling of these wells led to renewed interest in irrigation in this area in 1939.

In the autumn of 1939 there were three irrigation wells in the county and two other wells were formerly used for irrigation. Descriptions of three of these wells are given in the well tables and all are described in more detail in the following paragraphs. At least three new irrigation wells were drilled in the vicinity of Rolla in 1940.

Watkins well.—The former irrigation well of E. M. Watkins is on a flat upland in the northwestern part of the county in sec. 11, T. 31 S., R. 43 W. It is omitted from the table of well records and from plate 2, as its exact location within the section was not determined. It was drilled as a gas test well to a depth of 1,160 feet. The depth to water level is reported to be about 72 feet. The well is 18 inches in diameter and is cased with galvanized iron, which has caved in at a depth of about 35 feet. The well probably obtained water from the Cheyenne sandstone (see log 25). It was used for a few years to irrigate a few acres, but it is now abandoned.

Ball well.—The irrigation well of Lloyd Ball is situated in sec. 31, T. 32 S., R. 43 W. It is omitted from the table of well records and from plate 2, as its exact location within the section was not determined in the field. It is a dug well about 50 feet deep, and the water level is 30 feet below the land surface. The Cockrum sandstone is the principal water-bearing bed and the water table here is near the top of the formation. The well is equipped with a 3-inch centrifugal pump operated by a gasoline engine and is reported to yield 200 gallons a minute. The owner irrigates several acres of land each year with this unit.

Milburn well.—The irrigation well (4) of P. E. Milburn is situated in the valley of North Fork of Cimarron river in the NE¼ sec. 30, T. 31 S., R. 39 W. It is a dug well 107 feet deep, cased with barrels that are 18 inches in diameter, and the static water level is 87 feet below the land surface. The well is equipped with a turbine pump that is powered by a tractor engine. The water-bearing bed is about 10 feet thick and consists of sand and gravel of the Ogallala formation. The well formerly provided water for irrigation, but it has not been used for several years. A 3-inch centrifugal pump powered by a gasoline motor formerly was used to pump water for irrigation from the creek during the seasons when it was flowing. Water flows in North Fork only after rains, so that water for irrigation is available only when least needed. This plant has not been operated for several years.

Artesian wells formerly supplied water for irrigation in the vicinity of Richfield. About 20 acres of alfalfa was irrigated by water from well 43. None of these wells is now used except well 43, which provides water used to irrigate a small garden plot.

Hayward well.—The irrigation well (58) of G. L. Hayward is situated in the NW¼ sec. 31, T. 33 S., R. 39 W. It was drilled by the Argus Production Company to supply water for drilling a gas well. It is reported to be 396 feet deep, to have a water level about 105 feet below the land surface, and to have a 6-inch steel casing. It is equipped with a turbine pump operated by a gasoline combine engine. The well yields about 60 gallons a minute from sand and gravel of the Ogallala formation.

Roy Connor drilled two test wells 1,300 feet apart in the SE¼ sec. 13, T. 33 S., R. 40 W., in October, 1939, preparatory to drilling a large irrigation well early in 1940. The first adequate supply of water was found in a fine buff sand at a depth of 125 to 204 feet and an additional supply was found in a coarse white sand at a depth of 280 to 376 feet. Both sands are in the Ogallala formation. The deeper test well is 376 feet deep and the water level is 88 feet below the land surface. The original plan was to drill the irrigation well about 409 feet deep and to install a 12.5-inch casing perforated from a depth of 280 to 409 feet.

DEEP-WELL IRRIGATION IN ADJACENT AREAS IN KANSAS AND OKLAHOMA

The following brief descriptions of ground-water development for irrigation in adjacent areas in Kansas and Oklahoma are included because the depth to water level is comparable to that in the uplands of Morton county. It should be understood, however, that the depth to water level, the yield of wells, the quantity of water available, and the type of soil differ greatly from place to place, and that these differences affect the cost of installation and operation, and otherwise limit the feasibility of irrigation from wells.

Three gravel-walled wells were drilled in the uplands of southwestern Ford county, Kansas, in 1937 (Lohman, 1938, pp. 4, 5). They range in depth from 149 to 211.5 feet and water levels range from 22 to 44 feet below the land surface. These wells were put down at the low cost of about $750 each, which economy was made possible by the use of a homemade drilling rig that was rented at virtually the cost of upkeep. The depth to water level was found to be about 112 feet in an irrigation test well north of Arkansas river in Ford county, and the depth to water level is about 165 feet in an irrigation well at Ensign, Gray county (Lohman, 1938, pp. 4, 5).

In 1937 the Liberal Deep Well Irrigation Company put down an irrigation well 1 mile north of Liberal. According to S. L. Schoff (1939, p. 124) the well is about 357 feet deep and the water level about 123 feet below the base of the pump. The well encountered a coarse water-bearing sand at a depth of 175 to 225 feet, which is within the Ogallala formation. The cost of the plant was about $6,300. Irrigation proved to be unprofitable and the well was abandoned.

The Panhandle Agricultural and Mechanical College at Goodwell, Okla., has two experimental irrigation wells that are 238 and 298 feet deep. The water levels are 135 and 118 feet below the land surface (Schoff, 1939, pp. 111-113). These wells are gravel-walled and yield 425 and 960 gallons a minute, respectively.

In 1939 two irrigation wells were drilled in Stanton county, Kansas. The depths are 160 and 182 feet and the static water levels are 52 and 63 feet (Latta, 1941). They were to be put in use in 1940.

POSSIBILITIES OF FURTHER DEVELOPMENT OF IRRIGATION FROM WELLS IN MORTON COUNTY

The quantity of water that can be pumped from the underground reservoir without causing a permanent lowering of the water table depends upon the capacity and permeability of the reservoir and on the amount of annual recharge. Much of Morton county is underlain by saturated sand and gravel of the Ogallala formation, locally more than 150 feet thick. In the northwestern part of the county, however, the principal water bearers are the Cockrum sandstone and the Cheyenne sandstone, which are productive locally, but may be thin or too fine-grained at other places. The capacity of the Ogallala and locally of the Cockrum and Cheyenne seems to be large enough to withstand considerably more pumping for irrigation. The amount of annual recharge to these formations probably would be insufficient to supply a considerable number of wells distributed evenly over Morton county. Conditions seem to be favorable for irrigation in only a small part of the county; however, in other parts the depth to water level is too great, the soil is not adapted, dust accumulates too readily, or the surface relief is too great for successful irrigation from wells.

In addition to the fundamental factors considered above, the success of irrigating from wells depends upon such factors as the initial cost of the well and pumping equipment, the cost of power or fuel, and the type and current price of the crops to be irrigated. Bulletins that discuss the cost of constructing irrigation wells (Davison, 1939) and the cost of pumping water for irrigation (McCall and Davison, 1939) are available from the Division of Water Resources, Kansas State Board of Agriculture, Topeka, Kan.

The most promising areas for additional irrigation development in Morton county are discussed below.

Northwestern area. — This area includes the northwestern one-fourth of the county in T.'s 31 and 32 S., R.'s 41, 42 and 43 W. Nowhere in this area is the water level more than 110 feet below the land surface and in about one-fourth of the area it is less than 50 feet below the land surface. The principal water-bearing bed is the Cockrum sandstone, which is 80 to 125 feet thick. In most parts of the area it is saturated and yields water freely, but at a few isolated points, especially in the north-central part of the area, the sandstone contains only a small amount of water and wells must be deepened to the underlying Cheyenne sandstone in order to get enough water for domestic and stock use. The Cheyenne sandstone is coarser grained and yields water more freely than the Cockrum sandstone, but its thickness is very uneven and it is absent in some parts of the area. The depth to water level in a small area directly to the south is also less than 100 feet, but the water-bearing bed is the Ogallala formation, the saturated part of which is less than 60 feet thick and probably would not yield sufficient water for extensive irrigation.

Small irrigation wells probably could be developed in this shallow-water area. Most of the land surface is relatively flat and is well suited for irrigation. The soils consist of dark silty loams and silty clay loams and are favorable for irrigation.

Northeastern area.—In a small area of about 12 square miles in the northeastern corner of the county, the depth to water level is 80 to 100 feet. A test well at the northwestern corner of sec. 4, T. 31 S., R. 39 W., penetrated 261 feet of the Ogallala formation, which is here underlain by the Cockrum sandstone. It is possible that as much as 180 feet of Ogallala may be saturated, and such a water-bearing bed probably would yield large quantities of water to irrigation wells. The area is near the edge of the Hugoton gas field, from which an abundance of cheap fuel can be obtained.

Eastern area.—The eastern area is northeast of Rolla and it includes the part of the county that lies south of the sand hills, east of Kansas highway 12, and north of Kansas highway 45. It is underlain predominantly by Ogallala sediments, partly covered by subdued sand dunes. The water level is about 70 to 110 feet below land surface. This is the area in which most of the new irrigation wells are being drilled, and it is probably the most suitable place in the county for additional irrigation development. The water-bearing beds are the sands and gravels of the Ogallala formation, which, according to drillers logs, is 500 to 585 thick in this part of the county. It is possible that as much as 500 feet of the formation may be saturated with water. Well 63, which is 376 feet deep, penetrated nearly 300 feet of saturated material. The area lies within the Hugoton gas field where cheap fuel is available. The large area of sand dunes to the north and west provides an ideal catchment area for the recharge of the Ogallala formation.

The depth to water level in the Cimarron valley is less than 50 feet, but the condition of the soil and the surface irregularities tend to prevent widespread irrigation. The soil is very sandy and porous and the stream channel has widened until almost no bottom land is left in the valley.

If the irrigation from deep wells on the uplands of the High Plains in the future proves to be profitable, the above described areas in Morton county may be extensively developed.

QUALITY OF WATER

The chemical character of the ground waters in Morton county is shown by the analyses given in table 6. The analyses were made by Robert H. Hess in the Water and Sewage Laboratory of the Kansas State Board of Health. Thirty-eight samples of water were collected from representative wells distributed as uniformly as possible within the area and among the water-bearing formations. The analysis of the water supply at Elkhart (listed as well 138) is a composite analysis of the water from 5 wells.

The fluoride content of the waters was determined by the Modified Sanchis method, and the other constituents listed were measured by the methods used by the U. S. Geological Survey.

TABLE 6.—*Analyses of water from typical wells in Morton county, Kansas*

(Analyzed by Robert H. Hess. Quantities are expressed as parts per million.* Reacting values† given in italics.)

Well No. Plate 2.	Location, depth, geologic zone.	Date of collection, 1939	Temperature (°F)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)‡	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Hardness (calculated as $CaCO_3$). Total	Carbonate	Noncarbonate
5	*T. 31 S., R. 39 W.* NE¼ NE¼ sec. 30, 105 feet, Ogallala	Oct. 13	60	0.47	65 *3.24*	29 *2.38*	22 *.95*	246 *4.03*	95 *1.98*	8.0 *.23*	1.7 *.09*	15 *.24*	359	282	202	80
7	*T. 31 S., R. 40 W.* NE¼ NE¼ sec. 9, 160 feet, Ogallala	do.	60	.30	45 *2.25*	29 *2.38*	37 *1.59*	195 *3.20*	118 *2.45*	11 *.31*	2.3 *.12*	8.4 *.14*	349	232	160	72
11	*T. 31 S., R. 41 W.* SE¼ SE¼ sec. 8, 145 feet, Cockrum	do.	59	§	45 *2.25*	16 *1.32*	9.2 *.40*	207 *3.39*	14 *.29*	4.5 *.15*	.6 *.03*	8.0 *.13*	201	179	170	9
15	*T. 31 S., R. 42 W.* NE¼ SE¼ sec. 3, 216 feet, Cockrum	Sep. 25	62	2.7	37 *1.85*	34 *2.79*	113 *4.93*	299 *4.89*	196 *4.08*	17 *.48*	2.3 *.12*	0 *.00*	601	237	§237	0
18	SE¼ SE¼ sec. 23, 44 feet, Cockrum	Oct. 13	59	§	70 *3.49*	19 *1.56*	19 *.82*	249 *4.08*	40 *.83*	12 *.34*	1.1 *.06*	35 *.56*	321	253	204	49
26	*T. 31 S., R. 43 W.* SW¼ NW¼ sec. 22, 51 feet, Cockrum	Sep. 25	59	§	42 *2.10*	25 *2.06*	33 *1.42*	232 *3.80*	63 *1.31*	9.0 *.25*	2.2 *.12*	6.2 *.10*	296	208	190	18
30	*T. 32 S., R. 39 W.* NE¼ NE¼ sec. 18, 170 feet, Ogallala(?)	Oct. 13	60	1.5	74 *3.69*	47 *3.86*	67 *2.92*	242 *3.97*	270 *5.62*	24 *.68*	1.9 *.10*	6.2 *.10*	613	380	198	182
32	*T. 32 S., R. 40 W.* SW¼ SW¼ sec. 6, 180 feet, Ogallala(?)	do.	61	1.7	71 *3.54*	49 *4.03*	49 *2.11*	237 *3.89*	246 *5.12*	12 *.34*	2.8 *.15*	11 *.18*	561	382	194	188
37	NE¼ NW¼ sec. 34, 168 feet, Ogallala(?)	do.	60	1.6	44 *2.20*	40 *3.29*	48 *2.10*	215 *3.53*	157 *3.27*	17 *.48*	1.9 *.10*	13 *.21*	430	78	176	102

Table 6.—Analyses of water from typical wells in Morton county, Kansas—*Continued*

Well No. Plate 2.	Location, depth, geologic zone.	Date of collection, 1939	Temperature (°F)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)‡	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Hardness (calculated as $CaCO_3$)		
														Total	Carbonate	Noncarbonate
	T. 32 S., R. 41 W.															
38	SW¼ NW¼ sec. 7, 94 feet, Cockrum	Oct. 13	59	.71	59 *2.94*	34 *2.79*	48 *2.07*	246 *4.03*	146 *3.04*	12 *.34*	3.5 *.18*	13 *.21*	439	288	202	86
42	NW¼ SE¼ sec. 16, 72 feet, Cockrum	Sep. 18	59	.19	74 *3.69*	86 *7.07*	122 *5.32*	435 *7.17*	325 *6.76*	58 *1.64*	3.3 *.17*	21 *.34*	908	539	358	181
43	NW¼ SW¼ sec. 16, 590 feet, Permian	do	66	§	596 *29.74*	109 *8.96*	36 *1.55*	149 *2.44*	1796 *37.36*	8.5 *.24*	2.6 *.14*	4.4 *.07*	2627	1935	122	1813
46	NW¼ NE¼ sec. 35, 136 feet, Cockrum	Oct. 13	60	1.3	44 *2.20*	48 *3.95*	51 *2.23*	217 *3.56*	176 *3.66*	28 *.79*	3.4 *.18*	12 *.19*	472	310	178	32
	T. 32 S., R. 42 W.															
50	NE¼ NW¼ sec. 29, 96 feet, Cockrum	Oct. 12	60	.41	32 *1.00*	34 *2.79*	49 *2.12*	251 *4.12*	85 *1.77*	9 *.25*	2.5 *.13*	15 *.24*	352	220	206	14
	T. 32 S., R. 43 W.															
52	SW¼ SW¼ sec. 9, 112 feet, Cockrum	Sep. 18	60	§	31 *1.55*	34 *2.79*	44 *1.91*	238 *3.89*	89 *1.85*	8.5 *.24*	3.8 *.20*	4.4 *.07*	333	217	194	23
	T. 33 S., R. 39 W.															
58	NW¼ NW¼ sec. 31, 390 feet, Ogallala	Sep. 19	62	§	85 *4.24*	33 *2.71*	36 *1.58*	196 *3.21*	206 *4.28*	34 *.96*	.4 *.02*	4.0 *.06*	495	348	161	167
59	NW¼ NW¼ sec. 32, 123 feet, Ogallala	Oct. 13	61	.74	74 *3.69*	22 *1.81*	28 *1.20*	161 *2.64*	151 *3.14*	29 *.82*	.4 *.02*	4.9 *.08*	391	277	132	145
	T. 33 S., R. 40 W.															
61	SE¼ SW¼ sec. 12, 84 feet, Ogallala	Oct. 13	59	.33	62 *3.09*	22 *1.81*	80 *3.46*	295 *4.84*	139 *2.89*	18 *.51*	.7 *.04*	4.9 *.08*	474	246	242	4
	T. 33 S., R. 41 W.															
67	NW¼ NW¼ sec. 6, 96 feet, Ogallala	Oct. 12	59	.41	36 *1.80*	43 *3.53*	37 *1.61*	307 *5.03*	67 *1.39*	9.0 *.25*	2.4 *.13*	8.4 *.14*	357	267	252	15

Table 6.—Analyses of water from typical wells in Morton county, Kansas—*Continued*

Well No. Plate 2.	Location, depth, geologic zone.	Date of collection, 1939	Temperature (°F)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)‡	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Hardness (calculated as $CaCO_3$). Total	Carbonate	Noncarbonate
69	SE¼ NE¼ sec. 23, 64 feet, Triassic(?)	Oct. 12	59	.84	64 *3.19*	40 *3.29*	63 *2.73*	301 *4.94*	177 *3.68*	12 *.34*	2.4 *.13*	7.5 *.12*	517	326	247	79
70	SE¼ NE¼ sec. 23, 20 feet, Alluvium	do	58	§	167 *8.35*	92 *7.56*	174 *7.55*	400 *6.56*	632 *13.15*	73 *2.06*	2.0 *.11*	97 *1.56*	1437	795	328	467
	T. 33 S., R. 42 W.															
77	NW¼ NW¼ sec. 21, 100 feet, Ogallala	Sep. 25	60	§	58 *2.89*	63 *5.18*	59 *2.58*	249 *4.08*	214 *4.45*	64 *1.80*	2.4 *.13*	12 *.19*	597	404	204	200
	T. 33 S., R. 43 W.															
81	SE¼ SE¼ sec. 7, 95 feet, Ogallala	Sep. 18	61	.35	32 *1.60*	37 *3.04*	41 *1.79*	244 *4.00*	81 *1.58*	12 *.34*	2.7 *.14*	17 *.27*	345	233	200	33
85	NE¼ SE¼ sec. 22, 116 feet, Ogallala	do	63	.16	38 *1.90*	38 *3.12*	60 *2.59*	250‡ *4.10*	130 *2.70*	11 *.31*	2.5 *.13*	13 *.21*	423	252	213	39
	T. 34 S., R. 40 W.															
92	NE¼ SE¼ sec. 2, 280 feet, Ogallala			.08	69 *3.45*	29 *2.38*	42 *1.82*	212 *3.48*	160 *3.33*	21 *.59*	.2 *.01*	15 *.24*	503	291	174	117
97	SW¼ SW¼ sec. 24, 208 feet, Ogallala	Oct. 2	67	64	57 *2.84*	14 *1.15*	12 *.54*	225 *3.69*	20 *.42*	6.0 *.17*	.10 *.01*	15 *.24*	237	201	184	17
	T. 34 S., R. 41 W.															
105	NE¼ NE¼ sec. 18, 135 feet, Ogallala	do	61	.93	169 *8.43*	54 *4.44*	50 *2.18*	193 *3.16*	543 *11.29*	13 *.37*	.8 *.04*	12 *.19*	939	645	158	487
106	NE¼ SE¼ sec. 21, 175 feet, Ogallala	do	62	2.6	70 *3.49*	21 *1.73*	23 *1.01*	198 *3.25*	111 *2.31*	17 *.48*	.5 *.03*	9.7 *.16*	354	266	162	104
107	NW¼ NW¼ sec. 24, 220 feet, Ogallala	Sep. 19	63	.37	63 *3.14*	12 *.99*	19 *.83*	225 *3.69*	47 *.98*	6 *.17*	.1 *.01*	4.2 *.10*	266	207	184	23
	T. 34 S., R. 42 W.															
115	SW¼ NW¼ sec. 33, 154 feet, Ogallala	Sep. 18	62	.66	57 *2.84*	18 *1.48*	25 *1.09*	234 *3.84*	50 *1.04*	12 *.34*	.9 *.05*	8.8 *.14*	289	217	192	25

Table 6.—Analyses of water from typical wells in Morton county, Kansas—*Concluded*

Well No. Plate 2.	Location, depth, geologic zone.	Date of collection, 1939	Temperature (°F)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)‡	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Hardness (calculated as $CaCO_3$). Total	Carbonate	Noncarbonate
116	SE¼ SE¼ sec. 35, 185 feet, Ogallala	Sep. 19	64	.63	68 *3.39*	16 *1.32*	38 *1.66*	261 *4.28*	77 *1.60*	13 *.37*	.6 *.03*	5.8 *.09*	350	237	214	23
119	*T. 34 S., R. 43 W.* SE¼ SW¼ sec. 8, 153 feet, Triassic(?)	Sep. 18	62	.79	29 *1.45*	31 *2.55*	38 *1.66*	246 *4.03*	46 *.96*	10 *.28*	2.8 *.15*	15 *.24*	296	202	202	0
122	*T. 35 S., R. 39 W.* SE¼ SW¼ sec. 6, 216 feet, Ogallala	Oct. 2	65	2.7	94 *4.69*	19 *1.56*	33 *1.44*	195 *3.20*	198 *4.12*	10 *.28*	.4 *.02*	4.4 *.07*	450	318	160	158
127	*T. 35 S., R. 40 W.* NW¼ SW¼ sec. 15, 230 feet, Ogallala	Sep. 19	62	.49	93 *4.64*	16 *1.32*	47 *2.05*	161 *2.64*	230 *4.78*	16 *.45*	.5 *.03*	6.6 *.11*	490	299	132	167
128	*T. 35 S., R. 41 W.* NE¼ SE¼ sec. 4, 196 feet, Ogallala	Oct. 2	64	.71	61 *3.04*	20 *1.64*	32 *1.41*	227 *3.72*	91 *1.89*	12 *.34*	.6 *.03*	7.1 *.11*	338	236	186	50
136	*T. 35 S., R. 42 W.* NE¼ NW¼ sec. 12, 194 feet, Ogallala	do	63	2.7	99 *4.94*	34 *2.79*	59 *2.57*	249 *4.08*	274 *5.70*	13 *.37*	.7 *.04*	7.1 *.11*	614	392	204	188
138	SE¼ sec. 17, 5 wells, 260-308 feet, Ogallala	......	......	.10	66 *3.39*	33 *2.71*	41 *1.79*	310 *5.08*	99 *2.06*	16 *.45*	.7 *.04*	13 *.21*	455	300	254	46
151	*T. 35 S., R. 43 W.* NE¼ NW¼ sec. 22, 220 feet, Ogallala	Sep. 18	63	1.10	56 *2.79*	34 *2.79*	97 *4.22*	344 *5.64*	168 *3.49*	21 *.6*	.8 *.04*	2.2 *.04*	554	279	††279	0

* One part per million is equivalent to 1 pound of substance per million pounds of water or 8.33 pounds per million gallons of water.
† Equivalents per million.
‡ Calculated.
§ Less than .15 part.
¶ Total alkalinity, 244 parts per million; excess alkalinity, 7 parts per million.
# Sample also contains 4.8 parts per million of carbonate.
†† Total alkalinity, 282 parts per million; excess alkalinity, 3 parts per million.

Chemical Constituents in Relation to Use

The following discussion of the chemical constitutents of ground water has been adapted from publications of the United States Geological Survey.

Total dissolved solids.—The residue left after a natural water has evaporated consists of rock materials, with which may be included some organic material and a small amount of water of crystallization. Water containing less than 500 parts per million of dissolved solids generally is entirely satisfactory for domestic use, except for the difficulties resulting from its hardness, and in some areas, because of excessive iron corrosiveness. Water having more than 1,000 parts per million is likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in some other respects.

The total dissolved solids in samples of water collected in Morton county ranged from 201 to 2,627 parts per million. The samples from about two-thirds of the wells contained less than 500 parts per million, and such water is suitable for most ordinary purposes. About one-third of the samples contained between 500 and 1,000 parts per million, and the sample from two wells (43 and 70) contained more than 1,000 parts per million.

Hardness.—The hardness of water, which is the property that receives the most attention as a general rule, is most commonly recognized by its effects when soap is used with the water in washing. Calcium and magnesium cause almost all the hardness of ordinary water. These constituents are also the active agents in the formation of the greater part of all the scale formed in steam boilers and in other vessels in which water is heated or evaporated.

In addition to the total hardness the table of analyses shows the carbonate hardness and the noncarbonate hardness. The carbonate hardness is that due to the presence of calcium and magnesium bicarbonates. It is almost entirely removed by boiling. In some reports this type of hardness is called temporary hardness. The noncarbonate hardness is due to the presence of sulphates or chlorides of calcium and magnesium, but it cannot be removed by boiling and has sometimes been called permanent hardness. With reference to use with soaps, there is no difference between the carbonate and noncarbonate hardness. In general the noncarbonate hardness forms harder scale in steam boilers.

Water having a hardness less than 50 parts per million is generally rated as soft, and its treatment for removal of hardness under ordinary circumstances is not necessary. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most purposes, but it does slightly increase the consumption of soap, and its removal by a softening process is profitable for laundries or other industries using large quantities of soap. Waters in the upper part of this range of hardness will cause considerable scale in steam boilers. Hardness exceeding 150 parts per million can be noticed by anyone, and if the hardness is 200 or 300 parts per million it is common practice to soften water for household use or to install a cistern to collect soft rain water. Where municipal water supplies are softened, an attempt is generally made to reduce the hardness to 60 or 80 parts per million. The additional improvement from further softening of a whole public supply is not deemed worth the increase in cost.

The hardness of the samples of water from Morton county ranged from 179 to 1,935 parts per million. The softest water analyzed was from well 11 in the Cockrum sandstone, and the hardest water was obtained from well 43 in the Permian redbeds. Twenty-five of the samples analyzed had a hardness between 200 and 300 parts per million and seven had a hardness between 300 and 400 parts per million. The hardness of five samples exceeded 400 parts per million.

Iron.—Next to hardness, iron is the constituent of natural waters that in general receives the most attention. The quantity of iron in ground waters may differ greatly from place to place, even though the waters are from the same formation. If a water contains much more than 0.1 part per million of iron the excess may separate out and settle as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste and to stain cooking utensils, may be removed from most waters by simple aeration and filtration, but a few waters require the addition of lime or some other substance.

Most of the water from wells in Morton county contained more than 0.1 part per million of iron. Five samples contained between 1.0 and 2.0 parts per million of iron and three samples (106, 136, and 15) contained between 2.0 and 3.0 parts per million.

Fluoride.—Although determinable quantities of fluoride are not so common as fairly large quantities of the other constituents of natural water, it is desirable to know the amount of fluoride present in water that is likely to be used by children. Fluoride in water has been shown to be associated with the dental defect known as mottled enamel, which may appear on the teeth of children who, during the period of formation of the permanent teeth, drink water containing fluoride. It has been stated that waters containing 1 part per million or more of fluoride are likely to produce mottled enamel, although the effect of 1 part per million is not usually very serious (Dean, 1935, pp. 1269-1272). If the water contains as much as 4 parts per million of fluoride, 90 percent of the children exposed are likely to have mottled enamel, and 35 percent or more of the cases will be classified as moderate or worse.

More than half of the water samples collected in Morton county contained more than 1 part per million of fluoride. Four samples contained between 1 and 2 parts per million, 13 samples contained between 2 and 3 parts per million, and 4 samples contained more than 3 parts per million. The maximum fluoride content, 3.8 parts per million, was in a sample of water from well 52.

Water for irrigation.—The suitability of water for use in irrigation is commonly believed to depend mainly on the total quantity of soluble salts and on the ratio of the quantity of sodium to the total quantity of sodium, calcium, and magnesium together. The quantity of chloride may be large enough to affect the use of the water and in some areas other constituents, such as boron, may be present in sufficient quantity to cause difficulty. In a discussion of the interpretation of analyses with reference to irrigation in southern California, Scofield (1933) states that if the total concentration of dissolved salts is less than 700 parts per million there is not much probability of harmful effects in irrigation use. If it exceeds 2,100 parts per million there is a strong probability of damage to either the crops or the land, or both. Water containing less than 50 percent sodium (the percentage being calculated as 100 times the ratio of the sodium to the total bases, in equivalents) is not likely to be injurious, but if it contains more than 60 percent its use is inadvisable. Similarly, a chloride content less than 142 parts per million is not objectionable, but more than 355 parts per million is undesirable. It is recognized that the harmfulness of irrigation water is so dependent on the nature of the land and the crops and on the manner of use and the drainage that no hard and fast limits can be adopted.

All but one of the samples of water collected in Morton county are well within the limits suggested by Scofield for safe waters for use in irrigation. Water from well 43 contained 2,627 parts per million of total dissolved solids and probably would not be suitable for irrigation.

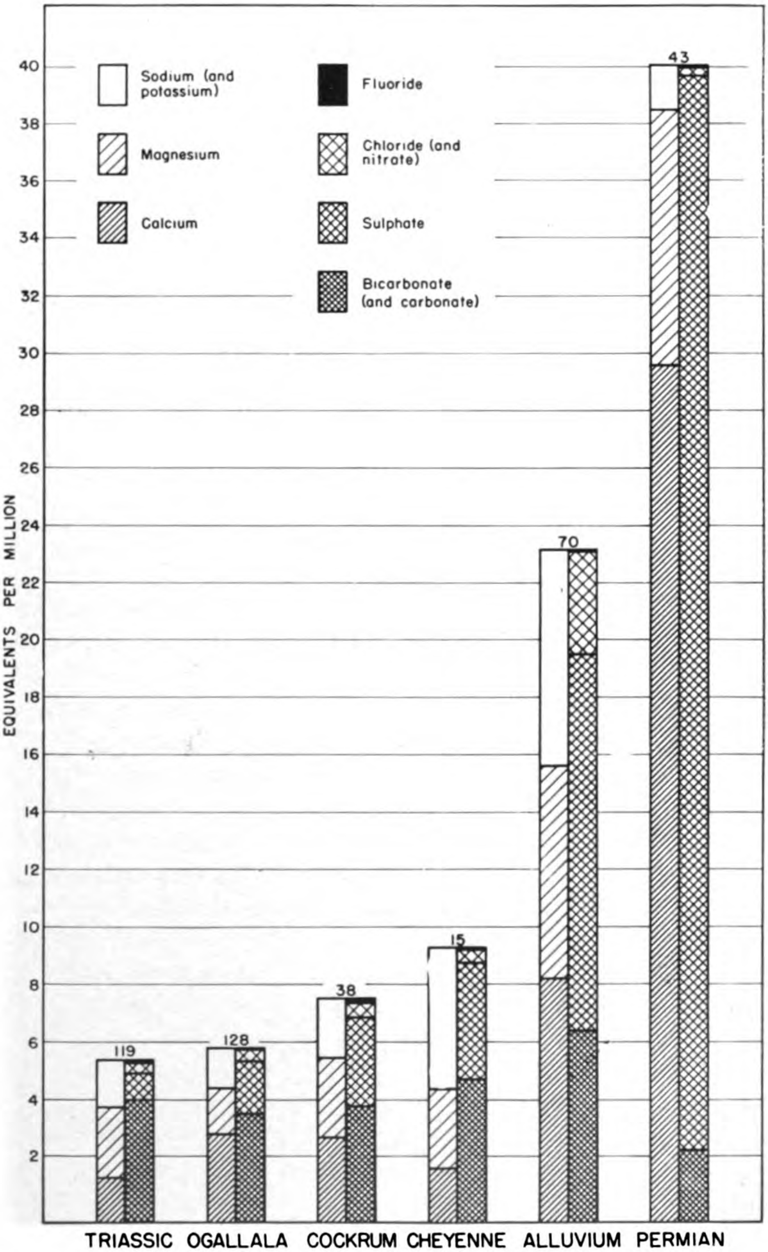

FIG. 6. Analyses of typical waters from the six principal water-bearing formations in Morton county.

Sanitary Considerations

The analyses of water given in the tables show only the amounts of dissolved mineral matter in the water and do not indicate the sanitary quality of the water. An abnormal amount of certain mineral matter such as nitrate, however, may indicate pollution of the water.

About 50 percent of the population of Morton county is dependent on private water supplies from wells, and every precaution should be taken to protect these supplies from pollution. A well should not be located where there are possible sources of pollution. Every well should be tightly cased to a level somewhat below the water table. As a general rule dug wells are more subject to contamination from surface water than are drilled wells, owing mainly to the fact that generally they are not effectively sealed at the surface. Fortunately, more than 95 percent of the wells in Morton county are drilled wells.

Relation to Stratigraphy

The typical quality of water in the six principal water-bearing formations in Morton county is shown in figure 6, and is discussed below.

Permian redbeds.—The artesian wells at Richfield penetrate the Permian redbeds. The water contains a large amount of calcium and sulphate and a relatively small quantity of iron. These beds are cemented by iron oxide but the water has a small iron content because the iron in the rock is ferric oxide, which is relatively insoluble. These beds yield water that contains more than 2 parts per million of fluoride, which might be injurious to the enamel of children's teeth.

Triassic(?) redbeds. — Water from the Triassic(?) beds may be moderately hard or very hard, depending upon the zone from which the water is taken. The upper part of the Triassic(?) consists predominantly of buff and gray sandstones and yields moderately hard water to wells. The lower part is predominantly red siltstone and sandstone, but contains some gypsum, and yields strongly mineralized water under artesian pressure. An old artesian well (86) at the old town of Point of Rocks was reported to yield a "strong alkali water" (Parker, 1911, p. 144). Well 140 at Elkhart encountered strongly mineralized water at a depth of 460 feet in redbeds that are probably Triassic(?). The water from well 119, a zone near the top of the Triassic(?), has a total hardness of 202 parts per million and contains 2.8 parts per million of fluoride.

Cheyenne sandstone.—Waters from wells in the Cheyenne sandstone have a moderate hardness and contain 1.5 to 2.3 parts per million of fluoride. The water from well 15 in this sandstone has a hardness of 237 parts per million and has a fluoride content of 2.0 parts per million. The quality of the water from the Cheyenne sandstone is very similar to that of water from the Cockrum sandstone.

Cockrum sandstone.—Most of the wells in the northwestern part of the county get their water from the Cockrum sandstone. Most of the Cockrum water has a hardness of 200 to 300 parts per million and a fluoride content of 1.1 to 3.8 parts per million. The sample of water from well 11 in the Cockrum sandstone was the softest water of any of the 38 samples analyzed, 179 parts per million, and its fluoride content was only 0.6 part per million. The four samples from Morton county having the greatest fluoride content, however, were also from wells in the Cockrum sandstone. In general the Cockrum water is moderately hard and contains only a small amount of iron, but contains sufficient fluoride to be harmful to children's teeth.

Ogallala formation.—The hardness of the water from wells in the Ogallala formation ranges from 201 to 645 parts per million, which averages slightly more than that of the water from the Cockrum sandstone.

In some respects the water from the Ogallala formation north of Cimarron river differs from the water from the Ogallala south of the river. Water from the Ogallala north of the river contains 1.9 to 2.8 parts per million of fluoride, whereas water from the Ogallala south of the river contains less than 1 part per million. The greater fluoride content north of the river is probably caused by recharge of the Ogallala formation by water from the Cockrum sandstone, whereas the Ogallala formation south of the river is probably recharged by precipitation on the sand dunes in southern Morton and Baca counties.

Water from the Ogallala formation south of the river contains more iron than water from the Ogallala north of the river or from the Cockrum.

Alluvium.—Water from wells in the alluvium of Cimarron river is very hard. The sample from well 70 had a hardness of 795 parts per million and the sulphate and fluoride contents were 632 and 2.0 parts per million respectively. There are only a few wells in the alluvium in the Cimarron valley and most of these are stock wells. Supplies of softer water for domestic use are obtained in the valley from wells that penetrate the Triassic(?) redbeds or the Ogallala formation below the alluvium.

WATER-BEARING FORMATIONS

The classification and nomenclature of the rocks described in this report have been adopted by the State Geological Survey of Kansas. They differ somewhat from the classification and nomenclature in reports of the Federal Geological Survey.

PERMIAN SYSTEM

Undifferentiated Redbeds

Character.—The Permian redbeds consist principally of red siltstone and sandstone, but include interbedded salt, gypsum, anhydrate, and dolomite. The redbeds are not exposed in Morton county and, as the only data available are the logs of gas test wells drilled in this area, no detailed lithologic description can be given. The Hydraulic Oil Company No. 1 Butts well, in sec. 22, T. 34 S., R. 43 W., encountered about 730 feet of red shale and siltstone, 320 feet of sandstone, 95 feet of salt, 20 feet of gypsum, and 5 feet of "lime" (probably dolomite). Most of the sandstones were red and buff.

Distribution and thickness.—The Permian redbeds underlie all of Morton county, but the nearest outcrops of these beds are in Texas county, Oklahoma, and in Meade and Clark counties, Kansas. The thickness of these beds is not definitely known, for their upper limit is not established, but in Morton county they probably are about 1,250 feet thick. Well logs indicate a thickness of 1,350 feet in Cimarron county, Oklahoma, and 1,550 feet in Hamilton county, Kansas.

Age and correlation.—As exactly as can be determined from well logs, the redbeds underlying Morton county include representatives of all the formations above the Ninnescah shale and below the Day Creek dolomite. The Day Creek dolomite and the Taloga formation of some authors probably are absent, and well logs indicate the presence of only about 70 to 100 feet of sandstone that probably represents the Marlow formation of the Whitehorse group. Farther east the Marlow formation is about 110 feet thick (Norton, 1939, pp. 1803-1811).

Water supply.—A few deep wells (43, 44, and 45) have encountered Permian water-bearing beds and in each of these wells the artesian pressure was sufficient to cause the water to flow. The water from these wells is strongly mineralized, the principal mineral constituents being calcium and sulphate. The water-bearing bed seems to be very permeable, for one artesian well (43) had a reported initial flow of 1,200 gallons a minute. In 1939, however, this well was observed to flow only 20 gallons a minute. Water from Permian redbeds probably could be obtained from deep wells in a large part of the county, but the great depth and the poor quality of the water discourage any drilling of wells to this zone.

TRIASSIC(?) SYSTEM

Undifferentiated Redbeds

Character.— The Triassic(?) redbeds are made up of red siltstone; buff, red, and white sandstone; and a small amount of gypsum. The siltstone is thinly and unevenly bedded, is maroon when freshly exposed, but weathers to a pink or light red, is generally hard, and breaks into irregular chips and nodules. The sandstone is massive and fine-grained, and ranges from white to gray, tan, brown, and red. Test hole 8 (fig. 2) at Point Rock near Cimarron river in sec. 12, T. 34 S., R. 43 W., was drilled 200 feet into the redbeds. The rocks encountered included about 150 feet of maroon siltstone and about 50 feet of buff and red sandstone. Test hole 4, at the southeast corner of sec. 36, T. 31 S., R. 42 W., was drilled 41 feet into Triassic(?) redbeds, of which about 35 feet was red siltstone and 6 feet was buff, brown, and gray siltstone and sandstone. Test hole 6, in sec. 8, T. 33 S., R. 42 W., was drilled through 55 feet of fine reddish-brown sandstone, 49 feet of tan to buff sandstone containing a small amount of gypsum, and 25 feet of maroon-red sandstone, all of which is believed to be Triassic(?) in age. Test hole 7, in sec. 31, T. 33 S., R. 43 W., on the Kansas-Colorado line, penetrated 35 feet of Triassic(?) material of which 9 feet was maroon-red sandstone and 26 feet was fine-grained buff sandstone.

The Triassic(?) redbeds crop out at two places along the Cimarron valley; at Point Rock, on the north side of the river in sec. 12, T. 34 S., R. 43 W., and on the south side of the river in sec. 5,

T. 34 S., R. 42 W. A section at Point Rock (pl. 5B) was measured by Perry McNally as follows:

Section of Triassic(?) rocks at Point Rock, sec. 12, T. 34 S., R. 43 W.

	Feet
7. Sandstone, massive, soft, buff to brown; weathers yellow and yellow brown	8
6. Siltstone, massive, soft, maroon red; weathers pink	3
5. Sandstone, massive, hard, gray to brown; weathers yellow brown	7
4. Sandstone, fine grained, soft, buff	10
3. Sandstone, fine grained, soft, gray; weathers yellow brown	2
2. Sandstone, massive, fine grained, orange yellow	3
1. Sandstone, fine grained, massive, white	9
Base not exposed	
Total	42

Distribution and thickness.—The contact between the Triassic(?) redbeds and Permian redbeds is not definitely established, owing to the lithologic similarity of the rocks of the two systems and to the lack of exposures; therefore the total thickness of the Triassic(?) redbeds is not known. A test hole in southern Hamilton county penetrated 320 feet of redbeds that was probably Triassic(?). A test hole in Cimarron county, Oklahoma, encountered 260 feet of Triassic, and Sanders (1934, pp. 860-870) reports as much as 575 feet of Triassic beds in that area. Along Cimarron river in northeastern New Mexico the Triassic is more than 600 feet thick (Parker, 1933, pp. 38-51).

Logs of test wells in Morton county indicate that the Triassic(?) underlies only the western half of the county (pl. 6). In Texas county, Oklahoma, however, the formation probably extends farther eastward.

Age and correlation.—The redbeds at Point Rock are lithologically very similar to those in the Red Point district in Texas county, Oklahoma, which Schoff (1939, pp. 49-51) and others have called Triassic(?). In 1900 Gould (1900, p. 139) wrote:

> it has been demonstrated that the upper part of the problematic Kansas-Oklahoma redbeds is Triassic. Vertebrates taken from the lower part of these beds, in eastern Oklahoma, have been identified by Dr. S. W. Williston as Permian forms similar to those from the Texas Permian. On the other hand, invertebrates obtained from near the top of the redbeds in western Oklahoma are classed as Triassic forms, on the authority of Dr. J. W. Beede and Mr. Charles Schuchert.

The beds at Point Rock and Red Point generally are correlated with the Dockum group of Texas, New Mexico, and Colorado, rocks which are Triassic, probably Upper Triassic. The beds are lithologically similar to the Tecovas formation, the lower part of the Dockum group of the Texas panhandle. The buff and red sandstones encountered in test hole 7 (fig. 2) are similar to the sandstone that caps Two Buttes, in southeastern Colorado about 45 miles northwest of Morton county. Sanders (1934, pp. 860-870) describes the sandstone, locally called "Big sandstone," that caps Two Buttes as a massive cross-bedded medium-grained friable sandstone about 240 feet thick. Generally it is gray to buff, but locally it is reddish. He correlates this sandstone with the Dockum group for the following reasons: (1) It overlies redbeds of probable Permian age. (2) It is correlated by well logs with the Dockum group of Cimarron county, Oklahoma. (3) The Morrison formation rests on progressively older beds toward the east. (4) If the "Big sandstone" is Jurassic, then there is no Triassic. This would raise the question, What happens to the 575 feet of Triassic of Cimarron county, Oklahoma?

Water supply.—The Triassic(?) redbeds yield moderate quantities of water to wells in Morton county, including wells 86, 110, 118, and 119. Water from wells in the upper part of the Triassic(?) redbeds is moderately hard as shown by analysis 119 in table 5. Artesian water from well 86 in the lower part of the Triassic(?) was reported to be "strongly alkaline" and artesian water from well 140, which was initially drilled to the Triassic(?) redbeds, was reported to be strongly mineralized. Artesian water has been found in these beds along the Cimarron river valley at depths of 200 to 215 feet and north of the river in R. 43 W. at depths of 250 to 300 feet. Because of the poor quality, however, the water from the lower part of the Triassic(?) redbeds is no longer used.

JURASSIC(?) SYSTEM

Morrison(?) Formation

Test hole 4, at the southeast corner of sec. 36, T. 31 S., R. 42 W., penetrated 28 feet of blue-green clay and marl and 12 feet of blue-green, light-gray, and brown sandstone. These beds occur between the Cheyenne sandstone and the Triassic(?) redbeds and are believed to be a part of the Morrison formation. The color and lithology of these beds are very similar to those of the Morrison formation of southeastern Colorado. The Morrison formation crops out in Cimarron county, Oklahoma; Union county, New Mexico; and at Two Buttes, Baca county, Colorado. At Two Buttes the Morrison consists of 160 feet of green and purple shale, and white sandstone.

These beds probably thin eastward and pinch out a few miles east of the Kansas-Colorado line. The beds classed as Morrison(?) probably yield little or no water to wells in Morton county.

CRETACEOUS SYSTEM

Dakota Group

The Cretaceous rocks found in Morton county are those that overlie the Permian or Triassic(?) redbeds and are correlated with beds that underlie the Graneros shale elsewhere in western Kansas. This series of sandstones, clays, and shales in Kansas and adjacent areas has been described in earlier reports under various classifications.

Cragin (1886, 1889, 1895) classified the Cretaceous sediments of southern Kansas into the Cheyenne sandstone, the Kiowa shale, and the Dakota sandstone, named in ascending order. A little later Gould (1898) made a similar classification, but used the term Medicine beds for strata that lie between the Kiowa shale and the Dakota sandstone. Stose (1912) classified equivalent rocks in eastern Colorado into the Purgatoire formation, containing a lower sandstone member and an upper shale member, and the Dakota sandstone. In 1920, Darton (p. 2) subdivided the Cretaceous rocks that lie below the Graneros shale in western Kansas into the Cheyenne sandstone, the Kiowa shale, and the Dakota sandstone. Twenhofel (1924, pp. 12-30) used the terms Cheyenne sandstone, Belvidere formation, and "Dakota" formation for the Cretaceous sediments of southern Kansas, and retained the term Kiowa for the lower shale member of the Belvidere formation. In describing similar beds in Hamilton county, Kansas, Bass (1926, pp. 59, 73-76) used the term Dakota sandstone for all sediments between the Permian redbeds and the Graneros shale. He recognized, however, that part of these sediments were probably equivalent to the Purgatoire formation of eastern Colorado. Lee (1927, p. 17) correlated the Purgatoire formation and the Dakota sandstone of southeastern Colorado with sediments designated by him as the Dakota group at the Bellvue section in northern Colorado. Elias (1931, p. 28; 1937, p. 10) classified equivalent sediments in western Kansas as the Dakota group. In 1931, Tester (1934, pp. 234-283) applied the name Dakota "stage" to the succession of strata lying between the Graneros shale and Pennsylvanian sediments at the type locality of the Dakota in eastern Nebraska. Saunders (1934, pp. 862-865) divided similar sediments of the Two Buttes area of southeastern Colorado into the

Purgatoire formation and the Dakota sandstone. Schoff (1939, pp. 54-57) classified the Cretaceous sediments of western Oklahoma into the Purgatoire formation, including the Cheyenne sandstone and the Kiowa shale members, and the Dakota sandstone.

The term Dakota group has been used by the State Geological Survey of Kansas (Moore and Landes, 1937, Moore, 1940, p. 40) to include all Cretaceous strata that lie below the Graneros shale. At a meeting in Lawrence in January, 1941, the members of the State Geological Survey decided to adopt this usage of the term Dakota group and to use local names for the sandstone forming the uppermost formation of the group and called by some writers the Dakota sandstone. This is the classification used by the Nebraska Geological Survey and by many oil geologists (Kansas Geological Society Guidebook, 1940, pp. 14, 55). In a report on Stanton county, Kansas, Latta (1941, p. 70) states:

Accordingly, under conditions of present knowledge, it seems best to recognize the Dakota group as including the somewhat variable, partly undifferentiated succession of clastic deposits of Cretaceous age below the Graneros shale and to use local names for the subdivisions of the group in those areas where it is possible to subdivide the Dakota group.

All Cretaceous strata in Stanton county belong to the Dakota group. They comprise the Cheyenne sandstone, Kiowa shale, and an upper sandstone (formerly called the Dakota) that is here named the Cockrum sandstone.

Stanton county borders Morton county on the north, and the Cretaceous deposits in both areas are very similar. The classification of Cretaceous sediments used by Latta is followed in the present report for beds of equivalent age in Morton county, and the term Cockrum sandstone is used in this report for the upper sandstone division of the Dakota group.

CHEYENNE SANDSTONE

Character.—The Cheyenne sandstone does not crop out in Morton county, but it is known from the records of wells 15 and 17 to underlie the northwestern part of the county (pl. A). Where present, the Cheyenne sandstone generally is encountered at a depth of about 80 to 100 feet below the base of the Cockrum sandstone. It is described by well drillers as a white to gray coarse-grained sandstone. In adjacent areas, in which the formation crops out, it is a white to yellow quartz sandstone of medium to coarse grain and contains subordinate amounts of shale. In some areas the sandstone is conglomeratic near the base.

Distribution and thickness.—The Cheyenne sandstone underlies an area of about 50 to 75 square miles in the northwestern part of the county. It was absent in test hole 4, in sec. 36, T. 31 S., R. 42 W., in the artesian well (43) at Richfield, and in test holes 6 and 7, which are farther south. It is encountered in many wells in Stanton county and probably underlies a large part of that county.

The Cheyenne sandstone ranges greatly in thickness. Twenhofel (1924, p. 14) states that—

The bedding is extremely irregular and discontinuous and most beds are merely lenses of limited extent. The writer does not consider it possible definitely to recognize any member beyond the limits of one locality.

The E. M. Watkins well in sec. 11, T. 31 S., R. 43 W., penetrated 125 feet of white sandstone between the Kiowa shale and the Triassic(?) redbeds, which is probably all Cheyenne sandstone, but which may include a part of the Morrison formation. A few miles north of this well the Cheyenne is reported to be 60 feet thick, and 8 miles southeast it is absent. A test hole on the Hamilton-Stanton county line penetrated 48 feet of the Cheyenne sandstone. The thickness of the Cheyenne is 15 to 50 feet in Cimarron county, Oklahoma; 50 feet at Two Buttes, in southeastern Colorado; 30 to 60 feet in northeastern New Mexico; 15 to 60 feet in Las Animas county, Colorado; and 10 to 55 feet in Kiowa and Commanche counties, Kansas.

Age and correlation.—No fossils were obtained from the Cheyenne sandstone in Morton county, so its age can be determined only by correlation with sandstones that crop out in adjacent areas. Its lithology is very similar to that of the lower part of the Purgatoire formation of Colorado, New Mexico, and Oklahoma and to the Cheyenne sandstone of south-central Kansas. Its stratigraphic position also aids in correlation, for it is found below 50 to 100 feet of dark shale that is correlative with the Kiowa shale and with the shale in the upper part of the Purgatoire formation, and it overlies Permian or Triassic(?) redbeds.

Bullard (1928, p. 116) collected marine fossils from the Cheyenne sandstone in Cimarron county, Oklahoma, which he believes are of Washita (Lower Cretaceous) age. Marine pelecypods found by Schoff (1939, p. 55) in the Cheyenne sandstone in the Red Point district in Texas county, Oklahoma, were identified by T. W. Stanton as representing a horizon near the base of the Washita group (Lower Cretaceous).

Origin.—The presence of marine pelecypods in the Cheyenne sandstone in Texas county, Oklahoma, is proof of the marine origin of the sandstone in that area, but in Kiowa and Comanche counties, Kansas, the discontinuous bedding, the cross-lamination, the presence of land plants, and the absence of marine fossils seem to indicate a nonmarine origin. It is possible, however, that the Cheyenne in Kansas is also marine, for Twenhofel (1924, pp. 19, 20) states that

The vegetable matter appears to have floated in, for nothing has been found suggesting that the vegetation grew where it now occurs.

Water supply.—The Cheyenne sandstone yields moderate quantities of water to wells in the northwestern part of the county. The coarse, friable character of the sandstone makes it a good water-bearing bed. In northwestern Morton county the Cheyenne is overlain by the Kiowa shale and that in turn by the Cockrum sandstone (pl. 6C). Wells have been drilled into the Cheyenne sandstone only in those places where the Cockrum does not yield sufficient water for domestic and stock use. In these places the Cheyenne yields adequate quantities of moderately hard water at depths of 175 to 225 feet. The water in the Cheyenne rises in wells to about the same level as the water in the Cockrum. Farther west, near Blaine, in southeastern Colorado, the Cheyenne yields water in flowing artesian wells.

Water from wells in the Cheyenne sandstone is similar to water from the Cockrum sandstone, but is slightly harder and contains more iron than the Cockrum water (see analysis of water from well 15).

KIOWA SHALE

Character.—Deep wells in the northern part of the county penetrate dark shale below the Cockrum sandstone and above the Cheyenne, Morrison(?), or Triassic(?) beds. It consists of dark-gray or dark-bluish-gray thin-bedded shale containing small amounts of sand and brown clay. Some of the beds are calcareous.

Distribution and thickness.—Kiowa shale underlies most of the northern third of the county, is encountered in wells in the northwestern and north-central parts of the county, and probably extends eastward beyond the Morton-Stevens county line. Test holes 6, 7, 8, and 11 (fig. 2), failed to encounter the Kiowa shale. Logs of gas test wells in the southeastern part of the county indicate that the formation is also absent in that area.

The thickness of the Kiowa shale is much more nearly uniform than that of the Cheyenne sandstone, and in Morton county ranges from 35 to 85 feet, being greatest in the western part of the county. The Kiowa is 60 feet thick at Two Buttes, Colorado; 70 to 115 feet in Stanton county, Kansas; and reaches a maximum thickness of 150 feet at the type locality in Kiowa county, Kansas.

Age and correlation.—No fossils were obtained from the shale in this county, but it seems to correlate clearly with the Kiowa shale on the basis of its lithology and stratigraphic position. The nearest outcrops in adjacent areas are very fossiliferous, and its Comanche (Lower Cretaceous) fauna indicates that it may be equivalent in age to the Glencairn shale member of the Purgatoire formation of Colorado, and to the Fuson shale of Wyoming, Montana and South Dakota.

Water supply.—The Kiowa shale is relatively impremeable and yields little or no water to wells in Morton county.

COCKRUM SANDSTONE

Character.—The character of the Cockrum sandstone in Morton county is revealed only from two small exposures along a tributary of North Fork of Cimarron river (pl. 7) and from the cuttings of two test holes (4 and 5, fig. 2). The Cockrum sandstone is made up of fine-grained sandstones containing clay and lesser amounts of shale and siltstone. A microscopic study of the well cuttings indicates that about 60 to 65 percent of the Cockrum is made up of sandstone and that the rest is principally clay or shale.

The color of the sandstone is principally light buff or brown but may display various shades of red and purple. The distribution of color may be uniform, in irregular splotches, or irregular bands, the color bands being semi-parallel and fairly uniform in width. The banding is due to coloration of the cementing material, not to the color of the sand grains, and there is no change in the character, size, or shape of the sand grains from one colored band to another. About 60 to 65 percent of the standstone is made up of fine-grained sand and the rest is very fine-grained sand and a small amount of silt. In individual beds the sand grains are very well sorted. The fine sand grains are subangular and subrounded and consist almost entirely of white quartz, but there are a few grains of pink and red quartz. The very fine sand and silt grains are composed mainly of white quartz and are mostly angular to subangular, but a few are subrounded.

The sandstones may be very friable, moderately compact, or quartzitic, depending upon the cementing material and the degree of cementation. The friable and moderately compact material is cemented mainly with iron oxide and the quartzitic material is cemented by pale-gray quartz. The quartzitic material is so tightly cemented that fractures extend through the individual quartz grains.

PLATE 7. Outcrop of Cockrum sandstone along a tributary of North Fork of Cimarron river (photo by H. T. U. Smith).

The clay, which makes up about 35 to 40 percent of the Cockrum sandstone, is principally brown but may be buff, tan, or light greenish gray. The light-greenish-gray material is a thin-bedded, silty clay, but the buff, tan, and brown material contains very little silt.

The bedding in the Cockrum ranges from thin laminae of silty clay to massive ledges of quartzitic sandstone. One test hole penetrated 62 feet of sandstone containing very few if any partings of clay or shale. Some of the thin-bedded sandstones in the Cockrum are ripple-marked.

Distribution and thickness.—The Cockrum sandstone crops out along a tributary of North Fork of Cimarron river in the northern tier of townships. Along most of the stream's course the sandstone is covered by a few feet of alluvium, but it is exposed in small areas in sec. 33, T. 31 S., R. 41 W., and in sec. 21, T. 31 S., R. 43 W. The Cockrum underlies the northern two tiers of townships in Morton county, and in the western half of the county the formation may extend as much as 1 mile south into the third tier of townships. Test holes drilled in the southwestern quarter of the county failed to encounter the Cockrum sandstone, and logs of gas test wells in the southeastern part of the county indicate that the formation is also absent there. Part of the rocks at Point Rock previously mapped as the Cockrum sandstone are now believed to be Triassic(?) in age. The rocks bear no resemblance to the Cockrum sandstone, and the Cockrum was not encountered in nearby test hole 6 (fig. 2) and in gas test wells.

Only a small part of the Cockrum sandstone is exposed in the county, so the thickness is known only from test holes and from drillers logs. Only two test holes (4, 5) in Morton county were drilled through the Cockrum sandstone. In test hole 4, which is 3 miles northwest of Richfield, the Cockrum was found to be only 37 feet thick and in test hole 5, which is 6.5 miles east-northeast of Richfield, it was 150 feet thick. Drillers' logs indicate 130 feet of Cockrum sandstone at Richfield and 75 feet in the northwestern corner of the county.

Origin.—The Cockrum sandstone contains both marine and nonmarine fossils, so its origin is problematical. It has been suggested by Moore (1933, p. 443) that the Cockrum is a stream-laid and sea-worked deposit.

Age and correlation.—For a discussion of the age and correlation of the Cockrum sandstone, see pages 73 and 74.

Water-supply.—The Cockrum sandstone ranks second in importance to the Ogallala formation as a source of ground water in this county. It supplies many wells in the northwestern part of the county in T's. 31 and 32 S., R's. 41, 42, and 43 W. The Cockrum generally is well sorted and moderately permeable, but locally, however, it is relatively impermeable, owing presumably to cementation by quartz, and yields little or no water to wells. In the northeastern quarter of T. 31 S., R. 42 W., the Cockrum contains little or no water, and wells are drilled to the Cheyenne sandstone in order to get a sufficient supply for domestic and stock use. The yields of wells in the Cockrum range from 1 gallon a minute from some windmill wells to 200 gallons a minute from the irrigation well on the Lloyd Ball farm (p. 54). In about one-third of the Cockrum wells the depth to water level is less than 50 feet, and in about two-thirds of the wells it is between 50 and 100 feet, but in a few wells it is 100 to 120 feet.

In general the water from the Cockrum is relatively hard. It is harder than the average water from the Ogallala, but is softer than the water from the Cheyenne sandstone. Most of the water from the Cockrum sandstone contains 2 to 4 parts per million of fluoride and hence is likely to mottle the enamel of children's teeth.

TERTIARY AND QUATERNARY SYSTEMS

Pliocene (Including the Ogallala Formation) and Pleistocene Undifferentiated

There is evidence that the silts, sands, and gravels that overlie the Paleozoic and Mesozoic bedrocks and that underlie the loess, dune sand, and alluvium may represent more than one age. This evidence is discussed under "Age and correlation".

In this report the undifferentiated Pleistocene sediments are included with the Ogallala formation because the Pleistocene sediments cannot be distinguished from the Ogallala (Pliocene) and because the Pleistocene may be absent in some parts of the county.

Character.—The Ogallala formation consists of calcareous silt, sand, gravel, and clay. In most places it is capped by caliche, but locally the caprock may be limestone or chert or both. Examination of the cuttings from 11 test holes that penetrated the Ogallala showed that the formation is composed principally of silt. The percentage of silt ranges from about 35 to 85 and averages about 55. About 35 percent of the Ogallala is sand and about 10 percent is gravel. As a rule, the coarser material is found toward the base of the formation and the fine sand and silt are near the top. Clay and caliche occur in lesser amounts in parts of the formation especially near the top. The silt is made up almost entirely of quartz grains, which are angular to subangular and are pale gray, pink, and red. The sand is predominantly very fine grained, but may range from very fine to coarse, and it consists of rounded grains of quartz and some magnetite. The gravel is fine to coarse and is made up of quartz and feldspar and other material derived from igneous rocks.

Much of the Ogallala formation is logged as clay by many of the drillers, but examination of the cuttings from more than a dozen wells in Morton county revealed that the material being called clay was mostly silt and very fine sand. Small amounts of clay may be intermixed with the silt, but beds consisting wholly of clay were found only in one well (144).

The material comprising the Ogallala formation is poorly sorted. Individual beds generally are discontinuous and within very short distances may grade vertically or laterally into material of different composition. Logs of the wells (138-144) of the Kansas City Power and Light Company at Elkhart, which are only a few hundred feet apart, show marked changes in the character of the Ogallala from well to well. Similarly, certain beds along the outcrop of the Ogallala can be traced for only short distances.

In most parts of the county where the Ogallala is exposed it is capped by a thin limestone underlain by a thick bed of caliche. The limestone is a buff to light-brown compact rock that generally contains disseminated well-rounded grains of quartz and magnetite. An unusual feature of the cap rock of the Ogallala in this area is the presence of bands of white and gray chert that are 0.5 to 6 inches thick and are 1 to 3 inches apart. They are especially prominent near Point Rock.

The color of the beds in the Ogallala is gray, buff, and white, and locally red. Most of the cap rock of caliche or limestone is white, but some is gray or light tan. A well 2.5 miles north of Elkhart (115) penetrated several feet of redbeds in the Ogallala. The material was a brick-red siltstone that looked so nearly like the Triassic(?) redbeds that it was at first mistaken for them. This zone of red silt is also encountered in the municipal wells at Elkhart at a point about 125 feet above the Triassic(?) redbeds.

The Ogallala material is loosely cemented except for the cap rock.

The cementing material is principally calcium carbonate and occurs throughout the formation, but it is most abundant near the top.

Distribution and thickness.—Almost the entire county is underlain by the Ogallala and associated Pleistocene deposits, but a thin mantle of dune sand covers these deposits in most of the area south of Cimarron river, and a mantle of loess covers them in much of the upland north of the river. In small areas along the Cimarron and its tributaries the Ogallala is covered by alluvium or has been eroded away, exposing the Cockrum sandstone or the Triassic(?) redbeds.

The thickness of the Ogallala ranges from a few feet to nearly 600 feet. In the northwestern quarter of the county it is 80 feet thick in places, but locally it is absent. It thickens toward the east and south. In the southwestern part of the county it is 300 feet thick and in the northeastern part it is 275 feet thick. The maximum thickness is found in the southeastern corner of the county, where gas test wells have penetrated as much as 595 feet of the Ogallala before reaching the redbeds.

Many drillers' logs lead to erroneous estimates of the thickness of the Ogallala because the Ogallala and Cockrum generally are grouped into one unit that may be called simply sand and gravel. Test hole 1 in sec. 4, T. 31 S., R. 39 W., (fig. 2) encountered only 261 feet of the Ogallala formation overlying the Cockrum sandstone, but the log of a gas test well only a few miles to the southeast indicated 520 feet of sands and gravels referred to the Ogallala overlying the redbeds.

Origin.—The silt, sand, and gravels of the Ogallala formation were carried in from the Rocky Mountains by shifting streams. This explains the rapid gradations in lithology both vertically and laterally. Johnson (1900, p. 638) states that—

> The original smooth plain . . . was alluvial—*i. e.*, stream built. It was spread, in substantially its present position as to elevation and inclination, by widely shifting, heavily loaded, and deposition streams from the mountains. Shifting deposition, burial, and plain building constitute the normal habit of desert streams. Virtually the same mountain streams are at present cutting away and degrading where formerly they made broad fan-form deposits and built up. They are running in fixed courses and have excavated valleys.

Age and correlations. — The silts, sands, and gravels in Morton county that were formerly assigned to the Ogallala formation (Pliocene) are probably in part Pleistocene in age. Recent studies by Smith (1941) and others have shown that much of the so-called

Ogallala formation in southwestern Kansas is late Pliocene or Pleistocene in age.

A gravel pit in the NE¼ sec. 21, T. 34 S., R. 42 W., (pl. 8) contains many well-rounded fragment as large as 10 inches in diameter composed of Cockrum sandstone, of caliche, and of lava and other igneous rocks. These gravels are probably post-Ogallala in age. Beds of volcanic ash in post-Ogallala beds in southern Hamilton county seem to be correlative with similar beds of volcanic ash in Meade county that contain undoubted Pleistocene fossils.

Although a part of the post-Cretaceous silts, sands, and gravels in Morton county seem to be post-Ogallala in age, the greater part of the material probably was laid down in middle Pliocene time. Schoff (1939, p. 61) reports that more than 10,000 middle Pliocene horse teeth have been taken from excavations in these beds at a point near Optima, Okla., which is only about 20 miles south of the Morton-Texas county line.

Water supply.—In Morton county as in most of the southern High Plains region the Ogallala formation is the most important water-bearing formation. The saturated part of the undifferentiated Pliocene and Pleistocene sediments is probably entirely within the Ogallala formaticn in Morton county. About 70 percent of the domestic and stock wells, all the municipal wells, and most of the irrigation wells obtain their water from this formation. The yield of these wells ranges from 1 gallon a minute from wells pumped by windmills to about 1,000 gallons a minute from some of the wells used in supplying water for the drilling of gas test wells (123, etc.). The largest yields from the Ogallala are obtained from the coarse sands and gravels that are most abundant in the lower part of the formation.

The Ogallala formation serves as a huge underground reservoir. The reservoir may at one time have been nearly full, but down-cutting streams such as Cimarron river have cut below the zone of saturation and are draining part of the water from the reservoir. Drillers speak of the water in the Ogallala as occurring in "sheets" separated by zones that yield little or no water. Some drillers have reported as many as 8 or 10 such "sheets" within the formation. It is probable that these are not separate zones of saturated material, but simply one saturated zone containing alternating beds of fine and coarse material. The fine material, although saturated, probably does not yield enough water for domestic or stock use so the drillers regard it as dry. The coarse material yields water freely and is

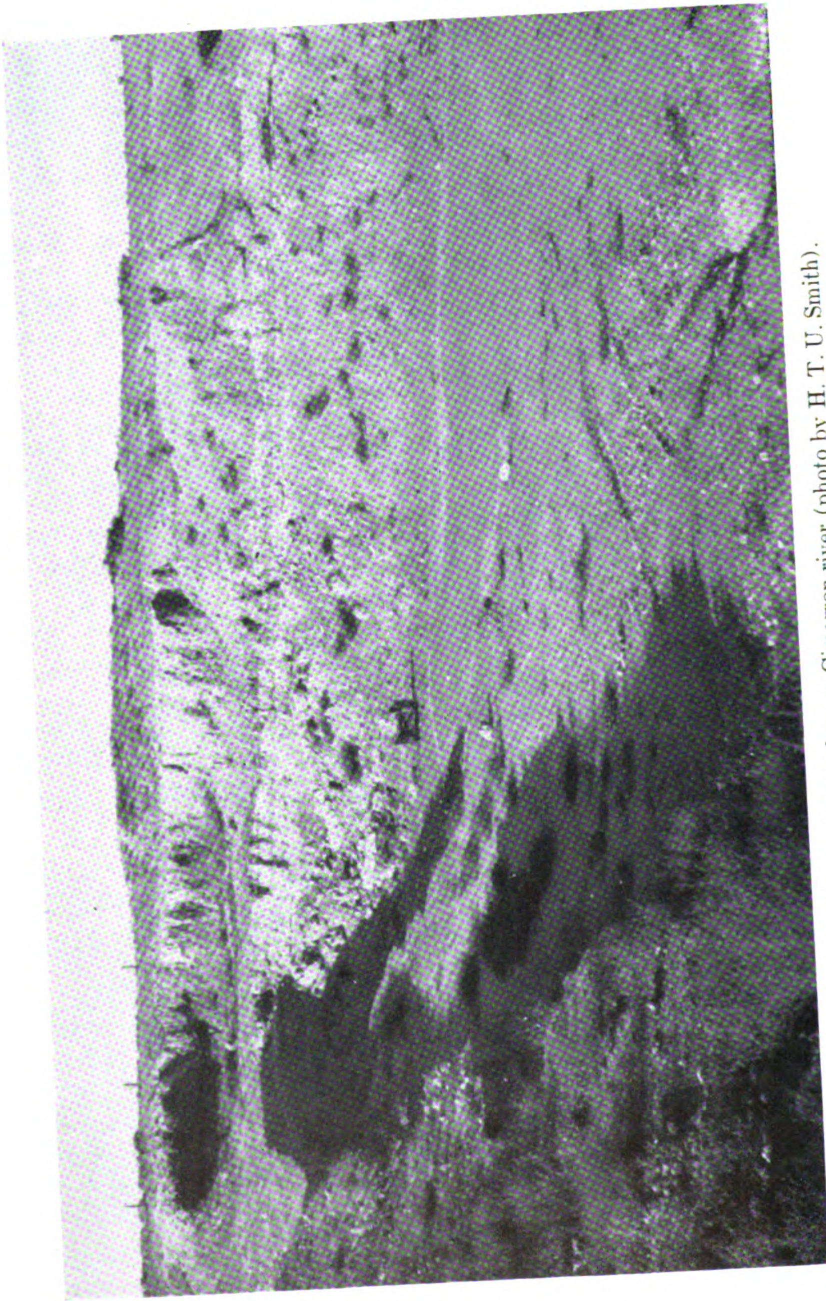

PLATE 8. Quarry in gravels near Cimarron river (photo by H. T. U. Smith).

logged as "water sand." A well for irrigation (63) was reported to have penetrated "water sands" at depths of 125 to 204 feet, and 280 feet, and 376 feet, and to have had a static water level 88 feet below the land surface. Thus the Ogallala in this well is saturated from a depth of 88 feet to 376 feet.

The altitude of the water level in well 148, in the southwestern part of the county, is 3,521 feet, but in neighboring wells it is only 3,450 to 3,475 feet. Well 148 may penetrate a small saturated zone held above the normal water table by relatively impermeable material. The municipal well at Rolla (92) encountered water at a depth of 280 feet and it rose to a point 200 feet below the land surface. The water in this well probably was held below a bed of relatively impermeable material. Most of the wells in the Ogallala obtain water from sand; only a few deep wells get water from beds of gravel and coarse sand.

The water from the Ogallala is hard, but it is suitable for most ordinary uses. Its fluoride content is small except in that from wells north of the river, where the fluoride content may exceed 2 parts per million because of recharge of the Ogallala by water from the Cockrum sandstone. Locally the water in the lower part of the Ogallala is slightly softer than water from the upper part.

QUATERNARY SYSTEM

Pleistocene and Recent Series

LOESS

General features.—A thin deposit of loess overlies the Ogallala formation and undifferentiated Pleistocene deposits in about two-thirds of the area north of Cimarron river and in a small area east of Elkhart along the Kansas-Oklahoma line. It occurs principally on the uplands and has been eroded away along stream valleys and in some interstream areas (pl. 1). The loess is buff to brown and, near the surface, black. In general about 65 to 75 percent of the loess is made up of silt, and the rest is clay and fine sand. The soils formed from the loess are dark compact heavy silt loams, clay loams, and silty clay loams underlain by a lighter-colored calcareous clay subsoil. The maximum thickness of the loess is not known, but cuttings from test holes drilled in this area indicate that in most places the loess is 4 to 6 feet thick. A dug well in the northeastern part of the county, however, is reported to have penetrated 15 feet of loess.

Water supply.—No water is obtained from the loess, because it is relatively impermeable and lies above the zone of saturation. As it is relatively impermeable, it retards the downward movement of rain water and thus hinders the recharge of the ground-water reservoir.

DUNE SAND

Character.—The Ogallala formation is overlain by thin deposits of dune sand in about three-fourths of the area south of Cimarron river and in several isolated areas north of the river (pl. 1). The small areas of dunes that are being built in the northern part of the county are composed of reworked sand derived from adjacent outcrops of the Ogallala formation. The sand is made up of quartz grains, clusters of fine quartz, and fragments of caliche. The dune sand south of the river and just north of the river in the eastern part of the county consists of uniform medium-grained well-rounded quartz grains. In the southern part of the county, where a good soil zone has developed, the dune sand contains a small amount of clay and organic material.

Two distinct types of topography are recognized in the sand dunes south of Cimarron river. The first type lies just south of the river and is characterized by typical sand-dune topography. The grass-covered dunes are moderately steep irregular hills between which are valleys and undrained basins. The second type lies south of the first type and is marked by broad subdued swells and swales. It has a thicker soil cover and is extensively cultivated.

Distribution and thickness.—The dune sand covers most of the southern half of Morton county and extends into Stevens county, Kansas, Baca county, Colorado, and Cimarron county, Oklahoma.

The thickness of the dune sand ranges from a few inches to a maximum of about 75 feet.

Origin.—The dune sand was probably derived from the sands of the alluvium of the Cimarron river valley and perhaps in part from adjacent outcrops of the Ogallala formation. The dunes may have been formed originally south of the river by a prevailing north wind. Later prevailing winds from the south probably caused the dunes to encroach upon the Cimarron river valley.

In his discussion of the origin of sand dunes in western Kansas, Smith (1941) describes an ideal dune cycle consisting of two phases: First, an eolian or active phase during which the dune is built up, and second, an eluvial or passive phase during which vegetation prevents further growth and the dune is subdued by weathering and creep. He divides the eluvial phase into stages of youth, maturity, and old age. In the youth stage the soil zone is formed and slopes are somewhat reduced. The dune becomes mature when its profile is smooth and regular and when its soil becomes thicker and more stable. Old age is reached when the dune form is undistinguishable. He states that the eluvial phase in any stage may be interrupted by rejuvenation.

Both the eluvial and eolian phases are represented in the Morton county sand dunes, but most of the dunes are in the eluvial phase at the present time. The dunes just south of the river represent the youth stage, for they are covered by grass and are being lowered by erosion and creep. The area farther south is covered by dune sand in the mature or old stage. The dune profile is smooth and regular or is entirely erased, and a thick soil has developed and is now being cultivated. The dunes in this area have lost so many of their former characteristics that they were not recognized as sand dunes until recently. Over-cultivation in recent years, however, has removed much of the protective cover of vegetation and the dunes in many places have been rejuvenated and are again in the active eolian phase (pl. 9). Similarly recent strong wind action has rejuvenated some of the dunes near Cimarron river that were in the youth stage (pl. 5A). In places the soil zone in the old dunes is sufficiently thick to permit safe cultivation, but in others it is too thin and cultivation has proved unprofitable.

Age.—The dune sand was originally deposited before or contemporaneously with the loess. The fact that the Ogallala formation rather than loess crops out in the "windows" between the sand dunes indicates that the sand was not laid down on a preëxisting deposit of loess. Such a "window" in the dune area is found northeast of Rolla (pl. 1). Furthermore, along the southern margin of the sand dunes the sand is in contact with the Ogallala formation rather than with loess, except in one small area where recent winds have blown the sand southward into the loess mantle. The age relation of the dune sand and the alluvium of Cimarron river is difficult to determine, for both deposits represent continuous deposition over long periods of time. The alluvium is still being laid down and the sand is being rejuvenated and reworked.

It is possible that some of the sand dunes now cover a part of of a once broader Cimarron river valley. The absence of bluffs along the south side of the river, the lesser depths to the water table just south of the river, and the different chemical content of the water from wells south of the river may indicate that Cimarron

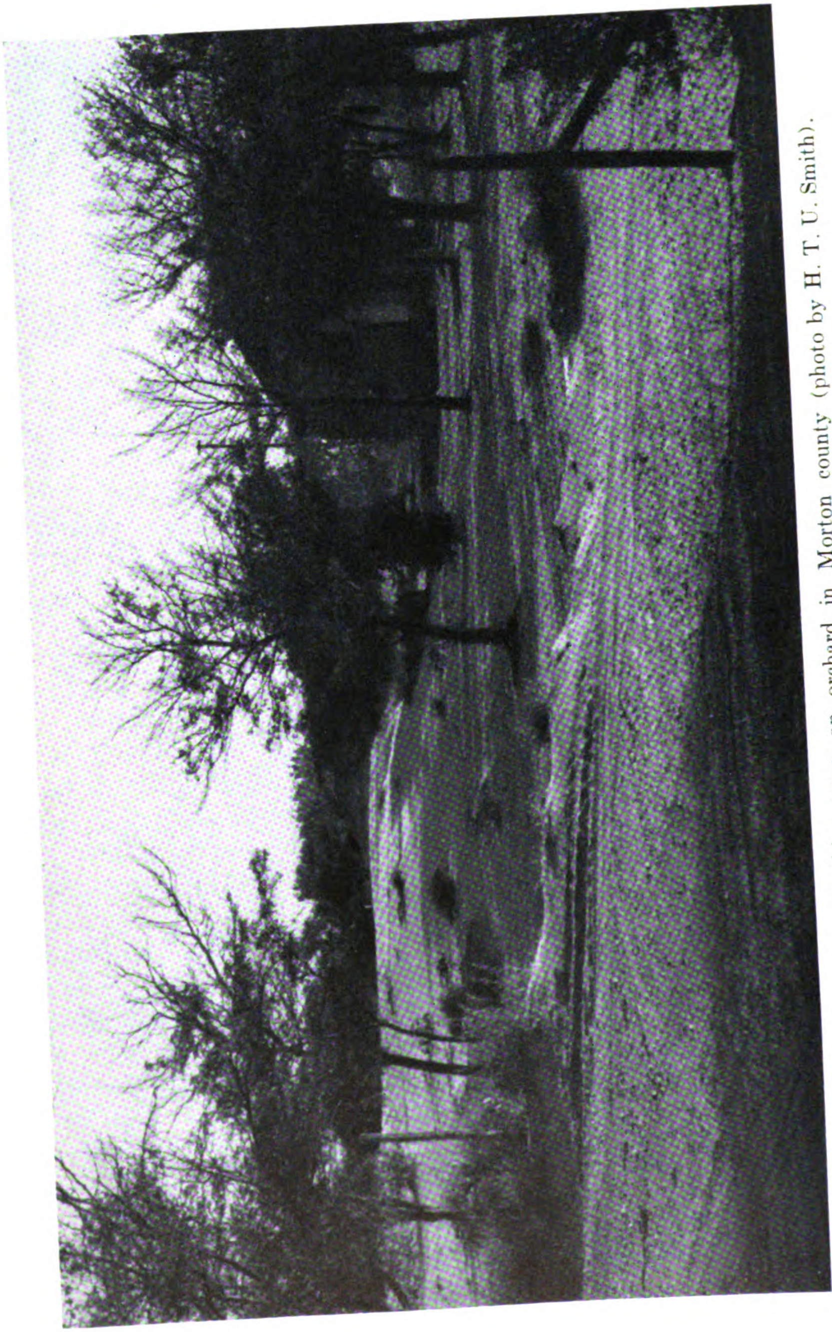

PLATE 9. Dune sand encroaching upon an orchard in Morton county (photo by H. T. U. Smith).

river has been forced to flow along the north side of the valley by the encroachment of dunes from the south. A few miles west of Morton county in southeastern Colorado the Cimarron valley is more than 5 miles wide and the stream is more nearly in the middle of the valley, whereas in Morton county the valley is only 0.5 to 1 mile wide.

Water supply.—The dune sand lies above the water table, so it does not supply water to wells, but the porous sand dunes provide excellent recharge facilities for the underlying ground-water reservoir. The rain that falls on the sand dunes probably recharges the Ogallala in southern Morton county and in areas to the south and east.

ALLUVIUM

General features.—Cimarron river and its tributaries have deposited alluvium in their valleys. It is made up mainly of sand, but contains smaller amounts of gravel and silt, and some clay. The sands consist mostly of subrounded quartz grains, although some of the coarse-grained sands and gravels contain grains of quartz and mica and other material derived from igneous rocks.

Only a few wells penetrate the alluvium, and data on its thickness are meager. Well 70, in sec. 23, T. 33 S., R. 41 W., is 20 feet deep and does not reach the underlying bedrock; well 69, in sec. 23, T. 33 S., R. 43 W., penetrates 20 to 50 feet of alluvium, but obtains its water supply from the underlying bedrock. If well 105 ends in alluvium it is possible that the thickness of the alluvium of the Cimarron river valley may in places exceed 75 feet.

Only one well (20) penetrated the alluvium of North Fork of the Cimarron and it was reported to have struck the Cockrum sandstone after having passed through 30 feet of alluvium.

The material in the alluvium of the Cimarron was probably derived from sands and gravels of the Ogallala formation along the headwaters of the river in northeastern New Mexico, western Oklahoma, and southeastern Colorado.

Water supply.—The alluvium is very permeable and yields moderate quantities of water to stock wells in the Cimarron valley. Sufficient water would probably be available to wells for irrigation in the Cimarron valley, but the stream channel has widened until little if any irrigable land is left.

The water from the alluvium is very hard. Water from well 70 had a hardness of 1,437 parts per million and contained 632 parts per million of sulphate.

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TABLE OF WELL RECORDS

On the following pages are tabulated the information pertaining to water wells in Morton county (table 7). The numbers in the first column correspond to the well numbers on the map (pl. 2) and in the table of analyses (table 5). The wells are listed in order by townships from north to south and by ranges from east to west. Within a township the wells are listed in the order of the sections. Depths of wells and water levels that were reported rather than measured are indicated by a footnote and are subject to error. Depths of wells not classed as "reported" are measured and given to the nearest 0.1 foot below the measuring point described in the table. Similarly, measured water levels are given to the nearest 0.01 foot. Records of a few wells in adjoining counties are included.

TABLE 7.—*Records of drilled wells in Morton county*

Well no. on plate 2.	LOCATION.	Owner.	Topographic position.	Depth of well, feet*	Diameter of well, inches	Principal water-bearing bed.		Method of lift†	Use of water‡	Measuring point.			Depth to water level below measuring point, feet§.	Date of measurement, 1939	Remarks.
						Character of material.	Geologic age.			Description.	Height above (+) or below (—) land surface, feet	Height above sea level, feet			
	T. 31 S., R. 39 W.														
1	NW¼ NE¼ sec. 8	Viola Hubbard	Upland flat	100	6	Sand	Ogallala	C,W	D, S	Land surface	0		80		
2	SW¼ SW¼ sec. 9	J. W. Daniels	do	90		do	do	C,W	D, S	do	0		70		
3	NE¼ NE¼ sec. 20	Viola Hubbard	Slope	95		do	do	C,W	N	Top of casing	0		80		Abandoned, formerly a domestic and stock well.
4	NW¼ NE¼ sec. 30	P. E. Milburn	Upland flat	107	18	Sand and gravel	do	T,G	N	Land surface	0		87		Dug well, barrel casing. Formerly an irrigation well. Reported to yield 300 gallons a minute.
5	NE¼ NE¼ sec. 30	do	Crest of low hill	115	6	Sand	do	C,W	D, S	do	0		100		Drill penetrated 15 feet of loess. See analysis.
	T. 31 S., R. 40 W.														
6	NE¼ NE¼ sec. 2	Howard Brehm	Upland flat	127.5	4.5	do	do	C,W	N	Top of concrete block, northwest side of hole.	+1.0	3,251.1	117.39	Aug. 3	Abandoned, formerly a domestic and stock well.
7	NE¼ NE¼ sec. 9	Jesse Williams	Crest of low hill	160	6	do	do	C,W	D, S	Land surface	0		145	Sept. 7	See analysis.
8	NE¼ NW¼ sec. 15	C. M. Crocker	Upland flat	188.1	4.5	do	do	C,W	N	Base of pump head, south side.	+0.8	3,289.0	152.37	July 21	Abandoned, formerly a domestic and stock well.
9	NE¼ NE¼ sec. 28	E. O. Palmer	do	179.8		Gravel	do	C,W	N	Top of plate covering casing.	0	3,319.0	157.64	Sept. 7	Abandoned, formerly a domestic well.
	T. 31 S., R. 41 W.														
10	NE¼ NW¼ sec. 6	John Hentschel	do	240		Sandstone	Cockrum	C,W	D, S	Land surface	0		160	Aug. 28	
11	SE¼ SE¼ sec. 8	J. L. McGee	do	145	4.5	do	do	C,W	D, S	Top of casing	0		110		Drill penetrated black shale before entering the Cockrum sandstone. See analysis.
12	SE¼ SW¼ sec. 9	Mrs. Leo Everett	do	216	5.5	do	do	C,W	N	Top of casing, east side.	+0.7	3,400.9	111.63	July 8	Abandoned, formerly a domestic and stock well.
13	SE¼ NE¼ sec. 13	Harmon Shinogle	do	183.2	4.5	do	do	C,W	N	Top of concrete block, south side.			138.04	Aug. 1	Do
14	SW¼ SW¼ sec. 34	Gracia Mitchell	do	109.6	4.5	do	do	C,W	N	Top of casing, west side.	±0.3	3,405.2	79.16	July 29	Do

	T. 31 S., R. 42 W.														
15	NE¼ SE¼ sec. 3	F. M. Walker	do	216	4.5	Coarse sandstone	Cheyenne	C, W	D, S	Land surface	0		94		Iron casing. See analysis. Very little water in Cockrum sandstone.
16	NE¼ SE¼ sec. 7	C. C. Crow	do	115.1	5.5	Sandstone	Cockrum	C, W	N	Top of casing, north side.	+1.0	3,528.6	101.91	Aug. 3	Abandoned, formerly a domestic and stock well.
17	NE¼ SE¼ sec. 10	P. Jefferson	do	218		do	Cheyenne	C, W	D, S	Land surface	0		95		Cockrum sandstone reported to yield very little water.
18	SE¼ SE¼ sec. 23	Fred Johnson	Valley bottom	44	4.5	do	Cockrum	C, W	D, S	Top of casing	0		36		See analysis.
19	SE¼ SW¼ sec. 26	W. T. Martin	Upland flat	86.8	4.5	do	do	C, W	N	Top of casing, east side.	+0.7		68.43	Aug. 2	Abandoned, formerly a domestic and stock well.
20	SW¼ SW¼ sec. 28	J. W. Baughman	Valley bottom	31		Coarse sandstone	Cockrum	C, H	N	Top of casing, south side.	+0.4	3,467.6	28.57	July 29	Dug well used in bridge construction. Encountered Cockrum sandstone at depth of 30 feet.
21	SW¼ NW¼ sec. 30	A. J. Collingwood	Upland flat	183.2	4.5	do	Cheyenne	C, W	N	do	+0.3		105.92	Aug. 2	Abandoned, formerly a domestic well. Inadequate supply. Iron casing.
22	NE¼ SE¼ sec. 36	B. R. McCray	do	68.1	4.5	Sandstone	Cockrum	C, W	N	Top of casing, north side.			62.07	do	Abandoned, formerly a domestic and stock well.
	T. 31 S., R. 43 W.														
23	SE¼ NE¼ sec. 3	J. W. Bitner	do	76.9	5.5	do	do	C, W	N	Top of hole in concrete block.	+0.6	3,589.6	70.18	July 8	Do
24	SE¼ SE¼ sec. 14	E. A. Wilcox	do	86.8	5.5	do	do	C, W	N	Top of casing, south side.	+1.2		74.99	do	Do
25	SE¼ NE¼ sec. 18	J. W. Baughman	do	64	5.5	do	do	C, W	D, S	Land surface	0		46		See analysis.
26	SW¼ NW¼ sec. 22	H. H. Sipes	Side of valley	51	6	do	do	C, W	D, S	do	0		42		Encountered Cockrum sandstone at depth of 46 feet. See analysis.
27	SW¼ NE¼ sec. 31	J. B. Dean	Upland flat	65	6	do	do	C, W	D, S	do	0		48		Encountered Cockrum sandstone at depth of 60 feet.
28	NE¼ SE¼ sec. 36	L. C. Rutledge	do	70		do	do	C, W	N	do	0		60		
	T. 32 S., R. 39 W.														
29	SE¼ NE¼ sec. 18	R. R. Ricksecken	do	174.9	4.5	Sand and gravel	Ogallala	C, W	N	Top of bolt in clamp, north side.	+0.3	3,286.6	136.82	Aug. 4	Abandoned, formerly a domestic and stock well.
30	NE¼ NE¼ sec. 18	do	do	170	4.5	do	do	C, W	D, S	Top of casing	0		125		See analysis.
	T. 32 S., R. 40 W.														
31	SW¼ SE¼ sec. 2	G. L. Hayward	do	150.1	4.5	Sand	do	C, W	N	Top of casing, north side.	0		138.94	July 17	Abandoned, formerly a domestic and stock well.
32	SW¼ SW¼ sec. 6	W. B. Walters	do	180		do	do	C, W	D, S	Land surface	0		100		See analysis.
33	NE¼ SE¼ sec. 7	Helen J. Spear	Side of valley	102.4	4.5	do	do		N	Top of casing, east side.	0		87.19	July 29	Abandoned, formerly a domestic and stock well.
34	SW¼ NW¼ sec. 13	G. G. Rhorer	Upland flat	147.5		Sand and gravel	do	C, W	N	Top of hole in concrete block.	+0.6	3,305.0	133.68	Aug. 4	Abandoned, formerly a domestic well.
35	SE¼ NE¼ sec. 23	School	Side of valley	126.9	4.5	Coarse sand	do	C, W	N	Top of casing, north side.	+0.2	3,296.7	120.51	Aug. 5	Abandoned, formerly supplied rural school.

Table 7.— Records of drilled wells in Morton county—*Continued*

Well No. plate 2.	LOCATION.	Owner.	Topographic position.	Depth of well, feet*	Diameter of well, inches	Principal water-bearing bed.		Method of lift†	Use of water‡	Measuring point.			Depth to water level below measuring point, feet§	Date of measurement, 1939	Remarks.
						Character of material.	Geologic age.			Description.	Height above (+) or below (—) land surface, feet	Height above sea level, feet			
	T. 32 S., R. 40 W.														
36	NE¼ SE¼ sec. 28	Lillie B. Jones	Upland flat	171.7	5.5	Sand and gravel	Ogallala	C,W	N	Top of casing, north side.	+0.3	....	137.89	Aug. 4	Abandoned, formerly a domestic and stock well. Iron casing.
37	NE¼ NW¼ sec. 34	B. L. Kraber	do	168	......	do	do	C,W	D, S	Top of casing	0	....	134	....	See analysis.
	T. 32 S., R. 41 W.														
38	SW¼ NW¼ sec. 7	E. C. Martin	do	94	4.5	Sandstone	Cockrum	C,W	D, S	do	0	....	66	....	Do........
39	SW¼ NW¼ sec. 10	A. M. Dean	do	165	6	do	do	C,W	D, S	Land surface	0	....	145	....	Well pumps dry in strong wind.
40	SE¼ SW¼ sec. 14	E. B. Newcomb	Valley flat	84.9	4.5	do	do	C,H	D, S	Top of casing, southwest side.	+0.2	3,377.4	65.36	Aug. 4	
41	SW¼ NW¼ sec. 16	Townsite	do	62.9	4.5	do	do	C,W	D	Top of casing, northwest side.	+0.5	....	60.27	do	
42	NW¼ SE¼ sec. 16	Morton county	do	72	4.5	do	do	C,W	D	Top of casing	+0.3	....	61	....	See analysis.
43	NW¼ SW¼ sec. 16	E. C. Wilson	do	596	6	do	Permian	F	I	Land surface	0	....	....	July 29	Flows 20 gallons a minute. Initial flow was 1200 gallons a minute. Water is strongly mineralized. Iron casing. See analysis.
44	SW¼ NE¼ sec. 21	C. W. Orth	do	558	6	do	do	F	N	do	0	....	....	Aug. 1	Flows less than one gallon a minute. Strongly mineralized. Iron casing.
45	NW¼ SE¼ sec. 28	A. C. Dean	do	610	10	do	do	F	N	do	0	....	....	July 29	Flows 7.5 gallons a minute. Strongly mineralized. Iron casing.
46	NW¼ NE¼ sec. 35	A. C. Bowker	Upland flat	136	4.5	do	Cockrum	C,W	D, S	do	0	....	116	....	See analysis.
	T. 32 S., R. 42 W.														
47	SE¼ NW¼ sec. 9	K. Elsosser	do	78.9	4.5	do	do	C,W	N	Top of casing, west side.	0	3,513.8	70.94	July 31	Abandoned, formerly a domestic and stock well.
48	NW¼ NW¼ sec. 13	Lucy Hobbs	do	104.9	4.5	do	do	C,W	N	Top of casing, east side.	+1.2	....	68.86	July 20	Abandoned, formerly a stock well.

	NW¼ NW¼ sec. 27	H. O. Bean	do	80	5.5	do	do	C,W	D, S	Land surface	0	......	60	......	
	NE¼ NW¼ sec. 29	F. B. Smith	do	96	5.5	do	do	C,H	D	do	0	......	61	......	See analysis.
	SE¼ NE¼ sec. 31	Grant Harman	Valley bottom.	35	8	do	do	C,W	D, S	do	0	......	27	......	Encountered Cockrum sandstone at depth of 25 feet.
	T. 32 S., R. 43 W.														
2	SW¼ SW¼ sec. 9	E. C. Wilson	Upland flat	112	6	Sand	do	C,W	D, S	do	0	......	50	Aug. 23	See analysis.
3	NE¼ SW¼ sec. 23	W. L. Bromhal	do	69.9	4.5	Sandstone	do	C,W	N	Top of 12-inch iron casing, north side.	+1.5	......	65.46	July 21	Abandoned, formerly a domestic and stock well.
4	NW¼ NW¼ sec. 33	N. A. Yarnell	Side of valley	43.8	4.5	do	do	N	N	Top of casing, north side.	0	3,586.3	31.42	Aug. 10	Do.
	T. 33 S., R. 39 W.														
5	Center SE¼ sec. 4	A. O. Mangels	Upland flat	213	6	Coarse sand	Ogallala	N	......	Land surface	0	......	104	Sept. 18	Water used in drilling gas well. Iron casing.
6	SW¼ SE¼ sec. 8	Dottie M. Thompson.	Sand dunes	94.6	4.5	Sand and gravel	do	C,W	N	Top of casing, southeast side.	+0.5	......	83.25	July 28	Abandoned, formerly a domestic and stock well.
7	SW¼ SE¼ sec. 29	Carey M. Higgins	Upland flat	129.1	4.5	do	do	C,W	N	Top of casing, east side.	+0.5	......	111.43	do	Do.
8	NW¼ NW¼ sec. 31	G. L. Hayward	do	390	6	Sand	do	T,G	I	Land surface	0	......	105	Sept. 19	Water first used in drilling gas well. Reported to yield 60 gallons a minute. Iron casing. See analysis.
9	NW¼ NW¼ sec. 32	George Hunt	do	123	4.5	do	do	C,W	D, S	Top of casing	0	......	108	......	See analysis.
	T. 33 S., R. 40 W.														
0	NW¼ NW¼ sec. 1	Western Royalty and Development Co.	Sand dunes	76.9	4.5	Gravel	Alluvium	C,W	N	Top of casing, southeast side.	......	......	61.16	Aug. 4	Abandoned, formerly a domestic and stock well.
1	SE¼ SW¼ sec. 12	E. O. McCammon	do	84	4.5	Sand	Ogallala	C,W	D, S	Top of casing	0	......	73	......	See analysis.
2	SW¼ SW¼ sec. 13	V. W. Dickinson	Upland flat	82.4	4.5	Sand and gravel	do	C,W	N	Top of casing, east side.	+0.5	......	76.96	July 6	Abandoned, formerly a domestic and stock well.
3	SE¼ SE¼ sec. 13	Roy Connor	do	376	......	Coarse sand	do	N	N	Land surface	0	......	88	......	A test well for irrigation. Penetrated more than 300 feet of saturated material.
	NE¼ NE¼ sec. 26	Elizabeth Stout	do	117.8	4.5	Sand	do	C,W	N	Top of casing, west side.	+0.7	......	93.65	Aug. 4	Abandoned, formerly a domestic and stock well.
	T. 33 S., R. 41 W.														
55	NW¼ NW¼ sec. 2	W. E. Moore	do	150	6	Sand and gravel	do	C,W	N	Land surface	0	......	115	......	Abandoned, formerly a stock well.
56	NW¼ NE¼ sec. 4	Isaac Collins	do	83.9	4.5	do	do	C,W	N	Top of plate covering casing.	−0.6	3,401.0	59.31	Aug. 3	Abandoned, formerly a domestic and stock well.
57	NW¼ NW¼ sec. 6	Daila Ball	Side of valley	96	4.5	Sand	do	C,W	D, S	Top of casing	0	......	58	......	See analysis.
58	SE¼ NE¼ sec. 22	W. E. Moore	Valley bottom.	18	6	do	Alluvium	C,W	N	Land surface	0	......	8	......	Abandoned, formerly a stock well.
59	SE¼ NE¼ sec. 23	do	do	64	6	Sand and gravel	Ogallala	C,W	D	do	0	......	30	......	Water used to irrigate small area. See analysis.

Table 7.—Records of drilled wells in Morton county—*Continued*

ll o. te	Location.	Owner.	Topographic position.	Depth of well, feet*	Diameter of well, inches	Principal water-bearing bed. Character of material.	Principal water-bearing bed. Geologic age.	Method of lift†	Use of water‡	Measuring point. Description.	Measuring point. Height above (+) or below (—) land surface, feet	Measuring point. Height above sea level, feet	Depth to water level below measuring point, feet§.	Date of measurement, 1939	Remarks.
	T. 33 S., R. 41 W.														
70	SE¼ NE¼ sec. 23	W. E. Moore	Valley bottom	20	6	Coarse sand	Alluvium	C,W	S	Land surface	0		12		See analysis.
71	NE¼ sec. 26	do	do	50	6	Sand	do	C,W	N	do	0		30		Abandoned, formerly a stock well.
72	NE¼ sec. 27	do	do	50	6	do	do	C,W	N	do	0		30		Do
73	SE¼ sec. 36	do	Sand dunes	160	6	Sand and gravel	Ogallala	C,W	N	do	0		115		Do
	T. 33 S., R. 42 W.														
74	SE corner sec. 8	R. L. Jewell	Upland flat	180	4	Sand	do	N	N	do	0	3,518.5	64		No casing.
75	SE¼ NE¼ sec. 8	John Hentschel	Edge of valley.	61	5.5	do	do	C,W	N	Top of casing, northeast side	+0.4		53.61	July 20	Abandoned, formerly a domestic and stock well.
76	NW¼ SW¼ sec. 15	E. Shirley	Upland flat	100	6	do	do	C,W	D	Land surface	0		75		
77	NW¼ NW¼ sec. 21	J. W. Baughman	do	100	4.5	Sand and gravel	do	C,W	D, S	do	0		95		See analysis.
78	NE¼ NW¼ sec. 27	Rose Hentschel	do	93.3	5.5	do	do	N	N	Top of casing, north side.	+1.7		86.74	Aug. 21	Abandoned, formerly a domestic and stock well.
79	SW¼ sec. 34	U. S. Department of Agriculture.	Valley bottom	18.3	5.5	Sand	do	C,W	N	Top of casing, east side.	+1.0		15.77	Aug. 30	Abandoned, formerly a stock well.
	T. 33 S., R. 43 W.														
80	SW¼ SW¼ sec. 2	J. H. Hancock	Upland flat	86.6	4.5	do	do	C,W	N	Top of casing, north side.	+0.4		64.78	Aug. 10	Abandoned, formerly a domestic and stock well.
81	SE¼ SE¼ sec. 7	T. E. Bookstore	do	95	4.5	do	do	C,W	D, S	Top of casing	0		86		See analysis.
82	SE¼ SE¼ sec. 12	Burdett Johnson	Side of valley	47.6	4.5	do	do	C,W	N	Top of casing, east side.	0		42.01	Aug. 10	Abandoned, formerly a domestic and stock well.
83	NE¼ NE¼ sec. 15	School	Upland flat	82.6	4.5	Sand and gravel	do	C,W	N	On concrete block, east side.	+0.5		80.19	do	Abandoned, formerly supplied rural school.
84	NE¼ NE¼ sec. 17	Thos. A. Ball	do	93.3	4.5	do	do	C,W	N	Top of casing, south side.	+2.4	3,629.3	88.03	July 11	Abandoned, formerly a domestic and stock well.
85	NE¼ SE¼ sec. 22	E. M. Watkins	do	116		do	do	C,W	D, S	Land surface	0		104		See analysis.

86	NW¼ SW¼ sec. 23	M. Colyer	do	254.2	5.5	do	do	C,W	N	Top of casing, east side.	+0.3	....	103.2	Aug. 10	Iron casing. Formerly obtained an artesian flow of strongly mineralized water from redbeds.
87	NE¼ SE¼ sec. 24	F. W. Gerdes	do	110.1	4.5	Gravel	do	C,W	N	Top of casing, west side.	+0.2	....	90.52	do	Abandoned, formerly a domestic and stock well.
	T. 34 S., R. 39 W.														
88	SW¼ NW¼ sec. 7	Ethyl B. Weber	Sand dunes	163.4	4.5	Sand and gravel	do	C,W	N	do	+0.4	....	147.71	July 18	Do.
89	NW¼ SW¼ sec. 7	F. A. Thompson	do	284	6	Sand	do	N	N	Land surface	0	....	138	....	Water used in drilling gas well.
90	NE¼ NW¼ sec. 9	S. M. Dreibelbis	Crest of low hill.	181.9	4.5	Sand and gravel	do	C,W	N	Top of casing, northeast side.	+1.0	....	175.8	Aug. 8	Abandoned, formerly a domestic and stock well.
91	SW¼ SE¼ sec. 19	V. C. Grossman	do	206.9	4.5	Sand	do	C,W	N	Top of casing, west side.	+0.6	....	198.26	Aug. 7	Do.
	T. 34 S., R. 40 W.														
92	NE¼ SE¼ sec. 2	City of Rolla	Upland flat	280	8	do	do	T,E	P	Land surface	0	....	200	....	Water rose 80 feet. Reported to yield 200 gallons a minute. See analysis.
93	NE¼ SE¼ sec. 4	Jos. Britz	Sand dunes	140.7	4.5	do	do	C,W	N	Top of casing, north side.	+0.8	3,332.9	131.72	July 28	Abandoned, fo merly a domestic and stock well.
94	NE¼ NE¼ sec. 9	E. Long	do	150	6	do	do	C,W	D, S	Land surface	0	....	138	....	
95	SE¼ SE¼ sec. 9	U. S. Department of Agriculture.	do	160	......	do	do	C,W	N	do	0	....	140	....	Do.
96	NE¼ NE¼ sec. 14	L. J. Markillie	Low hill	175.1	4.5	do	do	C,W	N	Top of casing, west side.	+0.5	....	162.81	Aug. 7	Do.
97	SW¼ SW¼ sec. 24	W. R. Littell	Sand dunes	208	4.5	do	do	C,W	D, S	Top of casing	0	....	204	....	See analysis.
98	NE¼ NW¼ sec. 25	H. L. Littell	Slope	201.9	4.5	Sand and gravel	do	C,W	N	Top of casing, south side.	+1.0	....	199.42	Aug. 7	Abandoned, formerly a domestic and stock well.
	T. 34 S., R. 41 W.														
99	SE¼ SE¼ sec. 1	G. L. Hayward	Sand dunes	140.4	4.5	do	do	C,W	N	do	+0.8	3,369.7	129.69	July 18	Do.
100	SE¼ SW¼ sec. 7	F. W. Canfield	do	139.3	4.5	do	do	C,W	N	do	+0.2	....	93.24	July 27	Do.
101	SE¼ NE¼ sec. 9	Sarah E. Crane	do	129.1	4.5	do	do	C,W	N	Top of casing, west side.	+2.0	3,418.3	127.02	do	Do.
102	NE¼ sec. 11	W. E. Moore	do	146	6	Sand	do	C,W	S	Land surface	0	....	120	....	
103	NE¼ NE¼ sec. 14	Ralph Engleman	do	171.7	4.5	do	do	C,W	N	Top of casing, southeast side.	+0.5	3,406.6	165.12	July 28	Do.
104	SE¼ SW¼ sec. 17	E. E. Hill	do	136.2	4.5	do	do	C,W	N	Top of concrete block, south side.	+1.2	3,450.2	129.11	July 27	Do.
105	NE¼ NE¼ sec. 18	H. B. Lewis	do	135	4.5	do	do	C,W	D, S	Top of casing	−2.3	....	118	....	See analysis.
106	NE¼ NE¼ sec. 21	Townsite	do	175	4.5	Gravel	do	C,W	D	do	0	....	152	....	Do.

Table 7.—Records of drilled wells in Morton county—*Continued*

[illegible]	Location.	Owner.	Topographic position.	Depth of well, feet*	Diameter of well, inches	Principal water-bearing bed.		Method of lift†	Use of water‡	Measuring point.			Depth to water level below measuring point, feet§	Date of measurement, 1939	Remarks.
						Character of material.	Geologic age.			Description.	Height above (+) or below (—) land surface, feet	Height above sea level, feet			
	T. 34 S., R. 41 W.														
[illegible]	NW¼ NW¼ sec. 24	C. M. Tucker	Sand dunes	220	4.5	Sand	Ogallala	C,W	D, S	Land surface	0	......	174	......	See analysis.
[illegible]	NE¼ SE¼ sec. 28	Ira Webb	do	188.4	5.5	do	do	C,W	N	Top of casing, south side.	+1.5	3,435.7	160.08	July 7	Abandoned, formerly a domestic and stock well.
[illegible]	SE¼ sec. 36	W. E. Moore	do	250	6	do	do	C,W	N	Land surface	0	......	225	......	Abandoned, formerly a stock well.
	T. 34 S., R. 42 W.														
[illegible]	NW¼ NW¼ sec. 5	State land	Edge of valley	119.5	4.5	Sand and gravel	Alluvium	C,W	N	Top of casing, north side.	+1.2	3,493.5	67.5	July 10	Abandoned, formerly a domestic and stock well.
[illegible]	SE¼ SW¼ sec. 13	Chas. Knight	do	133.6	4.5	do	Ogallala	C,W	N	Top of iron rim, east side.	+0.4	......	124.16	July 27	Do
[illegible]	SE¼ SE¼ sec. 20	N. H. Udell	do	83.2	4.5	do	do	C,W	N	Top of casing, north side.	+0.2	3,508.1	80.54	July 22	Do
[illegible]	SE¼ SE¼ sec. 22	W. B. Cushman	do	136.1	4.5	do	do	C,W	N	Top of casing, south side.	+1.3	3,502.0	113.91	July 14	Do
[illegible]	NW¼ NE¼ sec. 33	H. W Roberts	do	131.9	4.5	do	do	C,W	N	Top of casing, north side.	+0.3	3,529.5	115.38	July 22	Do
[illegible]	SW¼ NW¼ sec. 33	U. S. Department of Agriculture.	do	154	6	Fine sand	do	C,W	D	Land surface	0	......	124	......	Iron casing. See analysis.
[illegible]	SE¼ SE¼ sec. 35	D. A. Westerfield	do	185.2	4.5	Coarse gravel	do	C,W	S	Top of casing, east side.	+0.4	......	171.14	July 24	See analysis.
	T. 34 S., R. 43 W.														
[illegible]	NE¼ NE¼ sec. 3	Archie Rollins	Upland flat	158	4.5	Sand	do	C,W	D, S	Land surface	0	......	118	......	
[illegible]	NE¼ SE¼ sec. 4	E. L. Bitner	do	142.1	4.5	Sandstone	Triassic(?),	C,W	N	Top of casing, northwest side.	+2.0	3,626.2	137.88	Aug. 21	Abandoned, formerly a domestic and stock well.
[illegible]	NE¼ SW¼ sec. 8	Edith Coursey	Side of valley	153	......	do	do	C,W	D, S	Land surface	0	......	133	......	See analysis.
[illegible]	NE¼ SE¼ sec. 35	Wm. Dulahahn	Sand dunes	95.9	4.5	Sand	Ogallala	C,W	N	Top of casing, south side.	+1.0	......	90.18	July 14	Abandoned, formerly a domestic and stock well.

T. 35 S., R. 39 W.													
NW¼ NW¼ sec. 5	S. J. Willits	do.	215.3	4.5	do.	do.	C,W	N	Top of casing, northeast side.	+0.2	....	198.69	July 18	Do.
SE¼ SW¼ sec. 6	Harvey L. Green	do.	216	4.5	do.	do.	C,W	D, S	Top of casing	0	....	201	....	See analysis.
NE¼ SE¼ sec. 9	R. S. Phillips	Upland flat	300+	6	Sand and gravel	do.	N	N	Top of casing, east side.	+0.6	3,312.3	192.58	Aug. 30	Wate used in drilling gas well. Iron casing.
T. 35 S., R. 40 W.														
SE¼ SE¼ sec. 3	Sam Presley	do.	207.1	4.5	do.	do.	C,W	N	Top of casing, north side.	+0.1	....	201.74	Aug. 8	Abandoned, formerly a dometic and stock well.
SE¼ SW¼ sec. 5	T. Caldwell	Sand dunes	216	4.5	do.	do.	C,W	N	Top of casing, south side.	+0.8	....	210	....	Do.
NE¼ SE¼ sec. 14	O. J. Weitzel	Upland flat	230	......	do.	do.	C,W	D, S	Land surface	0	....	220	....	
NW¼ SW¼ sec. 15	J. H. Johnson	do.	230	6	do.	do.	C,W	D, S	do.	0	....	213	....	See analysis.
T. 35 S., R. 41 W.														
NE¼ SE¼ sec. 4	W. P. Crawley	do.	196	4.5	do.	do.	C,W	D, S	do.	0	....	184	....	Do.
NE¼ NE¼ sec. 7	M. T. Miller	do.	180.9	4.5	Gravel	do.	C,W	N	Top of casing, east side.	+0.3	....	179.75	July 27	Abandoned, formerly a domestic and stock well.
NW¼ NW¼ sec. 13	Mary Stiggins	do.	235.2	4.5	Sand	do.	C,W	N	Top of casing, north side.	+0.7	3,462.5	224.04	Aug. 7	Do.
SE¼ SE¼ sec. 13	J. L. Kniffen	do.	252.4	4.5	do.	do.	C,W	N	Top of casing, northeast side.	+1.0	3,452.5	226.85	July 6	Do.
NW¼ NW¼ sec. 18	W. Cavanaugh	do.	213.2	4.5	Sand and gravel	do.	C,W	N	Top of 2-inch pipe, north side.	+2.3	3,546.4	201.22	July 24	Do.
T. 35 S., R. 42 W.														
SW¼ NW¼ sec. 1	A. F. Cyr	do.	203	......	Coarse gravel	do.	C,W	D, S	Land surface	0	....	179	....	Small yield.
SW¼ SW¼ sec. 4	W. C. Washburn	do.	215.9	6	Sand	do.	C,W	N	Top of casing, west side.	+1.2	....	167.51	July 6	Abandoned, formerly a domestic and stock well. Iron casing.
SE¼ SW¼ sec. 7	Wm. Eversoll	do.	159.7	4.5	Sand and gravel	do.	C,W	N	Top of casing, north side.	+1.1	3,605.7	149.87	July 25	Abandoned, formerly a domestic and stock well.
NE¼ NW¼ sec. 12	T. E. Lewis	do.	194	......	Gravel	do.	C,W	D, S	Land surface	0	....	182	....	See analysis.
SW¼ NE¼ sec. 17	Prudential Life Insurance Co.	Low hill	216.6	4.5	Sand	do.	C,W	N	Top of bolt in clamp, west side.	—3.2	3,623.3	201.41	July 25	Abandoned, formerly a domestic well. Small yield.
NW¼ SW¼ sec. 16	Kansas City Power and Light Co.	Upland flat	287	6	do.	do.	P, E	P	Land surface	0	3,615	205	....	Iron casing. Reported to yield 28 gallons a minute. See composite analysis of water from wells 138-144.
NE¼ SE¼ sec. 17	do.	do.	300	8	do.	do.	P, E	P	do.	0	3,614	202	....	Iron casing. Reported to yield 36 gallons a minute.

Table 7.—Records of drilled wells in Morton county—*Concluded*

ll). te	Location.	Owner.	Topographic position.	Depth of well, feet*	Diameter of well, inches	Principal water-bearing bed. Character of material.	Principal water-bearing bed. Geologic age.	Method of lift†	Use of water‡	Measuring point. Description	Measuring point. Height above (+) or below (—) land surface, feet	Measuring point. Height above sea level, feet	Depth to water level below measuring point, feet§	Date of measurement, 1939	Remarks.
	T. 35 S., R. 42 W.														
)	NE¼ SE¼ sec. 17	Kansas City Power and Light Co.	Upland flat	300	8	Sand	Ogallala	P, E	P	Land surface	0	3,610	203	......	Originally drilled to 460 feet but was plugged back to 300 feet because of strongly mineralized artesian water. Iron casing. Reported to yield 42 gallons a minute.
ι1	SW¼ SW¼ sec. 21	do	do	299	......	do	do	......	N	do	0	3,621	212	......	Abandoned, formerly a public supply well. Iron casing.
ι2	do	do	do	308	......	do	do	......	N	do	0	3,631	220	......	Do
ι3	NE¼ NE¼ sec. 20	do	do	260	12	do	do	T, E	P	do	0	3,610	200	......	Iron casing. Reported to yield 80 gallons a minute with a drawdown of 30 feet.
ι4	NW¼ NW¼ sec. 21	do	do	278	12	do	do	T, E	P	do	0	......	200.33	......	Iron casing. Reported to yield 120 gallons a minute with a drawdown of 30 feet.
ι5	SW¼ SW¼ sec. 16	A. T. & S. F. Ry	do	370	......	Sand and gravel	do	P, E	R	do	0	3,621	208	......	Originally drilled to 218 feet. Deepened to 277 feet in 1927 and to 370 feet in 1928. Iron casing.
	T. 35 S., R. 43 W.														
ι6	NE¼ SE¼ sec. 4	A. E. Meggenberg	Sand dunes	124.1	4.5	do	do	C,W	N	Top of hole in concrete block.	+0.3	3,584.4	107.76	July 22	Abandoned, formerly a stock well.
ι7	SE¼ SE¼ sec. 6	H. Schweitzer	Crest of low hill,	114.9	4.5	do	do	C,W	N	Top of casing, north side.	+2.0	3,598.7	101.46	July 24	Abandoned, formerly a domestic and stock well.
ι8	NW¼ NE¼ sec. 14	L. V. Laviele	Sand dunes	169.9	4.5	Sand	do	C,W	N	do	+0.4	3,683.7	162.87	July 27	Do
ι9	NE¼ SE¼ sec. 18	Nellie Shipley	do	179.1	4.5	do	do	C,W	N	Top of casing, southwest side.	+0.5	3,674.5	178.6	July 22	Do
ι0	NE¼ NE¼ sec. 21	J. M. Hardwick	do	227.1	4.5	do	do	C,W	N	Top of board over casing, west side.	+0.6	3,687.2	211.25	July 7	Do
ι1	NE¼ NW¼ sec. 22	Leona Hardwick	do	220	4.5	do	do	C,W	D, S	Top of casing	0	......	210	......	See analysis.

T. 6N., R. 10 E.¶ NE¼ NE¼ sec. 15	Owner unknown	Low hill	209.3	4.5	Sand and gravel	do	C,W	N	Top of casing, east side.	+1.0	....	208.26	July 10	
T. 6 N., R. 12 E.¶ NW¼ NW¼ sec. 15	E. S. Ingraham	Upland flat	224.2	5.5	do	do	C,W	N	Top of bolt in clamp, east side.	+1.1	3,482.3	210.51	Aug. 25	Abandoned, formerly a domestic and stock well.
SE¼ NE¼ sec. 17	A. Harris	do	235	4.5	do	do	C,W	D, S	Land surface	0	....	225	....	
T. 30 S., R. 41 W.‖ SW¼ sec. 33	S. L. Florey	Sand dunes	40	5	Sandstone	Cockrum	C,W	D, S	Land surface	0	....	32	....	No casing. Cockrum sandstone encountered at a depth of 30 feet.
T. 33 S., R. 39 W.†† SW¼ NW¼ sec. 3	Owner unknown	do	92.9	4.5	Sand	Ogallala	C,W	N	Top of casing, north side.	+0.6	....	79.54	July 28	Abandoned, formerly a domestic and stock well.
T. 34 S., R. 39 W.†† NE¼ sec. 15	do	Upland flat	263	6	Sand and gravel	do	......	N	Land surface	0	....	180	....	Water used in drilling gas well.
T. 35 S., R. 39 W.†† SW¼ NW¼ sec. 15	R. S. Phillips	do	200	......	do	do	C,W	D, S	Top of casing	0	....	188	....	

Measured depths given in feet and tenths of a foot, reported depths given only in feet.
† Pumps: C, cylinder; T, turbine; P, plunger. Power: W, wind; H, hand; F, artesian flow; E, electric motor; G, gasoline engine.
‡ D, domestic; S, stock; I, irrigation; P, public; R, railroad; N, not in use.
§ Measured water levels given in feet and in tenths and hundredths of a foot, reported water levels given only in feet.
¶ Wells in Texas county, Oklahoma.
‖ Well in Baca county, Colorado.
†† Well in Stevens county, Kansas.

WELL LOGS

Listed in the following pages are the logs of 45 wells and test holes in Morton county, including 11 test holes drilled by the State and Federal Geological Surveys (1-11), 11 water wells (12-22), and 23 gas test wells (23-45). The locations of the test holes are shown in figure 2 and of the wells in plate 2.

About three-fourths of the logs were made by well drillers. Many of the drillers' rock names have been changed to conform with geologic terminology. "Gyp" or "gyp rock" has been interpreted to mean caliche, and "soapstone" has been changed to shale or clay. The term "sand rock" is used by drillers to describe a rock that is so well consolidated that no casing is needed to prevent caving. Much of the Ogallala formation has been logged as clay, but in those wells from which cuttings were available for study it was found that most of the so-called clay was silt.

1. Log of test hole 1 at the NW corner sec. 4, T. 31 S., R. 39 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,192.7 feet. (Samples studied by Perry McNally and Thad McLaughlin.)

	Thickness, feet	Depth, feet
Loam, brown to black	3	3
Ogallala formation		
Clay, silty to fine sandy, light brown	5	8
Silt, fine sandy, brown	3	11
Silt, fine sandy, light brown	2	13
Sand, fine, brown, containing caliche and clay	4	17
Silt, light brown and gray, and caliche	8	25
Silt, fine sandy, brown	4	29
Clay, silty, light brown, and caliche	12	41
Silt, light gray, fine sandy	2	43
Silt, fine sandy, light brown	3	46
Sand, fine, reddish brown	8	54
Silt, fine sandy, brown, and caliche	10	64
Clay, silty, light brown	5	69
Sand and silt, fine, brown	4	73
Silt and caliche	5	78
Sand, fine, brown, and caliche	9	87
Sand, fine, light brown to gray, and caliche	10	97
Sand, fine, brown	11	108
Silt, light gray to white	6	114
Sand, fine, brown to gray	23	137
Sand, medium, brown	4	141
Silt, fine sandy, brown	6	147
Sand and gravel, brown	11.5	158.5
Silt, sandy, brown	6.5	165
Sand and gravel, brown	11	176
Silt, caliche, and sand	4	180
Sand and gravel, brown	10	190
Sand and gravel, coarse	10	200
Sand, fine, brown, and silt	10	210

	Thickness, feet	Depth, feet
Silt, brown, and loose sand	13	223
Silt, brown and gray	5	228
Sand, fine to coarse, brown	9	237
Sand and gravel	11.5	248.5
Silt, brown, sandy	7.5	256
Silt, sand, and gravel	5.5	261.5
Cockrum sandstone		
Sandstone, brown, and clay, varicolored	8.5	270

2. Log of test hole 2 at the NW corner sec. 3, T. 31 S., R. 40 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,266.2 feet. (Samples studied by Perry McNally and Bruce F. Latta.)

	Thickness, feet	Depth, feet
Loam, brown to black	4	4
Ogallala formation		
Silt, sandy, brown	5	9
Sand, fine, brown, and clay	18	27
Caliche, gray, and sand	10	37
Silt, sandy, brown	4	41
Sand, fine, and clay	2	43
Silt, brown, and sand	7	50
Sand, fine to medium, brown	10	60
Silt, sandy, brown	5	65
Sand, fine to medium, brown	5	70
Sand, fine, and gravel, coarse	25	95
Clay, silty, brown	1.5	96.5
Sand and gravel, brown	18	114.5
Silt, sandy, brown	16.5	131
Silt, caliche, and sand	7	138
Silt, limy, brown	4	142
Silt, limy, gray, some sand and gravel	3	145
Sand, fine to coarse, brown	23	168
Silt, limy, light brown	6	174
Silt, brown, and sand	2	176
Sand and gravel, brown (predominantly fine gravel)	4	180
Sand and gravel	11	191
Cockrum sandstone		
Clay, varicolored	9	200

3. Log of test hole 3 at the NE corner sec. 4, T. 31 S., R. 41 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,387.8 feet. (Samples studied by Perry McNally and Thad McLaughlin.)

	Thickness, feet	Depth, feet
Loam, black	2	2
Ogallala formation		
Silt, brown, soft	6	8
Silt, brown, sandy	3	11
Silt, light gray, limy	6	17
Silt, pink	8	25
Silt, gray, limy	6	31
Silt, gray, and sand	2	33
Sand, fine, brown, and clay	2	35
Silt and caliche	3	38
Sand and gravel, coarse	2	40
Silt and sand	12	52
Sand and gravel, medium, brown	10	62
Silt, light brown	1.5	63.5
Sand, fine, reddish brown	5.5	69
Silt, gray, limy	2	71
Silt, pink, sandy	2	73
Clay, light gray, limy	8	81
Cockrum sandstone		
Sandstone, yellowish brown, gray, and maroon	9	90

4. Log of test hole 4 at SE corner sec. 36, T. 31 S., R. 42 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,440.7 feet. (Samples studied by Perry McNally and Thad McLaughlin.)

	Thickness, feet	Depth, feet
Loam, dark, silty	2	2
Silt, yellowish brown	1	3
Ogallala formation		
Silt, light gray to white	4	7
Silt, brown to pink	4	11
Silt, light gray, limy	5	16
Sand, fine to medium, brown	2	18
Silt, brown, sandy, and caliche	4	22
Silt, brown, sandy	1	23
Sand, medium, brown	2	25
Silt, brown and gray	3	28
Caliche	1	29
Cockrum sandstone		
Sandstone, very fine, gray and yellow	11	40
Sandstone, fine, light gray	4	44
Sand, very fine, yellow	3	47
Sandstone, fine, light gray	6	53
Sand, fine, brown	1	54
Sandstone, gray	4	58

	Thickness, feet	Depth, feet
Sandstone, fine, dark brown	1	59
Clay, varicolored	11	70
Kiowa shale		
Clay shale, black	20	90
Shale, black, and sand, light gray	8	98
Clay, brown, and shale, black	6	104
Morrison(?) formation		
Clay, blue green	15	119
Sandstone, blue green	5	124
Clay, blue green	7	131
Sandstone, gray and brown	7	138
Clay, blue gray	6	144
Triassic(?) redbeds		
Clay, reddish brown	4	148
Siltstone, dark red brown	2	150
Siltstone, red brown, hard	9	159
Siltstone, red and gray	2	161
Siltstone and clay, yellow	1	162
Siltstone, yellow	3	165
Clay, red, and sandstone	5	170
Siltstone, red brown	5	175
Siltstone, dark red	2	177
Siltstone, red, and clay, gray	1.5	178.5
Siltstone, red, and sand, medium	6.5	185

5. Log of test hole 5 at the NW corner sec. 10, T. 32 S., R. 40 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,313 feet. (Samples studied by Perry McNally.)

	Thickness, feet	Depth, feet
Loam, silty	2	2
Soil, brown	2	4
Ogallala formation		
Silt, calcareous	5	9
Silt, brown, calcareous	20	29
Silt, yellow brown	12	41
Silt and sand, brown	20	61
Clay, white	4	65
Silt, greenish to brown	61	126
Silt and sand, medium to coarse	13	139
Sand, fine to coarse	15	154
Sand and gravel, brown	6	160
Sand, light gray	2	162
Sand and gravel, brown	6	168
Silt, brown	2	170
Cockrum sandstone		
Sandstone, brown to tan	10	180
Sandstone, white, and clay, varicolored	20	200

	Thickness, feet	Depth, feet
Sandstone, gray to tan	62	262
Clay, brown	39	301
Sandstone, brown	11.5	312.5
Clay, white, and sandstone	7.5	320

6. Log of test hole 6 at SE corner sec. 8, T. 33 S., R. 42 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,518.5 feet. (Samples studied by Perry McNally and Thad McLaughlin.)

	Thickness, feet	Depth, feet
Loam, dark, silty	1	1
Ogallala formation		
Silt, light brown	4	5
Silt, light reddish brown	5	10
Silt, light gray and brown	9	19
Caliche	4	23
Silt, brown	2	25
Caliche	4	29
Sand, fine, light brown	2	31
Silt, light gray, and caliche	1	32
Sand, fine, brown, and clay	14	46
Limestone sand, and caliche	5	51
Sand, fine to medium	4	55
Caliche and sand	6	61
Silt, gray to white, and caliche	5	66
Silt, brown to gray, and caliche	4	70
Silt, brown to gray green	6	76
Sand and gravel, brown	5	81
Sand, fine to medium, brown	7	88
Silt, brown, and caliche	2	90
Sand, fine to medium, brown	10	100
Sand, fine to coarse, and clay	5	105
Sand, brown	1	106
Silt, light brown	15	121
Triassic(?) redbeds		
Sand, fine, light red brown	39	160
Sand, fine, dark red brown	16	176
Sandstone, buff, some clay and gypsum	5	181
Sandstone, light red, and gypsum	3	184
Sandstone, buff and red, and gypsum	21	205
Sandstone, fine, maroon red, and gypsum	9	214
Sandstone, fine, yellowish brown	6	220
Sandstone, buff, and gypsum	7	227
Sandstone, fine, maroon red, and gypsum	13	240

7. Log of test hole 7 at SW corner sec. 31, T. 33 S., R. 43 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,686.5 feet. (Samples studied by Perry McNally and Thad McLaughlin.)

	Thickness, feet	Depth, feet
Loam, dark	1	1
Soil, silty	2	3
Ogallala formation		
Silt, brown	5.5	8.5
Silt, light brown and gray	4.5	13
Silt, gray to brown, and caliche	6	19
Sand, fine, light brown	2	21
Silt, white, and caliche	4	25
Sand, fine, brown	7	32
Sand, fine to coarse, brown	5	37
Sand, fine, brown	6	43
Sand, light gray and brown	2	45
Sand, fine, brown	2	47
Sand and gravel, fine, brown	11	58
Sand, light gray to light brown	9	67
Sand, fine, brown	4	71
Silt, light brown	6	77
Sand, fine, brown	4	81
Sand, light brown	4	85
Limestone, light gray, and sand	4	89
Silt, light gray, and sand	11	100
Sand and gravel, coarse, brown	5	105
Clay, brown	8.5	113.5
Sand and gravel, coarse, brown	19.5	133
Sand, gravel, and clay	8	141
Limestone, pink, some sand and caliche	3	144
Triassic(?) redbeds		
Sandstone, maroon and gray, and clay, white	5	149
Sandstone, buff and yellow, siltstone, red, and gypsum	1	150
Sandstone, buff, yellow, and blue green	1.5	151.5
Sandstone, fine, maroon	2	153.5
Sandstone, buff	4.5	158
Sandstone, very fine, light gray and brown	2	160
Sandstone, very fine, maroon	2	162
Sandstone, light gray, and clay	3	165
Sandstone, very fine, buff and clay	3	168
Sandstone, buff and red	1	169
Sandstone, fine, buff to yellow brown	16	185
Sandstone, buff to red	5	190

8. **Log of test hole 8 at Point Rock, in the NE¼ sec. 12, T. 34 S., R. 43 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,427.6 feet. (Samples studied by Perry McNally and Thad McLaughlin.)**

	Thickness, feet	Depth, feet
Soil, brown	1	1
Alluvium		
Sand and gravel	3	4
Sand, fine, light brown	8	12
Triassic(?) redbeds		
Sandstone, very fine, buff	7	19
Sandstone, very fine, maroon	4.5	23.5
Sandstone, very fine, tan	3.5	27
Sandstone, very fine, buff to red	2	29
Sandstone, very fine, maroon	2	31
Siltstone, dark red	29	60
Siltstone, dark red, and sandstone, gray	23	83
Sandstone, very fine, buff to red brown	4	87
Siltstone, dark red	9	96
Sandstone, buff, and clay	1	97
Siltstone, maroon	50.5	147.5
Sandstone, gray, and clay	5.5	153
Siltstone, maroon, and gypsum and sandstone, tan	37	190
Siltstone, brick red, and gypsum (artesian flow)	10	200

9. **Log of test hole 9 at SE corner sec. 19, T. 35 S., R. 40 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,428.6 feet. (Samples studied by Perry McNally and Thad McLaughlin.)**

	Thickness, feet	Depth, feet
Road fill	2	2
Soil, brown	2	4
Ogallala formation		
Silt, light brown	6	10
Silt, gray, and caliche	4	14
Silt, light brown	10	24
Sand, fine to medium, brown	6	30
Silt, brown, and caliche	4	34
Silt, brown	10	44
Silt, brown, and caliche	16	60
Sand, fine to medium	40.5	100.5
Silt, brown, and caliche	8.5	109
Sand, fine, reddish brown	11	120
Sand, fine, reddish brown, and caliche	8	128
Sand, fine, brown	42	170
Sand, gray, and clay	21	191
Sand, fine to medium, brown	9	200
Silt, brown	22	222
Silt, gray, and sand	27	249
Sand, medium to coarse, gray	11	260

	Thickness, feet	Depth, feet
Silt, gray and brown, and caliche	18	278
Silt, yellow to brown	5.5	283.5
Sand, fine to medium, gray	5.5	289
Silt, gray green	29	318
Sand and gravel, brown (predominantly fine gravel)	10	328
Silt, maroon	12	340
Silt, brown, gray green, and red	49	389
Permian(?) redbeds		
Siltstone, maroon, and clay	41	430

10. Log of test hole 10 at SE corner sec. 19, T. 35 S., R. 41 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,545.4 feet. (Samples studied by Perry McNally and Thad McLaughlin.)

	Thickness, feet	Depth, feet
Soil, brown	6	6
Ogallala formation		
Silt, light brown	3	9
Silt, light brown, caliche, and sand	6	15
Sand, fine to medium, brown	9	24
Silt, gray, and caliche	5	29
Silt, gray to brown	7	36
Sand, fine to medium, brown	7	43
Silt, gray to brown	2	45
Sand, fine to medium, and clay	2	47
Silt, brown	8	55
Sand, fine to medium	5	60
Silt, brown	7	67
Sand, medium, brown, and clay	2	69
Sand clusters, cemented with calcium carbonate	2.5	71.5
Sand, fine, brown	5	76.5
Sand clusters, cemented with calcium carbonate	2.5	79
Sand, fine to medium, brown	7	86
Silt, brown	21	107
Sand, fine to medium, brown	9	116
Sand, medium to coarse, brown	2	118
Sand, fine, reddish-brown, and clay	3.5	121.5
Silt, light brown to gray	2.5	124
Silt, brown	7	131
Silt, brown, and caliche	10.5	141.5
Silt, brown, sandy	35.5	177
Sand and gravel (25 percent dark igneous pebbles)	19.5	196.5
Silt, pink brown	6.5	203
Sand, fine to medium, brown	2	205
Silt, brown and gray	4.5	209.5
Sand, medium, brown	3.5	213
Silt, gray brown	7	220
Sand and gravel (predominantly coarse sand)	6.5	226.5

	Thickness, feet	Depth, feet
Sand, gray	6.5	233
Silt, brown and maroon	17	250
Silt, brown to pink	12	262
Sand and limestone	4	266
Permian(?) redbeds		
Siltstone, dark brick red	9	275

11. Log of test hole 11 at SW corner sec. 21, T. 35 S., R. 43 W., drilled by State and Federal Geological Surveys, 1940. Surface altitude 3,673.2 feet. (Samples studied by Perry McNally and Thad McLaughlin.)

	Thickness, feet	Depth, feet
Soil, brown	4	4
Ogallala formation		
Sand, fine to medium, brown	22	26
Silt, caliche, and sand	9	35
Sand, fine, brown	10	45
Silt, light gray to brown, and some sand	11	56
Sand, fine to medium	8	64
Sand and gravel, coarse	6	70
Silt, brown	12	82
Sand, fine, and clay	4	86
Sand, fine to coarse, brown	6	92
Silt and sand	3	95
Sand, medium and fine, tan	3	98
Silt and sand	1.5	99.5
Sand and gravel	6.5	106
Gravel, fine to coarse	4	110
Silt and some sand	6	116
Silt, sandy, and caliche	8	124
Silt, gray green to brown, and caliche and sand	27	151
Sand, fine, brown	11	162
Silt, gray green to brown	3	165
Sand, medium and fine, brown	25	190
Sand and gravel	27	217
Silt and caliche, gray	3	220
Silt, brown	4	224
Gravel, fine to coarse	46	270
Gravel, fine to coarse, and silt	10	280
Sand, fine to coarse, red brown	14	294
Triassic(?) redbeds		
Siltstones, gray to red brown	8.5	302.5
Siltstone, red brown	1.5	304
Silt, gray green	6	310
Silt, gray green, and sandstone	10	320

12. Log of well 1 (138) of the Kansas City Power and Light Company (Elkhart), sec. 16, T. 35 S., R. 42 W. (Authority, Thomas Harford, superintendent.)

	Thickness, feet	Depth, feet
Soil	3	3
Ogallala formation		
Clay, sandy	15	18
Clay, sandy, and caliche	22	40
Clay, calcareous	5	45
Sand	9	54
Clay, calcareous	16	70
Caliche	16	86
Caliche and clay	12	98
Caliche	24	122
Caliche and clay	14	136
Clay, sandy	18	154
Caliche	4	158
Caliche and Clay	5	163
Clay, sandy	9	172
Clay, red, and sand	16	188
Clay, red	4	192
Sand and gravel	33	225
Clay and sand	20	245
Sand and gravel	5	250
Sand, brown	7	257
Triassic(?) redbeds		
Clay, red, sandy	8	265
Sand, pink	12	277
Sand, light yellow	9	286
Shale, red	1	287

13. Log of well 2 (139) of the Kansas City Power and Light Company (Elkhart), 100 feet north of Oklahoma line and 900 feet east of SW corner of sec. 21, T. 35 S., R. 42 W. Surface altitude 3,614 feet. (Authority, Thomas Harford, superintendent.)

	Thickness, feet	Depth, feet
Soil	2	2
Gumbo, black	10	12
Ogallala formation		
Clay	13	25
Clay, sticky	5	30
Clay, hard	25	55
Clay, sandy	5	60
Clay, hard, sticky	42	102
Clay, sandy	8	110
Caliche and clay	25	135
Clay, soft, sandy	30	165
Clay, soft, sticky	10	175
Clay, soft, sandy	25	200

	Thickness, feet	Depth, feet
Clay, sticky, and sand, water-bearing	40	240
Sand, medium, water-bearing	8	248
Clay, yellow, sticky	11	259
Sand, fine, muddy, water-bearing	25	284
Sand rock, soft, muddy, some water	4	288
Triassic(?) redbeds		
Shale, red	2	290

14. Log of well 3 (140) of the Kansas City Power and Light Company (Elkhart), sec. 17, T. 35 S., R. 42 W. Originally drilled to 460 feet, but plugged back to 266 feet because of the strongly mineralized artesian water encountered at the greater depth. (Authority, Thomas Harford, superintendent.)

	Thickness, feet	Depth, feet
Soil	5	5
Ogallala formation		
Sand	50	55
Clay and caliche	37	92
Caliche	18	110
Clay and sand	35	145
Gravel, coarse	13	158
Not logged	32	190
Clay and sand	50	240
Rock, hard	5	245
Sand and clay	10	255
Sand and gravel, coarse (strong flow of water)	11	266
Triassic(?) redbeds		
Shale, red, at bottom of hole	..	460

15. Log of well 4 (141) of the Kansas City Power and Light Company (Elkhart), 100 feet north of Oklahoma line and 900 feet east of the SW corner sec. 21, T. 35 S., R. 42 W. Surface altitude 3,621 feet. (Authority, Thomas Harford, superintendent.)

	Thickness, feet	Depth, feet
Soil	2	2
Ogallala formation		
Clay, sandy	18	20
Clay	5	25
Clay, sandy	45	70
Sand	10	80
Clay, sticky	5	85
Caliche and clay	45	130
Sand and clay	20	150
Clay	15	165
Sand and Clay	17.5	182.5
Sand, fine, muddy	12.5	195
Clay and some fine sand	7	202
Sand, fine, muddy, water-bearing	6	208
Sand, clay, and some caliche	2	210

	Thickness, feet	Depth, feet
Clay and some caliche. Reported static water level, 212 feet	5	215
Clay and some sand	2.5	217.5
Clay, soft, and sand	22.5	240
Sand, fine, muddy, water-bearing	15	255
Clay, yellow	4	259
Sand, fine, brown, water-bearing	5	265
Clay, yellow	34	299

16. Log of well 5 (142) of the Kansas City Power and Light Company (Elkhart), 30 feet south and 15 feet west of the NE corner sec. 21, T. 35 S., R. 42 W. Surface altitude 3,631 feet. (Authority, Thomas Harford, superintendent.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand	50	50
Clay, sandy	25	75
Clay, sandy, and sand	25	100
Clay	10	110
Sand and gravel	7	117
Clay	8	125
Sand, clay, and caliche	5	130
Caliche and clay	15	145
Clay, sandy	35	180
Sand, caliche, and clay	10	190
Clay, sandy	47.5	237.5
Clay	8.5	246
Caliche, sandy, or white clay	2	248
Sand, fine, muddy, water-bearing	27	275
Clay, yellow, sticky	13	288
Quicksand	12	300
Quicksand and joint clay	5	305
Triassic(?) redbeds		
Shale, red	3	308

17. Log of well 7 (144) of the Kansas City Power and Light Company (Elkhart), at the NW¼ NW¼ NW¼ sec. 21, T. 35 S., R. 42 W. Surface altitude 3,608 feet (authority, Thomas Harford, superintendent). Samples from 200 to 245.5 feet studied by Thad McLaughlin.

	Thickness, feet	Depth, feet
Soil	2	2
Ogallala formation		
Sand	23	25
Clay, sandy	10	35
Sand	10	45
Clay, sandy	55	100
Clay and caliche	8	108
Clay	12	120

	Thickness, feet	Depth, feet
Clay, sandy	30	150
Clay, sticky	10	160
Clay, sandy	30	190
Sand, fine, muddy	10	200
Siltstone, light tan, some sand and caliche	5	205
Siltstone, buff, and quartz sand and caliche	10	215
Sand, fine, buff, and siltstone	2.5	217.5
Sand, fine, buff, and siltstone and caliche	2.5	220
Clay, white	5	225
Sand, fine, and buff siltstone and clay	5	230
Sand, very fine, and siltstone	5	235
Sand and gravel, medium to coarse	11.5	245.5
Sand and clay balls	4.5	250
Clay balls and some sand, water-bearing	2	252
Sand, brown, water-bearing	1	253
Sand and clay, water-bearing	5	258
Clay, hard, brown	2	260
Sand rock and clay	10	270
Sand rock, hard, water-bearing	7	277
Triassic(?) redbeds		
Redbeds	0.5	277.5

18. Log of well (145) of the Atchison, Topeka, and Santa Fe Railway Co., in the SW¼ SW¼ SW¼ sec. 16, T. 35 S., R. 42 W. Drilled in 1913 to a depth of 218 feet, deepened to 277 feet in 1927 and to 370 feet in 1928. No log was kept for the last 93 feet. Surface altitude 3,621 feet. (Authority, Mr. Waddell, station agent.)

	Thickness, feet	Depth, feet
Ogallala formation		
Clay, brown	20	20
Marl	5	25
Clay, light yellow	80	105
Marl	15	120
Clay, light yellow	35	155
Marl	10	165
Clay, red	17	182
Clay, sandy	8	190
Sand, red	4	194
Sand, coarse, water-bearing	24	218
Caliche and clay	25	243
Sand, water-bearing	5	248
Caliche and clay	3	251
Sand, water-bearing	2	253
Caliche and clay	1	254
Sand, water-bearing	1	255
Sand rock, soft, yellow	16	271
Triassic(?) redbeds		
Sand, red	6	277

19. Log of well (63) of Roy Connor, in the SE¼ sec. 13, T. 33 S., R. 40 W. (Authority, Roy Connor, owner.)

	Thickness, feet	Depth, feet
Ogallala formation		
Surface	125	125
Sand, fine, red, water-bearing	79	204
Sand and clay	76	280
Sand, coarse, white, water-bearing	96	376

20. Log of municipal well (92) of the city of Rolla, in the NE¼ NE¼ SE¼ sec. 2, T. 34 S., R. 34 W. (Authority, Perry Williams, superintendent.)

	Thickness, feet	Depth, feet
Ogallala formation		
Soil	2	2
Sand and clay	28	30
Clay, sandy	110	140
Sand and gravel, water-bearing	14	154
Clay	21	175
Sand and clay	7	182
Sand	5	187
Clay	8	195

21. Log of well (43) of E. C. Wilson, in the NW¼ NW¼ SW¼ sec. 16, T. 32 S., R. 41 W. (Cited by Darton, 1905.)

	Thickness, feet	Depth, feet
Ogallala formation		
Soil and tertiary grit (reported as gypsum)	40	40
Clay, yellow, and sand	12	52
Sand	19	71
Cockrum sandstone		
Clay, blue	1	72
Sandstone (large quantities of water)	130	202
Kiowa shale		
Shale, blue	49	251
Triassic(?) redbeds		
Sandstone, red (artesian flow at 637 feet)	459	710

22. Log of well (115) of the Soil Conservation Service, in the SW¼ NW¼ sec. 33, T. 34 S., R. 42 W. (Samples studied by Thad McLaughlin.)

	Thickness, feet	Depth, feet
Dune sand		
Sand, fine to coarse, light tan	5	5
Sand, fine, light	5	10
Sand, medium, light tan	45	55
Ogallala formation		
Sand, coarse, white, and gravel, medium	10	65
Sand and gravel, coarse	5	70
Sand, coarse, and gravel, medium	10	80
Sand, fine to medium	5	85
Sand and gravel, coarse	30	115
Sand, medium, buff (water at 124 feet)	29	144
Siltstone, red	5	149
Sand, fine, light red	5	154

23. Partial log of the Kuhn Brothers Production Company No. 1 O. B. Curtis well, in the middle of the NE¼ sec. 25, T. 31 S., R. 39 W. Surface altitude 3,200 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand	65	65
Clay, sand, and gravel	175	240
Sand and gravel	150	390
Shale and clay	130	520
Permian(?) redbeds		
Redbeds	180	700

24. Partial log of gas test well, in the SW¼ NE¼ sec. 1, T. 32 S., R. 39 W. Surface altitude 3,110 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Caliche and sand	172	172
Sand and gravel	91	263
Caliche	31	294
Caliche, sand, and gravel	182	476
Caliche	24	500
Permian(?) redbeds		
Redbeds	100+	600+

25. Partial log of well 1 of the Watkins Land Co., in the NW¼ NW¼ sec. 11, T. 31 S., R. 43 W. Total depth, 1,150 feet. (Cited by Darton, 1920.)

	Thickness, feet	Depth, feet
Soil	5	5
Ogallala formation		
Clay, yellow	20	25
Clay, sandy	10	35
Gravel, water-bearing	20	55
Caliche	25	80
Cockrum sandstone		
Clay, yellow	15	95
Sand, water-bearing	5	100
Clay, yellow	10	110
Sand, water-bearing	6	116
Clay, yellow	19	135
Sand, blue, water-bearing	35	170
Kiowa shale		
Shale, blue	80	250
Cheyenne sandstone		
Sand, white, water-bearing	125	375
Triassic(?) redbeds		
Shale, red	5	380

26. Partial log of the Texas Interstate and Saturn Company No. 1 J. F. Simmons well, in the middle of the SE¼ sec. 16, T. 32 S., R. 39 W. Surface altitude 3,245 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Surface sand	100	100
Shale, blue	220	320
Caliche	8	328
Sand, hard	53	381
Limestone	19	400
Sand and limestone	50	450
Sand, gypsum, and redbeds	130	580
Permian(?) redbeds		
Redbeds	18	598

27. Partial log of the Argus Production Company No. 1 A. O. Mangels well, in the middle of the SE¼ sec. 4, T. 33 S., R. 39 W. Surface altitude 3,227 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Surface	25	25
Clay, sticky	175	200
Sand and gravel	90	290
Sand	70	360
Shale, sticky	80	440
Shale	60	500
Permian(?) redbeds		
Shale, hard, red	75	575
Shale, red	145	720

28. Partial log of the Argus Production Company No. 1 Garner well, in the middle of the SE¼ sec. 18, T. 33 S., R. 39 W. Surface altitude 3,254 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand	30	30
Clay, yellow	30	60
Sand	190	260
Shale and streaks of gravel	100	350
Shale and gravel	175	525
Permian(?) redbeds		
Shale, red, and sand	37	562
Shale, red	38	600

29. Partial log of the Argus Production Company No. 1 William Mangels well, in the middle of the SW¼ sec. 19, T. 33 S., R. 39 W. Surface altitude 3,286 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Soil and clay	30	30
Sand	230	260
Sand and clay	260	520
Sand and gravel	30	550
Permian(?) redbeds		
Redbeds	110	660
Sand, red, and redbeds	40	700
Redbeds and gypsum	150	850

30. Partial log of the Argus Production Company No. 1 E. E. Mangels well, in the middle of the NE¼ sec. 20, T. 33 S., R. 39 W. Surface altitude 3,248 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand and clay	147	147
Clay and gravel	153	300
Sand, gravel, and clay	125	425
Clay and gravel	95	520
Permian(?) redbeds		
Redbeds	45	565
Shale, red	5	570
Redbeds and gypsum	145	715

31. Partial log of the Argus Production Company No. 1 R. E. Burton well, in the middle of the SE¼ sec. 11, T. 33 S., R. 40 W. Surface altitude 3,283 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand and clay	350	350
Sand, hard	80	430
Clay, yellow, and sand	153	583
Permian(?) redbeds		
Redbeds	117	700
Gypsum	80	780

32. Partial log of the Argus Production Company No. 1 E. F. Chambers well, in the middle of the NW¼ sec. 25, T. 33 S., R. 40 W. Surface altitude 3,281 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand and gravel	100	100
Gravel	20	120
Clay and sand	320	440
Sand	90	530
Caliche	10	540

	Thickness, feet	Depth, feet
Permian(?) redbeds		
Shale, red	50	590
Shale	20	610
Sand	70	680
Redbeds	20	700

33. Partial log of gas test well in sec. 2, T. 34 S., R. 39 W. Surface altitude 3,250 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand	150	150
Sand and gravel	50	200
Sand	300	500
Sand, coarse	35	535
Permian(?) redbeds		
Redbeds	65	600

34. Partial log of the Argus Production Company No. 2 Armstrong well, in the middle of the SW¼ sec. 4, T. 34 S., R. 39 W. Surface altitude 3,288 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand	230	230
Caliche	5	235
Sand	325	560
Sand and clay	3	563
Sand	17	580
Permian(?) redbeds		
Redbeds	20	600
Redbeds and gypsum	570	1,170

35. Partial log of the Argus Production Company No. 1 Minnie Mangels well, in the middle of the SW¼ sec. 6, T. 34 S., R. 39 W. Surface altitude 3,311 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand	90	90
Clay and gravel	50	140
Sand	70	210
Shale, sticky	10	220
Sand	55	275
Shale, sticky	125	400
Caliche, hard	155	555
Sand, hard	15	570
Permian(?) redbeds		
Redbeds	60	630

36. Partial log of the Argus Production Company No. 1 Armstrong well, in the middle of the NW¼ sec. 16, T. 34 S., R. 39 W. Surface altitude 3,323 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Soil and sand	20	20
Sand and gravel	88	108
Sand, hard	4	112
Sand, clay, and gravel	388	500
Sand and redbeds	61	561
Permian(?) redbeds		
Redbeds	205	766

37. Partial log of Argus Production Company No. 1 W. R. Littell well, in the middle of the SE¼ sec. 24, T. 34 S., R. 40 W. Surface altitude 3,349 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand	135	135
Sand and gravel	195	330
Clay	70	400
Shale, red	139	539
Permian(?) redbeds		
Redbeds	204	743
Anhydrite and gypsum	44	787

38. Partial log of the Argus Production Company No. 1 J. W. Watson well, in the middle of the NE¼ sec. 27, T. 34 S., R. 40 W. Surface altitude 3,364 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Surface	30	30
Clay, red	100	130
Sand	270	400
Sand and redbeds	160	560
Permian(?) redbeds		
Redbeds	150	710

39. Partial log of the Hydraulic Oil Company No. 1 Butts well, in the NW¼ NW¼ SE¼ sec. 22, T. 34 S., R. 43 W. Surface altitude 3,459 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand and gravel	44	44
Clay, yellow	19	63
Triassic(?) redbeds		
Redbeds	139	202
Flint	2	204
Sand (artesian flow)	8	212
Shale, red	24	236
Redbeds and gypsum	12	248
Shale, red	99	347

	Thickness, feet	Depth, feet
Shale, sandy	15	362
Sand	5	367
Sand, hard	4	371
Shale, red	59	430
Gypsum	17	447
Shale, red	123	570

40. Partial log of the Missouri-Kansas Gas Company No. 1 Rickart well, in the middle of the SE¼ sec. 5, T. 35 S., R. 39 W. Surface altitude 3,315 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Clay and sand	30	30
Sand	105	135
Sand and red clay streaks	280	415
Sand	109	524
Permian(?) redbeds		
Redbeds	46	570

41. Partial log of the Greening well No. 1, in sec. 6, T. 35 S., R. 39 W. Surface altitude 3,329 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand and clay	100	100
Sand	350	450
Sand and caliche	87	537
Permian(?) redbeds		
Redbeds	175	712
Redbeds and gypsum	38	750

42. Partial log of the Texas Interstate and Saturn Company No. 1 Rickart well, in the middle of the SE¼ sec. 8, T. 35 S., R. 39 W. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Sand, caliche and clay	470	470
Sand	10	480
Caliche and sand	50	530
Permian(?) redbeds		
Redbeds	170	700

43. Partial log of the Texas Interstate and Saturn Company No. 1 R. S. Phillips well, in the middle of the SE¼ sec. 9, T. 35 S., R. 39 W. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Surface sand	30	30
Sand and gravel	250	280
Caliche	200	480
Permian(?) redbeds		
Redbeds	220	700

44. Partial log of the J. Ehrhard well No. 1, in the NE¼ sec. 11, T. 35 S., R. 39 W. Surface altitude 3,295.67 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Soil and sand	84	84
Clay	166	250
Sand	75	325
Sand and gravel	75	400
Sand, hard	180	580
Permian(?) redbeds		
Sand and redbeds	20	600
Redbeds	27	627
Redbeds and gypsum	95	722
Gypsum	18	740

45. Partial log of the Texas Interstate and Saturn Company No. 1 R. S. Phillips well, in the middle of the SE¼ sec. 16, T. 35 S., R. 39 W. Surface altitude 3,303 feet. (Authority, Texoma Natural Gas Co.)

	Thickness, feet	Depth, feet
Ogallala formation		
Surface	30	30
Sand and gravel	80	110
Sand, soft	115	225
Sand	50	275
Clay, red	100	375
Sand	52	427
Sand, hard	98	525
Sand and shale	25	550
Shale, sticky	45	595
Permian(?) redbeds		
Redbeds	9	604

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