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GEOLOGY AND GROUND-WATER RESOURCES OF JEWELL COUNTY, KANSAS

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Prepared by the State Geological Survey of Kansas and the United States Geological Survey, with the cooperation 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 JEWELL COUNTY, KANSAS

By V. C. Fishel and Alvin R. Leonard

ABSTRACT

This report describes the geography, geology, and ground-water resources of Jewell County in north-central Kansas. The county has an area of 915 square miles and in 1950 had a population of 9,698. Jewell County lies in the Great Plains Pliocene to Cretaceous ground-water province. The county has three types of topography—the deeply dissected uplands in the northern and central parts of the county, a level or gently sloping plain which bounds the uplands on the east and south, and alluvial valleys.

The rocks that crop out at the surface in Jewell County are sedimentary, ranging in age from Late Cretaceous to Recent. The oldest rocks exposed in the county are sandstone and shale beds of the Dakota formation, which crops out in a small area on the south side of Buffalo Creek valley in the southeastern corner of the county. The Dakota is overlain by a conformable series of marine upper Cretaceous rocks classified, in ascending order: Graneros shale, Greenhorn limestone, Carlile shale, and Niobrara formation. Unconsolidated continental deposits of fluviatile and eolian origin represent at least three stages of the Pleistocene. These deposits include the Meade formation of Kansan age, in the northeastern part of the county between Republican River and White Rock Creek. Stream-laid deposits of the Meade formation also fill a narrow valley extending northward from near Mankato. Volcanic ash deposits and associated silt beds in the northwestern and southern parts of the county also are a part of the Meade formation. Later Pleistocene deposits that are present in Jewell County include terrace deposits of Illinoian and Wisconsinan age, the Loveland and Peoria silt members of the Sanborn formation, and Recent alluvium.

Ground-water recharge in the area is largely from local precipitation; ground-water discharge is mainly by seepage into streams and transpiration by plants. All municipal supplies and most domestic and stock supplies are obtained from wells. Most wells in the county are drilled or dug. No irrigation is practiced in Jewell County. On the whole, ground-water supplies are small.

Ground water in Jewell County is generally hard but otherwise suitable for most uses, except for water from certain wells which is excessively high in dissolved solids content or in nitrate.

The field data upon which this report is based are given in tables. They include records of 259 wells, chemical analyses of water from 36 representative wells, and logs of 13 test holes.

INTRODUCTION

Purpose and Scope of the Investigation

The investigation upon which this report is based is part of an extended program of ground-water investigations in Kansas begun in 1937 by the United States Geological Survey and the State Geological Survey of Kansas, in cooperation with the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture. Investigations of the ground-water resources in several other counties in Kansas have been made and additional investigations are planned until the area of the entire State has been studied. An observation-well program was started in 1934 in the Limestone Creek basin in Jewell County by the Federal Geological Survey in cooperation with the Soil Conservation Service. Since 1938, this observation-well program has been maintained as a part of the cooperative ground-water program in Kansas.

Jewell County was selected for study because it is typical of many areas where surficial deposits yield water meagerly and where the underlying bedrock yields either no water or highly mineralized water. The investigation in Jewell County also takes advantage of the records of the observation-well program that was begun in 1934.

The investigation was made under the general administration of A. N. Sayre, Chief of the Ground Water Branch of the U. S. Geological Survey.

Location and Extent of the Area

Jewell County lies in the first tier of counties from the northern border of the State and midway between the east and west borders of the State (Fig. 1). The county lies between meridians 97° 56′ and 98° 30′ west longitude and parallels 39° 34′ and 40° 00′ north latitude. It has an area of about 915 square miles and extends 30 miles north and south and about 30.5 miles east and west.

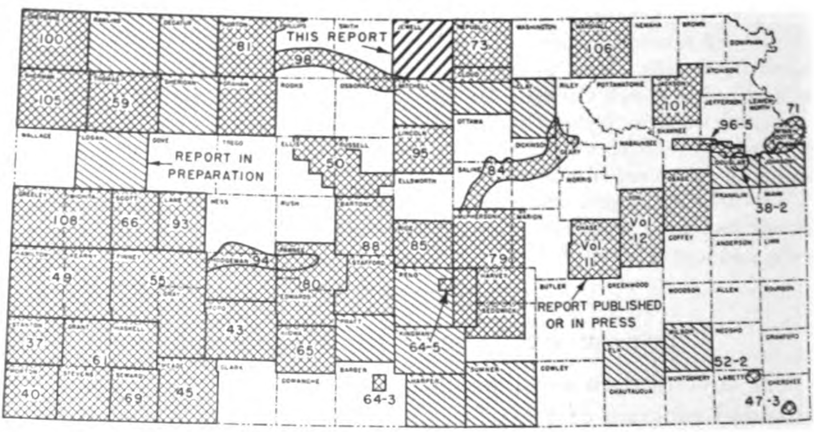

Fig. 1.—Index map of Kansas showing area covered by this report, areas for which reports have been published, and areas for which co-operative ground-water reports are in preparation.

Previous Geologic and Hydrologic Investigations

The more important studies dealing with the geology and ground-water resources of north-central Kansas that have a bearing on Jewell County are cited below. Specific references are cited at appropriate places in the text by author and date and are listed in the references at the end of the report.

The geology of upper Cretaceous rocks in Kansas was described by Logan in 1897. Darton (1905, p. 304) made reference to a few wells in this area in a preliminary report on the geology and ground-water resources of the central Great Plains. Because of the severe drought culminating in 1913 that resulted in water shortages in a large part of the State, Haworth (1913, pp. 40-43) prepared a special report on well waters in Kansas in which he discussed the availability of ground water in the Republican River valley. A report was prepared by Wing in 1930 on the geology of Cloud and Republic Counties. Also in 1930, a report was prepared by Landes on the geology of Mitchell and Osborne Counties. The Dakota formation in areas adjacent to Jewell County was described by Tester in 1931. In 1934 the U. S. Geological Survey in cooperation with the Soil Conservation Service started an observation-well program in the Limestone Creek area. The records of the water-level measurements of these wells have been published in the annual series of water-level reports of the U. S. Geological Survey (1936-54, Water Supply Papers 777, 817, 840, 845, 886, 908, 938, 946, 988, 1018, 1025, 1073, 1098, 1128, 1158, 1167, 1193, 1223). In 1940, Moore and others prepared a generalized report on the ground-water resources of Kansas. A study of the outcrop area of the Dakota formation was made by Plummer and Romary (1942). In 1948, Fishel prepared a report on the ground-water resources of Republic and northern Cloud Counties which included chapters on the Quaternary geology and Cenozoic geologic history. Construction-materials reports have been prepared for Jewell County (Byrne, Houston, and Mudge, 1950), Smith County (Byrne, Houston, and Mudge, 1948), Mitchell County (Byrne, Johnson, and Bergman, 1951), Cloud County (Buck, Van Horn, and Young, 1951), and Osborne County (Walters and Drake, 1952). In 1952, A. R. Leonard prepared a report on the geology and ground-water resources of the valley of the North Fork Solomon River.

Methods of Investigation

The field work upon which this report is based was started in August 1941. V. C. Fishel worked in the county from August through October 1941; H. A. Waite worked in the county in September and October 1941; and A. R. Leonard worked in the county in September and October 1946.

In making an inventory of 259 wells in the county, the total depths of the wells and the depths to water level below land surface were measured with a steel tape. Well owners and drillers were interviewed regarding the nature and thickness of the water-bearing formations penetrated by the wells, and all available well logs were collected. Records of wells that furnish public, industrial, domestic, and irrigation supplies were collected. Information obtained included the yield, drawdown, temperature of water, chemical character of the water, and the use of ground water. Samples of water collected from 36 representative wells were analyzed by H. A. Stoltenberg, Chemist, in the Water and Sewage Laboratory of the Kansas State Board of Health at Lawrence.

A pumping test on a well at Jewell City was made. The test consisted of pumping a centrally located well at a given rate and observing the decline of the water levels in near-by observation wells. After pumping stopped, the rate of recovery of the water level in the pumped well was observed. The pumping test was made to determine the yield of the well, the rate of movement of the water through the formation, and the cone of depression surrounding the well caused by the removal of the water, as a guide to the effects of future pumping in this and similar localities.

Field data were compiled on topographic maps of the Federal Geological Survey and on a county map from the Kansas Highway Department. Locations of roads were corrected from observations in the field and the drainage was corrected from aerial photographs obtained from the United States Department of Agriculture, Agricultural Adjustment Administration. The areal geology was studied by A. R. Leonard and a geologic map (Pl. 1) was prepared by him.

The locations of all wells for which descriptions are given in the table of well records are shown on Plate 2, with the exception of some wells near Formoso which are shown on Figure 9.

Well-Numbering System

The well and test-hole numbers used in this report give the location of wells according to General Land Office surveys and according to the following formula: township, range, section, 160-acre tract within that section, and 40-acre tract within that quarter section. The 160-acre and 40-acre tracts are designated a, b, c, or d, in

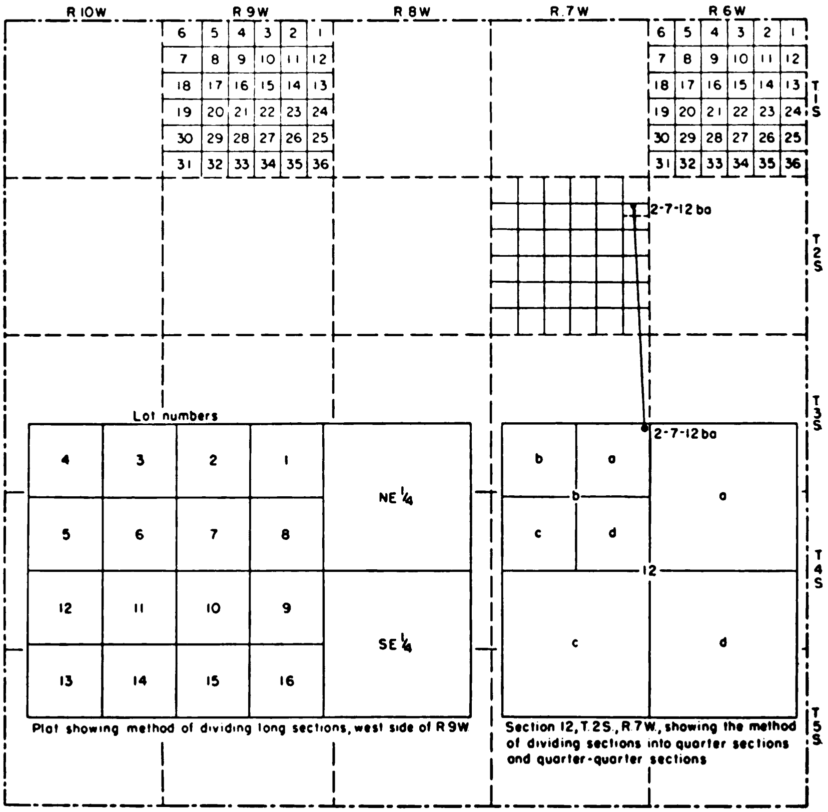

Fig. 2.—Map of Jewell County illustrating the well-numbering system used in this report.

a counterclockwise direction beginning in the northeast quarter. For example, well 2-10-6aa is located in the NE¼ NE¼ sec. 6, T. 2 S., R. 6 W. (Fig. 2). If two or more wells are within a 40-acre tract, they are numbered serially according to the order in which they are inventoried.

The sections of the west tier of R. 9 W. in Jewell County are about 1½ miles wide. Approximately the east third of the section is divided as in normal sections; the remainder of the section is divided into lots as shown in Figure 2. The well number of a well located in one of the lots contains only the township, range, and section. If more than one well is located in that part of the section the wells are numbered consecutively as inventoried.

Acknowledgments

Appreciation is expressed to the many persons who cooperated and assisted in the collection of field data. The water superintendents and other officials of the cities of Burr Oak, Esbon, Formoso, Jewell City, Mankato, and Randall supplied information concerning their municipal wells, the use of water, and other pertinent data. Geologic information was interchanged in the field and in the office with Frank E. Byrne, Max S. Houston, and Melville R. Mudge.

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

GEOGRAPHY

Topography and Drainage

Jewell County lies in the Great Plains Pliocene to Cretaceous ground-water province (Meinzer, 1923, p. 310). The county has three types of topography: the deeply dissected uplands, which are typical of Cretaceous areas and which cover the northern and central parts of the county; the level or gently sloping plain, which bounds the uplands on the east and south; and the alluvial valleys.

The major topographic features of Jewell County are controlled by the underlying bedrock or have been modified by the Pleistocene history of deposition and erosion. Figure 3 shows the major physiographic divisions of the county and the principal features are described briefly below.

The Greenhorn hills in the southeastern part of the county are a series of rolling rocky hills, moderately dissected, and utilized principally for pasture land. They are formed by the cropping out of the resistant Greenhorn limestone, which makes prominent escarpments along Marsh and Buffalo Creeks. The hills are covered with a thin discontinuous mantle of loess, which in places drapes across and obscures the escarpment.

The Jewell plain is one of the most striking physiographic features in Jewell County (Pl. 3B). In general, it is bounded on the northwest by the Niobrara escarpment and on the southeast by the Greenhorn hills so that it corresponds to the outcrop area of the Carlile shale. Along the foot of the prominent escarpment of the Fort Hays

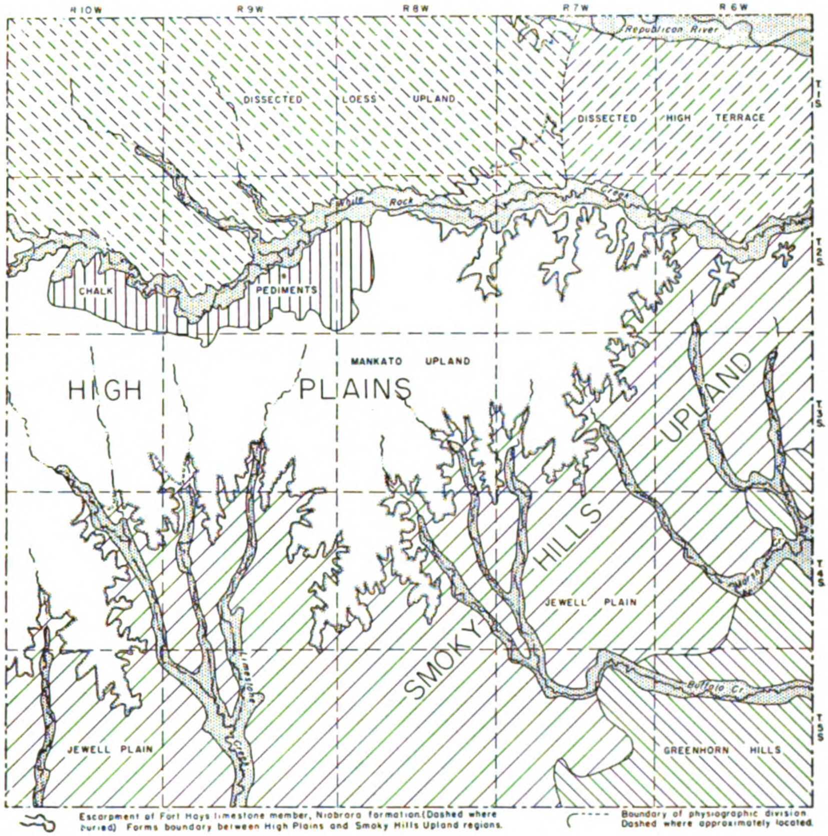

Fig. 3.—Physiographic divisions of Jewell County.

limestone member of the Niobrara formation, slopes on the Carlile shale are intricately dissected and locally form small badland areas. This slope area is not a part of the Jewell plain; it is narrow and insignificant areally and is included in the Jewell plain for simplification. The plain, which is typically very gently rolling and in places almost featureless, is intensively cultivated, for the flat gentle slopes

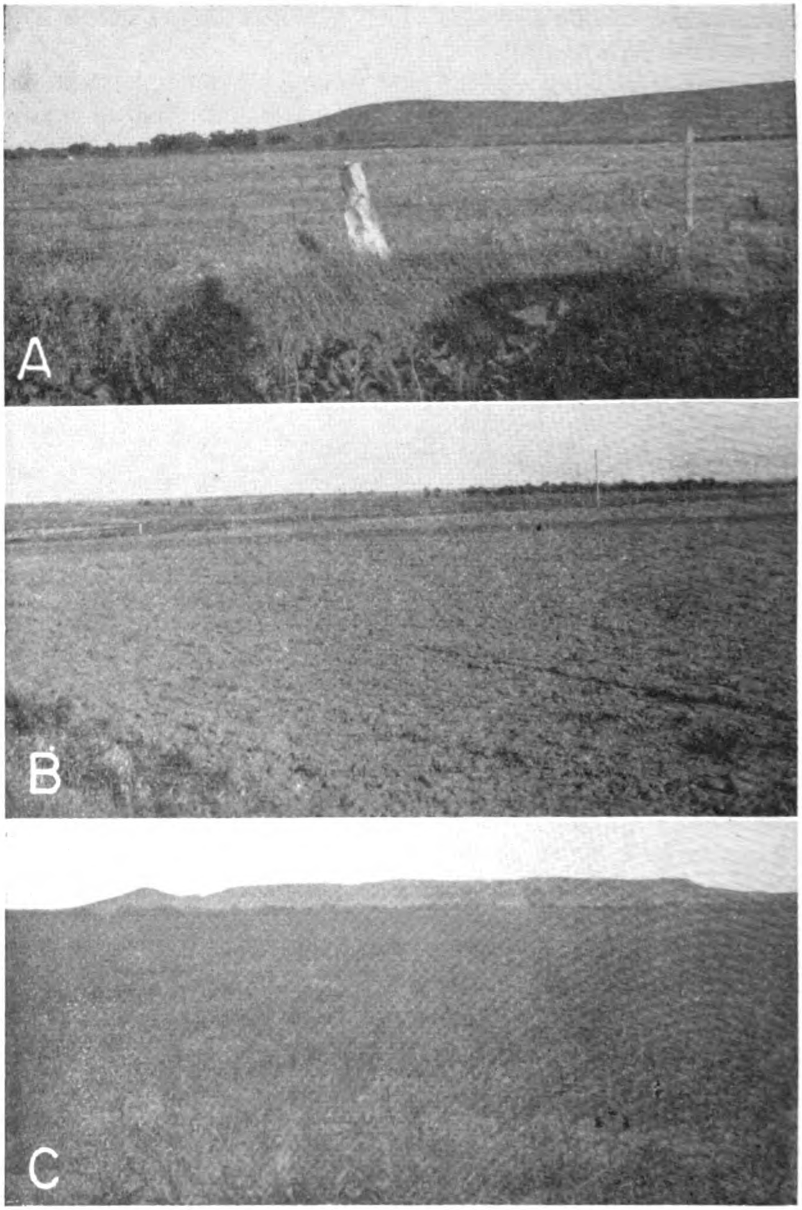

PLATE 3. Surface features of Jewell County. **A,** Late Wisconsinan terrace of Buffalo Creek valley in the SW¼ sec. 12, T. 5 S., R. 6 W.; hills of Greenhorn limestone in distance. **B,** Flat featureless surface of the Jewell plain. View southeastward from the NE¼ sec. 25, T. 4 S., R. 7 W. **C,** Flat terracelike surface of Pleistocene deposits in northeastern Jewell County; outlier of Fort Hays limestone member of Niobrara formation in background. View southeastward from the SW¼ sec. 2, T. 2 S., R. 6 W.

are easy to cultivate and the loess soil is fertile. Locally, hills of shale rise 40 or 50 feet above the general level of the plain, which is crossed by many streams, including Limestone, Buffalo, and Marsh Creeks and their tributaries.

The Niobrara escarpment, formed by the Fort Hays limestone member, is one of the most prominent limestone escarpments in Kansas. It crosses Jewell County as a sinuous wall extending from north of the southwestern corner to near Lovewell in the northeastern part. At Lovewell it swings westward along the south bluff of White Rock Creek, passing beneath the alluvial deposits about half way across the county. Small areas of the escarpment are observed north of White Rock Creek, but in that area most of the escarpment is covered with Pleistocene loess, has been eroded away, or is covered by stream deposits of the ancient Republican River. Near Lovewell, two outliers of the Fort Hays limestone member occur east of the principal escarpment. This escarpment forms the boundary between the High Plains on the west and the Smoky Hills on the east (Frye and Leonard, 1952, Fig. 16). These regions are part of the Great Plains physiographic province.

West and northwest of the Niobrara escarpment is a dissected upland area here called the Mankato upland. This upland is underlain by bedrock of the Niobrara formation at a relatively shallow depth. The loess cover overlying the bedrock is generally less than 10 feet thick. The area is moderately to deeply dissected along its margins where the Niobrara formation is cut through. Most of the upland is rolling hills and ridges and the streams are moderately entrenched. Locally, the Niobrara formation is eroded to form elliptical or irregularly shaped hills. The northwestern part of the area is more typical of the High Plains of which the area is a part (Frye and Leonard, 1952, pp. 201-202).

Just north of the northwestern part of the Mankato upland and between the upland and the alluvial valley of White Rock Creek is an area averaging about 2 miles in width and 12 miles in length here called the chalk pediments. This area is formed by a series of "flanking pediments" developed on the soft chalk of the Smoky Hill chalk member of the Niobrara formation. The chalk has been eroded to form smooth slopes that are concave upward and extend from near the stream divide on the south to the alluvial terrace along White Rock Creek on the north (Pl. 4A). Generally, the chalk slopes are covered with only a few inches of silt and soil (Pl. 4B) and locally weathered chalk is exposed in fields on the pediment surfaces. Near Burr Oak the surface of the pediment

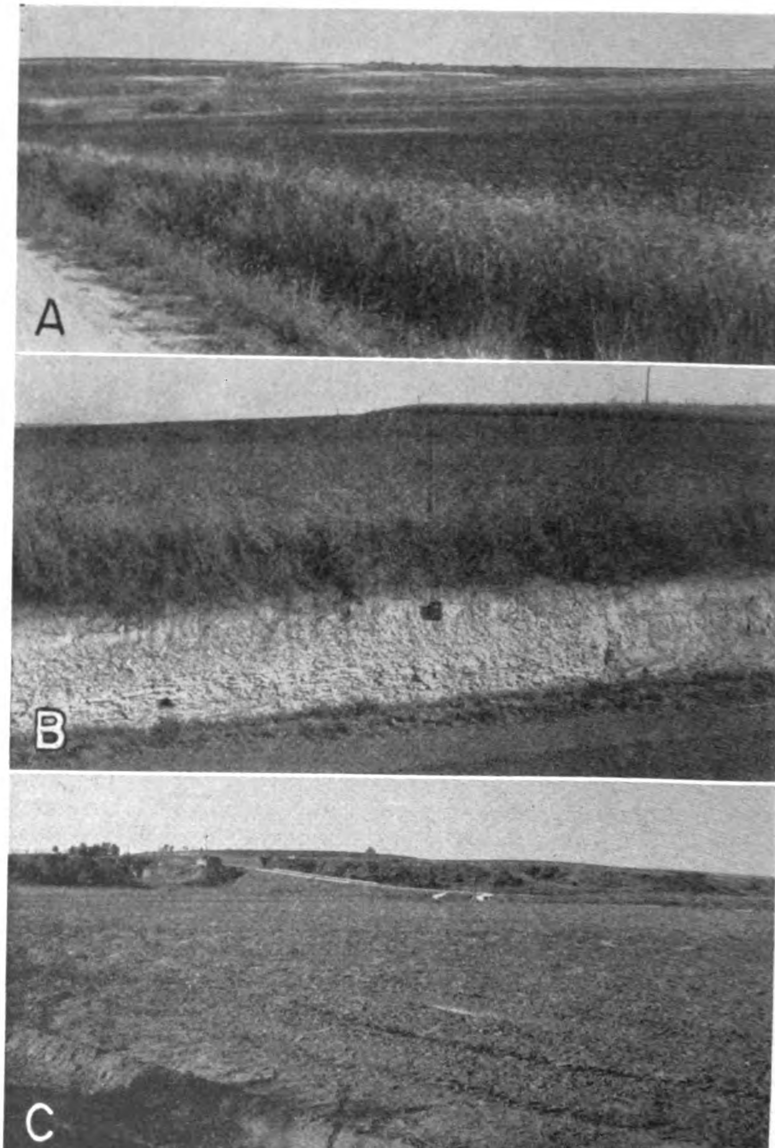

PLATE 4. Surface features of Jewell County. **A,** Flanking pediment developed on Smoky Hill chalk member of Niobrara formation in the N½ sec. 35, T. 2 S., R. 9 W. **B,** Thin soil cover overlying Smoky Hill chalk member beneath surface of flanking pediment, SW¼ sec. 26, T. 2 S., R. 9 W. **C,** Flood plain of Republican River and bluff formed by Peoria silt member of Sanborn formation. View southwestward from NE¼ sec. 4, T. 1 S., R. 7 W.

declines from an altitude of about 1,820 feet near the divide to about 1,680 feet near the stream, a distance of 2 miles (Fig. 4).

The dissected high terrace in the northeastern part of Jewell County extends from White Rock Creek to Republican River and about 9 miles westward from the eastern county line. This is the area underlain by stream deposits laid down by the ancestral Republican River in Kansan time and has no bedrock outcrop. The south margin of this area has moderate slopes and is moderately dissected. The north margin is deeply dissected and has many "loess canyons." The east-central part of the area is gently sloping, undissected and resembles the surface of an alluvial terrace (Pl. 3C). The western part is indistinguishable from the dissected loess upland to the west. Along the wall of Republican River valley, a narrow strip 0.1 to 0.3 mile wide and 50 to 65 feet above the flood-plain level has a flat

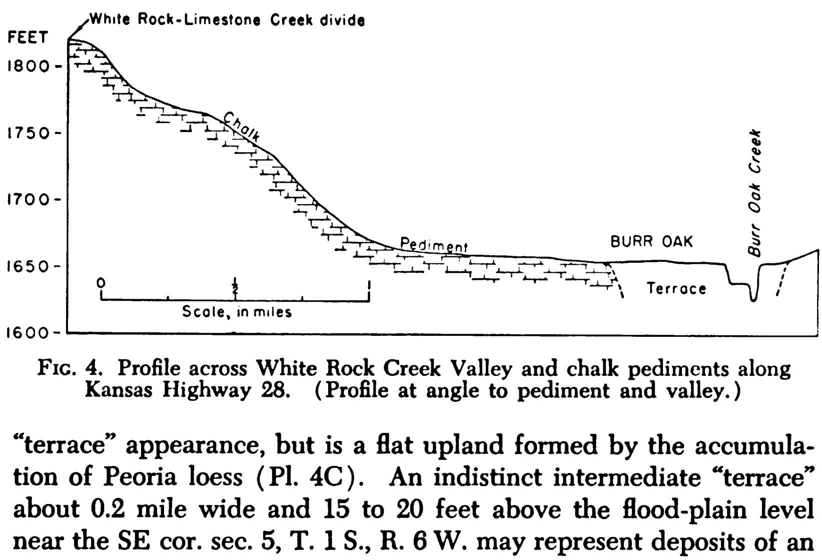

Fig. 4. Profile across White Rock Creek Valley and chalk pediments along Kansas Highway 28. (Profile at angle to pediment and valley.)

"terrace" appearance, but is a flat upland formed by the accumulation of Peoria loess (Pl. 4C). An indistinct intermediate "terrace" about 0.2 mile wide and 15 to 20 feet above the flood-plain level near the SE cor. sec. 5, T. 1 S., R. 6 W. may represent deposits of an alluvial cycle of Kansan to late Wisconsinan age that formed the present alluvial valley. Figure 5 is a profile across the south side of the Republican Valley showing the relationship of the "terraces."

North of White Rock Creek valley and west from the dissected high terrace area is the dissected loess upland. This area is formed principally by the thick (as much as 150 feet) blanket of eolian silt, or loess, that covers the central part. The loess is thinner on the north and south margins, which are characterized by outcrops of Cretaceous bedrock. In general, the area is rolling and has moderately well-entrenched streams with narrow valleys. The divide area, 1 to 2 miles south of the State line, is a gently rolling to flat upland that grades imperceptibly into the more dissected areas north and south.

The valley of each major creek in Jewell County has a narrow flood plain bordered by low terraces 10 to 20 feet above the flood-plain level. The valley of Republican River has a wide flood plain and remnants of low terraces occur only locally. The principal

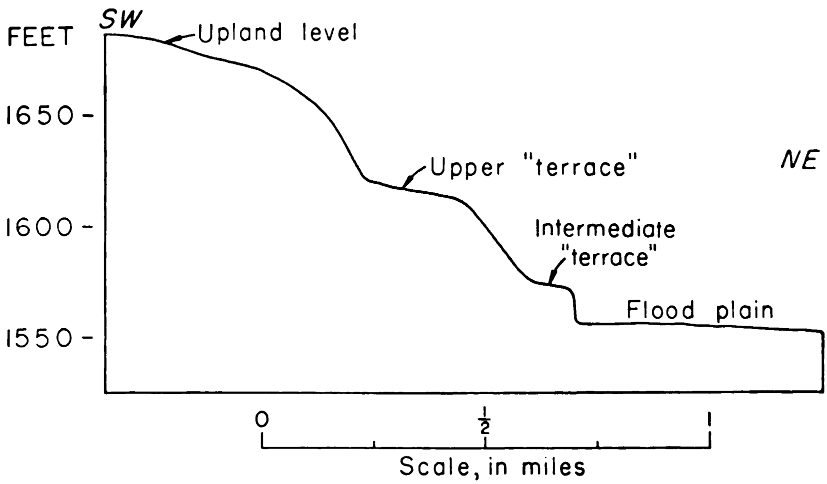

FIG. 5. Profile of south wall of Republican River valley from the flood plain in the SE¼ sec. 2, T. 1 S., R. 7 W. to the upland in the SE¼ sec. 10, T. 1 S., R. 7 W.

alluvial valley areas are shown in Figure 3 and on Plate 1, and the low terraces are described in the discussion of alluvium in the geology section.

The highest point in the county has an altitude of about 1,960 feet, and is about a mile south of the northwest corner of the county. Dog and Plum Creeks leave the southeastern part of the county at an altitude of slightly less than 1,400 feet. The maximum relief, therefore, is about 560 feet.

Jewell County is drained by Republican River and by tributaries of Republican and Solomon Rivers. Republican River is the only perennial stream in the county. The principal streams of the county besides Republican River are Brown, Buffalo, Dog, Hermes, Limestone, Marsh, Oak, Plum, and White Rock Creeks. White Rock Creek, the most prominent of the small streams, originates in Smith

County, flows in an easterly direction across the north-central part of Jewell County, and enters Republican River near Republic in Republic County. White Rock Creek may be classed as a perennial stream, but its flow has ceased during some dry seasons. Prior to 1900 a saw mill on White Rock Creek at Burr Oak was powered by water. In Jewell County all creeks south of White Rock Creek flow southeastward. They are all intermittent. Buffalo Creek originates near Mankato, passes near Jewell City and Randall, and enters Republican River above Concordia in Cloud County. Marsh Creek is a tributary of Buffalo Creek. Tributaries of Limestone Creek originate near Esbon and Eleon, unite south of Ionia, and join Hermes Creek, which enters Solomon River near Glen Elder in Mitchell County. Brown, Dog, Oak, and Plum Creeks are small intermittent streams that originate in the southern part of Jewell County and flow southward into Mitchell County where they enter Solomon River.

An interesting phenomenon connected with drainage was observed near Jewell City in September 1941. A local 5-inch rain at Jewell City resulted in deep soil cracks in a cornfield in the SE¼ sec. 30, T. 4 S., R. 7 W. (Pl. 5). The soil cracks had a depth in places of more than 7 feet and ranged in width from a few inches to 3 feet. The heavy rainfall occurred at night, and the soil cracks were observed the following morning. The development of the soil cracks has not been explained satisfactorily. The cracks had an outlet into Buffalo Creek and discharged considerable water into the creek. However, there was little surface runoff into the cracks, as shown by a lack of erosion along the top edges. The year 1941 followed a period of about 10 years of low rainfall. The vegetation may have removed much of the moisture in the subsoil causing shrinkage of the subsoil and the formation of large cracks in it. By wetting the upper soil zone the 5-inch rainfall may have lowered its bearing strength and permitted the soil to slip vertically into the crack in the subsoil below. Plate 5 shows some sections in which the upper soil dropped down and other sections in which the soil slumped but did not drop.

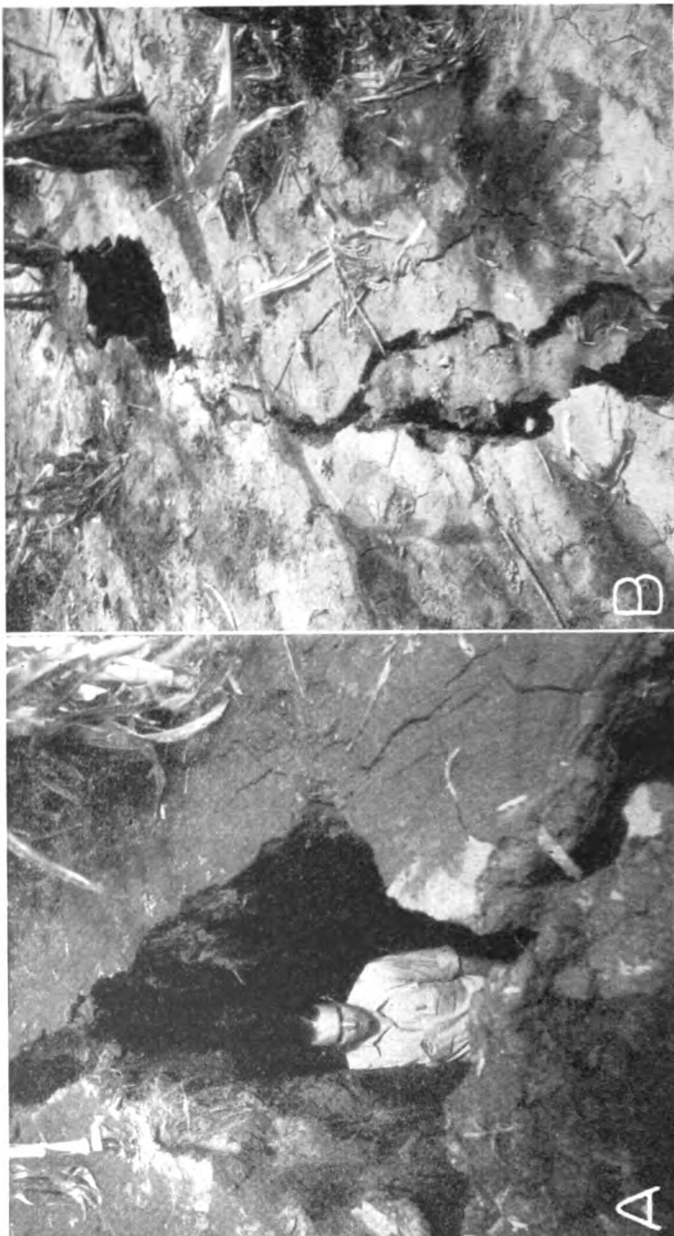

PLATE 5. Soil cracks in the SE¼ sec. 30, T. 4 S., R. 7 W. after heavy rain on September 16, 1941.

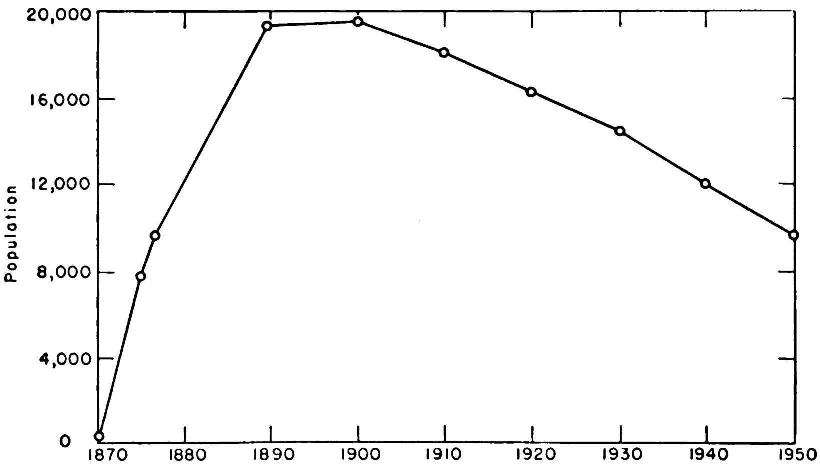

FIG. 6. Population of Jewell County for the period 1870 to 1950.

POPULATION

The first attempt to form a settlement in Jewell County was made in the spring of 1862 on land adjoining the now abandoned town of White Rock in the valley of White Rock Creek. A second attempt was made in 1866 about 5 miles west of White Rock. The hostility of some of the Indian tribes prevented a successful settlement until 1869. During 1870 when more than 200 settlers arrived, Jewell County was organized, Jewell City being designated the county seat. Two years later the county seat was moved to Mankato.

The population of Jewell County in 1870 was 205; in 1875, 7,651; 1877, 9,767; 1890, 19,349; 1900, 19,420; 1910, 18,148; 1920, 16,240; 1930, 14,462; 1940, 11,970, and in 1950, 9,698 (Fig. 6). In 1950 the population averaged about 10.5 persons per square mile, only half that of 1900. The chief towns and their respective populations as reported by the census for 1950 are: Mankato, 1,462; Jewell City, 593; Burr Oak, 505; Formoso, 271; Esbon, 278; Randall, 240; and Webber City, 96. Other smaller towns are Dentonia, Ionia, Lovewell, Montrose, North Branch, and Otego.

TRANSPORTATION

The county is well supplied with facilities for transportation. A main line of the Chicago, Rock Island and Pacific Railway Company traverses the county east-west through the central part and gives direct communication with Denver, Kansas City, and Omaha. The Missouri Pacific Railway, starting at Burr Oak, passes southeast across the county joining the central branch of this system at Jamestown, a few miles east of the county. The Atchison, Topeka and Santa Fe Railway, entering from the east, passes in a northerly direction across the eastern part of the county to Superior, Nebraska. Superior, which is only a mile north of the county line, is a shipping point of considerable importance having in addition to the Santa Fe, the Chicago and Northwestern, the Missouri Pacific, and the Burlington and Missouri River Railroads. Being on direct lines to Denver, Omaha, Kansas City, and St. Joseph, the county has excellent facilities for marketing crops and livestock.

U. S. Highway 36, paved throughout the county, traverses it east-west through the middle, passing through Formoso, Montrose, and Mankato. Kansas Highway 28 from Concordia through Randall, Jewell City, Mankato, and Burr Oak connects with Nebraska Highway 78. It is paved from the Cloud County line to its intersection with U. S. Highway 36 and graveled from U. S. Highway 36 to the Nebraska State line. Kansas Highway 14 traverses the county north-south through the middle part, extending from Superior, Nebraska, to Beloit, Kansas. It is graveled from Superior to its intersection with U. S. Highway 36 and paved from there to Beloit. Kansas Highway 128, which is graveled, extends from Glen Elder through Ionia to U. S. Highway 36 south of Otego.

Agriculture

Jewell County has a total area of approximately 585,600 acres. In 1950, there were 1,744 farms with a total area of 537,579 acres. There has been a gradual increase in the average size of the farms in Jewell County for many years. The tendency toward an increase in the size of the farms was pointed out by Kocher and others (1914, p. 14), as follows:

> In general, it may be said that for the last 40 years there has been a tendency to increase the size of individual farms. According to the census, the percentage of farms operated by owners in 1890 was 70.65, in 1900 it was 62.7. and in 1910, 61.1. According to the same authority, the average size of farms for the last four decades was 163, 166, 169.5, and 183.6 acres, respectively.

According to the 1950 census, the percentage of farms operated by owners was 66.5 and the average size of the farms was 307.4 acres. The number of farms of less than about 400 acres in size is diminishing, and the number of farms that are larger than 400 acres in size is increasing.

Land distribution according to use in Jewell County in 1950 is given in Table 1.

TABLE 1.—*Land use in Jewell County in 1950*
(1950 census)

	Acres
Crop land harvested	287,464
Crop failure	51,062
Crop land idle or fallow	15,494
Arable pasture	14,355
Woodland	14,429
Other uses	154,775

The soils of Jewell County have been formed primarily from the weathering of loess in the northern and northwestern parts of the county, and from the weathering of limestone, sandstone, and shale in the southern part (Throckmorton and others, 1937, p. 103). Sandstone predominated in the parent material only in a small area in the extreme eastern part of the county. The soils in the northern part are gray to yellowish-gray silty loams and silty clay loams that originally were brown in color. The subsoils are yellowish-brown silty clay loams to clay loams. In the southern part of the county, the soils are brown and relatively deep, and the subsoils are brown clay. The soils are not acid and, in general, carry sufficient plant food to meet the requirements of all crop plants. The adapted crops are alfalfa, sweet clover, corn, oats, wheat, and sorghums. The more rolling lands are adapted primarily for the production of grass for grazing purposes.

The principal crops grown in Jewell County and the acreage in 1950 reported by the Kansas State Board of Agriculture (1951) are given in Table 2.

TABLE 2.—*Principal crops grown in Jewell County in 1950, including crops not harvested*
(Kansas State Board of Agriculture, 1951)

	Acres
Wheat	143,000
Corn	92,200
Sorghums	31,900
Barley	4,400
Oats	26,000
Alfalfa	29,550
Rye	1,200

Jewell County has been an important producer of alfalfa. In 1910, about 10 percent of all farm land was in alfalfa. The acreage decreased from approximately 55,000 acres in 1910 to approximately 30,000 acres in 1930 and to 2,813 acres in 1939, then increased to

29,550 acres in 1950. During the years 1911 to 1932, the average yield per acre of wheat was 13.8 bushels and of corn was 17.2 bushels.

In Jewell County livestock production is economically important. In 1950, the livestock in Jewell County was as follows: cattle, 39,500; hogs and pigs, 41,720; and sheep and lambs, 2,500.

Mineral Resources

The mineral resources of economic importance in Jewell County are gravel and sand, limestone, building stone, road material, chalk, ceramic materials, volcanic ash, and lignite.

Sand and gravel deposits are found in the alluvium along Republican River in the northeastern corner of the county. The alluvium is predominantly silt, but many lenses of sand and a few lenses of gravel are included.

The Greenhorn limestone, which crops out extensively in southeastern Jewell County, is used as building stone. The Fencepost limestone bed at the top of the Greenhorn is quarried for use as a building stone. Quarrying is commonly done along the line of outcrop where the overburden is thin and the rock not badly weathered. The bed has a thickness of about 0.8 foot and is moderately fine and chalky in texture. It is soft enough to permit considerable ease in quarrying, but hardens on exposure. The Fort Hays limestone member has been used as construction material for some of the smaller buildings in Jewell County. Tests of this material indicate that it is slightly inferior to the Fencepost limestone for use as structural stone (Byrne, Houston, and Mudge, 1950, p. 20); however, ledges of the Fort Hays are many times thicker than the Fencepost, and much more of the stone is available. Analyses of the chalk of the Fort Hays limestone member in the NW¼ SW¼ sec. 10, T. 2 S., R. 8 W. show the calcium carbonate to range from 90.1 to 97.4 percent (Runnels and Dubins, 1949, p. 33).

Clays suitable for the manufacture of certain ceramic products are found in the Sanborn formation. A study of the ceramic uses of these beds in northern Kansas shows (Frye and others, 1949, pp. 80-83) that the silts and soil zones are the most suitable for the manufacture of brick, tile, and ceramic aggregate. Ceramic aggregate is used for concrete aggregate, road metal, and ballast.

Volcanic ash is found at many places in the Meade formation (Pl. 1). Test data for five samples of ash are given by Byrne, Houston, and Mudge (1950, p. 20, table 1). The occurrence of volcanic ash in Jewell County is discussed by Landes (1928, p. 28).

Lignite has been mined from the Dakota in two and possibly three places in Jewell County (Schoewe, 1952, p. 124). Lignite was mined south of Formoso from some time prior to 1887 to about 1900. Lignite was mined near Jewell City from about 1901 to about 1907. Lignite is not being mined now, but according to Schoewe (1952, p. 128) Jewell County has a reserve of inferred or potential lignite coal of about 22,400,000 tons.

Climate

The climate of Jewell County is typical of the High Plains—hot summers, cold winters, sudden changes of temperature in all seasons, and great variability in precipitation. The spring and fall months are marked by brisk wind movement. The average wind velocity at Concordia in Cloud County is 9.7 miles an hour.

The U. S. Weather Bureau has maintained a precipitation gauge at Burr Oak since 1901. The normal annual precipitation recorded

Table 3.—*Normal monthly precipitation at Burr Oak*

Month	Precipitation (inches)	Month	Precipitation (inches)
January	0.52	July	2.84
February	0.93	August	2.99
March	1.14	September	2.76
April	2.38	October	1.58
May	3.54	November	1.03
June	4.16	December	0.69

at Burr Oak is 24.56 inches; the normal monthly distribution is given in Table 3.

Approximately 75 percent of the precipitation falls during the 6-month period from April 1 to September 30. The annual precipitation and the cumulative departure from normal precipitation at Burr Oak for the period of record are shown graphically in Figure 7. The precipitation has ranged from 12.38 inches in 1936 to 44.70 inches in 1951. There have been 12 years when the precipitation was less than 20 inches. The cumulative departure from the normal precipitation shows the yearly trend of precipitation. The average precipitation and average departure from normal precipitation, by 10-year periods, from 1901 to 1950 are given in Table 4.

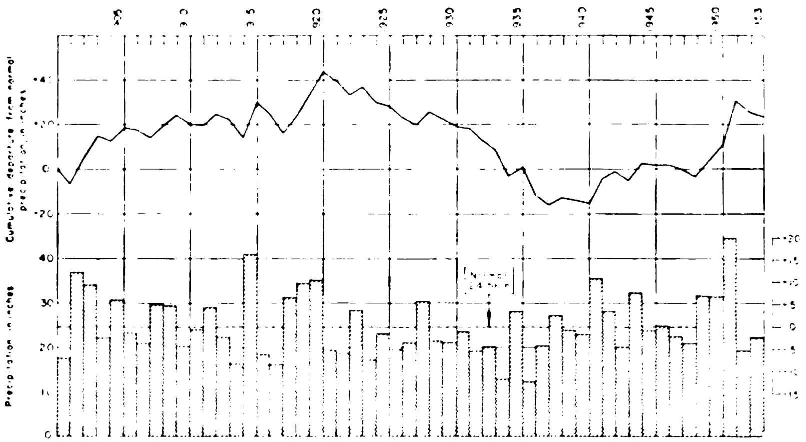

FIG. 7. **A,** Annual precipitation at Burr Oak; **B,** cumulative departure from normal precipitation at Burr Oak.

TABLE 4.—*Average precipitation and average annual departure from normal precipitation for 10-year periods, 1901-'50, at Burr Oak*

Period	Average precipitation, inches	Average annual departure from normal, inches
1901 to 1910	26.60	+2.04
1911 to 1920	26.95	+2.39
1921 to 1930	22.08	—2.48
1931 to 1940	21.09	—3.47
1941 to 1950	27.17	+2.61

The precipitation averaged below normal from 1921 to 1940. The cumulative excess from 1901 to 1920 was 44.32 inches but the cumulative deficit from 1920 to 1940 was 59.53 inches. In 1941, the precipitation was 11.04 inches above normal and in 1951, it was 20.24 inches above normal.

The mean temperature is about 52.7° F. Since 1930, the temperature has ranged from —23° to + 117° F. The annual maximum, minimum, and mean temperatures and the snowfall for the period 1930 to 1952 are given in Table 5.

TABLE 5.—*Maximum, minimum, and mean temperatures and snowfall at Burr Oak for the period 1930-'52*

Year	Maximum temperature, °F	Minimum temperature, °F	Mean temperature, °F	Total snowfall, inches
1930	111	—17	53.6	11.5
1931	109	—4	55.7	16.9
1932	109	—23	51.3	37.7
1933	110	—19	55.2	6.8
1934	116	—15	56.9	15.6
1935	111	—12	56.3	4.9
1936	117	—19	53.9	9.5
1937	112	—20	52.4	15.4
1938	108	—12	55.3	4.2
1939	113	—13	55.2	23.7
1940	115	—16	52.8	45.0
1941	105	—8	54.4	32.4
1942	103	—17	51.8	17.7
1943	106	—19	52.1	13.6
1944	101	—21	51.2	30.7
1945	103	—22	50.7	35.4
1946	109	—12	53.6	3.5
1947	111	—25	51.0	22.9
1948	104	—23	50.9	46.5
1949	107	—3	51.3	16.4
1950	103	—13	50.5	8.0
1951	102	—12	50.7	....
1952	108	—7	53.6	....

The average length of the growing season is 160 days. The average date of the last killing frost in spring is April 29, and the latest date of a killing frost was May 27. The average date of the first killing frost in the fall is October 6, and the earliest date of a killing frost was September 13.

GEOLOGY *

SUMMARY OF STRATIGRAPHY

The rocks that crop out at the surface in Jewell County are sedimentary and range in age from Late Cretaceous (Gulfian) to Recent. A generalized description of the geologic formations and their water-bearing properties is given in Table 6; their areal distribution is shown on Plate 1.

The oldest rocks exposed in Jewell County are sandstone and shale of the Dakota formation which crop out in a small area on the south side of Buffalo Creek valley in the southeastern corner of the

* The stratigraphic classification used in this report is that of the State Geological Survey of Kansas.

county. The Dakota formation is overlain conformably by a series of marine upper Cretaceous rocks classified, in ascending order: Graneros shale, Greenhorn limestone, Carlile shale, and Niobrara formation. Some of the higher hills in the southwestern and central parts of the county are capped by a few inches to a few feet of impure sandy caliche that may represent the Ogallala formation of Pliocene age, but which in this report is mapped with the Sanborn formation.

Unconsolidated continental deposits of fluviatile and eolian origin represent at least three stages of the Pleistocene series. These include the Meade formation of Kansan age, the most extensive deposit of which is over the northeastern part of the county between Republican River and White Rock Creek. Stream-laid deposits of the Meade formation also fill a narrow valley extending from near Mankato northward. Volcanic ash and associated silt beds in the northwestern and southern parts of the county also are a part of the Meade formation. Sand and gravel deposits of Illinoian age occur locally along White Rock Creek and Republican River beneath a high terrace. These deposits are overlain conformably by reddish sandy silt (the Loveland silt member), which may be in part stream laid but is eolian in the upland areas. Unconformably overlying the Loveland silt member and older rocks is the gray eolian silt of the Peoria silt member, which occurs in all parts of the county. Terrace deposits of late Wisconsinan age border each of the major streams and locally the smaller streams. The youngest rocks in the county are the deposits of Recent alluvium which are being formed along the streams at the present time.

Geomorphology

The topographic features of Jewell County are principally the product of Pleistocene erosion and deposition but are controlled, in part, by the character of the bedrock.

By the close of the Pliocene Epoch, Tertiary aggradation had created a broad alluvial plain across north-central Kansas that had buried the now prominent escarpments of the Niobrara formation and Greenhorn limestone. Locally, resistant hills of these rocks may have protruded as inliers above the general level of the alluvial plain, but the topography was one of low relief. The absence of deposits of the Ogallala formation overlying the Cretaceous rocks in Jewell County suggests that this part of Kansas was near the eastern edge of alluviation and may have been principally a degradational plain developed on Cretaceous rocks.

TABLE 6.—*Generalized section of geologic formations in Jewell County*

SYSTEM	Series	Formation	Member	Thickness, feet	Physical character	Water supply
Quaternary	Pleistocene*	Alluvium		0–75	Silt, sandy silt, and mixed gravel and silt along creeks. Sand and gravel along Republican River.	Yields small supplies of hard water in creek valleys, large supplies in Republican River valley.
		Limestone gravel		0–15	Subrounded to subangular limestone pebbles, sand and silt intermixed.	Yields meager to small supplies of hard water of shallow depth in the Jewell plain, small supplies locally beneath "high terraces."
		Sanborn formation		0–100	Friable, massive, eolian silt and sandy silt containing snail shells and calcium carbonate nodules. Locally has sand and gravel (Crete member) at base.	Locally, where present and above water table, Crete member yields small supplies of water to wells. In northwestern part of county small yields may be obtained from silt.
		Meade formation*	Sappa*	0–50	Massive reddish silt; contains calcium carbonate nodules, stratified silt, fine sand, and volcanic ash.	Yields small supplies to wells 100 feet or more in depth in northwestern Jewell County.
			Grand Island*	0–120	Cross-bedded sand and gravel containing lenticular beds of limestone gravel and silty clay.	Yields moderate supplies of water to wells penetrating the channel fill of ancient Republican River in northeastern part of county, small supplies where present beneath Sappa member in northwestern Jewell County.
Cretaceous	Gulfian*	Niobrara formation	Smoky Hill chalk	0–350±	Thin-bedded to fissile, blue-gray chalky shale and chalk; contains beds of massive chalk and thin bentonite and limonite seams.	Yields little or no water to wells.
			Fort Hays limestone	30–45	Massive white chalky limestone. Forms prominent scarp.	Yields little or no water to wells in this area.
		Carlile shale	Blue Hill shale	200	Fissile, noncalcareous, gray to black marine shale; contains thin sandy zone at top and septarian and discoidal concretions.	Yields little or no water to wells in this area.

TABLE 6.—*Generalized section of geologic formations in Jewell County*—CONCLUDED

SYSTEM	Series	Formation	Member	Thickness, feet	Physical character	Water supply
Cretaceous	Gulfian*	Carlile shale	Fairport chalky shale	100–110	Fissile, calcareous marine shale; contains abundant *Ostrea* shells, thin chalky limestone, discoidal calcareous concretions, and thin bentonite seams.	Yields little or no water to wells in this area.
		Greenhorn limestone		65–82	Calcareous blue-gray shale alternating with thin chalky fossiliferous limestones in upper part and thin crystalline petroliferous limestones in basal part. Contains bentonite beds.	Yields little or no water to wells in this area
		Graneros shale		15–30	Noncalcareous gray to dark-brown shale; contains persistent bentonite bed in upper part and locally pyrite, limestone, and siltstone.	Yields little or no water to wells in this area
		Dakota formation*		200–300	Clay, shale, siltstone, and sandstone. Contains lignite locally about 30 feet below top. (Only upper 28 feet exposed in Jewell County).	Yields small supplies of water suitable for domestic and stock use to a few wells in southeastern Jewell County. Elsewhere in county contains highly mineralized water.

* Classification of State Geological Survey of Kansas.

At the close of Tertiary time the plains area changed from a region of deposition to one of erosion. The Tertiary deposits and underlying Cretaceous rocks began to be eroded and the present drainage system began to form.

In early Pleistocene time the ancestral Republican River entered Kansas 5 or 6 miles west of the northeast corner of Jewell County, flowed southeastward, and passed into Republic County almost 5 miles south of the northeastern corner of Jewell County. The river then flowed northeastward across the northwest part of Republic County (Fishel, 1948, pp. 29-31). This ancient stream valley was cut during the Nebraskan and early Kansan Stages of the Pleistocene. During late Kansan time, the valley was filled with a thick accumulation of gravel, sand, and silt that now obliterates the valley features. A major stream, tributary to the Republican River of Kansan age, flowed eastward across the northern part of Jewell County, a few miles north of the present valley of White Rock Creek. This stream probably had tributaries from both north and south, and the deposits of the Meade formation a few miles northwest of Mankato were formed in the valley of one of those tributary streams. Stream deposits from a north-flowing stream in the SW¼ SW¼ sec. 16 and NE¼ NE¼ sec. 20, T. 3 S., R. 8 W., almost 1½ miles south of the present divide between White Rock and Buffalo Creeks, indicate that the drainage divide has shifted northward more than 1½ miles (Fig. 8). Volcanic ash of Kansan age in the SE¼ sec. 11, T. 4 S., R. 8 W. and in the SE¼ sec. 20, T. 5 S., R. 9 W. indicates that those localities were in areas of south-flowing drainage and probably the drainage pattern was similar to the present one. Probably the south and southeast flowing Marsh, Buffalo, and Limestone Creeks were well established by Kansan time.

The erosion in early Pleistocene time probably dissected a large part of the Cretaceous bedrock in the upland areas and formed the now prominent escarpment of the Fort Hays limestone member of the Niobrara formation. The deposit of Pearlette ash of Kansan age in the SE¼ sec. 11, T. 4 S., R. 8 W. about a mile from the face of the escarpment and 100 feet below it indicates that the escarpment must have been pronounced at the time the ash was deposited and has not retreated more than a short distance since its deposition.

Possibly most of the limestone gravel deposits, which are so extensive in southern Jewell County, were deposited during this early Pleistocene period of bedrock dissection and escarpment retreat.

During the Yarmouthian Stage which followed Kansan alluviation fine-grained sediments were deposited by the streams. Volcanic ash was blowing into the area and was concentrated into lenticular deposits by streams. During the latter part of the interval, soil formed over part of Jewell County (Frye and Leonard, 1952, p. 104).

Following the alluviation of the ancestral Republican River valley in northeastern Jewell County and adjoining areas during Kansan

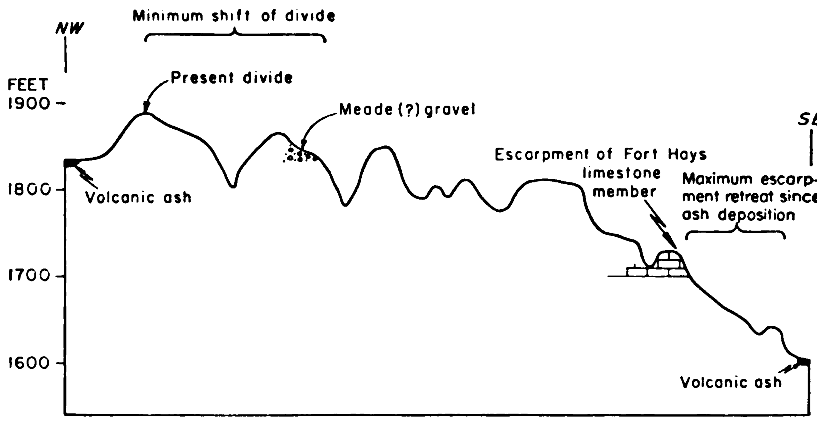

FIG. 8.—Profile through Meade formation northwest and south of Mankato showing shift of drainage divide and possible retreat of Fort Hays limestone member escarpment since deposition of the Meade formation.

time, Republican River was diverted to a southeast course similar to its present course. White Rock Creek, probably beginning as a small tributary to this new stream, rapidly extended its valley westward. Deposits of the Crete sand and gravel member of the Sanborn formation beneath a high terrace indicate that by Illinoian time White Rock Creek was well established at an elevation only a few feet above the present stream level in northeastern Jewell County. The position of the deposits indicates that Republican River also was cut to near its present level. During late Illinoian time, loess, presumably derived from the flood plains of glacier-fed streams, was spread widely over Jewell County and accumulated to great depths in the northern part of the county. In southern Jewell County the Illinoian and Sangamonian Stages were periods of little erosion, for valleys were deepened but a few feet in those areas. Following the loess deposition, a long interval of stability prevailed during which the wide-spread well-developed Sangamon soil formed.

Wisconsinan time was a period of slight erosion, principally in the more dissected upland areas and of slight lowering of the major stream valleys. During early Wisconsinan time, the Peoria loess was deposited over all the county. Along Republican River, deposits of Peoria loess are 50 to 75 feet thick. Over most of the county the loess accumulated to a depth of less than 20 feet.

Most stream valleys in Jewell County are bordered by broad alluvial terraces formed during late Wisconsinan alluviation. In the early part of this alluvial cycle, the streams were more vigorous than later and carried gravel intermixed with finer material. During the later phase, they carried only fine-grained materials, and these comprise the surface of the late terraces.

Since late Wisconsinan time, most streams have cut channels from 10 to 15 feet in Wisconsinan terrace deposits. The narrow, meandering flood plains suggest that the present cycle of erosion is in an early stage and the streams will continue to deepen and widen these flood plains until alluviation begins again.

GROUND WATER

Principles of Occurrence

The following discussion on the occurrence of ground water has been adapted from Meinzer (1923, pp. 2-102), and the reader is referred to his report for a more complete discussion of the subject. A summary of considerations on this subject is also given by Moore and others (1940, pp. 1-34).

Hydrologic Properties of Water-Bearing Materials

The principal hydrologic properties of water-bearing materials are permeability and specific yield. Permeability is a measure of the ability of a material to transmit water; specific yield is a measure of the quantity of water that the material will yield when it is drained. The permeability and specific yield are dependent upon the size and distribution of the pore spaces of the material, which in turn are dependent upon the size and distribution of the particles composing the material. The properties—interstices and porosity—that control the specific yield and permeability of rocks will be discussed in the following pages. Specific yield of rocks is taken up in the latter part of this section; permeability of rocks will be discussed in a later section.

Porosity.—The rocks and rock materials that form the crust of the earth contain many open spaces or voids called interstices, which are the receptacles that hold the water that is found below the surface of the land and that is recoverable through springs and wells. There are many kinds of rocks and rock materials in Jewell County—limestone, sandstone, shale, and alluvium—and they differ greatly in the number, size, shape, and arrangement of their interstices; hence, they differ greatly in their properties as containers of water. The occurrence of water in the rocks is therefore determined by the character, distribution, and structure of the rocks—that is, by the geology of the rocks. Most rocks have many interstices of very small size; however, some limestones are characterized by a few large openings, such as joints or caverns. In most rocks the interstices are connected, and the water can move through the rocks by percolating from one interstice to another; but in some rocks the interstices are largely isolated, and the water has little opportunity to percolate. The interstices are generally irregular in shape, and different kinds of rocks have different types of irregularities. The differences in rock interstices result from the differences in the minerals from which the rocks are composed and from the diversity of geologic processes by which they were produced or later modified.

The porosity of a rock is expressed quantitatively as the percentage of the total volume of the rock that is occupied by interstices—not occupied by solid rock material. The porosity of a sedimentary deposit depends chiefly on the shape and arrangement of its particles, the degree of assortment of its particles, the cementation and compacting to which it has been subjected since its deposition, and the fracturing of the rock resulting in joints and other openings. Well-sorted deposits of uncemented gravel, sand, or silt have a high porosity regardless of whether they consist of large or small grains. A material will have the same porosity whether it consists of large or small grains if other conditions are the same. If the material is poorly sorted, small particles occupy the spaces between the larger ones and the porosity is greatly reduced. Relatively soluble rock, such as limestone, though originally dense, may become cavernous as a result of the removal of part of its substance by the solvent action of percolating water. Hard, brittle rock, such as the Fort Hays limestone member, may acquire large interstices through fracturing resulting from shrinkage, deformation of the rocks, or other agencies.

A correlation need not exist between the porosity and permeability of a material; a rock may contain many large but disconnected interstices and thus have a high porosity yet a low permeability. A clay may have a very high porosity (higher than some gravels) but a very low permeability.

Specific yield.—Not all the water in the interstices is available for recovery through wells—a fact of great practical importance in making ground-water developments in Jewell County where the water supplies are obtained largely from storage and depend on periodic replenishment from precipitation. A part of the water in the interstices will drain into wells, and a part will be retained by the rock formations. The part that will drain into wells is called the specific yield, and the part that is retained by the rocks is called the specific retention. The specific yield and specific retention are expressed in percentages of the total volume of material. The specific yield and the specific retention of a rock or soil are together equal to the porosity. The porosity, however, is not an index to the specific yield. Clayey or silty formations may contain large amounts of water and yet be unproductive and worthless as a source of water supply, whereas a compact but fractured rock may contain much less water but yield abundantly.

Lugn and Wenzel (1938, p. 90) report that the loess in the Platte River valley, Nebraska, has a specific yield of about 20 percent. They reported that the Pleistocene sand and gravel near Grand Island, Kearney, and Lexington has a specific yield of about 24 percent. Two samples of soil collected near Lexington had specific yields of 4.4 and 21.7, respectively. R. C. Cady stated in an unpublished report on the geology and ground-water resources of Franklin, Webster, and Nuckolls Counties, Nebr., that a sample of Loveland loess collected in the Republican River valley in Nebraska had a specific yield of 10 percent and that the alluvium beneath the river flood plain has a specific yield of about 18 percent.

The Cretaceous shales in Jewell County yield essentially no water. Data are not available for making a reliable estimate of the specific yield of the Niobrara formation and the surficial deposits in Jewell County, but it is probably very low—possibly 10 percent or less.

CLASSIFICATION OF SUBSURFACE WATER

Water occurs underground in two major zones classified according to their water content. The lower zone is called the zone of saturation, and the voids in this zone are filled with water. It is this zone that furnishes water directly to springs and wells. Between the zone of saturation and the land surface, the interstices generally are only partly filled with water. This unsaturated zone is called the zone of aeration.

The upper surface of the zone of saturation in permeable soil or rock is called the water table. Where the upper surface is formed by impermeable rock, there is no water table. When a well is sunk, it yields no water until it reaches a saturated zone.

The zone of aeration varies in thickness from place to place according to the depth to the water table. In swampy tracts it is absent, the zone of saturation being about at the surface. In many places in Jewell County the water table is absent, and the zone of aeration extends down to the underlying shale.

The zone of aeration is divided according to the occurrence and circulation of its water into three belts—the belt of soil water, the intermediate belt, and the capillary fringe. The belt of soil water consists of soil and other materials that lie near enough to the surface to discharge water into the atmosphere in perceptible quantities through plants or by soil evaporation. The capillary fringe is the belt immediately above the water table that contains water drawn up from the zone of saturation by capillary action; the lower part of the fringe is saturated but the water is under tension and will not enter a well. Thus the "zone of saturation" as used in this report is that beneath the level at which the water is at atmospheric pressure—the water table. The intermediate belt lies between the capillary fringe and the belt of soil water. Where the water table lies near the surface, the capillary fringe and the belt of soil water join, and the intermediate belt is absent.

In Jewell County, ground water is derived almost entirely from precipitation in the form of rain or snow. Part of the water that falls as rain or snow is carried away by surface runoff and flows into streams, part of it evaporates, and part of it is absorbed by the soil and later transpired into the atmosphere by vegetation. The part that escapes surface runoff, evaporation, and transpiration percolates downward through the zone of aeration until it reaches the water table. According to Meinzer, percolation from the zone of aeration to the zone of saturation ceases when the amount of unsaturated pore spaces in the zone of aeration is equivalent to the specific yield; or, the amount of water retained in the zone of aeration is equal to the specific retention. The amount of water in the soil zone may be reduced below the specific retention by evaporation and transpiration; however, the definition of specific retention is based on the assumption that the water content in the intermediate belt becomes less than the specific retention only through long-continued slow evaporation, not through drainage.

The Water Table and Movement of Ground Water

shape and slope

The water table is not a level static surface. It fluctuates in response to recharge to and discharge from the zone of saturation; also, it has irregularities comparable with and related to those of the land surface, although it is less rugged. The shape of the water table, which in turn determines the direction of movement of ground water, is controlled by many factors—the differences in permeability of the water-bearing materials, topography, the configuration of the underlying Cretaceous floor, amount and distribution of precipitation, and the method of discharge of the ground water.

The water table is not continuous throughout Jewell County. Many test holes have been drilled to the impervious underlying shales without penetrating a saturated zone. Some producing water wells are within 10 feet of dry holes. In the areas tested, the underlying shale was generally within 50 feet of the land surface. The dry holes are caused partly by local differences in permeability. Some are caused by high rates of discharge by transpiration in local areas. The field work of this investigation was done during the growing season and many of the test holes that were dry then might not have been dry in more favorable seasons.

Other things being equal, the slope of the water table in general varies inversely with the permeability of the water-bearing material; that is, the water assumes a steeper gradient in flowing through fine material than through coarse material providing the same quantity of water per unit area is moving through both types of material. This is shown by the following law governing the movement of ground water:

$$Q = PIA$$

where Q is the quantity of water moving through a given cross-sectional area, P is a coefficient of permeability which gives the quantity of water moving through a unit area under unit hydraulic gradient, I is the hydraulic gradient, and A is the total cross-sectional area through which the water is moving. If Q and A in the equation are held constant, I must increase as P decreases. Thus, in loess, which has a low permeability, the hydraulic gradient will be much greater than it would be in a clean gravel if the same quantity of water per unit area is transmitted.

The water table follows in a general way the configuration of the land surface. Thus in Jewell County the ground water moves from the uplands towards the streams, and if not intercepted by transpiration, it joins with the ground water from the opposite side of the valley and percolates downstream. The water table in Jewell County is generally a few feet below the stream bed. With the exception of Republican River and White Rock Creek, the streams generally receive no ground-water seepage.

An investigation was made at Formoso to determine the direction of movement of the ground water in order to determine whether the municipal wells would receive recharge from a new city reservoir and to aid in the location of new municipal wells. A water-table contour map of the area (Fig. 9), is based on the elevation of the water levels in 26 wells. The data from which this illustration is drawn are given in Table 7. Each contour line has been drawn through points on the water table having approximately the same altitude. The altitude of the water surface in each of the wells used

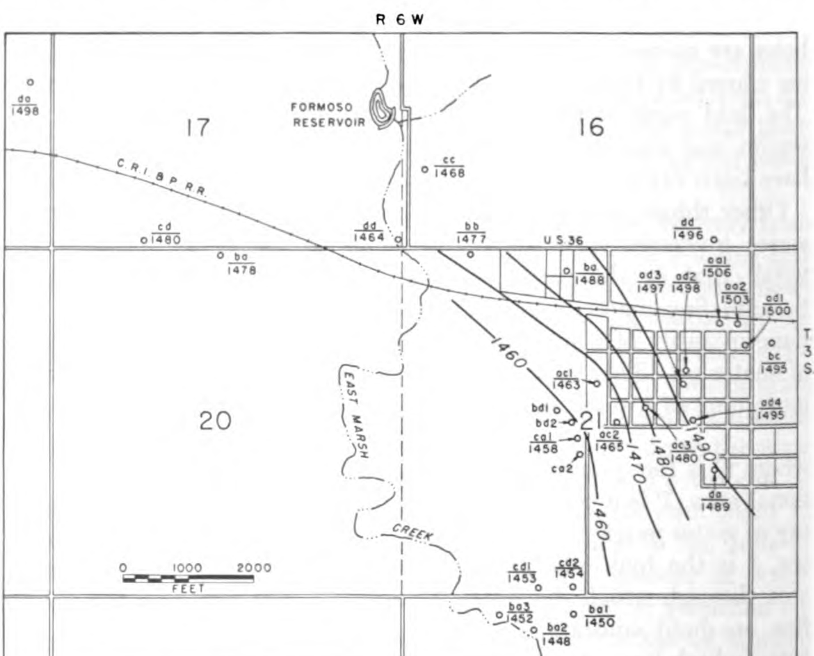

Fig. 9.—Water-table contours and direction of movement of ground water at Formoso.

in compiling the map has been referred to sea-level datum. Ground water moves in the direction of maximum slope, which is at right angles to the contours. Sufficient wells were not available near the city reservoir to complete the contours in that area. However, available wells in Formoso show that the ground water at Formoso is moving in a southwesterly direction toward East Marsh Creek. The ground water at the municipal wells comes from the northeast and not from the north and northwest, as generally believed by many residents of the area. Only three wells were measured west of the creek, but they tend to show that the direction of movement of the ground water west of the creek is in general toward the creek, where it joins the ground water moving in from the east side of the creek and then moves down the valley. Seepage water from the reservoir percolates to the south along the stream channel. In order to intercept the ground-water recharge from the reservoir,

TABLE 7.—*Altitude of measuring points and water levels of wells near Formoso**

Well No.	Owner	Date October, 1941	Height of measuring point above sea level, feet	Height of water level above sea level, feet
3–6–16dd	Don Keeler	22	1,522.00	1,496.38
3–6–16cc	Robert McCune	23	1,499.08	1,467.83
3–6–17cd	John Magnusson	22	1,489.34	1,479.54
3–6–17dd	R. C. Allen	22	1,483.65	1,463.86
3–6–18da	I. S. Cullen	23	1,506.87	1,498.38
3–6–20ba	Hale Estate	22	1,486.50	1,478.40
3–6–21aa1	C. R. I. & P. Ry.	22	1,515.75	1,505.62
3–6–21aa2	do	22	1,510.69	1,503.24
3–6–21ba	______ Williams	22	1,510.98	1,487.84
3–6–21bb	W. F. Logen	22	1,500.58	1,476.83
3–6–21ac1	John Lebhart	22	1,503.55	1,463.12
3–6–21ac2	Mrs. John Briggs	22	1,494.52	1,465.21
3–6–21ad1	H. E. Sloan	22	1,509.86	1,480.17
3–6–21ada	Bob Means	22	1,508.63	1,499.90
3–6–21ad2	Dr. C. W. Inge	22	1,527.87	1,498.47
3–6–21ad3	T. H. Shedden	22	1,526.16	1,497.10
3–6–21ad4	Mrs. Pantier	22	1,514.53	1,495.18
3–6–21da	Mrs. J. T. Marr	22	1,518.15	1,488.86
3–6–21ca	Walter Joerg	22	1,494.12	1,457.54
3–6–22bc	Mrs. George Young	22	1,499.22	1,494.55
3–6–21cd1	Edd Patterson	23	1,468.88	1,452.94
3–6–21cd2	Edd Patterson	23	1,481.84	1,454.16
3–6–28ba1	do	23	1,475.03	1,450.41
3–6–28ba2	do	23	1,467.11	1,448.16
3–6–28ba3	do	23	1,468.31	1,451.78

* More complete records of these wells are given in Table 17.

a well would have to be near the creek. Additional wells along the 1,460-foot contour line on the water table would intercept the ground water moving from the north and east.

An investigation was made at Jewell City in the municipal well field east of town to determine the permeability of the water-bearing materials and the availability of ground-water supplies. A water-

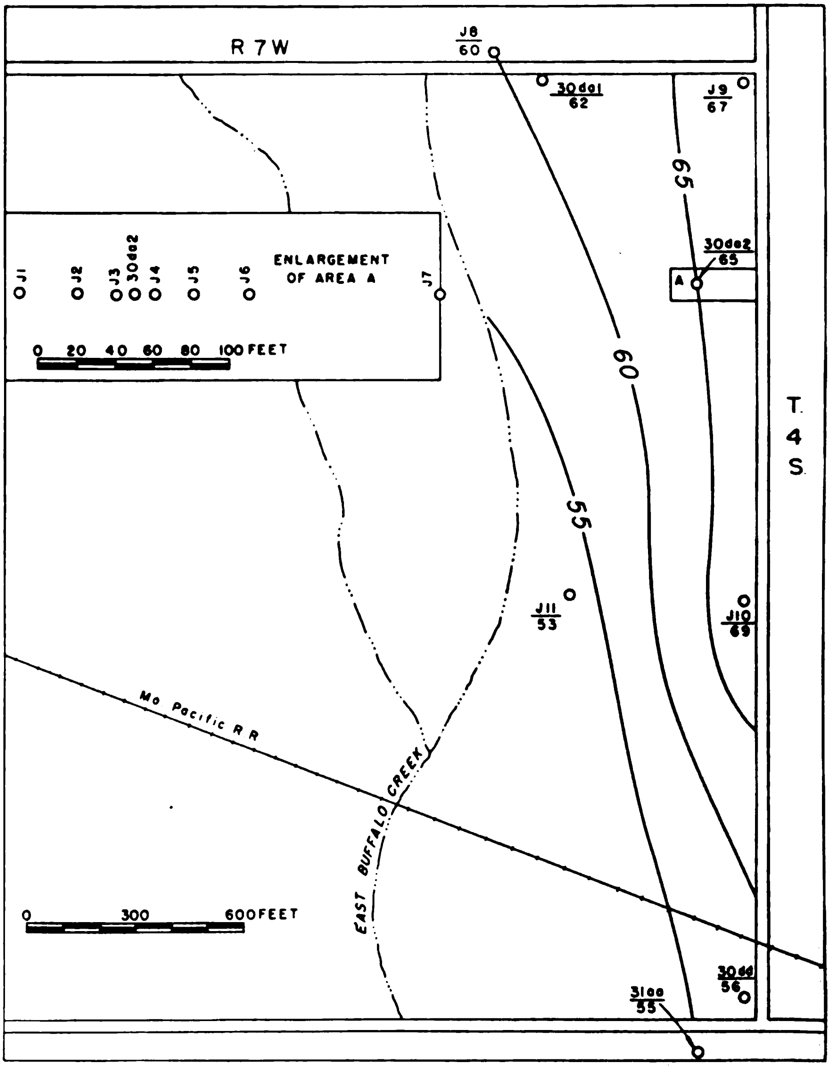

FIG. 10.—Water-table contours and direction of movement of ground water in well field at Jewell City.

table contour map of the area is shown in Figure 10. The data from which this illustration is drawn are given in Tables 14 and 16. The water-table contours show that the ground water is moving in a southwesterly direction toward the creek and that it has a slope of approximately 85 feet to the mile. The data upon which the map is based were collected in September 1941 when much ground water near the creek was being transpired by trees. During seasons of no transpiration, the water table probably slopes less toward the creek, and the ground water moves in a more southerly direction down the valley.

Other observations in Jewell County show that, in general, the ground water is moving from the uplands toward the valleys. This is contrary to a very prevalent belief among the residents that most of the ground-water recharge comes from seepage from the streams. If the recharge were derived chiefly from streams, the water table would slope from the valleys toward the uplands. The streams do contribute much ground-water recharge during the periods of surface runoff, but the recharge affects the water table only a short distance laterally from the streams, and much of the water drains back into the streams rather soon after their levels fall.

RELATION TO TOPOGRAPHY

In this area the water table follows in a general way the configuration of the surface; it rises under the hills and sinks under the valleys. Its slope nearly everywhere is less than that of the land. Its depth ranges from less than 10 feet along some of the streams to a maximum of about 125 feet in the uplands in the northeastern part of the county.

The relation of the water table to topography is affected and often obscured by variations in the permeability of the underlying rocks. An impervious layer may bring the water table to the surface on a hillside and result in a seep or spring. During periods of heavy precipitation, ground water has been observed to percolate down hillsides from the Fort Hays limestone member which overlies the impervious Carlile shale. The permeability of the material in the zone of aeration under a high hill determines the rate of movement of the soil moisture down to the water table. A thick column of material of low permeability retards ground-water recharge, and, as a result, the water table is lower during wet periods and higher during dry periods than it would be if the material had a high permeability.

FLUCTUATIONS IN WATER LEVEL

The water table is not a stationary surface but a surface that fluctuates much like the water level in a lake or reservoir. Approximate equilibrium existed between the amount of water that was added annually to the ground-water storage and the amount that was discharged annually by natural means prior to any artificial discharge. The addition of considerable artificial discharge to the natural discharge tends to displace the equilibrium and results in a decline of the water table. In general, the water table rises when the amount of recharge exceeds the amount of discharge and declines when the discharge is greater than the recharge. Changes in the water levels in wells indicate whether the ground-water reservoir is being depleted or replenished.

The principal factors controlling the rise of the water table in Jewell County are the amount of rainfall infiltration and the amount of water added to the underground reservoir by seepage from ponds and from streams during periods of flood flow. The principal factors controlling the decline of the water table are the amount of water lost through transpiration and evaporation in stream valleys, the amount percolating back into the streams after periods of high flow, the amount of water pumped from wells, and the amount of water leaving the county beneath the surface by percolation down the valleys. Some ground water discharges into White Rock Creek and Republican River. The other streams in the county receive only surface runoff.

An observation-well program was begun in the Limestone Creek area in 1934. Originally 30 wells were selected for observation; however, as the investigation progressed, new wells were added and several of the original wells were abandoned. A total of 52 wells have been under observation for various intervals. Prior to July 1939 the measurements were made weekly; from July 1939 to 1943 the measurements were made monthly or semimonthly; since 1943 the measurements have been less frequent. The water-level measurements have been published annually by the U. S. Geological Survey (1936-54). Table 8 correlates the observation-well numbers used in this report with those used in the annual water-supply papers. The location and description of each well are given in the table of well records at the end of this report.

Fluctuations caused by precipitation.—A relation, made complex by many factors, exists between the amount of water falling as rain or snow and the level at which the water stands in wells. Other things being equal, the greater the precipitation for a given period, the greater the rise in the water level. However, after a prolonged dry spell, the water contained in the soil becomes depleted; then when rain occurs, it must first replenish the soil moisture before any of the water can percolate down to the water table. The temperature also has an influence, for rain that falls on frozen ground is hindered from reaching the water table, and part of the water that falls during the hot summer months is evaporated directly into the air. With the coming of spring, vegetation begins to make heavy demands on soil moisture, and where the roots and trees and other vegetation extend to the water table, they draw water directly from the zone of saturation. Thus, although the rainfall is greater during the summer, the water table generally declines owing to the high consumption of water by vegetation. When the first killing frost occurs in the fall, transpiration of water ceases and, even though there may be no appreciable precipitation, the water level in wells on lowlands may rise. During the winter, at times when the ground is not frozen, precipitation may percolate down-

TABLE 8.—*Observation-well numbers used in this report and corresponding numbers given in annual series of U. S. Geological Survey Water-Supply Papers.* (U. S. Geological Survey, 1936-'54)

Well No. in this report	Well No. in water-supply papers	Well No. in this report	Well No. in water-supply papers
3-8-6cd	64	4-9-8dc8	59
3-9-5-aa	4	4-9-8dc9	60
3-9-5ac	49	4-9-13cd	44
3-9-5cd	6	4-9-15bd	40
3-9-17cb	8	4-9-17ab1	51
3-9-23dd	65	4-9-17ab2	61
3-9-24dd	14	4-9-17ab3	62
3-9-30 (1)	12	4-9-17ab4	63
3-9-31 (1)	50	4-9-28ca	30
3-10-18dd1	34	4-10-23cc	48
3-10-18dd2	34A	4-10-24ca	45
3-10-18dd3	34B	5-9-3cd	47
3-10-18dd4	34C	5-9-6 (1)	67
3-10-29cd	18	5-9-6 (2)	41
4-9-8dc1	52	5-9-7	69
4-9-8dc2	53	5-9-10ab	22
4-9-8dc3	54	5-9-19	46
4-9-8dc4	55	5-9-25dc	43
4-9-8dc5	56	5-9-29bb	25
4-9-8dc6	57	5-10-1ad	66
4-9-8dc7	58	6-9-27ab	42

ward with little loss from evaporation and transpiration; and when the soil moisture has been replenished, a moderate amount of precipitation may cause an appreciable rise in the water table.

Graphs of the fluctuations of the water levels in 12 wells and the cumulative departure from normal precipitation at Burr Oak are shown in Figures 11, 12, and 13. The average height of the water

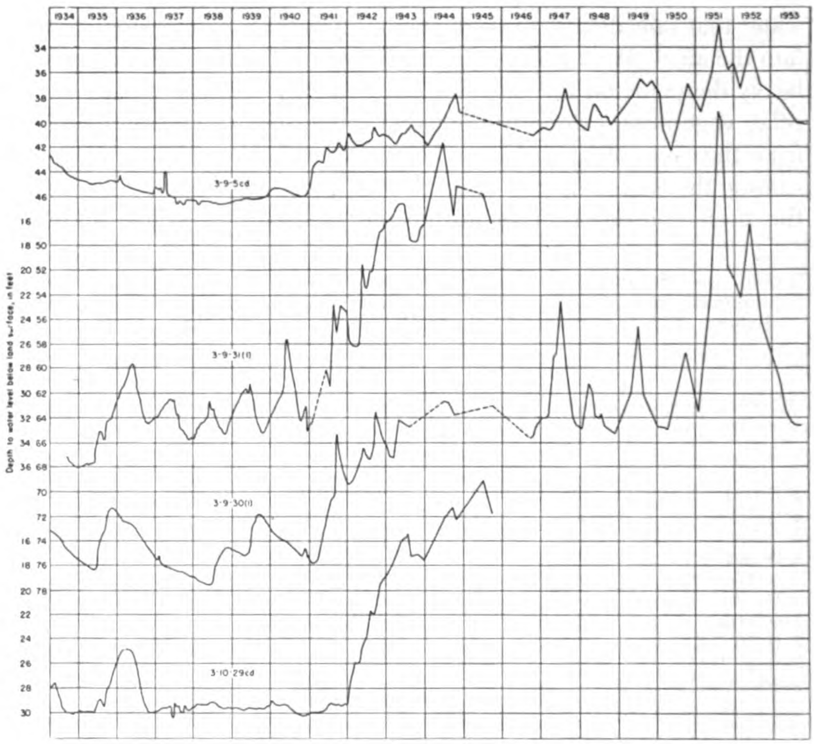

FIG. 11.—Hydrographs showing fluctuations of the water levels in four observation wells in Jewell County

levels in the 12 wells and the cumulative departure from normal precipitation are shown in Figure 14. These graphs show diverse types of water-level fluctuations. The water level in well 4-9-28ca has an annual fluctuation caused by precipitation. The water level declines during the growing season when the amount of water that escapes the roots of the vegetation is very small even though most of the precipitation occurs during the growing season. Beginning about September or October, the amount of infiltration exceeds the transpiration and the excess percolates down to the water table.

The water table then rises gradually until the beginning of the next growing season. These annual cycles are broken by abnormally low or high amounts of precipitation. Thus, few of the water levels showed a rise in 1934 when the precipitation was very low. In 1941 and 1942, when the precipitation was high, the water levels rose considerably.

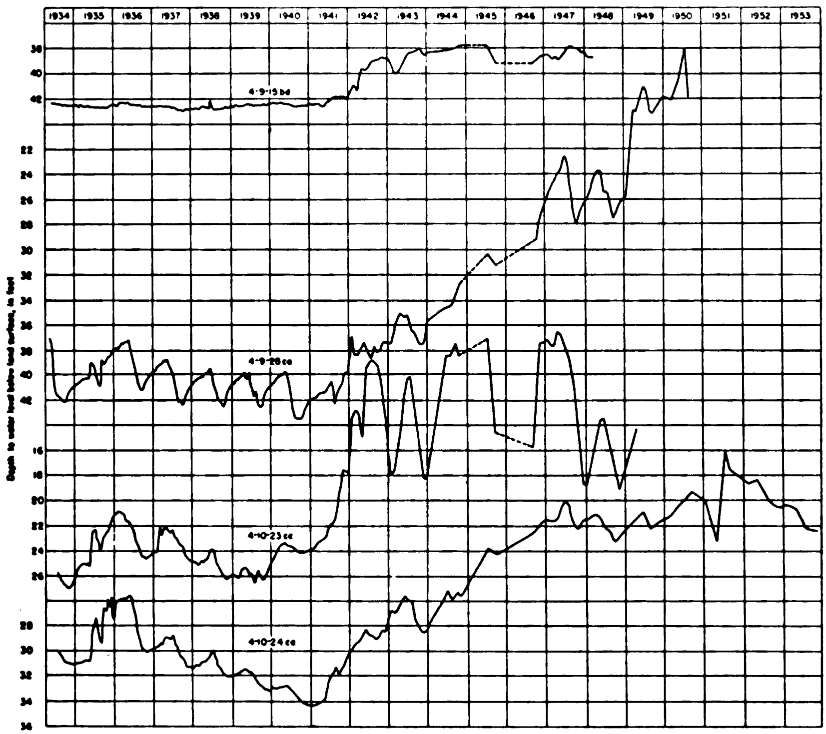

FIG. 12.—Hydrographs showing fluctuations of the water levels in four observation wells in Jewell County

During years of normal precipitation, the water levels in some wells have only minor fluctuations. During a period of abnormally high precipitation, the amount of infiltration exceeds the amount of transpiration, all soil-moisture deficiency is satisfied, and the excess water percolates down to the water table and causes a large rise of the water level. The water level in well 4-9-15bd generally has only minor fluctuations. From 1934 to 1941, the fluctuations were generally less than half a foot a year, but in 1941 and 1942, the water level rose nearly 4 feet. In 1935 and 1942, conditions were favorable for large rises of the water level in well 3-10-29cd. The rise in 1942 was more than 10 feet. At other times during the period of record, the annual rise of water level in this well was less than a foot.

The general trend of the water levels resulting from a balance between recharge from precipitation and discharge is shown in

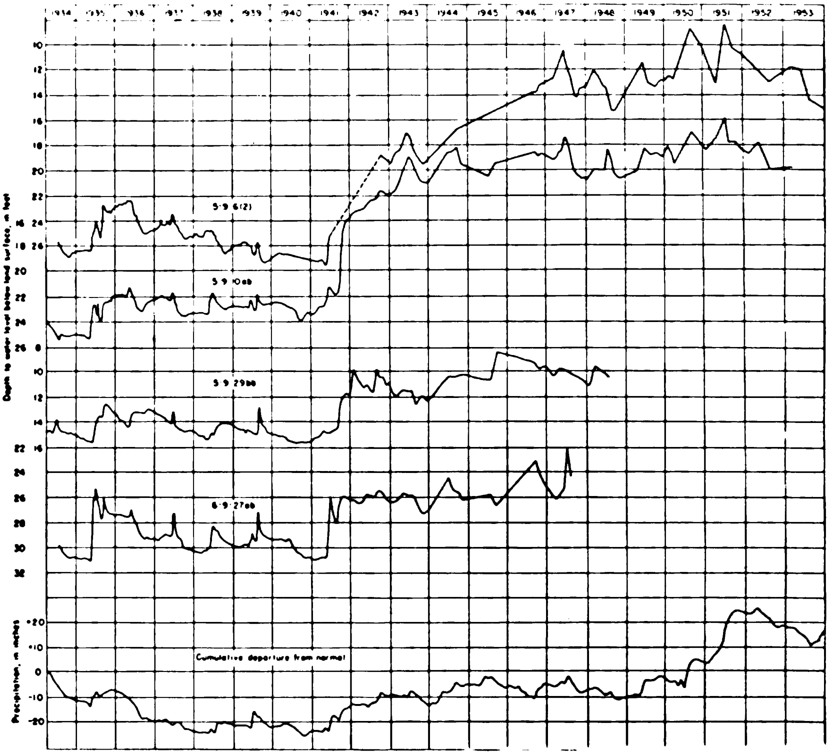

FIG. 13.—Hydrographs showing fluctuations of the water levels in four observation wells in Jewell County and the cumulative departure from normal precipitation at Burr Oak.

Figure 14. During 1934 and the first part of 1935, the precipitation was below normal. During this time, the water levels reached their lowest average level for the period of record. High precipitation in 1935 and early 1936 caused the water levels to rise an average of 3.5 feet by May 15, 1936. Low precipitation during the latter part of 1936 resulted in a decline of 2.4 feet by October 23. The precipitation in 1937 was 4.60 inches below normal and, as a result, the

water levels had an average net decline of 0.98 foot; however, in 1938, when the precipitation was 2.23 inches above normal, the water levels had an average net rise of 0.27 foot. The amounts of precipitation in 1939 and 1940 were 1.08 and 1.96 inches below normal, respectively. The water levels rose 0.14 foot in 1939, then declined 0.78 foot in 1940. The precipitation was 10.63 inches above normal in 1941 and 3.13 inches above normal in 1942. In response to this high precipitation, the water levels rose 4.50 feet in 1941 and 3.26 feet in 1942. The high stage reached by the water levels in 1942 was 10 feet higher than the low stage in 1934.

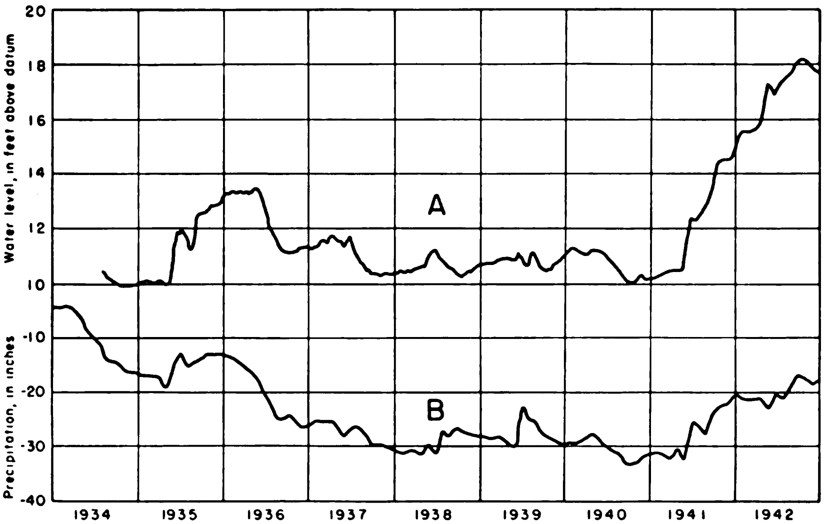

FIG. 14.—Hydrograph of average water level in 12 observation wells in Jewell County and the cumulative departure from normal precipitation at Burr Oak, 1934-42.

Fluctuations caused by transpiration.—Water-stage recorders were operated intermittently on some of the wells and continuously on others in the Limestone Creek basin during the period from March 1934 to December 1938. Daily fluctuations of the water level caused by transpiration in many wells were observed during the growing season. The water levels rose during the night and declined during the day. Figure 15 is a hydrograph of well 4-9-28ca for the period July 26-29, 1937, showing the fluctuations of the water level caused by transpiration of oak trees. This well is about 50 feet from Elm Creek in the NE¼ SW¼ sec. 28, T. 4 S., R. 9 W. The shelter covering the well, near-by trees that are causing the fluctuations, and a picture taken in the dry bed of Elm Creek just north of the well are shown in Plate 6. The observation well is an abandoned stock well, 10 inches in diameter and 52.6 feet deep. The water level was approximately 42 feet below the land surface in July 1937.

The hydrograph (Fig. 15) represents a cumulative curve of the

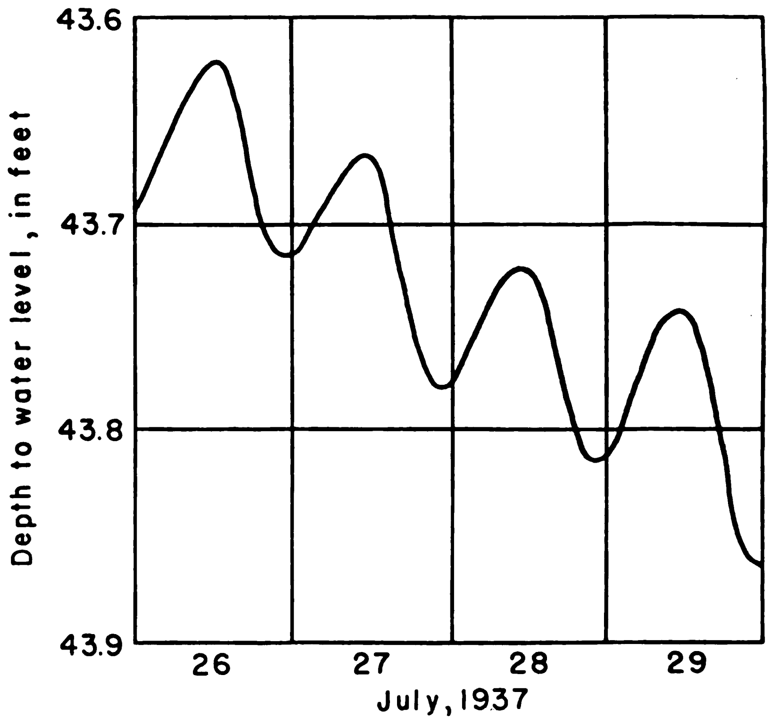

Fig. 15.—Hydrograph of well 4-9-28ca showing fluctuations of the water level caused by transpiration.

rates of ground-water inflow (plus) and the transpiration use (minus). The ground water to supply the needs of the vegetation can be drawn from the inflow to the area or from ground-water storage, or from both.

An analysis of the hydrograph shows that at about 10:00 a. m. the water level remains unchanged for a short period. During this period, the ground-water inflow is sufficient to supply all the transpiration needs. From 10:00 a. m. to about 11:00 p. m. the use of water by transpiration exceeds the ground-water inflow and water is

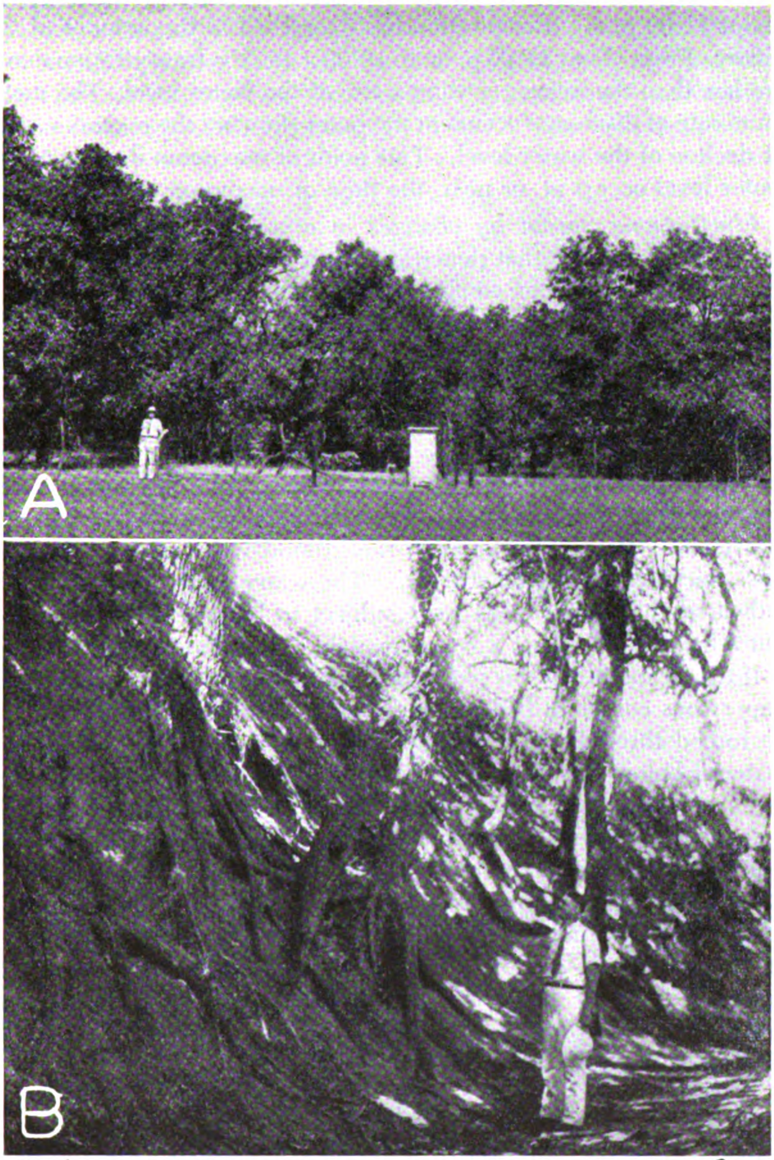

Plate 6. A, Observation well in the NE¼ SW¼ sec. 28, T. 4 S., R. 9 W. **B,** Limestone Creek just north of observation well. Water level, about 40 feet below land surface, affected by transpiration. Hydrograph shown in Figure 15. Photographs by S. W. Lohman.

drawn from storage resulting in a decline of the water level. By about 11:00 p. m., transpiration has decreased to the amount of the inflow. From about 11:00 p. m. to 10:00 a. m., the transpiration needs are less than the inflow, causing a rise of the water level. The maximum rate of discharge occurs at the point showing the maximum rate of decline of the water level. This point of maximum decline of the water level occurs at, or near, the time of maximum temperature.

Fluctuations caused by changes in atmospheric pressure.—The water levels in wells that penetrate water-bearing formations having a relatively impervious confining bed above the zone of saturation may fluctuate in response to changes in atmospheric pressure. The pressure on the water surface in a well increases with an increase of atmospheric pressure. If this increase in pressure is not transmitted uniformly to the entire ground-water body but acts only on the exposed water surface in the well, the water level in the well fluctuates according to the changes in pressure. However, if the pressure is transmitted freely through the pore spaces of the soil above the zone of saturation to the ground water, the water level does not fluctuate barometrically. The water-stage recorder charts indicated that many wells were subject to barometric fluctuations, but a barograph record was not available for comparison.

If the casing in wells is perforated between the water table and an impervious confining bed lying above an unsaturated zone, air may be forced through the well into the interstices of the unsaturated material below the impermeable layer when the atmospheric pressure increases, and out through the well when the atmospheric pressure decreases (Wenzel and Waite, 1941, p. 44). This may cause an appreciable amount of air to move into or out of the well at its top, which in some wells is of sufficient velocity to cause a whistling or roaring sound. The water level in such wells fluctuates only slightly, if at all, in response to changes in atmospheric pressure. Locally, these wells are known as "blowing" and "sucking" wells. This phenomenon was observed in well 1-6-20da in the NE¼ SE¼ sec. 20, T. 1 S., R. 6 W.

RECHARGE

Recharge is the addition of water to the ground-water reservoir and may be accomplished in several ways. Most usable ground water in Jewell County is derived from water that falls as rain or snow either within the county or on near-by areas north and west of the county. Once the water becomes a part of the ground-water body, it moves down the slope of the water table, later to be discharged at some point downstream.

The underground reservoir in Jewell County is recharged by local precipitation within the county, by percolation or subsurface inflow from areas north and west of the county, and by influent seepage from streams and ponds.

RECHARGE FROM LOCAL PRECIPITATION

The average annual precipitation in Jewell County is about 25 inches. Of this amount, part is returned to the atmosphere through evaporation, part is transpired by plants, and part is lost through immediate runoff as flood water. The remainder seeps downward through the soil and the underlying rocks into the zone of saturation.

In Jewell County, the amount of the annual precipitation that is

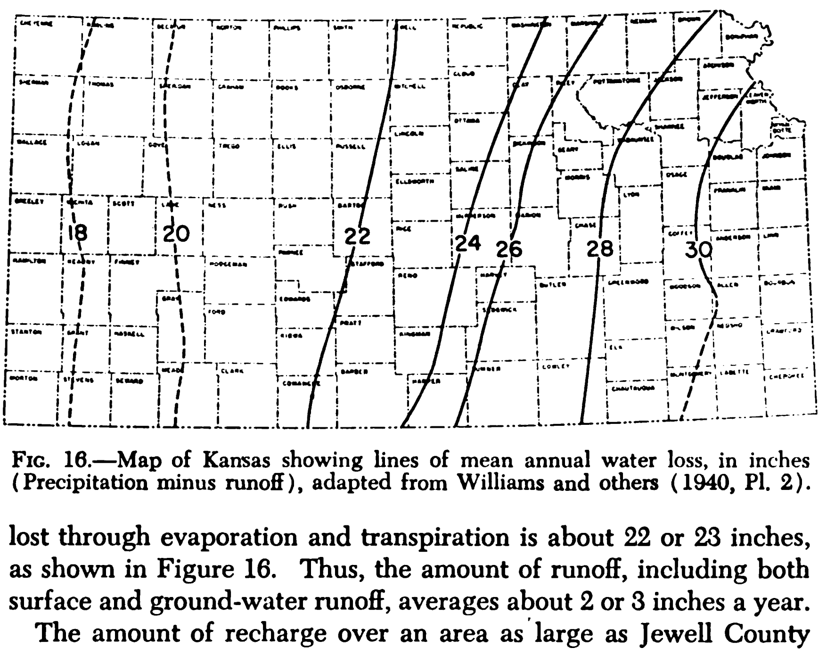

FIG. 16.—Map of Kansas showing lines of mean annual water loss, in inches (Precipitation minus runoff), adapted from Williams and others (1940, Pl. 2).

lost through evaporation and transpiration is about 22 or 23 inches, as shown in Figure 16. Thus, the amount of runoff, including both surface and ground-water runoff, averages about 2 or 3 inches a year.

The amount of recharge over an area as large as Jewell County is probably far from uniform because of variations in the amount of precipitation from one place to another and because of variations in the soil and geologic conditions affecting recharge.

Ground-water recharge may be determined by several recognized methods. A rise of ground-water levels and a decrease or halt in the decline of ground-water levels following precipitation or the melting of snow may indicate recharge. Increase in the discharge of springs or an increase of the ground-water discharge into a stream also may indicate recharge. Lysimeters for measuring the moisture penetration of soils and direct measurements of infiltration on experimental plots also have been used to determine the rate of recharge.

The records of 12 observation wells (Figs. 11-14) in the Limestone Creek area have been selected for a special study to determine the amount of ground-water recharge. The wells range in depth from 31 to 88 feet. They are water-table wells and most of them are not affected by pumping. In the following discussion the statements refer to the average water level in the 12 wells.

The annual cumulative rise of the water level in each well was determined from weekly and monthly measurements and is given in Table 9. The relation between the annual precipitation and the annual cumulative rise (summation of all the rises of the water level during the year) of the average water level in the 12 wells (Fig. 17A) indicates that for a year of normal precipitation (24.56 inches) the water levels rise an average of 2.86 feet, but when the annual precipitation is less than about 10 inches, generally the water levels do not rise. High rates of precipitation tend to steepen the curve, indicating that recharge to the zones of soil belt and aeration remains fairly constant in a favorable condition for recharge and a small increase in the annual precipitation results in a greater rise of the water levels. A higher percentage of the precipitation is ground-water recharge during years of above-normal precipitation and a lower percentage during years of below-normal precipitation.

The annual net rise or decline of the water levels is given in Table 10. The relation between the annual net change and precipitation (Fig. 17B) indicates that for a year of no precipitation the net decline of the water levels would be about 4.6 feet. For normal precipitation, the water levels would have a small net rise. A longer record of measurements or a larger number of wells might show that for normal precipitation there would be no net annual change of the water levels.

For a year of normal precipitation, the water levels have a normal cumulative rise of about 2.86 feet. The cumulative departure from the normal cumulative rise of the average water levels is given in Table 11. Graphs of the cumulative departure from normal annual rise of the average water levels, and the cumulative departure from normal precipitation are shown in Figure 18. The graphs indicate

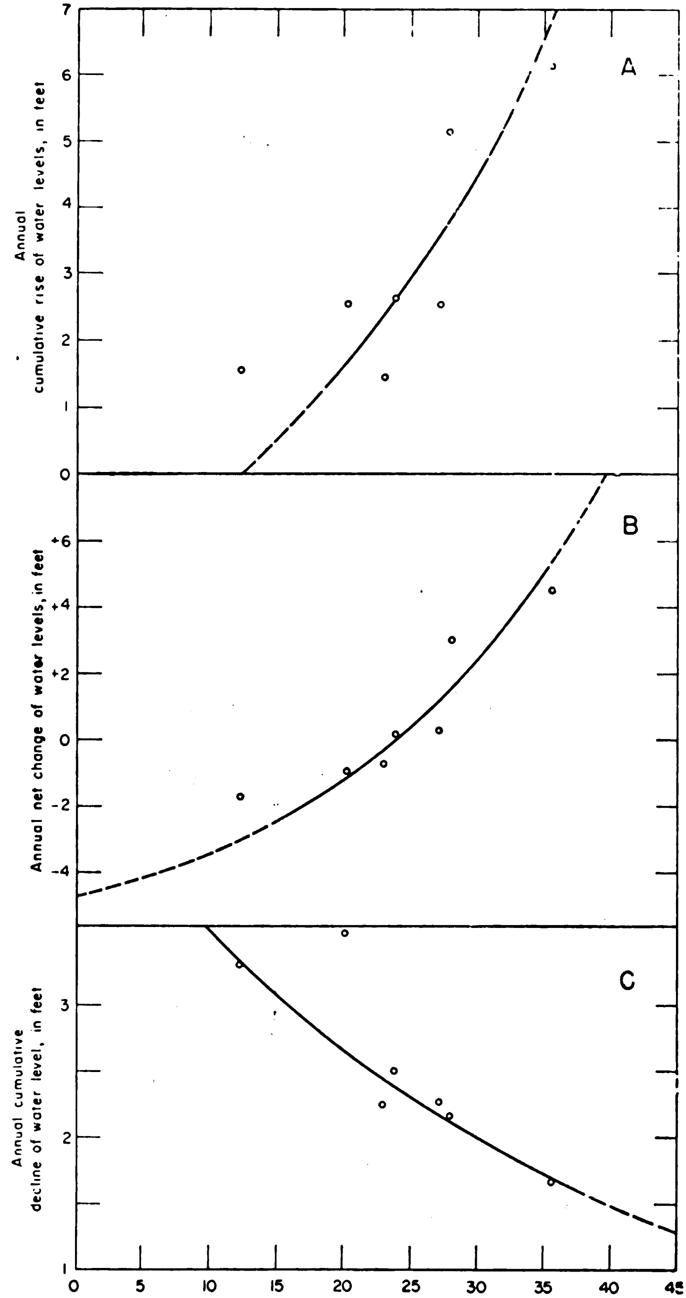

Fig. 17.—Graphs showing the relation of annual precipitation at Burr Oak to A, annual cumulative rise of water levels; B, annual net change of water levels; and C, annual cumulative decline of water levels.

that for a large part of the record there is a close correlation between precipitation and rise of the water levels and that for normal precipitation there is a normal rise of the water levels.

TABLE 9.—*Annual cumulative rise of water levels, in feet* (Based on weekly measurements)

Well number	Year							
	1935	1936	1937	1938	1939	1940	1941	1942
3-9-5cd	0.41	0.80	4.31	1.09	0.97	0.72	5.05	3.67
3-9-30 (1)	5.07	0.00	0.80	3.31	3.45	0.68	10.64	7.17
3-9-31 (1)	5.00	3.47	2.89	5.63	4.64	7.95	13.63	12.83
3-10-29cd	4.34	1.12	2.73	1.30	1.36	0.15	1.28	10.99
4-9-15bd	1.43	1.45	1.18	1.95	1.17	0.67	1.16	4.38
4-9-28-ca	6.04	3.05	3.31	3.68	4.38	2.54	4.55	6.28
4-10-23cc	6.92	0.96	3.04	1.96	3.27	1.55	6.45	11.51
4-10-24ca	7.34	1.38	1.71	1.91	0.56	0.25	4.90	4.43
5-9-6 (2)	6.85	1.35	2.52	2.96	2.11	......	......	......
5-9-10ab	6.46	2.12	2.31	2.73	2.94	0.92	8.30	2.24
5-9-29bb	3.58	1.87	3.33	1.89	9.01[1]	0.20	4.23	4.82
6-9-27ab	8.22	1.40	2.57	2.38	4.10	0.47	7.49	1.45
Average	5.13	1.58	2.56	2.57	2.63[2]	1.46[3]	6.15[3]	6.28[3]

1. Probably some surface inflow during period.
2. Average of 11 wells; well 5-9-29bb omitted.
3. Average of 11 wells. well 5-9-6(2) omitted; dry most of year.

TABLE 10.—*Annual net rise or net decline of water levels, in feet, in 12 wells in Jewell County*

Well number	Year							
	1935	1936	1937	1938	1939	1940	1941	1942
3-9-5cd	—0.20	—1.00	—0.50	—0.11	+0.71	+0.10	+3.48	+1.40
3-9-30 (1)	+2.90	—2.68	—1.50	+2.21	+1.62	—2.35	+6.12	+2.83
3-9-31 (1)	+5.60	—1.48	—1.86	+2.17	—0.23	—0.80	+9.00	+7.34
3-10-29cd	+4.17	—4.14	+0.27	—0.04	+0.44	—0.80	+0.90	+10.32
4-9-15bd	—0.06	+0.02	—0.30	+0.24	+0.18	+0.02	+0.53	+3.38
4-9-28ca	+2.80	—1.60	—1.12	—0.10	—0.03	—1.27	+2.22	+2.47
4-10-23cc	+4.80	—2.88	—0.75	—1.07	+1.10	+0.84	+6.76	+1.90
4-10-24ca	+4.00	—2.80	—1.59	—0.53	—1.08	—1.35	+4.25	+3.29
5-9-6 (2)	+3.60	—1.80	—0.68	—0.70	—0.97	......	......	......
5-9-10ab	+3.15	—0.29	—1.14	+0.63	+0.18	—0.87	+7.69	+2.00
5-9-29bb	+1.62	+0.20	—1.60	+0.48	—0.70	—0.60	+4.00	+1.06
6-9-27ab	+3.40	—1.90	—0.95	+0.45	+0.50	—1.55	+4.60	—0.12
Average	+2.98	—1.70	—0.98	+0.30	+0.14	—0.78	+4.50	+3.26

PERCOLATION FROM OUTSIDE THE AREA

The movement of ground water in Jewell County is, in general, from the northwest to the southeast. The drainage basin of White Rock Creek extends into Smith County. Thus, part of the ground-water recharge in Smith County percolates into Jewell County. As the permeability of the deposits overlying bedrock is very low, the amount of ground-water recharge to the water table by percolation from outside the county is very small.

Some wells in Jewell County obtain part of their water supply from the Dakota. The direction of movement of the water in the Dakota in Jewell County has not been determined, but this movement is limited by the permeability of the sandstone and the hydraulic gradient, neither of which is known. The Dakota is not an important source of ground water in Jewell County as the water is generally too highly mineralized for domestic use.

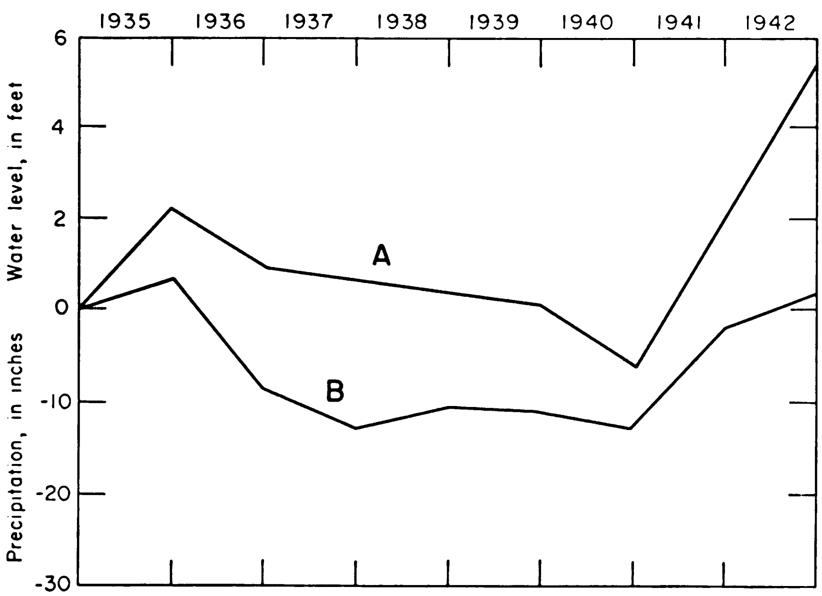

FIG. 18.—Relation between **A**, cumulative departure from normal annual rise of average water levels, and **B**, cumulative departure from normal precipitation.

TABLE 11.—*Average annual cumulative rise of the water levels in 12 observation wells in Jewell County, and departure from normal average cumulative rise of water levels, and cumulative departure from normal precipitation near Burr Oak*

Year	Cumulative rise of water levels, feet	Departure from normal cumulative rise of average water levels, feet	Cumulative departure from normal cumulative rise of average water levels, feet	Precipitation, inches	Departure from normal precipitation, inches	Cumulative departure from normal precipitation, inches
	(A)[1]	(B)[2]	(C)[3]	(D)	(E)[4]	(F)[5]
1935....	5.13	+2.27	+2.27	28.02	+3.46	+3.46
1936....	1.58	—1.28	+0.99	12.38	—12.18	—8.72
1937....	2.56	—0.30	+0.69	20.37	—4.19	—12.91
1938....	2.57	—0.29	+0.40	27.20	+2.64	—10.27
1939....	2.63	—0.23	+0.17	23.89	—0.67	—10.94
1940....	1.46	—1.40	—1.23	23.01	—1.55	—12.49
1941....	6.15	+3.29	+2.06	35.60	+11.04	—1.45
1942....	6.28	+3.42	+5.48	28.10	+3.54	+2.09

1. From Table 8.
2. Column A —2.86.
3. Column B cumulative.
4. Column D —24.56.
5. Column E cumulative.

SEEPAGE FROM STREAMS AND PONDS

Two factors determine whether a stream or pond is capable of supplying water to the underground reservoir. First, the water surface of the stream or pond must be above the water table; and second, the material between the stream channel or pond and the water table must be sufficiently permeable to permit water to percolate downward. If the water surface of the stream or pond is lower than the water table, the process is reversed—that is, the ground-water reservoir will discharge water into the stream or pond.

Republican River and part of White Rock Creek are the only perennial streams in Jewell County. The water table was below the bed of the other creeks at the time of this investigation during the summer of 1941. Most of the streams flow during and for a short time after a storm and the stream flow is composed almost entirely of surface runoff. The streams have an opportunity to recharge ground water only during intermittent periods of surface runoff.

A prevalent opinion among local residents is that nearly all ground-water recharge comes from streams and ponds. If this were true, the slope of the water table would be away from the streams instead of toward them as pointed out in the section discussing the shape and slope of the water table. In Jewell County the amount of recharge from streams is negligible compared to the recharge from local precipitation.

During 1934 and 1936, when many domestic wells went dry, many farmers constructed ponds for watering their stock and replenishing their ground-water supply. The farm-pond program, sponsored by Federal and State agencies, has proved very successful in Jewell County. Many farmers have been able to keep more stock by watering them directly from the ponds than would have been possible if they had depended on the meager ground-water supplies. Also, many data are available showing that the ponds contribute considerable recharge that becomes available to wells down gradient from the pond. Reports have been received from the farmers that many wells, which are now furnishing adequate water supplies for domestic use, had been dry prior to the construction of up-gradient ponds. Additional qualitative evidence that the water table receives recharge from the ponds is the luxurious growth of vegetation in the valley down gradient from the ponds.

Thirteen wells were bored near a pond on the L. C. Beeler farm northwest of Ionia to determine the effect of the pond on the water table. Periodic measurements of the water levels were made for several years subsequent to 1934 and have been published in the annual series of water-level reports of the Federal Geological Survey. The location of the wells with respect to the pond is shown by Meinzer and Wenzel (1938, p. 109). The water table slopes from the pond, showing that the movement of ground water is away from the pond. The water-level measurements show that the greatest effect of the pond is a short distance down gradient. At a greater distance downstream, much of the ground-water recharge is intercepted by transpiration and the effect of the pond on ground-water recharge is obscured.

Discharge

SEEPAGE INTO STREAMS

A stream whose bed is lower than the water table receives water from the zone of saturation, but a stream whose bed is above the water table cannot receive water from the zone of saturation. All streams in Jewell County except Republican River and part of

White Rock Creek are above the water table and carry water only after storms. Information for determining the amount of ground water discharged into streams in Jewell County is not available.

DISCHARGE FROM SPRINGS

There are a few small springs in Jewell County. Many seeps from the Fort Hays limestone member have been observed following periods of heavy precipitation. Percolating ground water in the Fort Hays limestone member reaches the impervious Carlile shale where it cannot continue to move downward so it moves laterally and seeps out on the hillsides.

DISCHARGE BY 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 transpiration (Meinzer, 1923a, p. 48). The discharge of ground water by transpiration and evaporation varies considerably with different plants. White (1932, p. 89) estimated that the seasonal discharge of ground water by alfalfa in the Escalante Valley, Utah, is about 24 inches, which is only 1 inch less than normal precipitation in Jewell County. According to the census reports, 10 percent of the county was in alfalfa at one time. The large alfalfa acreage may account for some of the reported declines in water level.

The total ground-water discharge—transpiration and evaporation, percolation out of the area, and discharge from wells and springs—in Jewell County is equal to the total recharge, as expressed by the cumulative rise of water levels minus or plus the annual net change of the water levels. Ground-water discharge from wells and springs is computed to be about 1 percent of the total discharge. The annual change in water level indicating ground-water discharge from 1935 to 1942 is given in Table 12 and is shown in Figure 17C. The graph shows that ground-water discharge decreases as precipitation increases, indicating that the greater part of the ground-water discharge may be by transpiration. During years of high precipitation, most of the water required for transpiration may be derived from soil moisture. During dry years, the soil moisture becomes nearly depleted and water to supply the needs of the vegetation is obtained from the zone of saturation. The curve indicates that for a year of normal precipitation, the total decline representing ground-water discharge is about 2.3 feet.

The cumulative rise of water levels, the net change of water levels,

TABLE 12.—*Annual cumulative rise of water levels, annual net change of the water levels, and annual ground-water discharge as expressed by decline of water levels in observation wells in Jewell County*

Year	Annual cumulative rise of water levels, feet	Annual net change of water levels, feet	Annual ground-water discharge, feet*
1935	5.13	+2.98	2.15
1936	1.58	—1.70	3.28
1937	2.56	—0.98	3.54
1938	2.57	+0.30	2.27
1939	2.63	+0.14	2.49
1940	1.46	—0.78	2.24
1941	6.15	+4.50	1.65
1942	6.28	+3.26	3.02

* Annual cumulative rise of water levels minus annual net change of water levels.

and the annual ground-water discharge depend not only on the amount of precipitation during the current year but also on the seasonal distribution of precipitation and on soil-moisture conditions at the beginning of the year, which are related to the precipitation during the preceding year. The curves in Figure 17 indicate the amount of groundwater recharge and discharge that might be expected for a given amount of annual precipitation. The annual cumulative rise of water levels, the annual net change of water levels, and the annual decline indicating ground-water discharge that might be expected for a given amount of precipitation are given in Table 13. If the precipitation in a given year amounted to less than about

TABLE 13.—*Expected annual cumulative rise, annual net change, and annual decline of water levels indicating ground-water discharge for given amounts of precipitation in the Limestone Creek area* (From Fig. 17)

Annual precipitation, inches	Annual cumulative rise of water levels, feet	Annual net change of water levels, feet	Annual ground-water discharge, feet*
0	0	—4.60	4.60
10	0	—3.58	3.58
15	0.52	—2.58	3.10
20	1.69	—1.01	2.70
24.56	2.86	0.52	2.34
25	2.90	0.56	2.34
30	4.45	2.43	2.02
35	6.52	4.78	1.74
40	10.00	8.50	1.50

* Annual cumulative rise of water levels minus annual net change of water levels.

10 inches, the curves in Figure 17 indicate that there would be little or no rise of the water levels and the net decline of the water levels in that year would be about equal to the ground-water discharge.

In Figure 17 it was shown that a relation exists between the amount of annual precipitation and the following three variables: (1) cumulative rise of water levels, (2) annual net change of water levels, and (3) annual ground-water discharge. If these three variables are related to precipitation, then each of the variables is related to the other two. These relations are illustrated in Figure 19.

DISCHARGE BY PERCOLATION

The water table in Jewell County slopes to the southeast, indicating that ground water is moving by percolation southeastward out of the county. Well records and test holes indicate that the saturated water-bearing material has an average thickness of about 15 feet. A pumping test at Jewell City indicated a permeability of about 25 gallons per day per square foot. However, judging from the character of the water-bearing material at Jewell City and that in other parts of the county, the average permeability throughout the county is probably less than 25. The water table has a slope of about 10 feet to the mile. The south and east sides of the county are 30 miles in length which gives a cross sectional length perpendicular to the direction of flow of about 42 miles. For the given conditions, the underflow leaving the county would be equal to the coefficient of permeability (25) times the hydraulic gradient in feet per mile (10) times the saturated thickness in feet (15) times the length of the cross section in miles (42), which is equal to about 150,000 gallons a day or about 7 million cubic feet a year. This would be equivalent to about 0.003 inch of water spread evenly over the county—a very low figure, yet one that probably is too high because of the assumed value of permeability.

Figure 17C indicates that when the amount of annual precipitation is high, the loss of ground water by transpiration will be small and underflow will constitute most of the natural ground-water discharge. The annual discharge by underflow remains approximately constant. If the curve in Figure 17C is correct as drawn and can be extrapolated to the right, it would flatten for high values of annual precipitation. Under such conditions of high precipitation, practically no ground water would be discharged by transpiration, and the ground-water discharge shown by the flattened

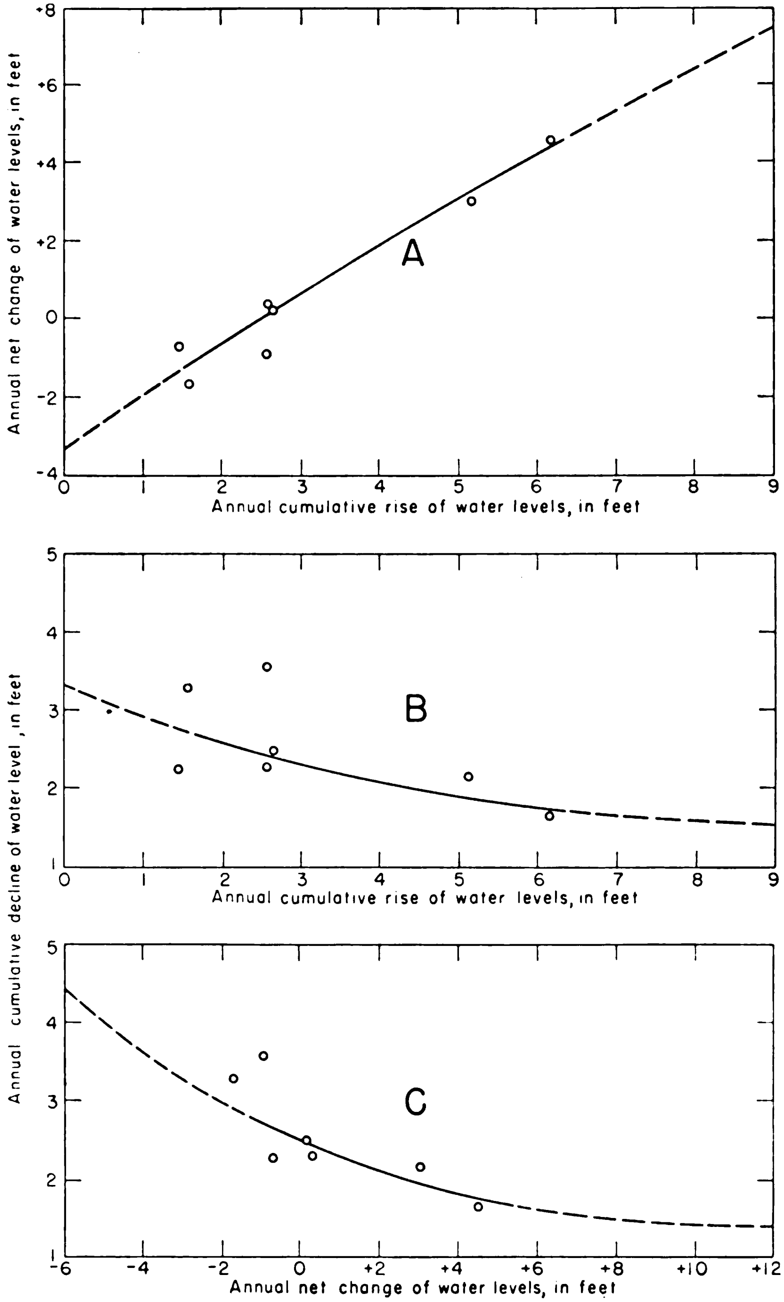

FIG. 19.—Graphs showing the relation of **A**, annual net change of water levels to annual cumulative rise of water levels; **B**, annual cumulative decline of water levels to annual cumulative rise of water levels; and **C**, annual cumulative decline of water levels to annual net change of water levels.

part of the curve would be almost entirely in the form of percolation out of the basin (excepting a negligible amount of discharge by pumping). If the precipitation became sufficient to produce effluent seepage, the curve would rise to the right, indicating an increase in ground-water discharge as the annual precipitation increases. If the flattened part of the curve were extended to the left, the extended line would indicate approximately the amount of discharge by percolation during years of normal or subnormal precipitation, and the remaining part above this extended line would represent the discharge of ground water by transpiration and evaporation.

DISCHARGE FROM WELLS

The discussion above relates to natural discharge of ground water in Jewell County. The remainder of the ground water discharged within the county comes from wells and is very small in comparison with the natural discharge.

According to the 1940 census, Jewell County had a population of 11,970. The total number of livestock was listed at about 65,000 and poultry at about 250,000. On the assumption that the average per-capita use of water is about 50 gallons a day, that each head of livestock averages 10 gallons a day, and that poultry averages 0.05 gallon a day, the average daily use of water in Jewell County is about 1,300,000 gallons. The annual use of ground water would amount to about 470,000,000 gallons or about 1,400 acre-feet, which would be equal to about 0.03 inch of water spread over the county.

PERMEABILITY OF WATER-BEARING MATERIALS

GENERAL CONSIDERATIONS

The permeability of a water-bearing formation is expressed by Meinzer's coefficient of permeability (Stearns, 1928, p. 148), as the rate of flow, in gallons per day, through a square foot of its cross section under a hydraulic gradient of 100 percent at a temperature of 60° F., or as the number of gallons a day, at 60° F., that is conducted laterally through each mile of water-bearing bed under investigation (measured at right angles to the direction of flow), for each foot of thickness of the bed and for each foot per mile of hydraulic gradient. Thus, the quantity of water that will percolate through a given cross section of water-bearing material under a known hydraulic gradient is directly proportional to the coefficient of permeability of the material. In order to compute the quantity of ground water that percolates into or out of a ground-water basin, reservoir, specific well, or well field, the coefficient of permeability of the material must be determined. The coefficient of transmissibility is equal to the field coefficient of permeability (same as the coefficient defined above, except that it is for the prevailing temperature of the ground water) multiplied by the saturated thickness of the aquifer, in feet.

PUMPING TEST

The pumping-test method of determining permeability consists of pumping a well that penetrates water-bearing material whose permeability is to be determined and observing the decline of the water table around the pumped well and the rate of recovery of the water level in the pumped well. In the above tests the rate of decline of the water table was determined by boring 3-inch observation wells in the vicinity of the pumped well and periodically measuring the depths to the water level in the observation wells.

Thiem method.—The Thiem method was used in computing the coefficient of permeability from the data collected at the Jewell City pumping test. This method is described by Wenzel (1942, pp. 81-87).

The Thiem formula for water-table conditions is

$$P = \frac{Q(\log_e r_2 - \log_e r_1)}{\pi(h_2 + h_1)(s_1 - s_2)}$$

in which P is the coefficient of permeability, Q is the discharge of the pumped well, h_1 is the saturated thickness of the water-bearing material at the nearer of two observation wells at a distance r_1 from the pumped well, h_2 is the thickness of the saturated water-bearing material at the other observation well at a distance r_2 from the pumped well, and s_1 and s_2 are the drawdowns in the observation wells. If m is defined as the average of the thickness of the saturated part of the water-bearing material at the two observation wells and if the logarithms with base e are converted to logarithms with base 10, the formula is reduced to the formula given by Wenzel (1942, p. 81).

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

in which P is the coefficient of permeability as defined above and q is the rate of pumping in gallons a minute.

Jewell City pumping test.—A pumping test was made on well 4-7-30da2 (Jewell City municipal well 2) from 9:20 a. m. September

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26, 1941, to 10:08 a. m. October 17, 1941. The locations of the pumped well and observation wells are shown in Figure 10 and their descriptions, water-level measurements, and the cumulative discharge of the pumped well are given in Table 14. The well, which was equipped with an electrically driven lift pump with a capacity of about 3.2 gallons a minute, discharged through a water meter into the city main. The yield of the well was less than the capacity of the pump resulting in a diminishing of the pumping rate from about 3.2 gallons a minute at the beginning of pumping to about 1.9 gallons a minute after 10 days of pumping. The rates of pumping for the first 10 days are shown in Figure 20. The curve in Figure 20 is extended to show what the pumping rate would be from 10 to 100 days after pumping started. The extension is based on the assumption that the yield of the well would continue to diminish at a rate defined by the equation of the curve for the first 10 days of pumping.

The Thiem method for determining the permeability of water-bearing materials assumes a constant pumping rate, a condition that was not fulfilled in this pumping test. The rate of pumping ranged from about 3.2 gallons a minute at the beginning of the test to about 1.9 gallons a minute on October 7 and averaged about 2.25 gallons a minute. The yield of the well was very low throughout the test and probably the coefficient of permeability computed from the pumping data is of the right order of magnitude.

Heavy rains during October resulted in considerable ground-water recharge. The pumping test data collected subsequent to October 5 were vitiated for use in computing the permeability. The water level in the observation well 10 feet west of the pumped well was 1.97 feet higher on October 10 than at the beginning of pumping on September 26 (Fig. 21).

When the data collected during the pumping test were applied to the Thiem formula, an average field coefficient of permeability of about 25 gallons a day per square foot was obtained.

The aquifer is not homogeneous at Jewell City, as shown by the irregular fluctuations of the water levels in the observation wells. The water level in the observation well 10 feet east of the pumped well was affected only slightly by the pumping. The water level in the well 60 feet east of the pumped well declined to a lower level than the water level in the well 30 feet east of the pumped well (Fig. 22).

Jewell City has four municipal wells in the E½ of SE¼ sec. 30, T. 4 S., R. 7 W. The locations of the wells and the water-table contours are shown in Figure 10. The ground water is moving in a

TABLE 14.—*Water levels in observation wells, in feet above datum plane, and cumulative discharge of well 4-7-30da2 (Jewell City well 2), in gallons a minute, during the Jewell City pumping test.* (For location of wells refer to Figure 7. The datum is 100 feet below a benchmark on south guard rail on bridge, 0.3 mile west of well.)

J1. 60 feet west of pumped well, diameter 3 inches, depth 38.4 feet. Measuring point, top of casing, 1.5 feet above land surface, 95.64 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 24	3:30 p.m.	64.08	Sept. 27	11:55 a.m.	63.06	Oct. 10	4:10 p.m.	76.46
25	8:30 a.m.	64.01	27	2:10 p.m.	62.98	11	4:05	73.83
26	8:35	64.15	27	3:25	62.94	13	2:15	70.94
26	9:20	a	27	6:36	62.64	14	3:45	69.14
26	11:25	64.10	28	8:17 a.m.	62.42	16	9:05 a.m.	67.98
26	11:45	64.10	28	10:30	62.35	17	9:55	67.79
26	12:25 p.m.	64.06	28	11:40	62.35	17	10:08	b
26	1:00	64.03	28	2:00 p.m.	62.27	17	10:24	67.79
26	1:25	64.00	28	4:00	62.25	17	10:53	67.78
26	2:00	63.97	28	4:40	62.26	17	11:08	67.78
26	2:26	63.95	29	8:55 a.m.	62.04	17	11:48	67.80
26	2:53	63.93	30	9:10	62.01	17	12:35 p.m.	67.83
26	3:25	63.91	30	3:45 p.m.	61.96	17	1:30	67.88
26	3:55	67.89	Oct. 1	10:00 a.m.	61.89	17	3:00	67.95
26	4:25	63.86	2	9:06	61.97	17	4:00	67.98
26	4:55	63.84	5	12:10 p.m.	61.74	17	4:48	68.00
26	10:50	63.56	6	3:00	c	18	9:10 a.m.	68.01
27	8:28 a.m.	63.17	7	....	c	18	2:15 p.m.	68.02
27	10:37	63.10	8	10:20 a.m.	68.97			

TABLE 14.—*Continued*

J2. 30 feet west of pumped well, diameter 3 inches, depth 39.4 feet. Measuring point, top of casing, at land surface, 95.26 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 24	3:31 p.m.	64.94	Sept. 27	11:55 a.m.	62.96	Oct. 9	4:05 p.m.	69.61
25	8:31 a.m.	64.55	27	2:10 p.m.	62.89	10	4:10	63.17
26	8:36	64.12	27	3:24	62.86	11	4:05	62.96
26	9:20	a	27	6:37	62.68	13	2:15	62.88
26	11:26	64.04	28	8:18 a.m.	62.27	14	3:45	63.57
26	11:46	64.03	28	10:30	62.27	16	9:05 a.m.	63.09
26	12:26 p.m.	63.98	28	11:40	62.26	17	9:55	63.07
26	1:00	63.94	28	2:00 p.m.	62.23	17	10:08	b
26	1:26	63.91	28	4:00	62.18	17	10:52	63.18
26	2:01	63.88	28	4:41	62.16	17	11:10	63.41
26	2:27	63.86	29	8:56 a.m.	61.96	17	11:49	63.69
26	2:54	63.83	30	9:02	62.46	17	12:36 p.m.	64.14
26	3:26	63.80	30	3:45 p.m.	62.30	17	1:31	64.64
26	3:56	63.77	Oct. 1	10:02 a.m.	62.02	17	3:01	65.19
26	4:26	63.74	2	9:05	61.86	17	4:01	65.45
26	4:56	63.71	5	12:10 p.m.	61.82	17	4:50	65.61
26	10:51	63.42	6	3:00	62.11	18	9:13 a.m.	66.68
27	8:29 a.m.	63.07	7	5:00	63.02	18	2:13 p.m.	66.81
27	10:38	63.01	8	10:20 a.m.	64.02			

TABLE 14.—*Continued*

J3. 10 feet west of pumped well, diameter 3 inches, depth 39.2 feet. Measuring point, top of casing, 0.3 foot above land surface, 96.51 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 24	3:30 p.m.	65.20	Sept. 27	11:55 a.m.	60.64	Oct. 9	4:10 p.m.	66.09
25	8:32 a.m.	65.16	27	2:10 p.m.	60.62	10	4:10	66.95
26	8:36	65.36	27	3:24	60.59	11	4:05	66.95
26	9:20	a	27	6:37	60.55	13	2:15	66.64
26	11:27	64.98	28	8:19 a.m.	60.41	14	3:45	65.69
26	11:47	64.88	28	10:30	60.38	16	9:05 a.m.	65.34
26	12:27 p.m.	64.62	28	11:40	60.36	17	9:55	65.26
26	1:00	64.30	28	2:04 p.m.	60.36	17	10:08	b
26	1:27	63.98	28	4:02	60.33	17	10:51	65.36
26	2:02	63.52	28	4:43	60.32	17	11:12	65.47
26	2:28	63.28	29	8:59 a.m.	60.25	17	11:53	65.78
26	2:54	62.99	30	9:04	60.35	17	12:37 p.m.	66.16
26	3:27	62.70	30	3:45 p.m.	60.32	17	1:33	66.57
26	3:54	62.47	Oct. 1	10:00 a.m.	60.29	17	3:03	67.00
26	4:27	62.26	2	9:06	60.28	17	4:02	67.20
26	4:57	62.11	5	12:10 p.m.	60.32	17	4:51	67.32
26	10:52	61.01	6	3:00	60.37	18	9:14 a.m.	68.25
27	8:30 a.m.	60.69	7	5:00	60.55	18	2:11 p.m.	68.36
27	10:40	60.66	8	10:20 a.m.	63.09			

TABLE 14.—*Continued*

J4. 10 feet east of pumped well, diameter 3 inches, depth 40.4 feet. Measuring point, top of casing, 0.3 foot above land surface, 97.09 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 24	3:30 p.m.	65.08	Sept. 27	6:37 p.m.	65.29	Oct. 13	2:15 p.m.	68.65
25	8:32 a.m.	65.28	28	8:19 a.m.	64.88	14	3:45	68.50
26	8:36	65.26	28	10:30	64.83	16	9:05 a.m.	68.31
26	9:20	a	28	11:40	64.80	17	9:55	68.32
26	11:27	65.37	28	2:04 p.m.	64.82	17	10:08	b
26	11:48	65.35	28	4:02	64.85	17	10:56	68.32
26	12:28 p.m.	65.33	28	4:43	64.82	17	11:14	68.31
26	1:05	65.30	29	8:59 a.m.	64.86	17	11:50	68.33
26	1:27	65.28	30	9:05	64.91	17	12:35 p.m.	68.34
26	2:02	65.26	Oct. 1	3:47 p.m.	64.89	17	1:35	68.35
26	2:28	65.25	2	9:03 a.m.	64.93	17	3:05	68.39
26	2:54	65.23	5	12:08 p.m.	64.99	17	4:03	68.41
26	3:27	65.21	6	2:58	65.11	17	4:52	68.42
26	3:58	65.20	7	5:00	65.09	18	9:15 a.m.	68.65
26	4:28	65.19	8	10:20 a.m.	65.57			
26	4:58	65.18	9	4:05 p.m.	66.61			
26	10:53	65.09	10	4:10	67.87			
27	8:32 a.m.	65.00	11	4:05	68.52			

TABLE 14.—*Continued*

J5. 30 feet east of pumped well, diameter 3 inches, depth 39.0 feet. Measuring point, top of casing, 0.1 foot above land surface, 96.70 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 24	3:30 p.m.	64.85	Sept. 27	11:59 a.m.	61.24	Oct. 9	4:05 p.m.	61.43
25	8:32 a.m.	64.87	27	2:13 p.m.	61.20	10	4:10	61.78
26	8:36	64.70	27	3:29	61.17	11	4:05	61.72
26	9:20	a	27	6:39	61.15	13	2:15	61.14
26	11:33	64.62	28	8:31 a.m.	61.01	14	3:45	61.95
26	11:49	64.50	28	10:44	60.98	16	9:05 a.m.	62.56
26	12:29 p.m.	63.94	28	11:54	60.98	17	9:55	62.92
26	1:04	63.51	28	2:09 p.m.	60.95	17	10:08	b
26	1:32	63.21	28	4:09	60.95	17	10:58	62.95
26	2:09	62.92	28	4:54	60.92	17	11:15	62.98
26	2:30	62.77	29	8:03 a.m.	60.85	17	11:51	63.04
26	2:58	62.57	30	9:07	60.90	17	12:39 p.m.	63.13
26	3:29	62.40	30	3:45 p.m.	60.86	17	1:36	63.13
26	3:58	62.20	Oct. 1	10:05 a.m.	60.78	17	3:06	63.77
26	4:28	62.04	2	9:00	60.71	17	4:04	64.22
26	4:59	62.00	5	12:02 p.m.	60.58	17	4:52	64.53
26	10:58	61.65	6	3:00	60.52	18	9:16 a.m.	66.98
27	8:34 a.m.	61.26	7	5:00	60.56	18	2:09 p.m.	67.14
27	10:44	61.24	8	10:20 a.m.	60.61			

TABLE 14.—*Continued*

J6. 60 feet east of pumped well, diameter 3 inches, depth 38.5 feet. Measuring point, top of casing, 0.4 foot above land surface, 96.30 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 24	3:30 p.m.	64.94	Sept. 27	2:14 p.m.	60.87	Oct. 9	4:05 p.m.	62.31
25	8:32 a.m.	64.90	27	3:29	60.87	10	4:10	62.42
26	8:36	64.86	27	6:39	60.84	11	4:05	62.32
26	9:20	a	28	8:31 a.m.	60.75	13	2:15	62.21
26	11:34	64.82	28	10:45	60.71	14	3:45	62.06
26	11:50	64.81	28	11:55	60.71	16	9:05 a.m.	61.98
26	1:05 p.m.	64.78	28	2:10 p.m.	60.69	17	9:55	62.01
26	1:32	64.72	28	4:10	60.67	17	10:08	b
26	2:09	63.08	28	4:55	60.65	17	10:57	62.02
26	2:31	62.53	29	9:04 a.m.	60.62	17	11:18	62.10
26	2:59	62.08	30	9:08	60.61	17	11:52	62.51
26	3:30	61.78	30	3:50 p.m.	60.61	17	12:40 p.m.	63.05
26	3:59	61.60	Oct. 1	10:10 a.m.	60.60	17	1:37	63.76
26	4:29	61.46	2	9:00	60.60	17	3:08	64.67
26	5:00	61.36	5	12:01 p.m.	60.42	17	4:05	65.06
26	10:59	61.03	6	3:00	60.32	17	4:53	65.31
27	8:35 a.m.	60.90	7	5:00	61.14	18	9:17 a.m.	67.00
27	10:45	60.89	8	10:20 a.m.	61.20	18	2:08 p.m.	67.12
27	11:59	60.90						

TABLE 14.—*Continued*

J7. 160 feet east of pumped well, diameter 3 inches, depth 37.5 feet. Measuring point, top of casing, at land surface, 97.21 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 27	8:25 a.m.	65.06	Sept. 30	3:50 p.m.	64.72	Oct. 17	9:55 a.m.	66.29
27	12:05 p.m.	65.04	Oct. 1	10:14 a.m.	64.71	17	10:40	b
27	2:15	65.01	2	8:59	64.76	17	11:00	66.29
27	3:35	65.01	5	12:01 p.m.	64.57	17	11:19	66.30
27	6:44	64.91	6	2:55	64.71	17	12:01 p.m.	66.33
28	8:40 a.m.	64.65	7	5:00	64.97	17	12:41	66.35
28	10:50	64.65	8	10:20 a.m.	65.16	17	1:38	66.38
28	11:59	64.61	9	4:05 p.m.	65.75	17	3:10	66.43
28	2:15 p.m.	64.65	10	4:10	66.10	17	4:06	66.46
28	4:15	64.67	11	4:05	66.17	17	4:57	66.47
28	5:00	64.68	13	2:15	66.27	18	9:18 a.m.	66.64
29	9:10 a.m.	64.68	14	3:45	66.13	18	2:06 p.m.	66.70
30	9:10	64.71	16	9:05 a.m.	66.21			

TABLE 14.—*Continued*

4-7-30da2. Pumped well, depth 47.7 feet, diameter 13.0 inches. Measuring point, floor of shelter, 0.4 foot above land surface, 97.22 feet above datum.

Date, 1941	Hour	Water level	Date, 1941	Hour	Water level	Date, 1941	Hour	Water level
Sept. 18	10:30 a.m.	65.04	Oct. 17	10:28 a.m.	56.70	Oct. 17	12:22 p.m.	62.46
19	8:30	65.38	17	10:32	57.26	17	12:32	62.70
26	9:20	a	17	10:35	57.63	17	12:42	62.94
26	11:18	56.00	17	10:40	58.11	17	12:50	63.12
26	12:32 p.m.	54.34	17	10:45	58.50	17	1:00	63.34
26	12:58	53.55	17	10:50	58.85	17	1:10	63.58
26	1:35	52.80	17	10:55	59.19	17	1:30	63.75
26	2:14	51.91	17	11:02	59.51	17	1:30	63.90
26	2:32	51.49	17	11:06	59.69	17	1:35	63.96
26	3:00	51.43	17	11:10	59.89	17	2:00	64.23
26	3:31	51.42	17	11:15	60.11	17	2:20	64.42
26	4:00	51.43	17	11:20	60.32	17	2:40	64.58
26	4:30	51.41	17	11:25	60.53	17	3:00	64.72
Oct. 17	9:30 a.m.	51.42	17	11:30	60.74	17	3:30	64.93
17	10:08	b	17	11:35	60.94	17	4:00	65.09
17	10:09	52.78	17	11:41	61.18	17	4:30	65.24
17	10:11	52.43	17	11:47	61.42	17	5:00	65.38
17	10:13	53.38	17	11:55	61.70	17	8:30	66.19
17	10:15	53.73	17	12:00 noon	61.86	17	11:30	66.56
17	10:20	55.11	17	12:06 p.m.	62.04	18	9:15 a.m.	67.12
17	10:24	55.99	17	12:13	62.23	18	2:05 p.m.	67.22

TABLE 14.—*Concluded*

4-7-30da2. **Cumulative discharge in gallons.**

Date, 1941	Hour	Cumulative discharge, gallons	Date, 1941	Hour	Cumulative discharge, gallons	Date, 1941	Hour	Cumulative discharge, gallons
Sept. 26	9:20 a.m.	a0	Sept. 27	8:35 a.m.	3,654	Sept. 30	3:50 p.m.	13,770
26	11:18	356	27	10:45	3,953	Oct. 1	10:14 a.m.	16,000
26	12:32 p.m.	580	27	12:00 noon	4,126	2	9:03	18,765
26	12:58	660	27	2:15 p.m.	4,434	5	12:06 p.m.	27,660
26	1:35	775	27	3:30	4,602	6	2:57	30,780
26	2:14	890	27	6:40	5,050	7	4:52	34,000
26	2:32	945	28	8:32 a.m.	6,860	8	10:25 a.m.	36,342
26	2:52	1,000	28	10:45	7,130	9	4:05 p.m.	40,640
26	3:00	1,028	28	2:10 p.m.	7,562	10	4:10	44,480
26	3:31	1,114	28	4:10	7,814	11	4:05	48,300
26	4:00	1,194	28	4:55	7,911	13	2:15	55,490
26	4:30	1,278	29	9:04 a.m.	9,945	14	3:45	59,380
26	5:01	1,360	30	9:10	12,970	16	9:05 a.m.	65,570
26	10:50	2,240				17	9:55	69,310

J8. 105 feet west and 60 feet north of well 4-7-30da1 (Jewell City well 1). Depth 40.1 feet. Measuring point, top edge of hole, 98.81 feet above datum. Water level September 18, 1941, 60.02 feet above datum.

J9. 54 feet south and 50 feet west of NE cor. NE¼ SE¼ sec. 30, T. 4 S., R. 7 W. Depth, 34.2 feet. Measuring point, top edge of hole, 97.75 feet above datum. Water level September 18, 1941, 66.71 feet above datum.

J10. 845 feet south and 105 feet east of well 4-7-30da2 (Jewell City well 2). Depth 24.2 feet. Measuring point, top edge of hole, 92.33 feet above datum. Water level September 18, 1941, 69.25 feet above datum.

J11. 470 feet west and 30 feet north of J10. Depth 43.0 feet. Measuring point, top edge of hole, 94.67 feet above datum. Water level September 17, 1941, 52.81 feet above datum.

4-7-30da1. (Jewell City municipal well 1). Measuring point, 99.49 feet above datum. Water level September 18, 1941, 66.99 feet above datum.

4-7-30dd. (Jewell City municipal well 4). Measuring point, 90.45 feet above datum. Water level September 12, 1941, 55.43 feet above datum.

4-7-31aa. Measuring point, 90.23 feet above datum. Water level September 12, 1941, 55.24 feet above datum.

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a. Pumping started at 9:20 a. m., September 26.
b. Pumping stopped at 10:08 a. m., October 17.
c. Flood water surrounded well 1-6-4dc.

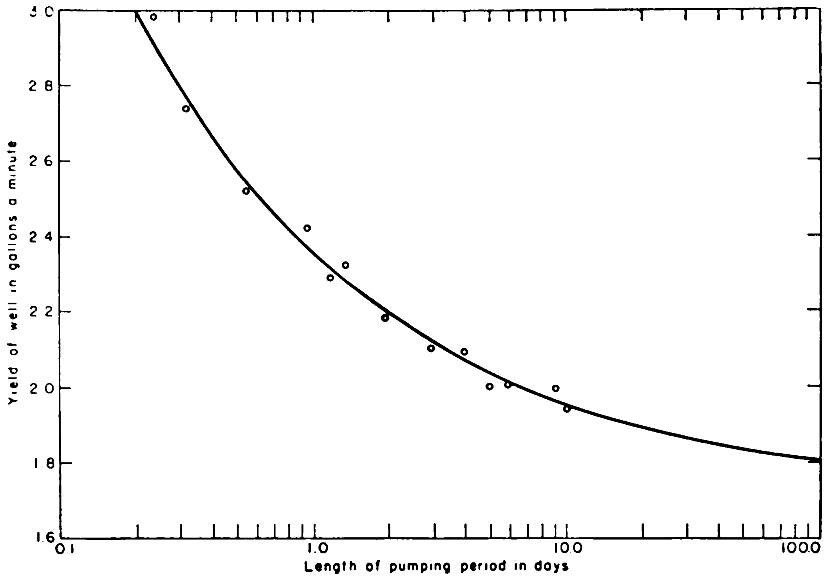

FIG. 20.—Graph showing the decrease of the yield of well 4-7-30da2 at Jewell City during an extended pumping test.

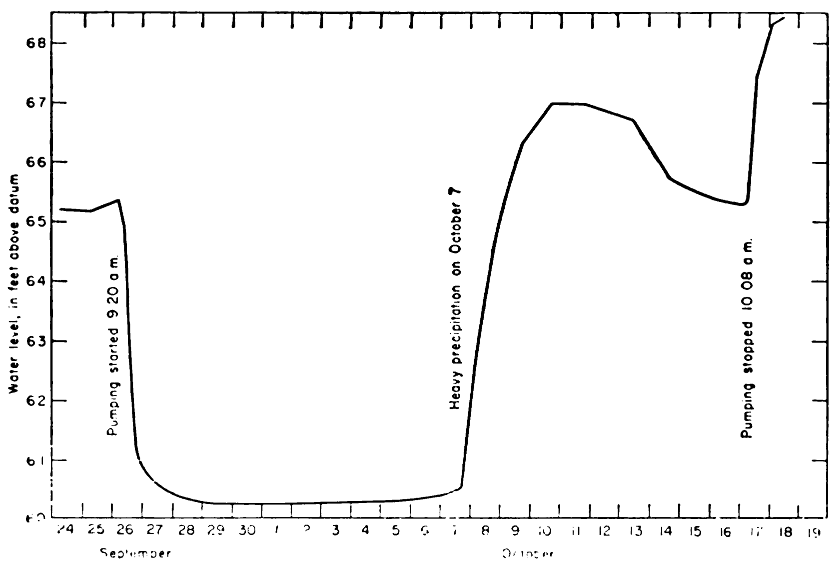

FIG. 21.—Hydrograph of observation well 10 feet west of pumped well during Jewell City pumping test.

southeasterly direction and has a hydraulic gradient of approximately 35 feet per mile. The quantity of water moving daily across the east boundary of the SE¼ sec. 30 that would become available for pumping is equal to the coefficient of transmissibility (25 times a thickness of about 12 feet = 300) times the length of the cross section in miles (0.5) times the hydraulic gradient in feet per mile (35) which is equal to about 5,000 gallons daily. The water-table contours at some distance west of the wells were not appreciably affected by the pumping from the wells, indicating that only a small part of the underflow was intercepted by the wells. The total

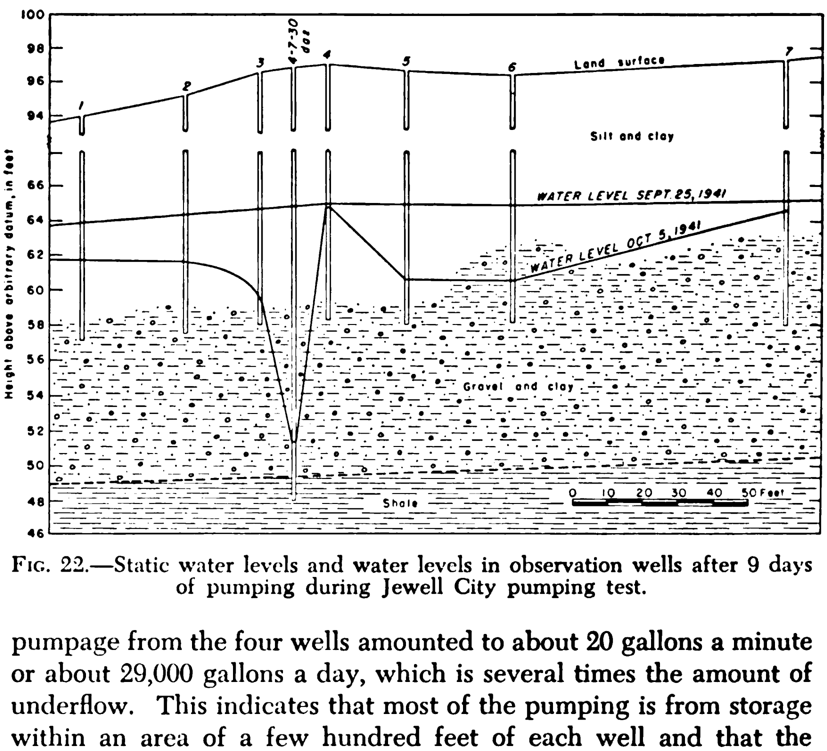

FIG. 22.—Static water levels and water levels in observation wells after 9 days of pumping during Jewell City pumping test.

pumpage from the four wells amounted to about 20 gallons a minute or about 29,000 gallons a day, which is several times the amount of underflow. This indicates that most of the pumping is from storage within an area of a few hundred feet of each well and that the ground-water reservoir must be periodically replenished by recharge from precipitation as there was no persistent decline of water level.

Recovery

GENERAL FEATURES

When water is withdrawn from a well, there is a difference in head between the water inside the well and the water in the surrounding material at some distance from the well. The water table in the vicinity of a well that is discharging water has a depression resembling in form an inverted cone, the apex of which is at the well. This depression of the water table is known as the cone of influence or cone of depression and the surface area underlain by it is known as the area of influence. In any given well the greater the pumping rate, the greater the drawdown (lowering of the water level, commonly expressed in feet).

The capacity of a well may be defined as 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 well is generally less than its total capacity; however, some wells are pumped at their total capacity.

The specific capacity of a well is its rate of yield per unit of drawdown and is determined by dividing the tested capacity in gallons a minute by the drawdown in feet. Well 4-7-30da2 at Jewell City had a yield of about 2 gallons a minute and a drawdown of 14 feet. The specific capacity of that well, therefore, is 0.14 gallon a minute per foot of drawdown, or simply 0.14.

When a well is pumped, the water level drops rapidly at first and then more slowly, but it may continue to drop for several hours or days. In testing the specific capacity of a well, therefore, the well must be pumped until the water level remains approximately stationary. When the pump is stopped, the water level rises rapidly at first, then more slowly, and may continue to rise long after pumping has ceased.

WELLS

In Jewell County, ground water is recovered from dug, drilled, and bored wells. No driven wells were observed, but some driven wells may be in use in the Republican Valley.

Dug Wells

Dug wells are wells that have been excavated by hand, generally with pick and shovel. They are walled with wood, rock, concrete, brick, or metal. They are generally less than 60 feet in depth and are from about 2 to 18 feet in diameter. Dug wells are more subject to surface contamination than are properly constructed drilled wells; nevertheless, in Jewell County dug wells are generally preferable for farm wells because the water-bearing material has a low permeability, and the wells have a low specific capacity. For intermittent pumping, a large dug well acts as a storage reservoir for collecting water during a nonpumping period, and it will then furnish moderate quantities of water for short periods of pumping. At one time nearly all municipal wells in Jewell County were large-diameter (10 to 18 feet) dug wells and were equipped with large-capacity pumps for intermittent pumping. More recent municipal wells were drilled and equipped with lower capacity pumps for continuous pumping.

Bored Wells

Many wells in the unconsolidated surficial deposits in Jewell County are bored and cased with tile. They are made by hand augers or posthole diggers and by a horse- or power-driven auger. They range from about 6 inches to 22 inches in diameter but are commonly about 12 inches. The deepest bored well that was measured was 138.6 feet (well 1-8-11cc).

Drilled Wells

A drilled well is one that is excavated by a percussion or rotary drill. In Jewell County, most of the drilled wells were drilled by the percussion method with portable cable-tool drilling rigs. This method of drilling consists of raising and lowering a heavy bit on the end of a steel cable that is threaded over a sheave at the top of a tower or mast. The crushed material in the bottom of the hole is mixed with water and removed by means of a bailer.

Most drilled wells in the county have galvanized-iron casing; a few have wrought-iron casing. The diameter of the casing ranges from 5 to 10 inches.

Wells in consolidated deposits.—Some of the wells in the southeastern part of Jewell County obtain water from consolidated deposits (Dakota formation and Greenhorn limestone) and have been drilled with portable cable-tool rigs. Some of the wells are open-end wells; that is, the hole is cased through the overlying Carlile shale and a few feet into the consolidated rocks, but the lower part of the hole is not cased.

Wells in unconsolidated deposits.—Drilled wells in the northern and northeastern parts of the county obtain water from unconsolidated Pleistocene deposits. These wells are cased the full depth of the hole to prevent caving. The casing is generally perforated in the lower part.

The Mankato public-supply wells in the White Rock Valley and the Jewell City public-supply wells are gravel-packed. In constructing this type of well, a hole of large diameter (48 to 60 inches) is first drilled and 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 filled with carefully sorted gravel—preferably of a grain size just slightly larger than the openings in the screen and also just slightly larger than that of the water-bearing material. The outer casing is then withdrawn to uncover the screen and allow the water to flow through the gravel packing from the water-bearing material. The envelope of selected gravel that surrounds the screen increases the effective diameter of the well and, hence, slightly increases the yield of the well.

Utilization

Ground water in Jewell County is used chiefly for domestic, stock, and public supplies. Some water is used from the public supplies by the railroads and industrial plants in the county, but the amount is very small. No agricultural crops are irrigated with ground water. Records of 258 wells in the county and 1 outside the county were obtained and are tabulated in Table 17.

DOMESTIC AND STOCK SUPPLIES

In Jewell County, domestic supplies are obtained from wells and cisterns; stock supplies are obtained from wells and ponds. Many wells do not furnish adequate water supplies for domestic and stock purposes, especially during dry years, and must be supplemented by cisterns and ponds. Also, much of the water is very hard and is unsuitable for domestic purposes. Many dug wells are in poor condition and may be contaminated easily. A large majority of the farms have cisterns, and most rural schools use cisterns for their water supply.

Dug wells are preferred for stock wells as they are pumped intermittently and between pumping periods they serve to accumulate and store water. A large-diameter dug well will hold enough water to supply the needs of a few head of stock, and the supply generally is replenished in time for the next pumping period.

The topography of Jewell County is well adapted for the construction of ponds. Many farmers use farm ponds to furnish stock water and to recharge ground water. Most wells are in the valleys and gullies, and if down gradient from ponds receive considerable recharge from the ponds. The construction of farm ponds was greatly encouraged during the drought by many Federal and State agencies.

DROUGHT EMERGENCY SUPPLIES

Jewell County was extremely hard hit by the droughts in 1934, 1936, and 1939. Stock ponds and wells failed in many instances. Farmers were compelled to haul water long distances or dispose of their livestock. The use of water was drastically restricted in most towns, especially Mankato, Jewell City, and Formoso. The Kansas Emergency Relief Committee was organized and placed under the direction of Ogden S. Jones. The committee's action resulted in the construction of ponds and community wells in the most distressed areas. Twenty-two community wells were constructed in Jewell County. They were dug in the alluvium of small valleys. A typewritten report prepared at the completion of the work contained some data on the fluctuations of the water table, logs of test holes, and descriptions of the wells that were constructed.

A committee was appointed by the Governor in December 1939 to investigate the water problems of the State and to recommend emergency measures to combat drought conditions. Among the many suggestions that were made by the committee is the following (Knapp and others, 1940, p. 10).

> It would be a wise precaution to dig several drought emergency wells on each farm. These wells should not necessarily be located near the improvements but low in the farm's drainage where water may best be expected. These wells could be dug and walled after the harvest season and would repay the labor manyfold in times of water shortage. It would not be advisable to pump these emergency wells except during drought periods because pumping during normal seasons might exhaust a supply which should be held for emergencies.

Two or more wells on each farm during years of below normal precipitation may be desirable, especially on farms where the water-bearing materials have very low permeability. The removal of small quantities of water creates a cone of depression. Continued pumping expands the cone of depression. As the cone of depression expands, the hydraulic gradient decreases and the water percolates into the well at a progressively slower rate until the yield of the well becomes so small that it will not furnish an adequate water supply for the needs of the farm. Another well, possibly 1,000 feet away and practically beyond the limits of the cone of depression, may then be pumped. The water level in the well in which pumping has been temporarily discontinued will gradually return to, or nearly to, its original level. By alternating the periods of pumping of two or more wells, many farmers who heretofore have depended on the meager supplies from one well can have an adequate supply of water during years of nearly normal precipitation.

During a period of several years of below-normal precipitation, the water table declines progressively. Available information indicates that the water table in Jewell County had a net decline of more than 10 feet from 1920 to 1939. In small areas the water table disappeared, and in large areas the wells were nearly dry. However, even during the driest years, there were scattered local areas where ground water was available in sufficient quantities to supply the needs of most farmers. The community-well program that was begun in 1934 may be the solution to which the farmers must resort for their water supply during similar emergencies in the future.

Public Supplies

Six towns in Jewell County have public water supplies—Burr Oak, Esbon, Formoso, Jewell City, Mankato, and Randall. All are supplied from wells.

Burr Oak.—Burr Oak receives its water supply from two wells (2-9-23bb and 2-9-23bc, Table 17), one dug and one bored, in the alluvium of White Rock Creek. The dug well, which is about 60 feet deep and 18 feet in diameter, was dug in 1912 and was the source of supply until the other well was added in 1936. It is equipped with a turbine pump rated at 250 gallons a minute and operated by a 12-horsepower electric motor. According to S. E. Colvin, city water superintendent, it can be pumped dry in 4 hours. The bored well, which is 2 blocks north of the dug well, has a depth of 62 feet and a diameter of 15 inches. It is equipped with a plunger-type pump rated at 25 gallons a minute. It has a drawdown of 3 feet when pumping at 25 gallons a minute. The static water level in both wells is about 28 feet below the land surface.

Average daily consumption is about 20,000 gallons and maximum consumption about 50,000 gallons. The railroad obtains about 3,000 gallons semiweekly. Althought the water is hard, it is satisfactory for all ordinary uses.

Esbon.—Esbon receives its water supply from four wells (2-10-15dd1, 2-10-15dd2, 2-10-34da, and 3-10-3da). Well 2-10-34da, which is 1 mile north of town, was dug to a depth of 60 feet and a diameter of 8 feet in 1918. This well receives its water supply from Quaternary limestone gravel. It is equipped with a 3-cylinder pump, operated by a 25-horsepower electric motor, which pumps about 1,500 gallons daily. Well 3-10-3da, in Esbon, was dug in 1924 and has a depth of 42 feet and a diameter of 8 feet. It obtains its water supply from Quaternary limestone gravel. It is equipped with a turbine pump rated at 60 gallons a minute operated by a 7-horsepower electric motor. This well has about 27 feet of water and is kept in reserve for fire protection. Wells 2-10-15dd1 and 2-10-15dd2 are bored wells that penetrate the alluvium of White Rock Creek. Well 2-10-15dd1, which was completed in 1925, has a depth of 66 feet and a diameter of 8 inches. It is equipped with a cylinder pump rated at 7 gallons a minute and operated by a 10-horsepower gasoline engine. Well 2-10-15dd2, completed in 1939, has a depth of 66 feet and a diameter of 8 inches. It is equipped with a 6-gallon a minute cylinder pump operated by a gasoline engine. The static water level in wells 2-10-15dd1 and 2-10-15dd2 is about 34 feet below the land surface. Average daily consumption is about 5,000 gallons and maximum consumption about 20,000 gallons.

Formoso.—Formoso is supplied by two wells (3-6-21bd1 and 3-6-21ca2) that obtain water from Quaternary limestone gravel on top of the Fairport chalky shale member. Well 3-6-21ca2, dug in 1931 in the southwest corner of town, is 49 feet in depth and 12 feet in diameter. It is equipped with a cylinder pump rated at 90 gallons a minute and operated with a 7.5-horsepower electric motor. This well yields about 1,000 gallons of water a day. Well 3-6-21bd1, which is north of well 3-6-21ca2, was dug to a depth of 51.5 feet and a diameter of 14 feet in 1935. It is equipped with a cylinder pump rated at 25 gallons a minute and operated by an electric motor rated at 3 horsepower. This well yields about 2,000 gallons a day. Formoso has experienced serious difficulties in obtaining an adequate water supply. The available water supply has averaged about 2,500 gallons a day, which is an average of only about 10 gallons per person.

Jewell City.—At the time of the investigation in 1941 the water supply for Jewell City was obtained from six wells (4-7-30ad, 4-7-30da1, 4-7-30da2, 4-7-30dd, 4-8-25da, and 4-8-25dd). These wells received their supply from limestone gravel in the valley of Buffalo Creek. The limestone gravel overlies the Fairport chalky shale member of the Carlile shale. Wells 4-8-25da and 4-8-25dd are dug wells on the west side of town. Well 4-8-25dd is near the dam on Buffalo Creek; well 4-8-25da is about half a mile north of the filtration plant. Wells 4-7-30ad, 4-7-30da1, 4-7-30da2, and 4-7-30dd, drilled wells east of town, have a depth of about 47 feet. They are equipped with cylinder pumps and operated with electric motors. The wells had yields ranging from about 2 to 10 gallons a minute. During some of the drought years, the wells failed to furnish an adequate water supply and the use of water was restricted.

Since 1941, two wells have been drilled in the SE¼ sec. 25, T. 4 S., R. 8 W. (wells 4-8-25da2 and 4-8-25db). Wells 4-8-25da2 and 4-8-25db have yields of 14 and 10 gallons a minute respectively. The water supply is now obtained from the four wells on the west side of town. The four wells on the east side are maintained only as an emergency supply.

According to Carl Carlton, water superintendent, the maximum daily consumption is about 68,000 gallons and the average is about 40,000 gallons.

Mankato.—The water supply of Mankato is obtained from nine wells. Wells 3-8-16ca, 3-8-22bc, and 3-8-22ca1 are dug wells in the city limits. Well 3-8-16ca is on the west side of town and is just below an impounding reservoir, well 3-8-22bc is near the Missouri-Pacific Railway depot in the southwest part of town, and well 3-8-22ca1 is in the south part of town. These wells obtain their water supply from the alluvium of a branch of Buffalo Creek. The water-bearing material consists chiefly of the limestone gravel that overlies the Smoky Hill chalk member. Six wells are in White Rock Creek valley about 8 miles north of town. Wells 2-8-11ca1, 2-8-11ca2, and 2-8-11cd2 were drilled in 1929; wells 2-8-11db1, 2-8-11db2, and 2-8-11cd1 were drilled in 1934. They range in depth from about 73 to 78 feet and yield from 5 to 15 gallons a minute. Maximum consumption of water is about 100,000 gallons a day. Mankato had considerable difficulty in obtaining an adequate water supply during some of the dry years. In 1927 they sought to obtain a deep water supply by drilling 1,200 feet into the Dakota formation, but the water was too salty for domestic use.

Randall.—The water supply of Randall is obtained from a well dug in 1928 in the alluvium of Buffalo Creek. The well, in the south part of town, has a depth of approximately 40 feet and a diameter of 16 feet. It is equipped with a turbine pump rated at 50 gallons a minute and operated by an electric motor rated at 7½ horsepower. Average daily consumption is about 10,000 gallons and maximum about 15,000 gallons.

POSSIBILITIES OF DEVELOPING ADDITIONAL SUPPLIES

Studies of the pumpage records from wells and the pumping tests that were made in Jewell County indicate that the greater part of the yield from a well is derived from storage in the immediate vicinity of the well. Also, water-table contour maps indicate that the pumping affects appreciably only those contours comparatively near the pumped well, even though the continuous pumping in the well field exceeds the amount of underflow moving into the pumped area. The water comes from the cone of depression, and as pumping continues the cone enlarges and the yield of the well diminishes. Unless recharge occurs periodically, the yield continues to diminish.

During the dry years between 1930 and 1940, many of the wells in Jewell County failed. Some of them failed because of a large decline of the water table; in some places the water table disappeared. Other wells failed because of the development of a large cone of depression and lack of periodical recharge. When wells fail because of the decline or disappearance of the water table, the development of additional supplies is difficult, if not impossible. The only immediate solution is to haul water. A long-range solution may be (1) the construction of reservoirs to furnish water for stock use and to recharge the ground water down gradient from the reservoir; (2) the adoption of farming practices that will increase infiltration and, under favorable conditions, increase ground-water recharge; and (3) a greater development of community wells. When wells fail because of the development of large cones of depression, the obvious solution is to obtain the water supply from a larger number of wells spread over a larger area. Some of the towns in Jewell County that have experienced considerable difficulty in obtaining an adequate water supply might consider the development of a water supply based on a system of several wells of low cost and low yield instead of trying to develop an adequate water supply from only two or three wells.

There will generally be some doubt whether a municipal well has failed because of a general decline of the water table or whether the failure was caused by the development of a large cone of depression. The cause of failure can be determined easily if a few properly distributed wells in the area, some of which are outside the cone of influence caused by pumping, are measured periodically for several years. The records of a few observation wells will save much time and expense in an investigation when additional water supplies must be developed.

Chemical Character of Ground Water

The chemical character of the well waters in Jewell County is shown by the analyses of water from 36 representative wells given in Table 15. The samples of water were analyzed by H. A. Stoltenberg, Chemist, in the Water and Sewage Laboratory of the Kansas State Board of Health. The analyses show only the dissolved mineral content of the waters and do not, in general, indicate the sanitary condition of the waters.

CHEMICAL CONSTITUENTS IN RELATION TO USE

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

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

The dissolved solids in samples of water collected in Jewell County ranged from 101 to 3,880 parts per million. Three samples had less than 300 parts per million; nine samples had more than 1,000 parts per million (Table 16).

Hardness.—The hardness of water, which is the property that receives the most attention generally, is most commonly recognized by its effect when soap is used with the water. Calcium and magnesium cause almost all the hardness of natural water. These con-

TABLE 15.—*Analyses of water from typical wells in Jewell County*

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

Well number	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ Total	Carbonate	Noncarbonate
1-6-24cb	58.6	Meade formation	11-4-41	56	311	0.28	82	11	22	284	19	28	0.1	6.2	250	233	17
1-7-9bb	39.5	do.	6-14-45	57	466	0.60	115	16	39	386	42	42	0.2	22	353	316	37
1-7-11bb	66.7	do.	11-4-41	56	101	1.8	23	5.7	2.1	57	11	6.8	0.1	22	81	46	35
1-7-17cd	46.8	do.	6-14-45	57	385	6.0	98	14	31	311	17	64	0.2	8.0	302	255	47
1-7-31dd	87.7	Pleistocene	6-14-45	56	378	1.8	71	9.8	63	346	19	23	0.2	22	217	217	0
1-8-2cc	87.8	Meade formation	11-4-41	55	348	9.5	92	15	18	326	21	28	0.2	1.7	291	268	23
1-8-13ba	110.3	do.	6-14-45	55	377	0.03	108	14	14	342	9.9	25	0.2	38	327	280	47
1-8-16cc	98.8	do.	6-14-45	55	319	0.10	82	22	13	327	7.4	32	0.4	1.5	295	268	27
1-9-14bb	73.6	Pleistocene	6-14-45	56	405	11	112	17	14	316	72	30	0.2	3.5	350	259	91
1-9-16aa	104.7	do.	11-4-41	56	362	4.6	101	20	7.8	315	15	52	0.2	3.8	334	258	76
1-10-3ab	28.4		11-5-41	55	356	15	105	15	11	351	12	26	0.2	11	324	288	36
1-10-34cd	101.1	Pleistocene	11-5-41	55	459	2.8	141	17	11	436	6.0	52	0.1	11	422	358	64
2-6-12dd	35.2	Alluvium	11-4-41	56	1,150	2.4	230	35	116	510	446	56	0.1	11	718	418	300
2-8-13dd	70.4	do.	6-14-45	56	460	1.1	106	33	20	394	72	27	0.9	6.6	400	323	77
2-8-26cc	59.5	do.	11-5-41	55	508	2.1	100	23	69	549	19	12	0.4	7.1	344	344	0
2-9-11cb	56.3	do.	11-4-41	56	788	4.6	176	25	80	599	158	43	0.1	0	542	491	51
2-9-28cb	51.5	do.	11-5-41	55	523	0.88	138	15	26	378	104	5.8	0.5	44	406	310	96
2-10-12ba	90.3	Meade formation	6-14-45	57	293	4.4	80	13	18	320	6.6	15	0.2	2.0	253	253	0
2-10-31cc	50.8	Pleistocene	11-5-41	55	403	5.4	101	10	40	349	16	52	0.1	4.0	293	286	7
3-6-4dc	24.0	Alluvium	11-4-41	57	3,460	2.3	642	176	166	349	1,238	425	0.6	637	2,326	286	2,040
3-7-19bd	30.1	Pleistocene	11-5-41	57	893	0.12	202	20	43	299	85	48	0.1	345	586	245	341
3-9-23dd	43.4	Alluvium	11-3-41	55	667	0.09	176	18	36	428	188	24	0.3	11	513	351	162
3-10-24ba	23.3	do.	11-3-41	58	1,088	8.0	296	20	30	476	228	72	0.2	195	820	390	430
4-7-26cc	25.8	Pleistocene	11-5-41	56	2,497	1.7	483	57	268	446	947	420	0.5	97	1,439	366	1,073
4-9-17aa	31.6	Alluvium	6-14-45	56	559	1.8	134	18	41	356	113	40	0.2	38	408	292	116

4-10-20dc	14.1	do.	11-3-41	57	682	0.37	182	22	40	572	113	24	0.3	14	544	469	75
5-6-26ba	138.3	Dakota formation	11-7-41	58	820	4.2	198	20	43	382	93	71	0.3	199	576	313	263
5-6-34cd	100+	do.	11-5-41	58	2,246	4.0	418	43	251	293	778	375	0.9	230	1,220	240	980
5-7-19cd	31.8	Alluvium	6-14-45	57	2,716	4.0	603	53	172	281	1,619	126	0.8	4.4	1,722	230	1,492
5-7-32dc	32.3	Pleistocene	11-3-41	56	3,880	1.2	658	129	442	495	1,754	625	0.9	23	2,172	406	1,766
5-8-4bb	30.9	Alluvium	11-3-41	56	3,050	0.53	505	54	339	438	713	224	0.3	996	1,482	359	1,123
5-8-11cd	55.0	do.	6-14-45	58	820	0.16	161	19	100	334	241	104	0.3	30	480	274	206
5-8-21cc	39.9	Pleistocene	6-14-45	58	72	0.84	25	1.4	1.2	76	0.8	3.0	0.1	3.8	68	62	6
5-9-23dc	26.1	Alluvium	11-3-41	57	1,824	1.2	449	20	87	422	673	126	0.2	248	1,235	346	889
5-10-16bb	41.5	Pleistocene	11-3-41	57	515	0.98	125	20	31	346	68	48	0.2	49	394	284	110
5-10-33ab	51.3	do.	11-3-41	57	815	0.42	180	24	67	331	181	222	0.5	75	548	272	276

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

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

In addition to total hardness, the table of analyses shows the carbonate hardness and the noncarbonate hardness. The carbonate or "temporary" hardness is that due to the presence of calcium and magnesium bicarbonates. It can be almost entirely removed by boiling. The noncarbonate hardness is due to the presence of sulfates 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 carbonate and noncarbonate hardness. In general, the noncarbonate hardness forms harder scale in steam boilers.

Water having a hardness of less than 50 parts per million is generally rated as soft, and its treatment for reduction of hardness under

TABLE 16.—*Summary of the chemical quality of the samples of water from wells in Jewell County*

Range in parts per million	Number of samples
Dissolved solids	
Less than 300	3
301-400	8
401-500	5
501-600	4
601-800	3
801-1,000	4
1,001-2,000	3
More than 2,000	6
Total hardness	
Less than 100	2
101-200	0
201-300	6
301-400	9
401-500	4
501-600	6
601-1,000	2
More than 1,000	7
Nitrate	
Less than 10	13
11-30	9
31-50	5
51-100	2
101-200	2
201-500	3
More than 500	2

ordinary circumstances is not necessary. Hardness between 50 to 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. Water 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 from 60 to 100 parts per million. The additional improvement from further softening of a whole public supply generally is not deemed worth the increase in cost.

The hardness of the samples of water from Jewell County ranged from 68 to 2,320 parts per million (Table 16).

Iron.—Next to hardness, iron is the constituent of natural water that in general receives the most attention. The quantity of iron in ground water may differ greatly from place to place even though the water is from the same formation. If water contains much more than 0.1 part per million of iron, the excess will normally precipitate and settle as a reddish sediment. Iron in sufficient quantity to give a disagreeable taste and to stain clothing and utensils may be removed from most waters by aeration and filtration, but some water requires the addition of lime or further treatment.

Of 36 samples of water from Jewell County, 34 contained 0.1 part per million or more of iron. Five samples of water had more than 5 parts per million of iron.

Fluoride.—Although fluoride generally is present only in small quantities in ground water, the amount of fluoride present in water used by children should be known. 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 drink water containing too much fluoride during the formation of the permanent teeth. Dean (1936) has described the effects of fluoride in drinking water on the teeth of children (p. 1270):

> . . . from the continuous use of water containing about 1 part per million, it is probable that the very mildest forms of mottled enamel may develop in about 10 per cent of the group. In water containing 1.7 or 1.8 parts per million, the incidence may be expected to rise 40 or 50 per cent, although the percentage distribution of severity would be largely of the "very mild" and

"mild" types. At 2.5 parts per million an incidence of about 75 to 80 per cent might be expected, with possibly 20 to 25 per cent of all cases falling into the "moderate" or severer type. A scattering few may show the "moderately severe" type.

At 4 parts per million the incidence is, in general, in the neighborhood of 90 per cent, and as a rule, 35 per cent or more of the children are classified as "moderate" or worse. In concentrations of 6 parts per million or higher an incidence of 100 per cent is not unusual.

Recent studies have indicated that, although more than 1.5 parts per million of fluoride may be detrimental to the teeth of children by causing mottling, less than 1.5 parts is beneficial in helping to prevent tooth decay (Dean, Arnold, and Elvove, 1942).

None of the samples of water collected in Jewell County contained more than 0.9 part per million of fluoride. Of the 36 samples of water, 31 had 0.5 part per million or less.

Nitrate.—The nitrate content of water used for drinking has been the object of a great deal of attention in the past few years since the discovery that high nitrate water may cause cyanosis of infants when the water is used in the preparation of baby formulas. Although some nitrate is derived from nitrate-bearing rocks and minerals in the water-bearing formations, high nitrate concentrations are probably due largely to direct flow of surface water into the well or to percolation of nitrate-bearing water into the well through the top few feet of the well. Nitrate compounds are readily dissolved from soils that have high concentrations of these salts. Other sources of nitrogenous material are privies, cesspools, and barnyards; consequently, a large amount of nitrate may indicate also that harmful bacteria are present in the water. Because they generally are poorly sealed, dug wells allow more contamination by surface seepage than drilled wells, which are commonly deeper and more tightly cased.

Ninety parts per million of nitrate as NO_3 in water is considered by the Kansas State Board of Health as dangerous to infants, and some authorities advocate that water containing more than 45 parts per million (as NO_3) should not be used for formula preparation (Metzler and Stoltenberg, 1950). Of the 36 samples of water collected from wells in Jewell County, 9 samples contained more than 50 parts per million of nitrate, 5 contained more than 200 parts, and 2 contained more than 500 parts (Table 16).

SANITARY CONSIDERATIONS

The analyses of water given in Table 15 show only the amounts of dissolved mineral matter in the water and do not indicate the sanitary quality of the water.

The entire population of Jewell County is dependent on water supplies from wells, and it rests chiefly with the drillers and individual well owners to observe precautions to insure a safe and wholesome water supply. Every precaution should be used to protect domestic and public water supplies from pollution by organic material. A well should not be located where there are possible sources of pollution. The drainage from cesspools and privies is particularly dangerous. Every well should be constructed to seal off all surface water, especially dug wells because they are more subject to contamination from surface water.

GEOLOGIC FORMATIONS IN RELATION TO GROUND WATER

Cretaceous System

GULFIAN SERIES

Dakota Formation

Character, distribution, and thickness.—The Dakota is the basal unit of the Gulfian series (Moore and others, 1951, p. 25, Figs. 11-12). In north-central Kansas, the Dakota consists of 200 to 300 feet of clay, shale, siltstone, and sandstone locally containing thin lignitic beds in the upper part. Plummer and Romary (1942), who made an intensive study of the Dakota formation in the outcrop area in central Kansas, showed the Dakota to be principally clay and shale containing irregular sandstone lentils, which are interconnected only locally.

In Jewell County the character of the Dakota formation is believed to be similar to that as shown by studies of the outcrop areas in Cloud and Republic Counties to the east (Wing, 1930, pp. 31-35; Fishel, 1948, pp. 79-84). In those areas it is composed largely of clay and shale containing sandstone and siltstone beds. The clays are gray, white, yellow, red, maroon, or variegated, are generally plastic, and many contain silt, limonite, or siderite.

The lenticular sandstone beds range from a few inches to many feet in thickness, may be poorly cemented or so well cemented with calcium carbonate that they are quartzitic, and contain limonite, hematite, and siderite. The sandstones range from fine to coarse

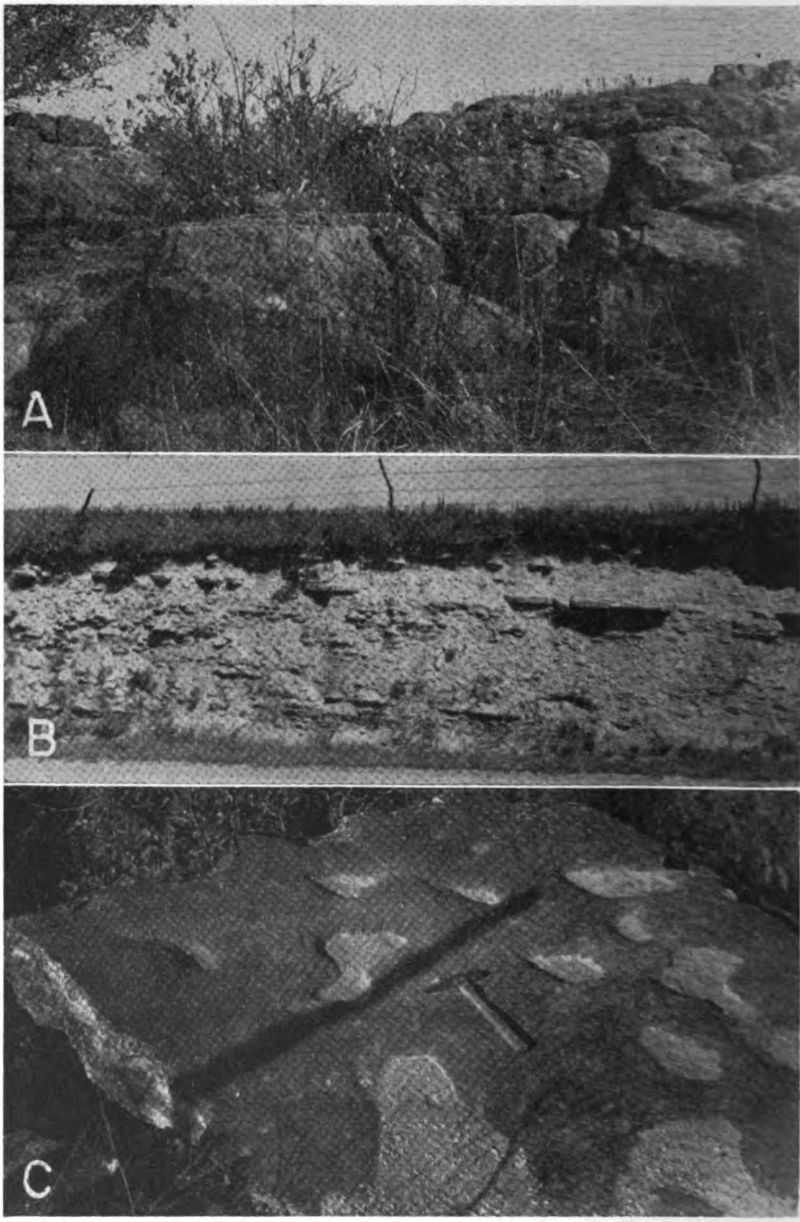

PLATE 7. Cretaceous rocks in Jewell County. **A,** Massive sandstone of the Dakota formation in the NW¼ NW¼ sec. 13, T. 5 S., R. 6 W. **B,** Lower part of Pfeifer shale member, Greenhorn limestone in road cut in NE¼ SE¼ sec. 12, T. 5 S., R. 7 W. **C,** Small solution pits developed in upper surface of "Shell-rock limestone" bed of Jetmore chalk member, NE¼ sec. 15, T. 5 S., R. 6 W.

grained, although fine-grained beds predominate, and may be cross bedded or ripple marked. They are highly lenticular and although present in one locality may be absent a short distance away laterally. Locally, in the upper 30 feet of the formation, lignite beds as much as 3 feet in thickness occur (Schoewe, 1952, pp. 81-87). Lignitic coal was mined from these beds 50 to 60 years ago at two localities in Jewell County (Schoewe, 1952, pp. 124-128).

The Dakota formation underlies all Jewell County but crops out in only one small area south of Buffalo Creek in secs. 12, 13, and 14, T. 5 S., R. 6 W. In this area the exposed Dakota formation consists of 11 to 28 feet of massive standstone, which underlies the Graneros shale, and about 3 feet of gray clay shale (Pl. 7A). The sandstone is fine grained, cross bedded, and loosely cemented with limonite, or, locally, well cemented with calcium carbonate to form ellipsoidal masses of hard resistant "quartzite." The sandstone weathers to a rusty brown and forms a small ledge at the base of the steep slope on the south side of Buffalo Creek valley.

Water supply.—Although the Dakota formation in this part of Kansas is composed of about 75 percent clay and shale, a well drilled at any spot is likely to penetrate one or more sandstone lentils that are water bearing. Oil and gas tests in Jewell County and wells drilled at Mankato and Jewell for municipal water supplies tapped only salt water in the sandstones of the Dakota formation. Several wells in the south part of T. 5 S., R. 6 W. are the only wells in the county known to obtain potable water from the Dakota formation. Wells 5-6-24cc, 5-6-26ba, and 5-6-34cd are more than 100 feet in depth, and had depths to water levels of 91.25, 17.35, and 98.66 feet respectively in October 1941. Analyses of water from wells 5-6-26ba and 5-6-34cd indicate that water in the Dakota formation in this area is high in mineral content, especially calcium, sodium, bicarbonate, and sulfate. The water is not the predominantly sodium-chloride water expected from reports of "salt water" in deep wells in the county and may represent water that has been mixed with water from other formations.

The origin of the mineralized waters in the Dakota formation has been a problem for half a century. Logan (1897, pp. 209-210) suggested that the minerals might come from saliferous beds in the upper part of the formation. Recent detailed surface work by Plummer and Romary (1942) and subsurface study by Frye and Brazil (1943) have failed to reveal any saliferous beds in the Dakota formation. The mineralized water in the Dakota formation in Jewell County is likely connate marine water that has not been completely flushed out of the sandstones and replaced by fresh water.

The depth to the top of the Dakota formation ranges from a few feet in southeastern Jewell County to more than 600 feet in the northwestern part of the county.

Graneros Shale

Character, distribution, and thickness.—The Graneros shale consists of the noncalcareous fissile marine shale and sandstone beds that lie conformably between the Dakota formation and the Greenhorn limestone (Moore and others, 1951, p. 25, Figs. 11-13).

The Graneros shale is black, weathering to lead gray or coffee brown. Locally it contains siltstone or sandstone beds, limonitic zones, and thin fossiliferous limestone beds. Selenite crystals occur in the formation in many places.

The Graneros shale crops out in only one area in Jewell County, but it underlies all parts of the county except in the area where the Dakota formation crops out, and also in Buffalo Creek valley adjacent to the outcrop area of the Dakota formation where the Graneros shale has been removed by erosion. In the outcrop area in the NW¼ sec. 14 and sec. 15, T. 5 S., R. 6 W., the Graneros consists of about 15 feet of black noncalcareous fissile shale containing limonitic and sandy layers. A massive bentonite bed, 1.0 to 1.4 feet thick, occurs about 1 foot below the top of the formation. The base of the formation is not exposed in these areas, but the covered slope formed by the Graneros shale can be traced 1 mile northeast of its outcrop, where it is underlain by sandstones of the Dakota formation.

The thickness of the Graneros shale in the subsurface of Jewell County is not known, but it is probably between 20 and 30 feet for most parts of the county. Wing (1930, p. 31) states that the thickness of the formation in Republic and Cloud Counties ranges from 20 to 30 feet, and Landes and Ockerman (1930, p. 30) report a thickness of 26 feet near Simpson in southeastern Mitchell County.

Water supply.—The Graneros shale is relatively impermeable and no wells are known to obtain water from it in Jewell County.

Greenhorn Limestone

Character, distribution, and thickness.—The Greenhorn limestone is the series of marine beds conformably overlying the Graneros shale and conformably underlying the Carlile shale. The Greenhorn limestone has been subdivided into four members, in ascending order: Lincoln limestone member, Hartland shale member, Jetmore chalk member, and Pfeifer shale member (Moore and others, 1951, pp. 24-25, Figs. 11-13). The predominant lithology of the Greenhorn limestone is chalky shale or shaly chalk. Interbedded with the shale are thin limestones, as much as 1 foot in thickness, and thin bentonites, as much as 0.5 foot in thickness. Limestone is most common in the basal part and upper third of the formation; the middle part contains very little limestone. The limestones in the basal part are thin, irregularly bedded to lenticular, hard, dark, and "petroliferous" (that is, they exude an odor of petroleum when freshly broken). The limestones in the upper part commonly range from 0.2 to 0.5 foot in thickness and are soft, chalky, and white to cream colored. Many of them are of uniform thickness over considerable areas, but others, particularly those in the Pfeifer shale member, are lenticular or are zones of flat discoidal concretions.

The principal outcrop areas of the Greenhorn limestone in Jewell County are south of Buffalo Creek valley in the southeastern part of the county and along Marsh Creek in the east part of T. 4 S., R. 6 W. The Greenhorn limestone forms a series of prominent rolling hills on the south sides of the two streams, but on the north sides of the valleys the outcrop is obscured by loess of the Sanborn formation and the limestone crops out only where deeply dissected. Except for small areas along Marsh and Buffalo Creeks where it has been removed by erosion, the Greenhorn limestone underlies all of Jewell County. Landes (1930, p. 23) gives the thickness of the Greenhorn limestone in Mitchell County as 82 feet. Measured sections of the Pfeifer shale member and Jetmore chalk member near Randall indicate that the thickness of the formation in that area is about the same as in Mitchell County. The formation thins rapidly toward the east, and the total thickness near the Cloud County line is only about 65 feet. Along the eastern border of Jewell County, in secs. 24, 25, and 36, T. 5 S., R. 6 W., the upper member, the Pfeifer shale member, has been eroded away and the hills are capped by the Jetmore chalk member. Locally in this area, the upper bed of the Jetmore chalk member, the "Shell-rock limestone," has been quarried for fence posts.

The basal member of the Greenhorn limestone, the Lincoln limestone member, overlies the Graneros shale and crops out in a small area in the southeastern part of Jewell County. In the outcrop area the Lincoln limestone member is about 15 feet thick and is composed

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principally of gray to cream-colored calcareous shale. Thin limestones commonly ranging from 0.5 to 1 inch in thickness occur irregularly in the lower part. They are generally hard, dark, and coarsely crystalline and contain fragments of fossil shells and shark teeth. On weathering they become brown and finely laminated. Many are "petroliferous" (give off a petroleum odor when freshly broken). The upper part of the Lincoln limestone member contains several limestone beds of the same type but ranging from 2 to 4 inches in thickness. Several beds of cream-colored to orange bentonite are present in the Lincoln member.

The Hartland shale member of the Greenhorn limestone crops out in about the same general area as the Lincoln limestone member. The Hartland shale member consists of about 25 feet of calcareous shale containing thin lenticular slabby limestones and many bentonite beds ranging from a featheredge to 6 inches in thickness. The shale is generally slaty in fresh exposures but becomes fissile and buff colored as it weathers. Some of the limestones are crystalline and resemble those of the Lincoln limestone member, but the limestones in the upper part of the member are soft and almost chalky in appearance.

The Jetmore chalk member crops out in most of the outcrop area of the Greenhorn limestone shown on Plate 1. The member contains several limestones in the upper part that are resistant to erosion and form the capping strata for the prominent Greenhorn hills in the southeastern part of the county. The topmost bed of the Jetmore chalk member is the "Shell-rock limestone". The bed, about 1 foot thick, has a thin shale parting in the center which contains many *Inoceramus* shells. Locally, where this limestone caps hills and ledges, small irregular pits may develop in the upper surface (Pl. 7C). This bed and three thinner underlying persistent limestones are the resistant strata that form the Greenhorn escarpment. The Jetmore chalk member consists of shale beds ranging from 0.5 to 1.0 foot in thickness alternating with beds of fossiliferous chalky limestone ranging from 0.2 to 0.5 foot in thickness. The shale is calcareous, slaty, and blue gray in fresh exposures but becomes fissile and cream colored as it weathers. The Jetmore chalk member in Jewell County ranges in thickness from about 10 feet in the SE¼ sec. 29, T. 5 S., R. 6 W., to about 16.7 feet in the SW¼ sec. 35, T. 3 S., R. 6 W. The thickness is probably 16 to 17 feet in the subsurface beneath most of Jewell County. A typical measured section of the Jetmore chalk member is given below.

The uppermost member of the Greenhorn limestone, the Pfeifer shale member, consists principally of calcareous chalky shale, thin lenticular limestone, and zones of flat discoidal concretions (Pl. 7B). The Fencepost limestone bed, a persistent chalky limestone about 0.8 foot thick at the top of the member, has been quarried at several places in southeastern Jewell County for building stone and for stone fence posts. This bed, the thickest persistent limestone in the Pfeifer shale member, is easily recognized by its thickness and a thin iron-stained band in the center. A second limestone bed, about 4.5 feet lower, is sometimes mistaken for the Fencepost. This limestone is only about 0.3 to 0.4 foot thick and lacks the prominent iron-stained band. Other limestone beds in the member are generally 1 to 4 inches thick, chalky, and lenticular or irregularly bedded, and contain *Inoceramus* shells. The concretionary zones are 1 to 2 inches thick and are generally formed by bands of discoidal concretions which are as much as 1 foot in diameter. The concretions are somewhat harder than the chalky limestones and also contain *Inoceramus* shells. The shale is calcareous, fissile, and generally white to cream colored in most exposures. Two or three thin bentonite seams occur in the member at some localities. The measured section below illustrates the lithology of the Pfeifer shale member and Jetmore chalk member.

Measured section of the Greenhorn limestone, in the east cut bank of a creek just west of north-south road in the NW¼ SW¼ sec. 35, T. 3 S., R. 6 W. Measured by H. A. Waite, October 2, 1941.

	Thickness, feet
CRETACEOUS—Gulfian	
Greenhorn limestone	
Pfeifer shale member	
44. Limestone, dense, fine-grained; fencepost limestone bed; contains characteristic reddish-brown seam near middle	0.75
43. Shale, chalky; contains gray bentonitic clay seam ¾ inch thick at base	0.6
42. Shale, calcareous, buff to orange-tan	2.8
41. Limestone, similar to bed 39	0.2
40. Shale, calcareous, fissile, light-buff streaked with brown laminae	0.9
39. Limestone, dense, fine-grained, buff to brown, rusty stained	0.3
38. Shale, calcareous, buff to orange-tan; contains several thin beds of fossiliferous slabby limestone	2.5
37. Limestone, fine-grained, buff to yellow	0.25
36. Shale, calcareous, gray to buff	0.5
35. Limestone, fine-grained, gray to buff	0.2
34. Shale, calcareous, platy, gray to buff	1.0
33. Limestone, fine-grained, gray to buff, rusty-brown near base	0.2
32. Shale, calcareous, fissile	1.7
31. Limestone, fine-grained, buff	0.15

	Thickness, feet
30. Shale, calcareous, gray to buff	0.5
29. Limestone, fine-grained, buff	0.15
28. Shale, calcareous, fossiliferous, gray to buff	2.2
Jetmore chalk member	
27. Limestone, fine-grained, dense, very fossiliferous, light-buff; shell-rock limestone	0.9
26. Shale, calcareous, light-gray to buff; contains several thin limestone beds	2.0
25. Limestone, fine-grained, fossiliferous, gray to cream	0.4
24. Shale, calcareous, platy, gray to buff	0.8
23. Limestone, dense, gray; contains small brown fossil impressions (*Inoceramus*)	0.3
22. Shale, calcareous, fossiliferous, gray to buff	0.7
21. Limestone, dense, fine-grained, fossiliferous, cream-colored to gray	0.3
20. Shale, platy; gray at top, gray to orange-tan at base	0.5
19. Limestone, fine-grained, gray to buff	0.25
18. Shale, calcareous, gray	0.5
17. Limestone, fine-grained, gray to buff	0.25
16. Shale, calcareous, light-gray	0.4
15. Limestone, fine-grained, cream-colored to buff stained with rusty-brown splotches	0.25
14. Shale, calcareous, fissile, light-gray with rusty-brown streaks; contains 2-inch limestone 3 inches above base	1.0
13. Limestone, fine-grained, dense, cream-colored to light-yellow; contains rather persistent rusty-brown band 1 inch thick near middle	0.5
12. Shale, calcareous, fissile, light-gray with rusty-brown laminae	0.4
11. Limestone, fine-grained, gray to bluish-gray	0.2
10. Shale, calcareous, fissile, light-gray to bluish-black	0.75
9. Limestone, fossiliferous, bluish-gray to tan	0.3
8. Shale, calcareous, fissile, orange-tan at top, bluish-gray in lower part; contains fossils	0.4
7. Limestone, fine-grained, gray with rusty streaks	0.2
6. Shale, calcareous, platy, bluish-gray	0.4
5. Limestone, fine-grained; contains rusty streaks	0.3
4. Clay, bentonitic, bluish-gray mottled with yellow	0.2
3. Shale, calcareous, platy, bluish-gray	3.5
2. Clay, bentonitic, gray; contains limonitic streaks	0.5
1. Limestone, dense, gray, limonite-stained near top	0.4
Base of section, water level in creek	
Total thickness of Greenhorn exposed	31.5

Water Supply.—In general, the predominance of shale in the Greenhorn limestone indicates that the formation has little potential as an aquifer. Elsewhere, small quantities of water have been obtained from wells penetrating the weathered and broken limestones in the upper part of the formation, but no wells in Jewell County are known to obtain water from the Greenhorn. A small spring in the NW¼ NW¼ sec. 13, T. 5 S., R. 6 W. flows from the basal beds of the Greenhorn. The water is reported to be of good quality and is stored in a small pond for livestock use.

Carlile Shale

Character, distribution, and thickness.—The Carlile shale consists of 300 feet of marine shale conformably overlying the Greenhorn limestone and conformably underlying the Niobrara formation (Moore and others, 1951, p. 24, Figs. 11-13). The lower part, the Fairport chalky shale member, consists predominantly of thin-bedded to fissile calcareous shale containing an abundance of *Ostrea* shells. On fresh exposures the shale is light gray to buff, but it weathers to form a bright-yellow clay that is distinctive and easy to recognize. The basal part of the Fairport chalky shale member contains several persistent bentonite seams, many thin chalky limestones, and concretionary beds similar to those in the upper part of the Greenhorn limestone. The limestones are generally white, buff, or pink, and seem to persist over some distance. The thickness of the Fairport member is about 100 to 110 feet. The following section illustrates the lithology of the member in Jewell County.

Measured section of lower part of Fairport chalky shale member of Carlile shale in SW¼ SE¼ sec. 9, T. 5 S., R. 7 W. Measured by A. R. Leonard, October 1946.

	Thickness, feet
CRETACEOUS—GULFIAN	
Carlile shale—Fairport chalky shale member	
8. Covered slope to top of knoll	
7. Shale, fissile, calcareous, gray and white, weathers bright yellow. Contains *Ostrea* shells, sandy streak near center	12.0
6. Limestone, fine-grained, pink, somewhat concretionary; contains pyritic zone in center	0.4
5. Shale, fissile, calcareous; gray, white, and buff, weathers yellow-buff; contains *Ostrea* shells	7.6
4. Limestone, concretionary in lower part; contains shale parting in upper part	0.4
3. Bentonite, gray and orange mottled	0.3
2. Shale, calcareous, white to gray; contains chalky concretionary limestones at 0.6 and 2.2 feet above base	3.7
1. "Fencepost limestone" bed, of Greenhorn limestone exposed at creek level	
Total exposed Carlile shale	24.4

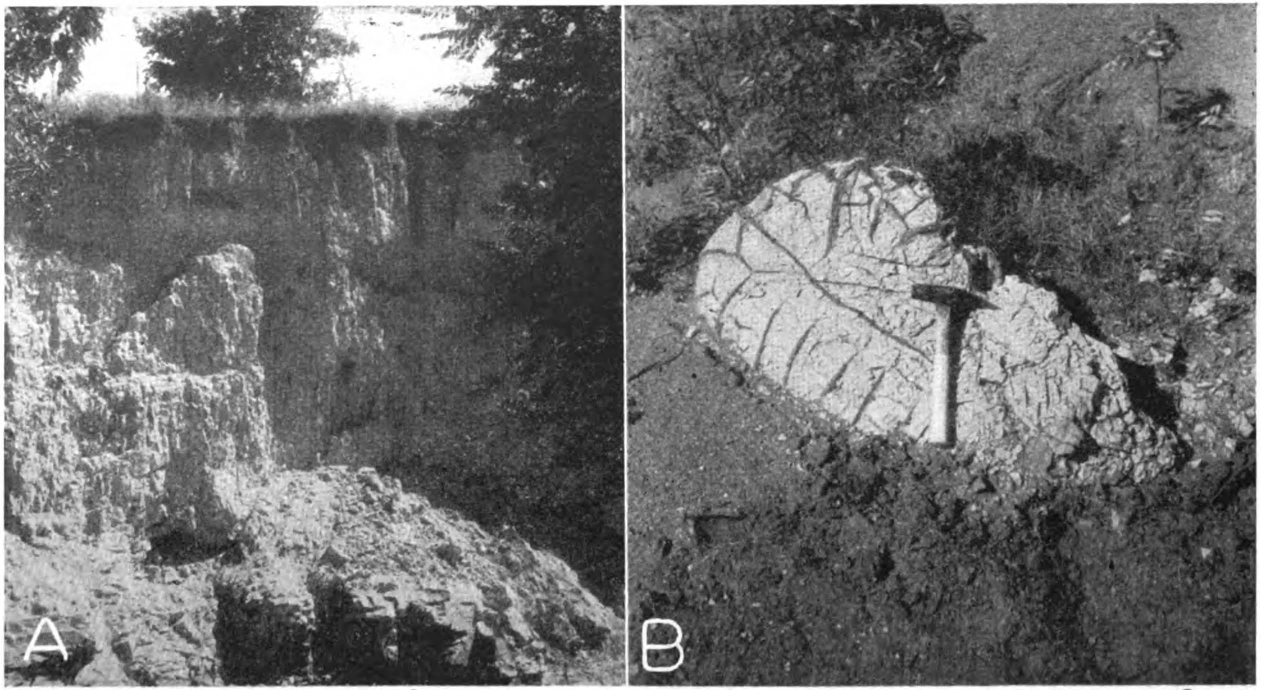

PLATE 8. **A,** Loess on Niobrara formation in east bank of creek in NE¼ sec. 7, T. 2 S., R. 9 W. **B,** Septarian concretion in the Blue Hill shale member of the Carlile shale near the NW cor. sec. 8, T. 5 S., R. 10 W.

The upper 200 feet of the Carlile shale, the Blue Hill shale member, consists principally of fissile noncalcereous black to blue-gray marine shale. The Blue Hill shale member is well exposed in many places below the prominent escarpment of the Fort Hays limestone member of the Niobrara formation, and smaller exposures occur along many of the stream banks in the outcrop area (Pl. 1, 9B). Many zones of septarian concretions, containing cross-cutting veins of brown calcite that weather in relief, are present in the upper part of the Blue Hill shale member (Pl. 8B). The concretions are spherical, discoidal, or lemon-shaped and in Jewell County have a maximum diameter of about 4 feet. Gypsum, generally in the form of selenite crystals, occurs in thin lenticular bands in the upper part of the member. Zones of thin discoidal concretions containing ammonite, gastropod, and *Inoceramus* shells occur in the lower part of the member. In southwestern Osborne and northern Ellis Counties several feet of sandstone and sandy shale in the uppermost part of the Blue Hill shale member make up the Codell sandstone zone. In Jewell County, the Codell sandstone zone is represented by about 6 to 15 inches of friable fine-grained limonitic sandstone at the top of the Blue Hill member. Locally, fossil shark teeth are present in the Codell sandstone zone.

Water Supply.—The shales of the Carlile shale are impervious and do not yield water to wells in Jewell County. The Codell sandstone zone is too thin and contains too much fine-grained material to serve as an aquifer in this area.

Niobrara Formation

Character, distribution, and thickness.—The Niobrara formation, the uppermost Cretaceous unit in Jewell County, conformably overlies the Blue Hill shale member of the Carlile shale and in the western part of Kansas is overlain conformably by the Pierre shale (Moore and Landes, 1937; Moore and others, 1951, pp. 22-24, Fig. 11). The total thickness of the Niobrara formation in north-central Kansas is about 650 feet (Landes and Keroher, 1942, p. 286), but only the lower 300 to 400 feet is exposed in Jewell County. The basal part of the Niobrara formation, the Fort Hays limestone member, forms a prominent escarpment trending irregularly northeastward from the southwestern part of the county toward Lovewell in the northeastern part. Northwestward from this escarpment the Niobrara formation is well exposed, the best exposures being along the divide and valley wall south of White Rock Creek. North of

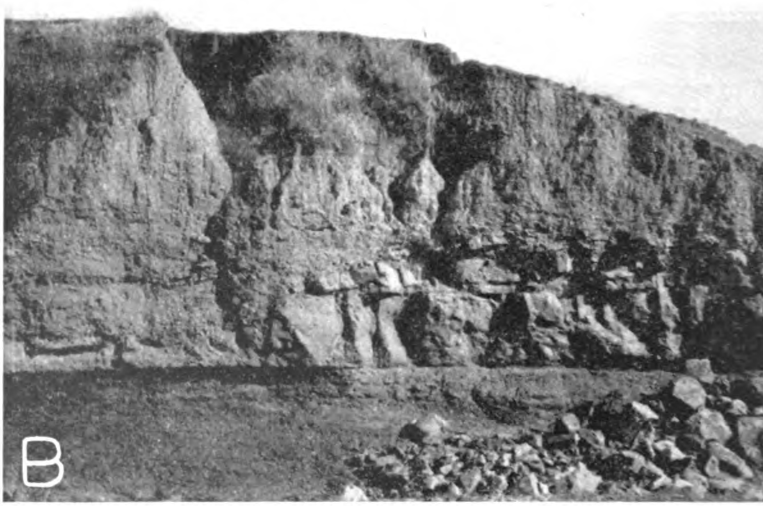

PLATE 9. **A,** Looking northeast at Fort Hays limestone member of the Niobrara formation in SW¼ SW¼ sec. 33, T. 3 S., R. 9 W. **B,** Contact of the Fort Hays limestone member and the Carlile shale in the east bank of creek near the middle of sec. 33, T. 1 S., R. 3 W.

White Rock Creek the Niobrara formation is buried, except locally, by Pleistocene deposits.

The Fort Hays limestone member consists of 30 to 45 feet of soft, massive white chalk beds ranging from 1 to 5 feet in thickness separated by thin shale or bentonite partings (Pl. 9A). The chalk beds contain large *Inoceramus grandis* and small *Ostrea congesta* shells. Small concretions of pyrite and limonite as much as an inch in diameter are in the chalk, and small particles of pyrite are disseminated widely through the chalk in some places. The Fort Hays limestone member has been quarried at many places along the outcrop for building stone and for road metal. It is quarried in sec. 5, T. 1 S., R. 7 W. as a source of lime for cement manufacture and is transported to the Nebraska Cement Company's plant at Superior, Nebraska, for processing. The section below illustrates the character of the Fort Hays limestone member.

Section of the Fort Hays limestone member of the Niobrara formation measured in the W. P. A. quarry in the SE cor. sec. 29, T. 3 S., R. 7 W., about 5 miles east and 2 miles south of Mankato, Kansas. Measured by H. A. Waite, September 17, 1941.

	Thickness, feet
CRETACEOUS—Gulfian	
11. Covered slope; contains hard white thin-bedded slabby zone near base (weathered Fort Hays member)	
Niobrara formation—Fort Hays limestone member	
10. Limestone, chalky, hard, yellow; weathers white	0.5
9. Limestone, similar to bed 10	0.4
8. Limestone, dense, hard, yellow	1.8
7. Limestone, similar to bed 8	2.7
6. Limestone, hard, cream-colored to white; contains very small *Ostrea*	0.9
5. Limestone, chalky, hard, massive, cream-colored to yellow; contains large *Inoceramus* shells, some specimens 5 inches in longest dimension	3.1
4. Limestone, chalky, massive, yellow	1.5
3. Limestone, chalky, massive, yellow; contains harder fossiliferous slab at top; speckled with small ironstone concretions, both nodules and root-like stems; contains *Inoceramus* shells, some specimens 6½ inches in diameter	4.5
Carlile shale—Blue Hill shale member	
2. Sandstone, argillaceous, very fine, rusty-brown (Codell sandstone zone)	1.0
1. Shale, platy, bluish-gray	——
Total thickness of Fort Hays limestone member exposed,	15.05

The Smoky Hill chalk member overlies the Fort Hays limestone member and is the upper unit of the Niobrara formation. Only the lower half, 300 to 350 feet, of the Smoky Hill chalk member is present in Jewell County, the upper part having been removed by erosion. The member consists principally of thin-bedded to fissile shaly chalk or chalky shale beds that are blue gray in fresh exposures but weather to yellowish buff, yellow, orange, or white. Locally, the member contains thin bentonite seams and beds of massive chalk as much as 1 foot in thickness, similar to the chalk in the Fort Hays limestone member. *Inoceramus* and *Ostrea* shells are common and concretions of limonite and pyrite are present. The Smoky Hill chalk member has been eroded to form rounded promontories and parabolic hills that are well exposed south of White Rock Creek in the southern part of T. 2 S., Rs. 7, 8, and 9 W. Near Burr Oak long colluvial slopes developed on the Smoky Hill chalk member extend from the drainage divide a few miles south of White Rock Creek to the low terraces bordering the stream. These slopes are examples of the "flanking pediments" described by Frye and Leonard (1952, pp. 25-28) and are underlain by a few inches to a few feet of colluvial debris and soil (Pl. 4B). The following section illustrates the lithology of the Smoky Hill chalk member.

Partial section of the Smoky Hill chalk member of the Niobrara formation near the NE cor. SE¼ sec. 33, T. 2 S., R. 8 W., about 2½ miles north of Mankato, Kansas. Measured by H. A. Waite, September 24, 1941. The top 13 feet of the section was measured and described from an exposure in the road cut on the east side of the north-south section road, at a point directly across from the cut bank on the east side of a small creek where the bottom part of the measured section is exposed.

	Thickness, feet
CRETACEOUS—Gulfian	
Niobrara formation—Smoky Hill chalk member	
20. Clay, yellow (covered slope)	2.0
19. Shale, chalky, fissile, cream-colored	7.5
18. Gypsum seam, persistent, deep rusty-brown, crystalline gypsum predominating; contains thin seam of yellow weathered bentonite	0.1
17. Shale, chalky, soft, fissile, cream-colored	1.8
(Section continued in east bank of creek near the Cen. E. line of sec. 33, T. 2 S., R. 8 W.,—about 150 feet west of road cut described above.)	
16. Chalk, cream-colored	2.0
15. Shale, chalky, soft, fissile, bluish-gray	11.2
14. Chalk, soft, bluish-gray	5.0
13. Chalk, soft, bluish-gray; contains horizontal stringers of calcite	4.3
12. Bentonite, thin seams; not very well developed	0.02
11. Shale, chalky, soft, bluish-gray	1.6
10. Chalk, soft, bluish-gray	1.2
9. Shale, chalky, bluish-gray	0.9

	Thickness, feet
8. Bentonite	0.02
7. Shale, chalky, bluish-gray	1.2
6. Bentonite, brown; very thin seam	0.02
5. Limestone, chalky; contains persistent ¼-inch black streak near middle	0.7
4. Shale, chalky, bluish-gray	0.3
3. Bentonite, brown, split seam	0.06
2. Chalk, soft, bluish-gray	2.1
1. Shale, chalky, fissile, bluish-gray	3.0
Base of section, dry bed of creek	
Total section measured	45

Water Supply.—In general, the chalk and chalky shale of the Niobrara formation are impervious and do not yield water to wells. Some wells may obtain small quantities of water from the formation where it is jointed and fractured. Large fractures filled with secondary calcite indicate that some water has circulated through the formation in the past. In most localities, however, the fractured part of the Niobrara formation is in the topographically higher parts of the area above the water table.

Quaternary System

PLEISTOCENE SERIES

Unconsolidated deposits of Quaternary age are the near-surface materials over a very large part of the area shown on the geologic map (Pl. 1), and they are the only important water-bearing rocks in the area. The entire Quaternary System is represented by the Pleistocene Series, of which the Recent Stage is the uppermost subdivision. The Pleistocene deposits in Jewell County range in age from Kansan (Meade formation) to Recent (alluvium) and include: Meade formation, undifferentiated limestone gravel, Sanborn formation, terrace deposits, and alluvium. Each is unconformable on the Cretaceous bedrock units or on older Pleistocene rocks. All the Pleistocene rocks are continental in origin and were deposited principally by flowing streams or by wind, although some rocks probably were formed by colluvial processes that moved them only a short distance and modified them only slightly.

Wind-deposited silts of the Sanborn formation have been recognized and mapped in all parts of the county. Recognition was based principally on distinctive lithology that has been used as a criteria for recognition elsewhere in north-central Kansas (Frye and Leonard, 1949; Leonard, 1952). In general, an attempt was made to map the Sanborn formation wherever it was at least 4 or 5 feet in thickness. In some places where the thickness of the Sanborn was greater than 5 feet, however, it was not mapped because it was desired to show other features such as the escarpment of the Fort Hays limestone member or small shale exposures. Along the south side of White Rock Creek thin loess and colluvium of the Sanborn formation, which may be thicker than 5 feet and overlie the Smoky Hill chalk member, were not mapped so that the flanking pediments developed on the Smoky Hill chalk member could be emphasized. Deposits of the Meade formation were mapped on the basis of the lithologically distinctive Pearlette volcanic ash lentil, on fossil evidence, and on the relation of the deposits to the younger Sanborn formation. In northeastern Jewell County the Meade formation includes sand and gravel deposits previously classed as the Belleville formation (Wing, 1930; Lohman, Fishel, 1948). The areas mapped as Meade formation on Plate 1 are those areas where it was recognized as such. In other areas, silt of the Meade formation, which is not readily distinguishable from the Sanborn formation, has been mapped with the Sanborn formation. Limestone gravel, probably equivalent in age to the Meade formation, at many places overlying Cretaceous bedrock and underlying silt of the Sanborn formation, has been mapped with the Sanborn formation. In other places the limestone gravel may represent deposits of Nebraskan age older than the Meade formation.

Meade Formation

Classification and correlation.—The Meade formation includes the continental deposits, principally stream-laid, formed during the late Kansan and Yarmouthian Stages. The formation consists of a lower sand and gravel unit, the Grand Island member, and an upper fine-grained unit, the Sappa member, which consists of silt, fine sand, clay, and, locally, volcanic ash (Pl. 10A). Both members are present in Jewell County, although the Sappa member is much more widely distributed.

The "Meade gravels" were named by Cragin (1896, p. 54) from exposures in central Meade County. Later, Frye and Hibbard (1941, p. 411) redefined the Meade formation to include all the beds of Pleistocene age between the top of the Rexroad deposits and the base of the Kingsdown silt. In 1948, Frye, Swinford, and Leonard (pp. 501-525) used the Pearlette volcanic ash and molluscan faunas in deposits associated with the ash to correlate deposits of late Kansan and Yarmouthian ages from the Plains region to the glaciated region. They proposed that the name Meade be applied to sediments formed during the Kansan cycle of alluviation and adopted the member classification used in this report.

In northeastern Jewell County, the Meade formation includes sand and gravel deposits continuous with those in Republic County formerly assigned to the "Belleville" formation (Wing, 1930, pp. 19-21; Lohman, Fishel, 1948, pp. 89-93). Wing assigned the Belleville to the middle Pliocene on the basis of *Trilophon* teeth found in a sand and gravel pit northwest of Belleville. Lugn (1935, p. 196) objected to the Tertiary classification of these deposits and to the name "Belleville." Although he published no faunal lists nor cited any specific locations, he stated: "Equus and other Pleistocene mammalian remains have been gotten from the same deposits at the same locations described by Mr. Wing." He stated his belief that these deposits were continuous with the Grand Island formation in Nebraska and suggested that name for them.

Lohman (Fishel, 1948, pp. 89-92) agreed with Lugn that these deposits were of Pleistocene age and cited the occurrence of teeth of *Stegomastodon* and *Equus cf. excelsus* Leidy in the gravels in Republic County as further evidence of the early Pleistocene age of these deposits. He redefined the "Belleville formation" to include the stream-deposited sand and gravel underlying the loess in northern Republic County, Kansas, and assigned it to the Pleistocene. Lohman suggested that the "Belleville formation" might include deposits equivalent to the Holdrege formation in Nebraska in addition to sand and gravel deposits equivalent to the Grand Island formation of Nebraska.

In northeastern Jewell County, the deposits classed as Grand Island member of the Meade formation, which are a westward extension of the stream-deposited sand and gravel classed as "Belleville" in Republic County are, in their upper part at least, clearly of Kansan and Yarmouthian age. They are conformably overlain by a thin section of silt and sandy silt that contains lenses of Pearlette volcanic ash. Sand and gravel deposits in the deeper part of the filled channel may, as Lohman suggested, be equivalent to older deposits. This part of the section does not crop out at the surface and is not separated by any persistent fine-grained bed from the sand and gravel in the upper part of the channel fill. In this report all the deposits filling the bedrock channel are assigned to the Meade formation.

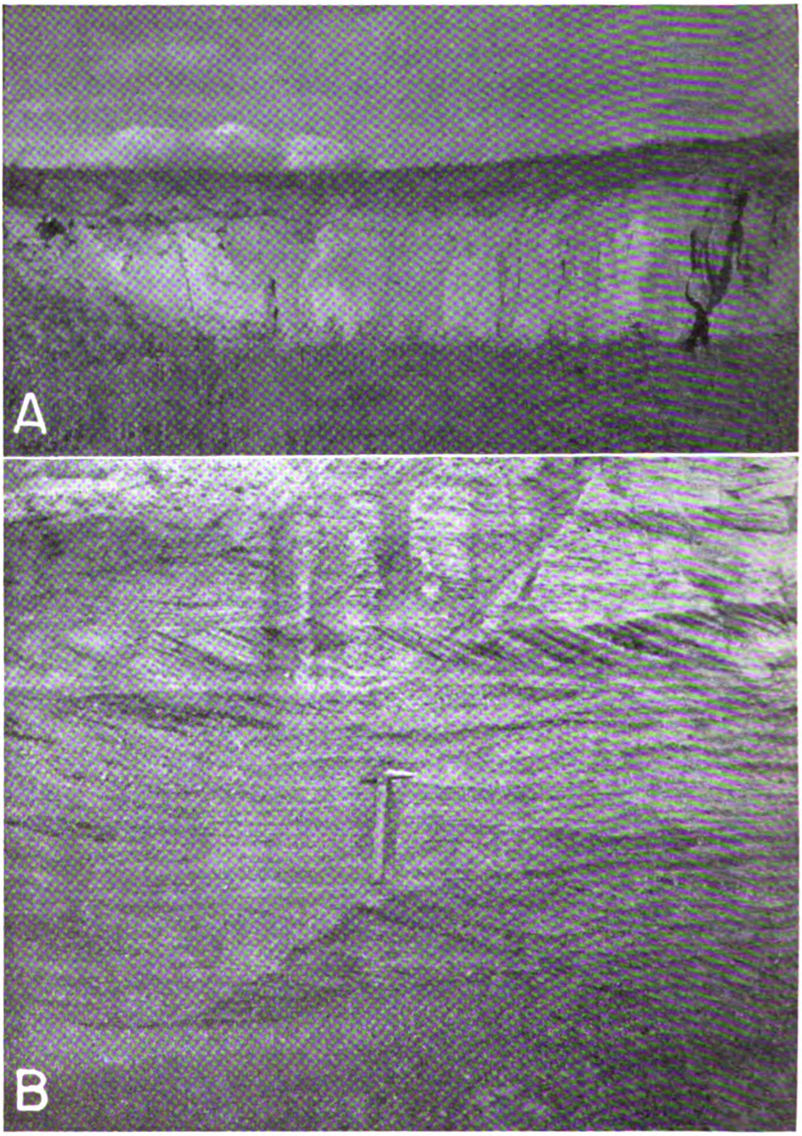

PLATE 10. Meade formation. **A,** Volcanic ash in Sappa member of the Meade formation; in the NE¼ NW¼ sec. 16, T. 1 S., R. 6 W. **B,** Cross-bedded sand and gravel of Grand Island member, Meade formation in gravel pit in the NE¼ sec. 11, T. 1 S., R. 6 W.

In northwestern Jewell County, the Pearlette volcanic ash lentil at many places directly overlies Cretaceous bedrock or is only a few feet above the top of the bedrock. Water wells in that area have reported volcanic ash at depths of 90 to 115 feet beneath the surface and just above bedrock. The lower Grand Island member is absent or very thin, and the Meade consists predominantly of the upper fine-grained part, the Sappa member. In the SW¼ SE¼ sec. 13, T. 2 S., R. 10 W., a fossil soil of Yarmouthian age marks the top of the Sappa member of the Meade formation and is unconformably overlain by silts of the Sanborn formation (Pl. 11B). The following section was measured on the east side of a small draw just north of a section-line road at that locality.

Section of the Sappa member, Meade formation, and Sanborn formation in the SW¼ SE¼ sec. 13, T. 2 S., R. 10 W., on east side of a small draw just north of section-line road.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation—Loveland silt member	
3. Silt, massive, structureless, reddish-buff; lower 5 feet contains many large nodules of calcium carbonate	12.5
Meade formation—Sappa member	
2. Silt (Yarmouth soil), dark-gray; exhibits soil structure; contains some calcium carbonate	1.5
1. Silt, friable, massive, grayish-white; small sandy zone containing fossil mollusks about 1 foot below top. To bottom of small gully	4.0
Total Pleistocene section exposed	18.0

Fossil mollusks from sandy silt about 2½ feet below top of Sappa member, Meade formation, SW¼ SE¼ sec. 13, T. 2 S., R. 10 W., Jewell County have been identified by A. Byron Leonard as follows.

Gastrocopta armifera
Succina grosvenori
Helisoma anceps
Valvata tricarinata
Sphaerium sp.
Strobilops sparsicosta
Discus cronkhitei
Physa anatina
Ferrissia parallela
Pupilla blandi
Pupilla muscorum
Vallonia gracilicosta
Helicodiscus parallelus
Hawaiia minuscula
Pisidium pyramidatum
Gyraulus labiatus
Zonitoides arboreus

Dr. A. Byron Leonard (personal communication dated June 8, 1948) stated concerning the fossil mollusks contained in bed 1 in the above section:

> This is a mixed fauna, terrestrial and aquatic, and is, in my judgment, a fauna that is quite characteristic of the Sappa [member of the Meade formation].

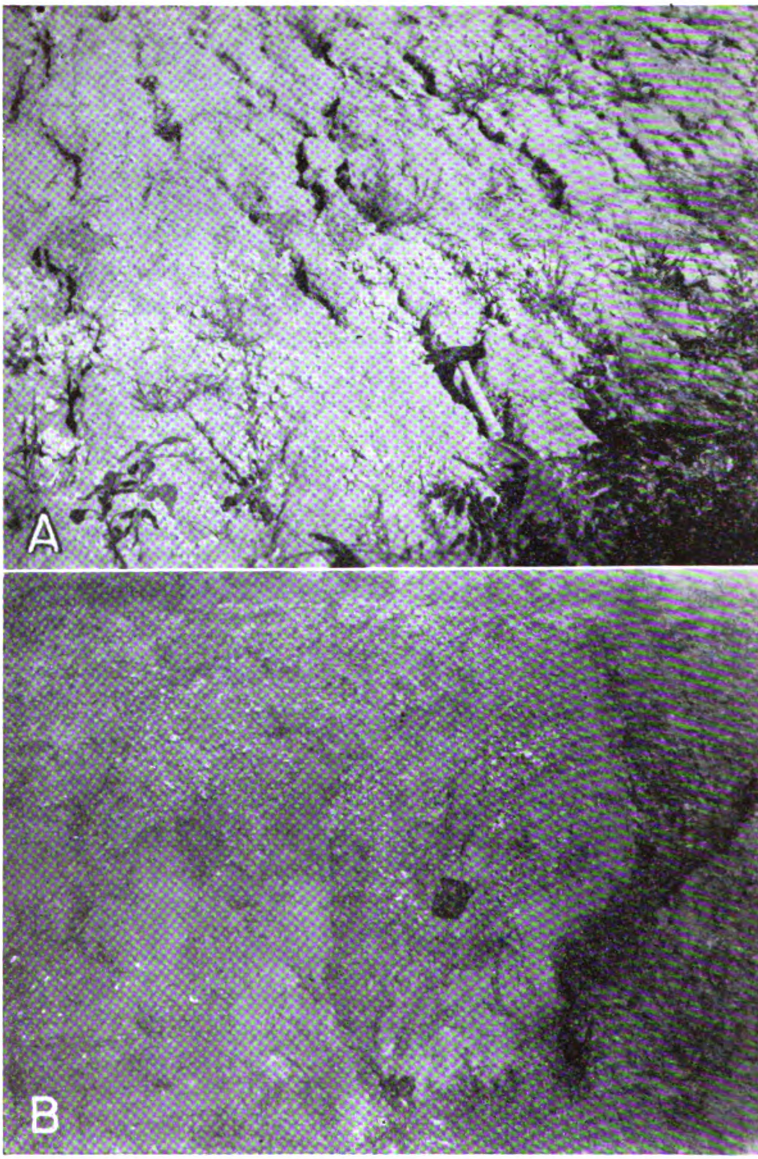

Plate 11. A, Friable massive silt in Sappa member (Meade formation) showing nodules of calcium carbonate; NW¼ SW¼ sec. 29, T. 1 S., R. 9 W. B, Humic zone in upper part of Yarmouth soil zone at top of Sappa member (Meade formation) overlain by Loveland silt member (Sanborn formation) containing nodules of calcium carbonate; SW¼ SE¼ sec. 13, T. 2 S., R. 10 W.

Character, distribution, and thickness.—In Jewell County the Meade formation contains deposits of a widely divergent lithology, from fine massive silt to coarse cross-bedded sand and gravel. The lower member, the Grand Island, consists of cross-bedded coarse sand and gravel of the Rocky Mountain type probably derived from the Ogallala formation to the west (Pl. 10B). Interbedded with the sand and gravel are lenses of sandy silt and green gritty clay. Locally, the sand and gravel are stained rusty brown by iron oxide. In the outcrop area a few miles northwest of Mankato (Pl. 1) some of the finer sand in the basal part of the Grand Island member is cemented with calcium carbonate to form a white "mortar bed," similar to the "mortar beds" described in the Ogallala formation (Frye and Leonard, 1949, p. 37). Near Mankato the Meade deposits fill a narrow channel cut into the Smoky Hill chalk member of the Niobrara formation and the calcium carbonate cement may have been derived by solution from the chalk beds.

The thickness of the Grand Island member is as much as 120 feet as penetrated in test hole 1-6-19aa. Along the bluff on the south side of the Republican River in the northeast part of T. 1 S., R. 6 W., 30 to 40 feet of sand and gravel is exposed and overlies the Blue Hill shale member of the Carlile shale. In the area between Republican River and White Rock Creek in northeastern Jewell County, the Grand Island member ranges from 20 to 120 feet and averages 30 to 40 feet in thickness in most of the area. In the SW¼ sec. 33, T. 1 S., R. 9 W., the Grand Island member is represented by about 3 feet of fine to coarse sand lying between the Niobrara bedrock and the overlying Pearlette volcanic ash. About 6 feet of greenish quartz sand containing gravel of granitic origin is exposed in a gravel pit in the SW¼ SW¼ sec. 16, T. 3 S., R. 8 W.

The most prominent outcrops of the Grand Island member are south of Republican River and east of Highway 14, in northeastern Jewell County. Although it does not crop out on the north side of White Rock Creek, the member probably underlies most of the area between White Rock Creek and Republican River in R. 6 W. and the eastern half of R. 7 W. (see cross section, Pl. 1). In that area the Meade formation, principally the Grand Island member overlain by thin deposits of silt of the Sappa member, fills a deep channel cut in the Cretaceous bedrock by the ancestral Republican River. This ancient channel entered Kansas about 5 or 6 miles west of the northeastern corner of Jewell County, trended toward the southeast, and passed eastward into Republic County about 5 miles south of the northeastern corner of Jewell County (Lohman, Fishel, 1948, p. 29). In this area the Meade deposits fill the channel and are spread out over an area several miles wide on the sides of the channel. In part of the area the surface is plane and gently sloping, resembling the undissected surface of a stream terrace (Pl. 3C). In northwestern Jewell County, thin deposits assigned to the Grand Island member occupy the lower part of a broad east-trending valley eroded in bedrock (Fig. 23). Scattered outcrops in the area northwest of Mankato suggest that the member underlies several square miles in that area and probably fills a channel cut into the bedrock by an ancient north-flowing stream.

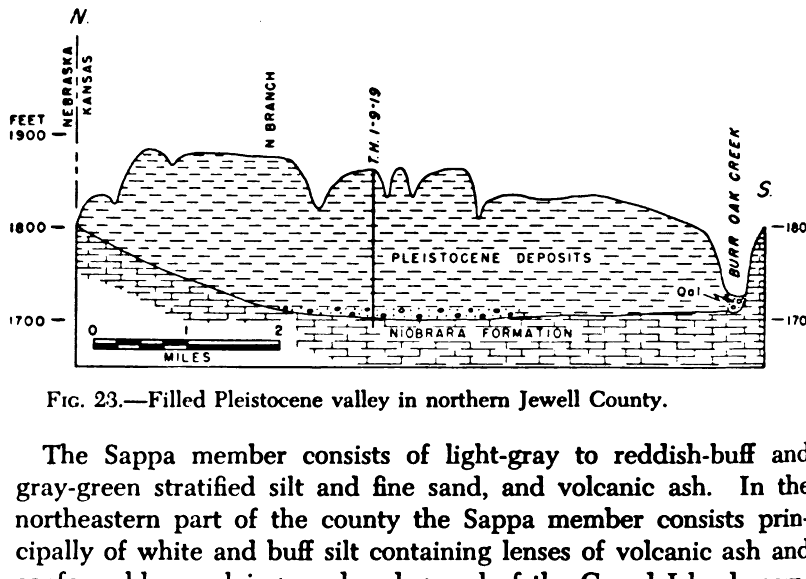

FIG. 23.—Filled Pleistocene valley in northern Jewell County.

The Sappa member consists of light-gray to reddish-buff and gray-green stratified silt and fine sand, and volcanic ash. In the northeastern part of the county the Sappa member consists principally of white and buff silt containing lenses of volcanic ash and conformably overlying sand and gravel of the Grand Island member. In northwestern Jewell County, the Sappa member consists principally of light reddish-buff silt, which is massive and friable and contains nodules of concretionary calcium carbonate as much as 3 inches in diameter (Pl. 11A). The following section of the Sappa was measured in a road cut in the NW¼ SW¼ sec. 29, T. 1 S., R. 9 W.

Section of the Sappa member of the Meade formation in a road cut in the NW¼ SW¼ sec. 29, T. 1 S., R. 9 W.

	Thickness, feet
QUATERNARY—Pleistocene	
Meade formation—Sappa member	
6. Silt, limy, grayish-tan; contains nodules of calcium carbonate up to 3 inches in diameter. To top of road cut	11.0
5. Large calcium carbonate concretions	1.0
4. Silt, buff; contains streaks and a few nodules of lime	2.2
3. Silt, limy, lenticular, tan; weathers to form a crumby-textured surface; contains nodules of lime	0-1.3
2. Silt, limy, friable, flaky, calcareous, white; upper part nodular,	1.2
1. Silt, somewhat limy, gray-tan; contains some nodules of calcium carbonate; basal 2 feet poorly exposed; to base of cut,	7.5
Total Pleistocene section exposed	24.2

The fine-grained, massive character, lack of stratification, and upland position of this material suggest that, in this area, it may have been deposited as eolian silt derived from the flood plain of the ancestral Republican River to the north and northeast and carried southward by the wind in the same manner that the Peoria silt was formed at a later time. The large calcium carbonate nodules were formed secondarily during the period of soil formation subsequent to the deposition of this silt, and the reddish color also is probably the product of soil-forming processes.

The thickness of the Sappa member of the Meade formation is difficult to determine over most of Jewell County because it resembles the overlying Loveland silt member of the Sanborn formation. Test holt 1-6-20aa penetrated 27 feet of silt containing caliche and fine sand, all of which is topographically lower than a near-by bed of volcanic ash. The entire silt section in this test-hole is judged to be assignable to the Sappa member. About 20 to 25 feet of silt of the Sappa member is exposed in many road cuts in northwestern Jewell County, and the thickness of the member is probably 20 to 50 feet over most of that area.

Thin deposits of fine-grained material of the Sappa member of the Meade formation probably lie beneath the younger loess and over the Grand Island member in northeastern Jewell County. The Sappa member probably makes up most of the fill of the broad bedrock valley that extends eastward from northwestern Jewell County between White Rock Creek and the north edge of the county. Many outcrops of volcanic ash in the southwestern part of T. 1 S., R. 9 W. and in the northwestern part of T. 2 S., R. 9 W.

are in the lower part of the member and, locally, lie directly on Cretaceous bedrock. Other outcrops of volcanic ash in the SE¼ sec. 11, T. 3 S., R. 8 W. and in the SE¼ sec. 20, T. 5 S., R. 9 W. indicate the presence of scattered remnants of deposits of the Sappa member in the southern part of the county. No extensive areas of the Sappa member are known in the southern part of the county, where the Sappa is probably thin and discontinuous.

Water supply.—In the filled-channel area in northeastern Jewell County, moderate supplies of ground water suitable for domestic and stock use can be obtained from the Grand Island member of the Meade formation in most places. In this area ground water in the Meade formation is under water-table conditions and the water table is continuous with the water table in northwestern Republic County. In northwestern Republic County ground water moves generally eastward and toward Republican River (Fishel, 1948, Pl. 8), and movement of ground water in northeastern Jewell County is probably in the same direction. The deep dissection of the land surface by Republican River and its tributaries has cut through the entire thickness of the Meade formation in secs. 11 and 12, T. 1 S., R. 6 W., allowing ground water to be discharged into surface streams. In general, the saturated material in the Meade formation in this area ranges from 20 to 45 feet in thickness (cross section, Pl. 1) and probably averages 25 feet. Locally, the bedrock extends above the water table so that no saturated material would be penetrated by a well drilled at that spot.

In northwestern Jewell County, ground water is under water-table conditions in the Sappa member of the Meade formation in the broad filled valley north of White Rock Creek. In this area many wells are reported to supply water adequate for domestic and stock needs. Movement of ground-water in these deposits is probably eastward toward the area of Meade deposits in the northeastern part of the county and southeastward toward the valley of White Rock Creek.

Small supplies of ground water adequate for domestic and stock wells for several farms in sec. 32, T. 2 S., R. 8 W. and secs. 5 and 6, T. 3 S., R. 8 W. are obtained from wells in the Meade formation. Well 3-8-6cd was a community well during the drought period of 1934 to 1938.

Except in the northeastern part of Jewell County, the saturated material in the Meade formation is generally too fine grained to yield large supplies of water to wells. In the northeastern part of the county, the saturated material is not thick enough to support wells of large yield. Therefore, only moderate supplies of ground water can be obtained from the Meade formation in Jewell County.

Undifferentiated Limestone Gravel

Character, distribution, and thickness.—One of the most widespread lithologic types in Jewell County is the limestone gravel deposits that are present in all parts of the county but are most common in the areas southeastward from the escarpment of the Fort Hays limestone member of the Niobrara formation. In most exposures the gravel consists principally of subangular to subrounded waterworn limestone pebbles commonly from 0.5 to 1 inch in diameter. In many localities the pebbles are derived almost entirely from the Fort Hays limestone member of the Niobrara formation, but in places in northern Jewell County they are derived from limestone beds in the Smoky Hill chalk member, and locally in southern Jewell County they contain limestone fragments from the Fairport chalky shale member of the Carlile shale or fragments of septarian concretions from the Blue Hill shale member. Intermixed with the limestone pebbles are fragments of shale from the Carlile shale, silt, and clay locally in the form of "clay-balls" as much as 6 inches in diameter. In most exposures the limestone gravel lies directly on the Carlile shale and is overlain by silt of the Sanborn formation. For this reason and because its age could not be determined, the gravel was mapped with the Sanborn formation.

The thickness of the limestone gravel, except where it underlies alluvial terraces or alluvial valleys, is probably 10 feet or less, although 14 feet is exposed in the Dietz quarry in the NW¼ sec. 7, T. 5 S., R. 9 W. The principal area of occurrence is the Jewell plain (Pl. 3B), that broad plain between the escarpments of the Fort Hays limestone member and the Greenhorn limestone. In this area, the Carlile shale bedrock lies at a relatively shallow depth and is overlain by a few feet of limestone gravel and weathered shale, and the surface is formed by silt of the Sanborn formation. Locally along some of the streams, the thin surficial deposits have been eroded away and shale bedrock is exposed.

Age relations.—No fossils have been found associated with the limestone gravel, so that its age is in question. It seems to be clearly Pleistocene in age because of its position below the general upland level on which the Pliocene Ogallala formation was deposited a few miles to the west. At many places, it underlies the Loveland and

Peoria silt members of the Sanborn formation so that it is probably Illinoian or older in age. In a road ditch in the SW¼ sec. 20, T. 1 S., R. 9 W., limestone gravel was observed underlying the Pearlette volcanic ash lentil and a gray-buff silt. At this locality the gravel is older than the ash and may belong to the Grand Island member of the Meade formation.

Probably the limestone gravel is of different ages in different localities in Jewell County, ranging from Nebraskan to Wisconsinan.

Origin.—Most of the limestone gravel deposits probably were formed by small streams that rounded and abraded weathered limestone from the Niobrara formation and spread it irregularly along their valleys. As the streams shifted their courses, limestone gravel was deposited in the new valleys until a large area was underlain by the gravel. Some of the gravel, however, may have originated as colluvial deposits. "Ramps" or "flanking pediments" probably of colluvial origin extend out from some of the elongated spurs of the Fort Hays limestone member and in places completely mask the underlying Carlile shale. In other places the "flanking pediments" have been eroded adjacent to the limestone escarpment, creating a second smaller escarpment about half a mile away where limestone gravel caps a small bluff of Carlile shale facing the limestone bluff (Fig. 24). In these localities the limestone gravel probably is largely of colluvial origin. Good examples of these eroded pediments can be seen in secs. 1 and 14, T. 5 S., R. 10 W., and sec. 14, T. 4 S., R. 9 W.

Water supply.—Limestone gravel is one of the most important aquifers in Jewell County, not because it contains large quantities of water, but because it contains the only ground water available for domestic and stock use over a very wide area. In the Jewell plain, many wells obtain small to moderate supplies of water from wells 10 to 30 feet in depth. The ground water probably occurs as a series of water bodies perched on the Carlile shale rather than as a single continuous water table. Movement of ground water is probably southward and southeastward principally along the alluvial deposits associated with the streams. Locally, seeps or springs occur where erosion has cut through the limestone gravel and exposed the underlying shale.

Sanborn Formation

Classification and subdivisions.—The Sanborn formation includes surficial deposits, principally loess and stream deposits, of late Pleistocene age, from Illinoian to late Wisconsinan. It is divided into four members, in ascending order: Crete sand and gravel member (late Illinoian age), Loveland silt member (late Illinoian and Sangamonian age), Peoria silt member (Iowan age), and Bignell silt member (late Wisconsinan age). All members are present in Jewell County,

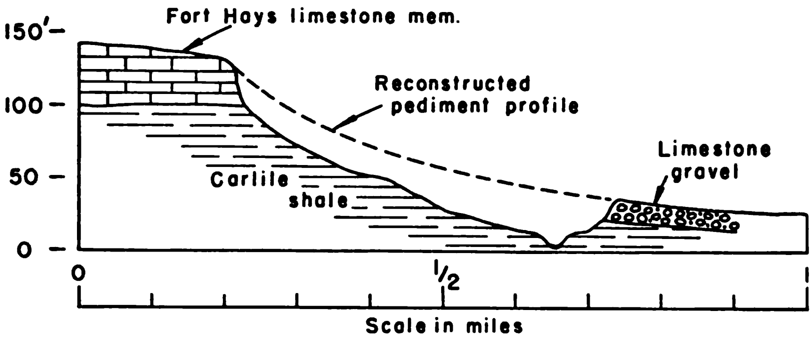

FIG. 24.—Cross section showing the origin of limestone gravel escarpments.

Character, distribution, and thickness.—The Sanborn formation is the most extensive deposit in Jewell County, comprising more than 80 percent of the land surface. Most of the surficial deposits of the formation are fine wind-deposited silt, but other lithologic types include sand and gravel, stratified silt and clay, limestone gravel, and fossil soil zones.

The Crete sand and gravel member of the Sanborn formation forms a high terrace locally along White Rock Creek and is well exposed in a road cut in the NE¼ SE¼ sec. 5, T. 2 S., R. 7 W. At this locality, about 20 feet of quartz and granitic-type gravel containing pebbles from the Cretaceous rocks is overlain by reddish sandy silt of the Loveland silt member. The base of the Crete sand and gravel member is not exposed and the thickness of the member could not be determined.

No deposits of the Crete sand and gravel member are known along Republican River in Jewell County, but subsurface exploration might reveal some deposits beneath the thick loess section adjacent to the river. Limestone gravel underlying the surfaces of high terraces along Limestone and Buffalo Creeks is probably equivalent to the Crete sand and gravel member, but it is not well enough exposed any place to relate it to other Pleistocene deposits.

The Loveland silt member of the Sanborn formation consists of reddish-buff silt, sandy silt, and locally stratified silt. Throughout most of the county, particularly the upland areas and the Jewell plain, the Loveland silt member is loess deposited by eolian activity. Locally, on the high terraces, the member may consist of stream-deposited silt formed in the later stages of the alluvial cycle that produced the underlying Crete sand and gravel member.

The top of the Loveland silt member is marked by a well-developed fossil soil zone, the Sangamon soil (Pl. 12A, 12B). In its characteristic development the soil zone is 2.5 to 3 feet thick, contains organic matter, and is a dark chocolate brown. The lower part of the soil profile contains an accumulation of clay, is red in color, and locally forms a slight bench on hillsides. The red color, a weathering or soil-forming product, generally extends all through the member. Calcium carbonate has accumulated in the form of small "caliche" nodules below the soil profile, and larger nodules as much as an inch in diameter are seen in the lower part of the member (Pl. 11B).

The following section measured in a gullied field in the NE¼ sec. 33, T. 3 S., R. 8 W., illustrates the character of the Sanborn formation in the upland area in Jewell County.

Section measured in a gullied field in the NE¼ sec. 33, T. 3 S., R. 8 W.; illustrates the character of the Sanborn formation in the upland area of Jewell County.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Peoria silt member	
3. Silt, friable, light-gray; contains small nodules of calcium carbonate	5.0
Loveland silt member	
2. Soil (Sangamon), compact, dark-brown; lower part chocolate-brown to red clay	4.0
1. Silt, compact, plastic, clayey, reddish-brown; contains snail shells and calcium carbonate nodules throughout, fine to coarse quartz sand in middle and lower parts, and chalk pebbles in base. To base of gully	9.0
Total Pleistocene section exposed	18.0

The Loveland silt member ranges in thickness from only a few feet in some of the upland areas to possibly 100 feet in the northern part of the county. In most of southern Jewell County the Loveland silt member is 5 to 10 feet thick. Locally the member is represented by 2 or 3 feet of silt forming a fossil soil resting directly on the eroded surface of Cretaceous rocks. Plate 12B shows the fossil Sangamon soil resting directly on the beveled surface of the

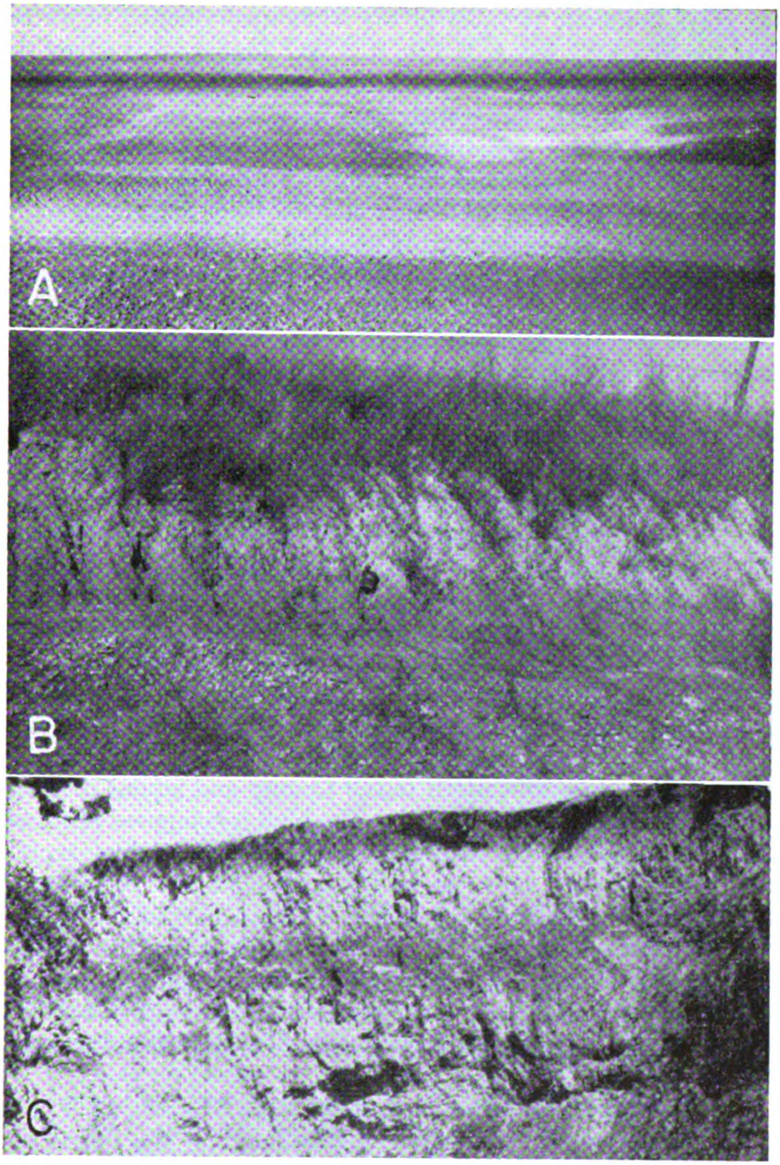

PLATE 12. Pleistocene soils in Jewell County. **A,** Dark zone of Sangamon soil forming band across plowed field in SW¼ sec. 2, T. 2 S., R. 9 W. **B,** Sangamon soil resting directly on beveled surface of Fort Hays limestone member and overlain by loess of the Peoria silt member in road cut in SW¼ SE¼ sec. 4, T. 1 S., R. 7 W. **C,** Brady (?) soil in cut bank of high terrace along small stream in NW¼ NE¼ sec. 4, T. 4 S., R. 9.W.

Fort Hays limestone member of the Niobrara formation in a road cut in the SE¼ SW¼ sec. 4, T. 1 S., R. 7 W. Similar areas where the bedrock was the Smoky Hill chalk member of the Niobrara formation (Pl. 8A) and the Carlile shale have been observed.

Test hole 1-8-19aa penetrated 148 feet of silt, a large part of which may be the Loveland silt member. In many places in that area the Peoria silt member is thin and the fossil Sangamon soil is only a few feet below the tops of the hills. Probably at least 120 feet of the silt section penetrated by this test hole is assignable to the Loveland silt member of the Sanborn formation and the Sappa member of the Meade formation. The Sappa member is probably less than 50 feet thick and the thickness of the Loveland must be at least 70 feet and may be nearly 100 feet.

The Peoria silt member overlies the Loveland silt member and directly underlies the land surface over much of the upland area and much of the Jewell plain area. The Peoria member consists of soft, friable, calcareous, light yellowish-gray silt containing many shells of small terrestrial snails. It forms a generally unbroken blanket over much of the upland, draping across the escarpment formed by the Fort Hays limestone member and extending out over the "flanking pediments" and the broad plain below the escarpment. In dissected upland areas it caps the higher hills and is well exposed in road cuts, gullied fields, and steep hillsides. The Peoria silt member forms a prominent 75-foot bluff on the south side of Republican River in northeastern Jewell County and attains its greatest thickness in that area (Pl. 4C). The bluff is composed of friable coarse silt of the Peoria silt member. The member thins rapidly away from the river, however, and is probably about 20 feet thick over most of the upland area in the northern part of the county. Over the uplands south of White Rock Creek where the bedrock is the Niobrara formation, the thickness is 5 to 15 feet and probably averages less than 10 feet. Over the Jewell plain area in southern Jewell County the thickness is commonly 5 to 10 feet and averages about 8 feet.

The following section measured in the NW¼ SE¼ sec. 25, T. 3 S., R. 8 W. illustrates the character and thickness of the Peoria and Loveland silt members near the edge of the escarpment of the Fort Hays limestone member.

Section of the Peoria and Loveland silt members of the Sanborn formation near the edge of the Fort Hays limestone member; measured in the NW¼ SE¼ sec. 25, T. 3 S., R. 8 W.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Peoria silt member	
4. Silt, friable, gray; contains calcium carbonate nodules; thicker on lower part of slope, average	6.0
Loveland silt member	
3. Soil (Sangamon), clayey, dark-brown; thins toward top of hill and follows contour of hill	3.5
2. Silt and clayey silt, reddish-brown; contains chalk fragments and sand; thickens down slope, average	3.0
CRETACEOUS—Gulfian	
Niobrara formation—Fort Hays limestone member	
1. Limestone, chalky, weathered and broken	
Total Pleistocene section measured	12.5

The upper member of the Sanborn formation, the Bignell silt member, has been noted at only a few localities adjacent to Republican River in northeastern Jewell County. In that area it consists of as much as 5 feet of light-gray silt overlying a thin, poorly developed soil zone, probably the Brady soil. The Bignell silt member is absent from the upland areas in northern and central Jewell County and has not been observed in the Jewell plain area in the southern part of the county. Locally along some of the major streams fossil soils that may be equivalent to the Brady soil are overlain by several feet of silt that may represent the Bignell silt member (Pl. 12C). The following section was measured in a stream bank in the NW¼ NE¼ sec. 4, T. 4 S., R. 9 W.

Section of the Sanborn formation measured in a stream bank in the NW¼ NE¼ sec. 4, T. 4 S., R. 9 W.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Bignell silt member (?)	
5. Silt, friable, gray-tan; upper 1 foot in modern soil profile	6.0
Peoria silt member	
4. Silt [Brady soil (?)], humic, clayey, dark; lower part blocky and claylike; base and top irregular and indistinct	4.0
3. Silt, gray-tan; contains snail shells and limestone pebbles; upper contact gradational into soil zone	2.0
2. Silt, clay, and stringers of limestone pebbles; stratified; contains snail shells; lower part blocky and composed principally of limestone pebbles	4.5
1. Silt, stratified, tan; contains fine sand and calcium carbonate nodules; lower 7 feet partly covered. To base of stream bed	11.0
Total Pleistocene section measured	27.5

Water supply.—In the upland areas where the deposits of the Sanborn formation are thin and dissected and overlie Cretaceous bedrock, they are not saturated and are not a source of water. Under the extensive area of the Jewell plain, the water table in the limestone gravels may extend upward into the silt of the overlying Sanborn formation. In those areas wells might obtain meager quantities of water from the Sanborn formation. Small quantities of water may be obtained from the Crete sand and gravel member of the Sanborn formation where the member underlies intermediate terraces along White Rock, Buffalo, and Limestone Creeks. In places along those streams the base of the Crete sand and gravel member is probably above the local water table and the deposits are dry. In northwestern Jewell County, the water table in the silts of the Sappa member may extend upward into the Loveland silt member, or the principal saturated material may be in the Loveland silt member of the Sanborn formation. In that area, moderate quantities of water adequate for domestic and stock use on farms are obtained locally from these fine-grained deposits.

Alluvium

Character, distribution, and thickness.—Alluvial deposits of Recent and late Wisconsinan age are present along all the main streams and their principal tributaries in Jewell County. Several of the major streams—Republican River, White Rock Creek, Limestone Creek, and Buffalo Creek—have well-defined low terraces (Pl. 3A) adjacent to their flood plains, but it was not feasible in this report to map these terraces separately from the alluvium of the flood plain. The general character of the terrace deposits and Recent alluvium is very similar and they are discussed together.

Except in Republican River valley, the terrace and flood-plain surfaces along the major valleys are underlain by stratified silt deposited by the streams occupying the valleys. Cut banks as much as 15 feet deep in the flood-plains and as much as 25 feet deep adjacent to the terrace surfaces indicate that the principal material in the upper part of the alluvial fills is silt containing sand and irregular thin lenses of gravel, principally limestone pebbles. As in other valleys in north-central Kansas, the lower part of the alluvial fill is probably composed of sand and gravel, or mixed sand, silt, and gravel. Several wells in White Rock Creek valley are reported to obtain water from "gravel and clay," probably a mixture of gravel, limestone pebbles, and fine silt. White Rock Creek heads in an area of outcrop of the Ogallala formation, so that quartz, granitic, and other igneous-type sand and gravel fragments are available to the stream and may be included in the gravel in the lower part of the alluvium. Limestone, Buffalo, and Marsh Creeks head in the area of Cretaceous outcrops in central Jewell County. The coarser material in the alluvium of these valleys is probably composed primarily of rock fragments derived from Cretaceous rocks, principally limestone. Exposures indicate that the upper part of the alluvial material along these streams is principally silt, which contains sand and limestone pebbles. The lower part of the fill is probably similar but may contain a higher proportion of sand and gravel.

The depths of the municipal wells and other wells in White Rock Creek valley reported to penetrate the entire thickness of alluvium indicate that the alluvium ranges in thickness from 50 feet in western Jewell County to about 75 feet in the area of the Mankato well field in sec. 11, T. 2 S., R. 8 W. The level of the low terrace becomes nearer the flood-plain level downstream from the well-field area, and the thickness of the alluvium may decrease in that direction. The thickness of alluvium in Limestone Creek valley is probably as much as 50 feet at the southern edge of the county and probably averages about 40 feet in the area south of Ionia. Upstream from Ionia the thickness of alluvium probably decreases until it is only a few feet in the head-water areas of Limestone Creek. The thickness of alluvium in Buffalo Creek valley is probably between 40 and 50 feet in the area downstream from Jewell City, but it may decrease somewhat east of Randall where the gradient of the stream is flattened as the valley crosses the resistant Greenhorn limestone. The thickness of alluvium in Marsh Creek valley may be less than in the other major valleys, perhaps not more than 30 feet. Marsh Creek valley does not have the well-developed terrace as do the other creek valleys, and the local marshy areas along the valley suggest that shale bedrock may be within a few feet of the surface.

The alluvium underlying the valley of Republican River consists principally of quartz and granitic sand and gravel containing silt in the upper part. The flood-plain surface is very irregular, and locally dunes 5 to 10 feet high have formed on it. At the Superior, Nebraska, well field in sec. 2, T. 1 S., R. 7 W., the thickness of alluvium averages about 32 feet. Beneath the low terrace along the valley margins, the thickness is probably about 40 feet.

Low terraces.—All the major streams in Jewell County have low terraces along them, although along some streams the terraces are discontinuous. Republican River valley is 1.5 to 2.5 miles in width in northeastern Jewell County, and the greatest part of the valley is occupied by the sandy irregular flood plain. Low terraces are present only locally, as in secs. 4, 5, 6, and 12, T. 1 S., R. 6 W., and range from 0.25 to 0.75 mile in width. The surface of this terrace is about 10 feet above the general level of the flood plain, is more level than the flood plain, and is generally underlain by silty material.

Most of the area along White Rock Creek shown on the geologic map as alluvium is a low terrace, the surface of which is 15 to 20 feet above the flood-plain level except in the area east of Lovewell where it is 10 to 15 feet above the flood plain. The alluvial valley ranges from about 0.3 mile to more than a mile in width and averages nearly a mile. The flood plain is very narrow, generally less than 0.2 mile and locally only about 100 yards in width; most of the valley is occupied by the low terrace.

The valley of Limestone Creek ranges in width from about 0.25 mile in its upper reaches to about 1 mile, averaging about 0.5 mile. The flood plain is narrow, generally less than 0.1 mile wide, and the low terrace about 15 feet above the flood-plain level occupies the largest part of the valley.

The low terrace along Buffalo Creek valley is well defined but is much closer to the flood-plain level than the terraces of White Rock and Limestone Creek valleys. Along North Fork Buffalo Creek in the SE¼ sec. 22, T. 3 S., R. 8 W., the terrace is about 13 feet above the general level of the flood plain and is about 0.25 mile wide, whereas the flood plain is only about 150 feet wide. Downstream the terrace level approaches the flood-plain level, so that the two are only 11 feet apart in the SW¼ sec. 9, T. 5 S., R. 7 W., 6 feet apart in the SE¼ sec. 10, T. 5 S., R. 6 W., and only 4 feet apart where Buffalo Creek leaves Jewell County. In general, the flood plain is narrow, 100 to 1,000 feet in width, and the terrace is 0.25 to 0.5 mile in width.

Well-defined terraces in Marsh Creek valley occur only in the upstream part where they are 10 to 15 feet above the flood plain and are discontinuous. Downstream they merge with the flood plain, and no terrace was recognized where the creek leaves Jewell County.

Water supply.—Large quantities of water can be obtained from wells in the alluvium of Republican River valley because the deposits are coarse and well sorted. The alluvium of the major creek valleys—White Rock, Limestone, Buffalo, and Marsh Creeks—is poorly sorted material capable of yielding only small to meager amounts of water to wells. The Esbon and Mankato municipal wells have yields of only 7 and 10 gallons per minute respectively—very low yields for alluvial aquifers. Ground water probably moves into the alluvium of White Rock Creek from adjacent deposits of the Meade and Sanborn formations to the north, and into the alluvium of the other valleys from small bodies of perched ground water in the limestone gravel and from silt of the Sanborn formation underyling the Jewell plain.

RECORDS OF WELLS

Descriptions of 259 wells visited in Jewell County are given in Table 17. All information classed as "reported" was obtained from the owner, tenant, or driller. Depths of all other wells are measured and are given to nearest tenth of a foot below the measuring point described in the tables, and depths to water level not classed as "reported" are measured and are given to the nearest hundredth of a foot. The well-numbering system in this table utilizes the General Land Office survey as described on page 13.

TABLE 17.—*Records of wells in Jewell County*

Well No. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 1 S., R. 5 W.														
1-5-7bb	NW NW sec. 7	U.S. Geological Survey	Dn	13.2	1¼	GP	Gravel and sand	Alluvium	N	O	Top of pipe	1.0	9.07	10-1-47	
1-5-7cb	NW SW sec. 7	do	Dn	25.0	1¼	GP	do	do	N	O	do	1.0	21.35	10-1-47	
	T. 1 S., R. 6 W.														
1-6-4dc	SW SE sec. 4	School land	Dr	27.4	6	GI	do	do	Cy, H	N	Bottom edge of pump base	0.5	18.83	10-8-41	
1-6-5da	NE SE sec. 5	U. S. Geological Survey	Dn	13.1	1¼	GP	do	do	N	O	Top of pipe	1.0	9.90	10-2-47	
1-6-5dd	SE SE sec. 5	do	Dn	......	1¼	GP	do	do	N	O	do	3.0	31.00	10-2-47	
1-6-7ab	NW NE sec. 7	J. E. Meador Estate	Dr	72	6	GI	do	Meade formation	Cy, W	D,S	Top of platform	0.5	61.48	10-8-41	
1-6-13ad	SE NE sec. 13	P. N. Steier	Dr	71.1	8	GI	Gravel	do	N	S	Top of casing, west side	0.9	63.46	9-25-41	Just completed.
1-6-16aa	NE NE sec. 16	_____ Renschler	Dr	85.4	6	GI	do	do	Cy, W	N	Bottom edge of pump base	0.3	82.21	10-8-41	
1-6-18da	NE SE sec. 18	E. Warden	Dr	122.7	6	GI	do	do	N	N	Top of casing, north side	0.8	114.18	10-8-41	
1-6-20da	NE SE sec. 20	F. A. Humiston	Dr	127.2	6	GI	do	do	N	N	do	0.0	125.54	10-8-41	Blowing well.
1-6-22dc	SW SE sec. 22	D. Clark	Dr	92.3	6	GI	do	do	N	N	Top of 2 by 12 board across platform	0.4	91.16	10-9-41	
•1-6-24cb	NW SW sec. 24	C. L. Myers	Dr	58.6	6	GI	do	do	Cy, W	S	Top of casing, north east side	1.2	55.23	10-9-41	
1-6-25cd	SE SW sec. 25	R. E. Stratman	Du	46.7	18	R	do	Pleistocene	Cy	N	Top of 3 by 12 board under pump	1.5	45.94	10-9-41	
1-6-27dc	SW SE sec. 27	A. L. Fuller	Dr	69.7	5	GI	do	do	Cy, G	S	Top of concrete platform	0.5	60.15	10-9-41	
1-6-29dd	SE SE sec. 29	Mrs. Lon Graham Estate	Dr	92.1	10	T	do	do	Cy	N	Top of casing, east side	0.8	49.99	10-9-41	
1-6-30cc	SW SW sec. 30	M. Peterson	B	43.3	....	W	do	do	Cy, H	N	Top of pump base	0.6	42.06	10-10-41	
1-6-32cd	SE SW sec. 32	_____ Davidson	Dr	35.2	8	T	do	do	Cy	N	Top of tile casing, east side	2.1	32.82	10-11-41	
1-6-33dd	SE corner sec. 33	Dean Smith	Dr	69.9	6	GI	do	do	Cy, W	D,S	Top of 6-inch hole in concrete platform	1.3	54.78	10-9-41	

	T. 1 S., R. 7 W.													
1-7-1bb	NW NW sec. 1	U. S. Geological Survey	Dn	16.0	1¼	GP	Sand and gravel	Alluvium	N	O	Top of pipe	1.0	10.93	10-2-47	
1-7-2da	NE SE sec. 2	do	Dn	13.0	1¼	GP	do	do	N	O	do	1.0	7.90	10-3-47	
1-7-6dc	SW SE sec. 6	F. E. Bodie	Dr	64.6	6	GI	Gravel	Meade formation	Cy, W	N	Top of casing, south side	1.8	54.65	10-15-41	
•1-7-9bb	NW NW sec. 9	J. F. Barry	B	39.5	14	T	do	do	Cy	N	do	1.0	38.19	10-14-41	
•1-7-11bb	NW NW sec. 11	Mrs. C. M. Harkins	Dr	66.7	8	T	Sand and gravel	do	Cy, W	D, S	Top of disc under pump base	1.2	58.81	10-8-41	
1-7-13bb	NW NW sec. 13	H. C. Wood	Dr	111.3	5	GI	Grvel	do	Cy, W	D, S	Bottom edge of pump base	0.6	99.35	10-7-41	
1-7-16dc	SW SE sec. 16	Mrs. Lucy Wyatt	B	64.1	6	GI	do	do	Cy, W	S	Top of casing, north side	0.6	44.67	10-14-41	
•1-7-17cd	SE SW sec. 17	C. E. Headrick	Dr	46.8	6	GI	do	do	Cy, W	S	Top of casing, east side	5.2	42.78	10-7-41	
1-7-21cc	SW SW sec. 21	W. O. Eiseman	Dr	43.4	8	GI	Limestone gravel	Pleistocene	Cy, W	S	Top of 1 by 10 board under pump base	1.2	42.36	10-7-41	
1-7-24dd	SE SE sec. 24	W. Johannes	Du	81.1	36	B	do	Meade formation	Cy, W	D, S	Top of 2 by 8 board under pump base	1.0	78.27	10-7-41	
1-7-26ab	NW NE sec. 26	Tom Fulton	Du	51.5	8	T	do	do	N	N	Top edge of square hole in platform	1.3	41.76	10-7-41	
1-7-28db	NW SE sec. 28	A. E. Wyatt	Dr	64.8	6	GI	do	Pleistocene	Cy, W	D, S	Top of 2 by 12 board under pump base	1.1	61.57	10-8-41	
1-7-30da	NE SE sec. 30	Wilbur Blair	Dr	33.5	6	GI	do	do	Cy, W	D, S	Top of casing, southeast side	3.6	30.85	10-7-41	Well ended in blue shale.
•1-7-31dd	SE SE sec. 31	C. C. Weatherbee	Dr	87.7	6	GI	do	do	Cy, H	D	Bottom edge of pump base	0.6	67.45	10-11-41	
1-7-33cd	SE SW sec. 33	Life Insurance Co.	Dr	62.2	6	GI	do	do	Cy	N	Top of casing, south side	1.6	58.57	10-11-41	
1-7-34dc	SW SE sec. 34	J. W. Collins	B	57.6	10	W	do	do	Cy, W	S	Top of 2 by 6 board under pump base	1.1	39.66	10-10-41	
	T. 1 S., R. 8 W.														
•1-8-2cc	SW SW sec. 2	C. W. Warren	B	87.8	......	T	Gravel	Meade formation	Cy, W	D, S	Top of 2 by 8 board in platform	0.8	82.01	10-15-41	
1-8-3bb	NW NW sec. 3	Henry Troudt	B	50.3	8	W	Limestone gravel	do	Cy, W	D, S	Top of cream can curb	0.5	32.94	10-15-41	Encountered blue shale at 40 feet.
1-8-4cc	SW SW sec. 4	S. W. Brenker	B	79.7	8	T	Gravel	do	Cy, W	D, S	Top of metal form in concrete platform	1.3	69.48	10-16-41	
1-8-8cb	NW SW sec. 8	J. A. Stansbury	Dr	130.4	6	GI	Limestone gravel	do	Cy, W	D, S	Top of casing, east side	0.5	82.85	10-16-41	Well ended in yellow chalk.
1-8-11cc	SW SW sec. 11	C. W. Warren	B	138.6	12	T	Gravel	do	Cy, W	S	Top of 2 by 8 board under pump base	1.2	107.05	10-15-41	Well ended in blue shale.
•1-8-13ba	NE NW sec. 13	Joe Warren	B	110.3	6	GI	do	do	Cy, W	S	Top of casing, southeast side	0.5	82.01	10-15-41	
1-8-15cc	SW SW sec. 15	Helena Kaaz	B	83.4	8	T	do	do	N	N	Top of casing, north side	1.6	78.65	10-14-41	
•1-8-16cc	SW SW sec. 16	W. N. Ward	Dr	98.8	6	GI	do	do	Cy, W	S	do	1.5	66.70	10-13-41	
1-8-18bc	SW NW sec. 18	O. J. Hafner	Dr	78.4	6	GI	do	do	Cy, W	D, S	Top of casing, south side	0.7	65.01	10-16-41	
1-8-19cc	SW SW sec. 19	J. Allington	Dr	59.4	6	GI	Limestone gravel	Pleistocene	Cy, W	S	Top of casing, west side	1.6	22.50	10-17-41	

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TABLE 17.—*Records of wells in Jewell County*—*Continued*

Well No. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed		Method of lift and type of power (5)	Use of water (6)	Measuring point		Depth to water level below measuring point, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
							Character of material	Geologic source			Description	Distance above land surface (feet)			
	T. 1 S., R. 8 W.														
1-8-20cc	SW SW sec. 20	H. C. Tegley	B	71.2	6	T	Limestone gravel	Meade formation	N	N	Top of concrete base	0.8	50.14	10-13-41	
1-8-21dd	SE SE sec. 21	do.	B	88.4	8	T	Gravel	Pleistocene	Cy, W	N	Top of casing, south side	0.5	65.12	10-14-41	Reported as excellent well.
1-8-24dd	SE SE sec. 24	C. J. States	Dr	59.8	6	GI	Limestone gravel	do.	N	N	Top of casing, east side	0.5	56.77	10-14-41	
1-8-26dc	SW SE sec. 26	W. W. Turner	B	37.9	6	T	do.	do.	Cy, H	N	Top of casing, south side	0.2	29.69	10-15-41	
1-8-32aa	NE NE sec. 32	M. J. Tegley	B	44.1	8	T	do.	do.	Cy, T	S	Top of 3 by 12 board in platform	1.6	28.74	10-13-41	Reported as excellent well.
1-8-34bb	NW NW sec. 34	Merle Semke	B	55.6	8	T	do.	do.	Cy, W	N	Top of casing, south side	1.5	38.78	10-13-41	
	T. 1 S., R. 9 W.														
1-9-1ba	NE NW sec. 1	George Darwin	B	11.3	22	T	do.	Meade formation (?)	Cy, W	D, S	Top of oil-drum curb	1.5	7.14	10-16-41	Used to be a spring that flowed into draw.
1-9-3aa	NE NE sec. 3	B. J. Rutt	Dr	31.1	6	GI	do.	Alluvium	Cy	N	Top of 2 by 12 board under pump	1.7	23.09	10-16-41	
1-9-6cc	SW SW sec. 6	H. L. Hunter Estate	Dr	101.8	6	GI	Gravel	Meade formation (?)	Cy, W	D, S	Top of casing, west side	1.0	89.74	10-27-41	
1-9-9bb	NW NW sec. 9	W. H. Francis	Dr	83.2	6	GI	do.	Pleistocene	Cy, W	D, S	Top of concrete platform	0.6	47.21	10-16-41	
•1-9-14bb	NW NW sec. 14	Delbert Kiehl	Dr	73.6	10	T	do.	do.	Cy, W	D, S	Top of casing, east side	1.0	65.61	10-16-41	
•1-9-16aa	NE NE sec. 16	C. B. Renard	B	104.7	8	T	do.	do.	Cy, W	D, S	do.	1.1	91.34	10-16-41	
1-9-20dc	SW SE sec. 20	Burr Oak State Bank	B	92.6	8	T	do.	Meade formation (?)	Cy, W	D, S	Top of casing, north side	0.6	87.03	10-21-41	
1-9-23aa	NE NE sec. 23	W. Billenwillms	Dr	67.1	6	GI	do.	Pleistocene	Cy, W	D, S	Top of 4 by 8 board under pump base	1.5	52.08	10-17-41	
1-9-27da	NE SE sec. 27	H. D. and A. Lyons	B	48.6	8	T	Limestone gravel	do.	Cy	N	Top of 3 by 12 board under pump base	0.6	27.18	10-17-41	
1-9-32dd	SE SE sec. 32	Price Estate	Dr	76.3	6	GI	do.	Meade formation (?)	Cy, W	D, S	Top of platform under pump base	1.0	63.42	10-21-41	

	T. 1 S., R. 10 W.													
*1-10-3ab	NW NE sec. 3	R. W. Sherman	Du	29.4	30	B	do	do	Cy, W	S	Top of 2 by 8 board in platform	2.5	21.48	10-6-41	Well ended in Fort Hays limestone.
1-10-6aa	NE NE sec. 6	C. J. Platt	Dr	73.2	8	T	Gravel	do	Cy, W	S	Top of 2 by 8 board under pump base	1.1	51.04	9-26-41	
1-10-9bb	NW NW sec. 9	C. N. Merrill	Dr	130.4	8	T	do	do	Cy, W	D, S	Top of 2 by 6 board in platform	1.4	92.06	10-6-41	
1-10-11bc	SW NW sec. 11	M. Shigley	Dr	108.3	8	GI	do	do	Cy, H	D, S	Top of casing, north side	1.5	82.47	10-6-41	
1-10-13dd	SE SE sec. 13	R. H. Pugh	Dr	87.3	8	GI	do	do	Cy	N	Bottom edge of pump base	0.8	79.20	10-27-41	
1-10-18bc	SW NW sec. 18	R. and M. Bullock	B	78.5	8	T	do	Pleistocene	Cy, W	D, S	Top of casing, west side	0.9	48.82	10-27-41	
1-10-19dc	SW corner SE sec. 19	Life Insurance Co.	B	92.1	8	T	do	Meade formation	Cy, H	D, S	Top of hole in 2 by 12 board	2.0	69.96	10-27-41	
1-10-22bb	NW corner sec. 22	R. Shagley	Dr	111.2	8	GI	do	do	Cy, W	D, S	Top of 1 by 6 board under pump base	0.9	91.85	10-27-41	
*1-10-34cd	SE SW sec. 34	T. J. Hajny	B	101.1	8	T	do	Pleistocene	Cy, W	D, S	Top of tile, south side	0.9	78.32	11-5-41	Has pumped as much as 10,000 gallons a day.
	T. 2 S., R. 6 W.														
2-6-2ba	NE NW sec. 2	H. E. Garman	Du	45.1	36	B	Limestone gravel	do	Cy, H	S	Top of 2 by 12 board under pump base	1.8	38.21	10-9-41	
2-6-5cd	SE SW sec. 5	H. M. Flora	Dr	74.9	10	T	do	do	Cy, W	D, S	Top of casing, north side	0.8	57.38	10-10-41	
2-6-9cb	NW SW sec. 9	Randall Cleveland	Dr	54.1	6	GI	Gravel and clay	Alluvium	Cy, W	S	Top of casing, east side	1.4	35.19	10-10-41	
*2-6-12dd	SE SE sec. 12	E. H. Smies	B	35.2	8	T	do	do	Cy, W	D, S	Top of 2 by 2 board under pump base	1.0	18.66	10-29-41	
2-6-24dd	SE SE sec. 24	Carl Swanson	B	36.3	16	W	Limestone gravel	Pleistocene	Cy, W	S	Top of casing, south side	1.4	16.07	10-29-41	
2-6-27ca	NE SW sec. 27	J. Hooker	Du	30.9	36	B	do	do	Cy, H	D, S	Top of 3 by 12 board under pump base	0.6	26.57	10-29-41	
2-6-36dd	SE SE sec. 36	Will Walters	B	69.1	12	T	do	do	Cy, W	N	Top of 2 by 12 board under pump base	0.7	50.06	10-29-41	
	T. 2 S., R. 7 W.														
2-7-1bb	NW NW sec. 1	N. W. Caskey	Dr	80.5	8	GI	do	do	Cy, W	S	Top of casing south side	1.3	58.67	10-10-41	
2-7-12ba	NE corner NW sec. 12	Lloyd Reed	Dr	54.0	5	GI	Gravel and clay	Alluvium	Cy, W	D, S	Top of pump base	0.9	33.99	10-10-41	
	T. 2 S., R. 8 W.														
2-8-11db1	NW SE sec. 11	City of Mankato	Dr	70	18	I	do	do	T, E	P	....	.....	50+	....	K.E.R.C. No. 12
2-8-11db2	NW SE sec. 11	do	Dr	73	18	I	do	do	T, E	P	....	.....	50+	....	K.E.R.C. No. 8
2-8-11ca1	NE SW sec. 11	do	Dr	70	18	I	do	do	T, E	P	....	.....	50+	....	Layne-Western No. 1; yield in 1934, 10 g.p.m.
2-8-11ca2	NE SW sec. 11	do	Dr	75	18	I	do	do	T, E	P	....	.....	50+	....	Layne-Western No. 2; yield in 1934, 10 g.p.m.
2-8-11cd1	SE SW sec. 11	do	Dr	75	18	I	do	do	T, E	P	....	.....	50+	....	K.E.R.C. No. 32.
2-8-11cd2	SE SW sec. 11	do	Dr	79	18	I	do	do	T, E	P	....	.....	50+	....	Layne-Western No. 3; yield in 1934, 10 g.p.m.

TABLE 17.—*Records of wells in Jewell County—Continued*

Well No. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 2 S., R. 8 W.														
•2-8-13dd	SE SE sec. 13	___ Myerly	B	70.4	10	W	Limestone gravel	Alluvium	Cy, W	S	Top of casing, north side	1.2	48.48	10-30-41	
•2-8-26cc	SW SW sec. 26	G. Swihart	B	59.5	6	GI	do	do	Cy, W	D, S	Top of casing, south side	1.3	47.39	10-31-41	
	T. 2 S., R. 9 W.														
2-9-2cb	NW SW sec. 2	L. W. Ogelvie	B	89.2	12	T	do	Pleistocene	Cy, H	N	do	0.5	71.28	10-17-41	Abandoned, formerly a domestic well.
2-9-10bb	NW NW sec. 10	Mrs. Abbie Francis	B	80.9	8	T	do	do	Cy, W	D, S	Top of casing, east side	0.6	60.32	10-27-41	
•2-9-11cb	NW SW sec. 11	Loren McNichols	Dr	56.3	6	GI	do	Alluvium	Cy, W	D, S	Top of 2 by 12 board under pump base	1.5	48.09	10-21-41	
2-9-19aa	NE NE sec. 19	W. Smith	B	96.3	8	T	do	Pleistocene	Cy, W	S	Top of casing, east side	1.6	32.19	10-25-41	
2-9-23bb	NW NW sec. 23	City of Burr Oak	B	60	15	GI	Gravel and clay	Alluvium	Cy, E	P			28		Pumps 25 g.p.m. with a drawdown of 2 feet
2-9-23bc	SW NW sec. 23	do	Du	60	216	B	do	do	T, E	P			29		
2-9-27aa	NE corner sec. 27	L. D. Gillette	Du	17.0	48	N	Limestone gravel	do	N	N	Edge of hole in board cover	0.3	11.55	10-21-41	Thirty feet west and 120 feet south of corner.
•2-9-28cb	NW SW sec. 28	Z. Moarman	B	51.5	8	T	Gravel and clay	do	Cy, W	S	Top of casing, north side	1.6	25.37	10-28-41	
	T. 2 S., R. 10 W.														
2-10-6aa	NE NE sec. 6	G. W. Shipley	B	101.9	8	T	Gravel	Pleistocene	Cy, H	N	do	0.2	79.20	10-27-41	Abandoned, formerly a domestic and stock well.
2-10-7dd	SE SE sec. 7	Walter Avison	Du	65.5	48		Limestone gravel	do	Cy, W	S	Top of 2 by 8 board under pump base	0.5	60.00	10-27-41	
2-10-9ba	NE NW sec. 9	M. M. Grubrish	B	67.3	8	T	do	do	Cy, W	N	Top of casing, west side	1.0	53.27	10-27-41	Domestic and stock well.
•2-10-12ba	NE NW sec. 12	J. H. McDonnel	B	90.3	8	T	do	Meade formation (?)	Cy, W	D, S	Top of 2 by 12 inch board under pump base	0.8	84.83	10-27-41	
2-10-15dd1	SE SE sec. 15	City of Esbon	B	66	8	I	Gravel and clay	Alluvium	Cy, G	P			34		Yield reported 7 gpm.
2-10-15dd2	SE corner sec. 15	do	B	66	8	I	do	do	Cy, G	P			34		do
2-10-24dd	SE SE sec. 24	Federal Land Bank	B		7	T	do	do	Cy, W	D, S	Top of railroad tie under pump base	0.8	36.34	10-28-41	

2-10-27dd	SE SE sec. 27	Frank Thompson	Du	33.6	36	B	Limestone gravel	Pleistocene	Cy, H	N	Top of 2 by 6 inch board under pump base	1.7	30.57	10-28-41	Stock well, seated on Smoky Hill chalk.
2-10-28dc	SW SE sec. 28	Claus Lantis	B	47.1	8	T	do	do	Cy, W	S	Top of casing, south side	0.7	43.81	10-28-41	
*2-10-31cc	SW SW sec. 31	Ed Regan	Du	50.8	48	CB	do	do	Cy, W	S	Top of 3 by 12 inch board under pump base	1.3	48.83	10-28-41	
2-10-34da	NE SE sec. 34	City of Esbon	Du	60	96	B	do	do	Cy, E	P					
	T. 3 S., R. 6 W.														
*3-6-4dc	SW SE sec. 4	J. O. Ellsworth	Du	24.0	36	R	do	Alluvium	Cy, W	S	Top of 2 by 12 inch board under pump base	1.7	9.2	10-29-41	
3-6-13aa	NE NE sec. 13	Albert Boline	Du	27.6	48	R	do	do	Cy, W	S	Top of 2 by 6 inch board under pump base	1.5	10.17	10-29-41	Well depends on nearby pond.
3-6-16cc	SW SW sec. 16	Robert McCune	B	36.0	12	W	do	do	Cy, H	D	Top of tile, west side	1.3	31.25	10-23-41	Well seated on Fairport shale.
3-6-16dd	SE SE sec. 16	Don Keeler	B	54.9	12	T	do	Pleistocene	Cy, W	S	Top of 2 by 8 inch board under pump base	1.7	25.62	10-22-41	do
3-6-17cd	SE SW sec. 17	John Magnusson	Du	......	36	R	do	Alluvium	N	D, S	Top of rock curb east side	0.4	9.80	10-22-41	Abandoned house.
3-6-17dd	SE corner sec. 17	R. C. Allen	B	38.7	12	T	Gravel and clay	do	Cy, H	S	Top of tile, west side	0.8	19.79	10-22-41	East side of creek.
3-6-18da	NE SE sec. 18	I. S. Cullen	Dr	27.0	10	GI	do	do	Cy, W	S	Edge of board beside pump base	0.7	8.49	10-23-41	Well located in pit.
3-6-20ba	NE NW sec. 20	A. W. Miller	B	32.5	12	T	do	do	Cy, H	D, S	Top of tile, north side	1.3	8.10	10-22-41	
3-6-21aa1	NE NE sec. 21	C.R.I. and P. Ry.	Du	42.6	36	B	Limestone gravel	Pleistocene	Cy, W	N	Top of 8-inch hole in metal platform	0.4	10.13	10-22-41	East of depot.
3-6-21aa2	NE NE sec. 21	do	Du	27.7	36	R	do	do	Cy, H	S	Top of platform	1.8	7.45	10-22-41	East of storage tanks.
3-6-21ba	NE NW sec. 21	______ Williams	B	41.7	12	T	do	do	Cy, H	D, S	Top of casing, south side	0.5	23.14	10-22-41	
3-6-21bb	NW NW sec. 21	W. F. Logen	B	43.7	6	GI	do	Alluvium	N	D, S	Top of casing, west side	1.9	23.75	10-22-41	Recently completed, well seated on Fairport shale.
3-6-21bd1	SE NW sec. 21	City of Formoso	Du	51.5	168	R	do	Pleistocene	Cy, E	P					Well seated on Fairport shale.
3-6-21bd2	SE corner NW sec. 21	Jake Spiegel	B	35.9	12	T	do	do	Cy, W	S	Top of platform	0.2	......	10-22-41	Dry at 35.9 feet.
3-6-21ac1	SW NE sec. 21	John Lebhart	B	48.4	12	T	do	do	Cy, H	S	Top of casing, south side	0.4	40.43	10-22-41	
3-6-21ac2	SW NE sec. 21	Mrs. John Briggs	B	37.8	12	T	do	do	Cy, H	S	do	0.6	29.31	10-22-41	100 feet east of corner.
3-6-21ac3	SW NE sec. 21	H. E. Sloan	B	49.2	12	T	do	do	N	S	Top of 2½ inch hole in platform	1.1	29.69	10-22-41	Out of use.
3-6-21ad1	NE corner SE NE sec. 21	Bob Means	B	34.7	12	T	do	do	Cy, H	S	Top of platform	0.4	13.73	10-22-41	do
3-6-21ad2	SE NE sec. 21	Dr. C. W. Inge	Dr	65	6	GI	do	do	Cy, W	I	Round hole in concrete platform	0.0	29.40	10-22-41	Used for watering garden.
3-6-21ad3	SE NE sec. 21	T. H. Shedden	Dr	57	5	GI	do	do	Cy, H	I	Top of casing, northwest side	0.7	29.06	10-22-41	do
3-6-21ad4	SE NE sec. 21	______ Pantier	B	22.0	10	T	do	do	Cy, H	S	Top of casing, east side	0.6	19.35	10-22-41	
3-6-21da	NE SE sec. 21	Mrs. J. T. Marr	B	50.5	12	T	do	do	Cy, H	S	Top of 2 by 8 inch board in platform	0.9	29.29	10-22-41	

TABLE 17.—*Records of wells in Jewell County—Continued*

Well No. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 3 S., R. 6 W.														
3-6-21ca1	NE corner SW sec. 21	L. A. Sloan	B	45.5	12	T	Limestone gravel	Pleistocene	Cy, W	S	Top of 2 by 12 inch board under pump base	0.3	36.58	10-22-41	
3-6-21ca2	NE SW sec. 21	City of Formoso	Du	49	114	CB	do	do	Cy, E	P	......	......	......	......	
3-6-22bc	SW NW sec. 22	Mrs. G. Young	Du	......	24	W	do	Alluvium	Cy, H	S	Top of 2 by 12 inch board under pump base	2.6	4.67	10-22-41	
3-6-21cd1	SE SW sec. 21	Ed Patterson	Du	25.0	12	T	do	do	Cy, W	S	Top of platform	0.2	15.94	10-23-41	Well overflowed during flood.
3-6-21cd2	SE SW sec. 21	do	Du	35.5	42	R	do	do	Cy, H	D, S	Top of 2 by 6 inch board under pump base	0.5	27.68	10-23-41	
3-6-28ba1	NE NW sec. 28	do	Dr	37.7	10	T	do	do	Cy, H	D	Top of platform	1.4	24.62	10-23-41	
3-6-28ba2	NE NW sec. 28	do	Du	43.9	36	R	do	do	Cy, W	S	do	0.5	18.95	10-23-41	
3-6-28ba3	NE NW sec. 28	do	B	46.5	12	T	Gravel and clay	do	Cy, W	S	do	1.5	16.53	10-23-41	
	T. 3 S., R. 7 W.														
3-7-6ad	SE NE sec. 6	W. L. Raynolds	B	53.1	8	T	Limestone gravel	Pleistocene	Cy,W	N	Top of casing, west side	1.2	42.70	10-30-41	Abandoned, formerly domestic stock well.
3-7-7cc	SW SW sec. 7	A. C. Colson	Du	84.1	36	R	do	do	Cy, H	N	Bottom edge of pump base, south side	0.3	47.65	10-30-41	Abandoned, formerly domestic well.
*3-7-19bd	SE NW sec. 19	Alvin L. Fall	Du	30.1	30	......	do	do	Cy, W	D, S	Top of 2 by 8 inch board under pump base	0.7	16.12	10-7-41	Well was dry during drought.
3-7-20bb	NW NW sec 20	F. Hastings	Du	40.6	32	B	Gravel and clay	Alluvium	Cy, H	S	Top of platform	4.0	21.49	10-7-41	
3-7-24aa	NE NE sec. 24	Della Atwood	B	26.6	12	T	Limestone gravel	Pleistocene	Cy, G	S	Top of casing, southwest side	1.5	7.22	10-7-41	
3-7-26ba	NE NW sec. 26	Dr. D. D. Allen	B	51.1	15	B	Gravel and clay	Alluvium	Cy, W	S	Top of platform	1.8	21.23	10-7-41	Flood water rose 6 feet on windmill.
3-7-27da	NE SE sec. 27	E. B. Paton	Du	30.4	54	B	Limestone gravel	Pleistocene	N	N	Top of casing, east side	1.8	26.36	10-7-41	Abandoned, formerly domestic and stock well.
3-7-29dc	SW SE sec. 29	I. E. Highbee Estate	B	25.3	15	W	Gravel and clay	Alluvium	Cy, W	S	Top of casing, north side	1.5	22.89	10-8-41	

	T. 3 S., R. 8 W.													
3-8-6cd	SE SW sec. 6	Chris Vandeventer	B	81.8	6	GI	Cemented sand	Meade formation	Cy, G	C	Top of 2 by 10 inch board in platform	1.0	59.05	....	S.C.S. observation well 64, excellent well.
3-8-11cc	SW SW sec. 11	Mrs. Zay Vermillion	B	70.5	12	T	Limestone gravel	Pleistocene	B	D, S	Top of casing, north side	2.8	28.77	10-29-41	
3-8-16ca	NE SW sec. 16	City of Mankato	Du	50	192	CB	Gravel and clay	do	Cy, G	P	....	.....	....	....	Near reservoir.
3-8-22bc	SW NW sec. 22	do	Du	50	96	CB	do	do	Cy, G	P	....	.....	35		
3-8-22ca1	NE SW sec. 22	A. D. Porter	B	39.9	10	W	do	do	N	N	Top of casing, south side	2.0	35.89	10-31-41	Formerly domestic well.
3-8-22ca2	NE SW sec. 22	City of Mankato	Du	50	96	CB	do	do	Cy, G	P	....	.....	35	....	
3-8-32da	NE SE sec. 32	Emily Belot Estate	B	29.7	10	W	do	do	Cy, H	S	Top edge of can over well, south side	0.7	12.25	10-30-41	
	T. 3 S., R. 9 W.													
3-9-5aa	NE NE sec. 5	Harvey Sloan	B	52.7	12	GI	do	do	N	N	Top of casing, north side	0.2	39.55	10-27-41	S.C.S. Observation well 4.
3-9-5ac	SW NE sec 5	E. Underwood	B	57.6	12	GI	do	do	N	N	Top of 2-inch slot in wooden cover	1.7	22.94	10-27-41	S.C.S. Observation well 49.
3-9-5cd	SE SW sec. 5	H. C. Doud	B	51.0	8	T	do	do	N	N	Top of platform	1.2	42.61	10-27-41	S.C.S. Observation well 6.
3-9-7ca	NE SW sec. 7	Anton Matousek	Du	16.6	36	W	Limestone gravel	do	Cy, H	S	Top of 2 by 4 inch sill, north side	3.1	5.29	10-28-41	Well seated on Smoky Hill chalk.
3-9-10aa	NE NE sec 10	W. E. Lamb	Du	22.1	24	B	do	Alluvium	Cy, W	S	Top of 2 by 4 inch board in platform	2.4	8.91	10-21-41	
3-9-17cb	NW SW sec. 17	Will Zadina	B	78.8	8	T	Gravel and clay	do	N	N	Top of 2-inch slot in wooden cover	2.0	31.94	10-27-41	S.C.S. Observation well 8.
•3-9-23dd	SE SE sec. 23	Mrs. B. M. Parkhurst	Du	43.4	60	R	do	do	Cy, G	C	Edge of casing, east side	1.9	29.59	10-27-41	S.C.S. Observation well 65.
3-9-24dd	SE SE sec. 24	C. Walker	Du	53.9	42	R	Fractured chalk	Niobrara	N	N	Top of platform	1.0	37.67	10-27-41	S.C.S. Observation well 14.
3-9-30(1)	Lot 4 of Sec. 30	M. W. Howe	Du	88.1	36	B	do	do	Cy, H	N	do	1.3	68.54	10-27-41	S.C.S. Observation well 12.
3-9-31(1)	Lot 15 of sec. 31	S. Strom	B	38.5	8	T	Gravel and clay	Alluvium	Cy, H	N	Top of lid inside casing	0.4	23.09	10-27-41	S.C.S. Observation well 50.
	T. 3 S., R. 10 W.													
3-10-1aa	NE NE sec. 1	Ivan Frost	Du	60.9	48	B	Limestone gravel	Pleistocene	Cy, W	D, S	Top of 2 by 12 inch board under pump base	1.3	24.60	10-28-41	
3-10-3da	NE corner SE sec. 3	City of Esbon	Du	42	96	B	do	do	T, E	P	....	.....	35	....	
3-10-14bb	NW NW sec. 14	M. Nebel	Du	56.6	36	B	do	do	Cy, W	D, S	Top of 2 by 12 inch board	0.9	32.74	10-25-41	Not being used at time of measurement.
3-10-18dd1	SE SE sec. 18	Glen Kindler	Du	36.2	48	R	Gravel and clay	Alluvium	N	N	Top of platform	0.8	17.59	10-27-41	S.C.S. Observation well 34.

TABLE 17.—*Records of wells in Jewell County—Continued*

Well No. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 3 S., R. 10 W.														
3-10-18dd2	SE SE sec. 18	Glen Kindler	B	55.3	1½	GI	Gravel and clay	Alluvium	N	N	Top of casing	3.7	29.67	10-27-41	S.C.S. Observation well 34A.
3-10-18dd3	SE SE sec. 18	do	B	49.4	1½	GI	do	do	N	N	do	1.9	25.88	10-27-41	S.C.S. Observation well 34B.
3-10-18dd4	SE SE sec. 18	do	B	47.2	1½	GI	do	do	N	N	do	3.0	23.28	10-27-41	S.C.S. Observation well 34C.
3-10-21ba	NE NW sec. 21	G. Johonek	Du	29.4	30	B	do	do	N	N	Top of platform	0.2	13.46	10-27-41	
3-10-24ba	NE NW sec. 24	A. F. Nelson	Du	23.3	30	B	do	do	Cy, W	S	Top of 2 by 12 inch board on curb	1.1	11.81	10-27-41	
3-10-29cd	SE SW sec. 29	Martin Johaneck	B	48.1	12	GI	do	do	N	N	Top of 2-inch, slot in wooden cover	1.6	31.41	10-27-41	S.C.S. Observation well 18.
	T. 4 S., R. 6 W.														
6-4-19bb	NW NW sec. 19	James Flinn	Du	29.6	48	R	Limestone gravel	Pleistocene	Cy, H	D, S	Top of 2 by 12 inch board in platform	0.6	25.48	10-8-41	
4-6-28cc	SW SW sec. 28	J. A. Long	Dr	100+	6	GI	do	do	N	N	Top of casing, north side	0.6	26.24	10-28-41	
	T. 4 S., R. 7 W.														
4-7-8ba	NE NW sec. 8	C. H. Ayers	Du	35.4	36	R	do	do	Cy, W	S	Top of platform	0.0	33.69	10-8-41	
4-7-11ba	NE NW sec. 11	C. A. Robinett	Du	27.2	36	R	do	do	Cy, W	S	do	0.3	25.28	10-8-41	Abandoned house.
4-7-17cd	SE SW sec. 17	C. E. Peatrie	B	44.0	12	T	do	Alluvium	Cy, W	S	do	0.2	39.05	10-8-41	Well is in pit.
4-7-19dd	SE SE sec. 19	______ Edwards	Du	28.7	36	R	Gravel and clay	do	N	N	Top of concrete platform	0.4	25.68	10-2-41	Abandoned house.
•4-7-26cc	SW corner sec. 26	S. N. Frank	Du	25.8	30	B	Limestone gravel	Pleistocene	Cy, W	S	Top of platform	0.2	18.70	10-28-41	
4-7-30ad	SE NE sec. 30	City of Jewell	Dr	46.8	12	GI	Gravel and clay	Alluvium	Cy, E	P					
4-7-30da1	NE SE sec. 30	do	Dr	46.8	12	GI	do	do	Cy, E	P	Top of casing	0.4	32.50	9-18-41	Layne-Western No. 1.
4-7-30da2	NE SE sec. 30	do	Dr	46.6	12	GI	do	do	Cy, E	P	do	0.4	32.08	9-18-41	Layne-Western No. 2.
4-7-30cd1	SE SW sec. 30	______ Minor	B	42.5	12	T	Limestone gravel	Pleistocene	Cy, H	N	Top of concrete curb	0.5	37.38	10-28-41	Two blocks east of city square.

4-7-30cd2	SE SW sec. 30	Mrs. Blacker	B	42.5	12	T	do.	do.	Cy, H	N	Inner edge of casing	0.0	36.54	10-28-41	Southwest corner of block, 3 blocks east of city square.
4-7-30dd	SE SE sec. 30	City of Jewell	Dr	46.6	12	GI	Gravel and clay	Alluvium	Cy, E	P	Top of casing	0.3	35.02	9-12-41	Layne-Western No. 4.
4-7-31aa	NE NE sec. 31	Ollinger	B	43.9	12	T	do.	do.	Cy, W	D, S	Top of platform	1.1	34.99	9-12-41	
4-7-36dd	SE SE sec. 36	A. C. Gordanier	Du	17.0	48	R	Limestone gravel	do.	Cy, W	S	do.	0.7	7.45	10-8-41	
	T. 4 S., R. 8 W.														
4-8-21cb	NW SW sec. 21	L. J. Bevington	B	24.8	18	W	do.	do.	N	N	Top of 2 by 12 inch board on concrete curb	2.6	16.59	10-30-41	Well seated on Blue Hills shale.
4-8-25da1	NE SE sec. 25	City of Jewell	Du	47	192	CB	Gravel and clay	Pleistocene	C, E	P					
4-8-25da2	NE SE sec. 25	do.	Dr				do.	do.	T, E	P					Yield 14 g.p.m.
4-8-25db	NW SE sec. 25	do.	Dr				do.	do.	T, E	P					Yield, 10 g.p.m.
4-8-25dd	SE SE sec. 25	do.	Du	39	192	CB	do.	Alluvium	C, E	P					
4-8-26cd	SE SW sec. 26	J. W. Berry	B	26.7	12	T	Limestone gravel	do.	Cy, W	S	Top of casing, northwest side	0.5	13.07	10-30-41	
	T. 4 S., R. 9 W.														
4-9-8dc1	SW SE sec. 8	L. C. Beeler farm	B	31.1	1½	GI	Clay	do.	N	N	Top of casing	0.1	10.38	10-27-41	Beeler pond well 52.
4-9-8dc2	SW SE sec. 8	do.	B	28.0	1½	GI	do.	do.	N	N	do.	0.3	7.58	10-27-41	Beeler pond well 53.
4-9-8dc3	SW SE sec. 8	do.	B	25.6	1½	GI	do.	do.	N	N	do.	0.7	7.87	8-26-41	Beeler pond well 54.
4-9-8dc4	SW SE sec. 8	do.	B	28.3	1½	GI	do.	do.	N	N	do.	0.4	7.47	7-24-41	Beeler pond well 55.
4-9-8dc5	SW SE sec. 8	do.	B	34.1	1½	GI	do.	do.	N	N	do.	1.2	14.70	2-21-41	Beeler pond well 56.
4-9-8dc6	SW SE sec. 8	do.	B	42.6	1½	GI	do.	do.	N	N	do.	0.1	15.88	10-27-41	Beeler pond well 57.
4-9-8dc7	SW SE sec. 8	do.	B	42.9	1½	GI	do.	do.	N	N	do.	3.0	23.22	6-7-39	Beeler pond well 58.
4-9-8dc8	SW SE sec. 8	do.	B	29.2	1½	GI	do.	do.	N	N	do.	3.3	14.12	4-12-39	Beeler pond well 59.
4-9-8dc9	SW SE sec. 8	do.	B	43.6	1½	GI	do.	do.	N	N	do.	3.2	12.85	6-17-39	Beeler pond well 60.
4-9-13cd	SE SW sec. 13	Cleo Gimple	B	37.0	6	T	Gravel and clay	do.	N	N	Top of 2-inch slot in wooden cover	1.5	17.58	10-27-41	S.C.S. Observation well 44.
4-9-15bd	SE NW sec. 15	R. L. McDaniel	Du	45.6	32	R	do.	Pleistocene	N	N	Top of platform	0.9	37.67	10-27-41	S.C.S. Observation well 40.
4-9-16dc	SW SE sec. 16	Earle Finch	B	38.2	10		do.	Alluvium	N	N	Top of concrete platform	0.6	28.69	10-2-41	Abandoned stock well.
*4-9-17aa	NE NE sec. 17	Eldon C. Finch	Du	31.6	36	R	do.	do.	Cy, W	S	Bottom edge of pump base	0.0	30.51	8-5-41	Below pond.
4-9-17ab1	NW NE sec. 17	L. C. Beeler farm	B	30.3	7	GI	Clay	do.	N	N	Top of casing	2.5	3.09	10-27-41	Beeler pond well 51.
4-9-17ab2	NW NE sec. 17	do.	B	32.5	1½	GI	do.	do.	N	N	do.	0.1	17.58	10-27-41	Beeler pond well 61.
4-9-17ab3	NW NE sec. 17	do.	B	20.6	1½	GI	do.	do.	N	N	do.	4.4	12.16	10-27-41	Beeler pond well 62.
4-9-17ab4	NW NE sec. 17	do.	B	37.8	1½	GI	do.	do.	N	N	do.	1.3	16.51	10-27-41	Beeler pond well 63.
4-9-17bb	NW NW sec. 17	Mrs. Belle Frasier	Du	21.5	36	R	Limestone gravel	Pleistocene	Cy, W	S	Top of platform	1.0	8.90	8-6-41	Used only for gold-fish tank.
4-9-17cc	SW SW sec. 17	Lee Cline	Du	36.2	48	R	do.	do.	Cy, W	S	do.	1.5	26.26	8-6-41	Located near pond.
4-9-21ba1	NE NW sec. 21	Emmit Henningsen	B	42.8	12	T	Gravel and clay	Alluvium	Cy, W	D, S	do.	0.8	40.71	8-6-41	
4-9-21ba2	NE NW sec. 21	do.	Dr	42.0	8	T	do.	do.	Cy, W	D, S	Top of casing	0.8	40.17	8-6-41	200 feet northwest of well 203.
4-9-28ca	NE SW sec. 28	Fred Van Wey	B	52.6	10	GI	do.	do.	N	N	Top of cover resting on casing	1.9	42.38	10-27-41	S.C.S.Observation well 30.
4-9-33db	NW SE sec. 33	R. W. Turner	Du	27.1	24	T	do.	do.	Cy, W	N	Top of platform	1.4	21.89	10-11-41	Used at times as stock well.

TABLE 17.—*Records of wells in Jewell County—Continued*

Well No. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed		Method of lift and type of power (5)	Use of water (6)	Measuring point		Depth to water level below measuring point, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
							Character of material	Geologic source			Description	Distance above land surface (feet)			
	T. 4 S., R. 10 W.														
4-10-5cb	NW SW sec. 5	G. N. Jones	Dr	162.6	5	GI	Limestone	Niobrara formation	N	N	Top of casing, south side	0.8	108.85	10-28-44	Abandoned Windmill
*4-10-20dc	SW SE sec. 20	M. R. Johnson	Du	14.1	60	R	do	Alluvium	Cy, W	C	Top of platform	0.9	7.44	10-27-41	Located near spring
4-10-23cc	SW SW sec. 23	Frank Rogers	B	39.6	8	T	Clay	Carlile shale	N	N	do	2.0	19.74	10-27-41	S.C.S. Observation well 48.
4-10-24ca	NE SW sec. 24	Victor Yapp	B	38.3	12	GI	Gravel and clay	Alluvium	N	N	Top of 2-inch slot in wooden cover	0.9	31.65	10-27-41	S.C.S. Observation well 45.
	T. 5 S., R. 6 W.														
5-6-20cd	SE SW sec. 20	Mrs. Susan Eychner	Dr	69.5	6	GI	do	do	Cy, W	N	Top of platform	1.4	49.15	10-11-41	Abandoned house.
5-6-24cc	SW SW sec. 24	A. Vincent	Dr	100+	4	GI	Sandstone	Dakota formation	Cy, W	S	Top of concrete platform	0.8	91.25	10-11-41	Abandoned house.
*5-6-26ba	NE NW sec. 26	G. C. McCoy	Dr	138.3	4	GI	do	do	Cy, W	S	Top edge of board, north side	0.1	17.35	10-11-41	
*5-6-34cd	SE SW sec. 34	Motes Estate	Dr	100+	6	GI	do	do	Cy, W	S	Top of casing, west side	0.7	98.66	10-29-41	
	T. 5 S., R. 7 W.														
5-7-7dd	SE SE sec. 7	H. W. Jarney	Du	17.5	30	B	Gravel and clay	Alluvium	Cy, H	S	Top of platform	1.5	6.18	10-16-41	
5-7-12aa	NE NE sec. 12	City of Randall	Du	40	192	R	Limestone gravel	do	T, E	P	....	.....	25	....	Excellent municipal well.
5-7-12ad	SE NE sec. 12	....	B	35.6	14	GI	do	do	N	N	do	1.4	17.07	10-8-41	Former community well.
*5-7-19cd	SE SW sec. 19	B. M. Fuller	Du	31.8	36	R	do	do	Cy, H	S	do	1.0	17.06	10-11-41	
5-7-21dd	SE SE sec. 21	C. S. Wells	Du	32.0	40	R	do	do	Cy, H	N	do	0.7	19.58	10-11-41	House burned.
*5-7-32dc	SW SE sec. 32	W. P. Jones	Du	32.3	30	R	do	Pleistocene	Cy, H	S	Top edge of rock beneath platform	0.1	29.12	10-29-41	
5-7-35cd	SE SW sec. 35	F. G. Budke	Du	24.8	30	.....	do	do	N	N	Top edge of rock beside well	0.0	22.19	10-29-41	

	T. 5 S., R. 8 W.													
*5-8-4bb	NW NW sec. 4	R. L. Crumrine	Dr	30.9	14	T	do	Alluvium	Cy, W	S	Beside 1-inch hole in concrete cover	1.0	20.87	10-30-41	
*5-8-11cd	SE SW sec. 11	C. Lienberger	B	55 0	15	W	do	do	Cy, W	S	Top of platform	0.9	37.37	10-16-41	
5-8-16ab	NW NE sec. 16	R. H. Graff	Du	31.5	15	W	do	do	Cy, H	N	do	0.2	13.76	10-16-41	
5-8-19cc	SW SW sec. 19	A. F. Riley	B	38.5	12	W	do	Pleistocene	Cy, W	S	Top of casing, south side	2.0	13.76	10-11-41	Abandoned house.
*5-8-21cc	SW SW sec. 21	Mrs. Ina Warden	Du	39.9	20	R	do	do	Cy, W	S	Top of platform	0.7	32.12	10-11-41	
5-8-22dd	SE SE sec. 22	J. Wagner Estate	Du	29.4	36	R	do	Alluvium	Cy, W	S	do	2.0	10.35	10-11-41	
5-8-30dc	SW SE sec. 30	J. H. Goffield	Du	28.2	36	R	do	Pleistocene	N	N	Top edge of rock, east side of well	0.0	27.21	10-10-41	
5-8-36ab	NW NE sec. 36	M. H. Menhos	Du	17.1	36	R	do	do	Cy, H	S	Edge of hole in 2 by 10 inch board	0.6	6.82	10-10-41	
	T. 5 S., R. 9 W.														
5-9-3cd	SE SW sec. 3	Meyer Miles	B	16.7	7½	GI	do	Alluvium	N	N	Top of 2-inch slot in wooden cover	1.5	4.86	10-27-41	S.C.S. Observation well 47.
5-9-6(1)	Lot 14 of sec. 6	Albert Rose	B	45.4	12	GI	Gravel and clay	do	N	C	do	0.5	23.25	10-27-41	S.C.S. Observation well 67.
5-9-6(2)	Lot 16 sec. 6	Walter Dietz	B	31.1	8	T	do	do	N	N	do	1.5	26.07	8-26-41	S.C.S. Observation well 41.
5-9-7	Lot 2 of sec. 7	do	Dr	37.5	12	GI	do	do	N	N	Top of casing in pit	—4.5	13.14	10-27-41	S.C.S. Observation well 69.
5-9-10ab	NW NE sec. 10	Meyer Miles	B	47.6	20	T	do	do	N	N	Top edge of wooden cover	3.0	19.88	10-27-41	S.C.S. Observation well 22.
5-9-12dd	SE SE sec. 12	I. E. Abram	Du	39.2	24	R	Limestone gravel	Pleistocene	Cy, W	N	Top of platform	0.2	27.40	10-16-41	Abandoned house.
5-9-16bb	NW NW sec. 16	F. Beeler	Du	24.7	36	R	do	do	N	N	do	0.3	23.50	10-10-41	Used at times as stock well.
5-9-19	Lot 3 of sec. 19	Ralph Wierenga	B	28.6	8	T	Clay	Alluvium	N	N	Top edge of 2-inch slot in wooden cover	2.2	4.16	10-27-41	S.C.S. Observation well 46.
*5-9-23dc	SW SE sec. 23	W. M. Olson	Dr	26.1	6		Limestone gravel	Pleistocene	Cy, H	S	Top edge of 2 by 6 inch board	0.1	18.92	10-11-41	
5-9-25dc	SW SE sec. 25	S. Branagan	B	24.0	12	GI	Gravel and clay	do	N	N	Top edge of 2-inch slot in wooden cover	2.0	14.74	5-23-41	S.C.S. Observation well 43.
5-9-29bb	NW NW sec. 29	J. N. Sorrell	Du	34.4	40	R	do	do	N	N	Top edge of wooden platform	1.6	13.46	10-27-41	S.C.S. Observation well 25.
5-9-33ad	SE NE sec. 33	C. Bingesser	Du	36.	36	R	do	do	Cy, H	D	Top of platform	0.3	34.68	10-10-41	Walls have been caving.
5-9-36cc	SW SW sec. 36	J. A. Muck	Du	36.3	48	R	do	do	Cy, H	S	Top edge of board under pump base	0.5	22.91	10-10-41	
	T. 5 S., R. 10 W.														
5-10-1ad	SE NE sec. 1	A. E. Cook farm	B	31.1	20	GI	do	Alluvium	N	N	Top of casing, north side	0.3	18.98	10-27-41	S.C.S. Observation well 66.
5-10-10dd	SE SE sec. 10	John Hancock Insurance Co.	Du	32 3	48	R	do	do	N	N	Top of concrete curb	0.6	10.22	10-27-41	Abandoned house.
*5-10-16bb	NW NW sec. 16	School District	Dr	41.5	6	GI	Limestone gravel	Pleistocene	Cy, H	Sc	do	0.7	29.22	10-27-41	School well.

TABLE 17.—*Records of wells in Jewell County—Concluded*

Well No. (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 5 S., R. 10 W														
5-10-23cc	SW SW sec. 23	Life Insurance Co.	Du	19.0	48	R	Limestone gravel	Alluvium	Cy, W	D, S	Top of platform	1.0	3.77	10-27-41	Near pond.
5-10-24ad	SE NE sec. 24	Ralph Wierenga	Du	26.5	40	R	do.	do.	Cy, W	S	do.	0.1	8.95	10-30-41	Near pond.
5-10-31ad	SE NE sec. 31	J. Vandergiesen	Du	33.1	36	R	do.	Pleistocene	Cy, W	S	do.	0.6	30.55	10-27-41	
*5-10-33ab	NW NE sec. 33	Mrs. Jane Renken	Du	51.3	36	R	do.	do.	Cy, W	D, S	do.	0.0	48.06	10-30-41	
5-10-35ab	NW NE sec. 35	A. D. Coad	Du	19.9	40	R	do.	Alluvium	Cy, W	S	do.	0.5	9.31	10-30-41	
	T. 6 S., R. 9 W.														
6-9-27ab	NW NE sec. 27	L. Lowdermilk	Du	37.2	48	R	Gravel and clay	do.	N	N	do.	0.5	26.39	10-27-41	S.C.S. Observation well 42.

1. An asterisk (*) before a well number indicates that analysis of water is given in Table 15.
2. B, bored well; DD, dug and drilled well; Dn, driven well; Dr, drilled well; Du, dug well.
3. Reported depths below the land surface are given in feet; measured depths are given in feet and tenths below measuring points.
4. B, brick; C, concrete; CB, concrete blocks; GI, galvanized sheet iron; GP, galvanized-iron pipe; I, iron; N, none; OB, oil barrels; R, rock; T, tile; W, wood.
5. B, bucket; C, horizontal centrifugal; Cy, cylinder; N, none; Pr, pressure; R, removed; T, turbine; VC, Vertical centrifugal.
   Type of power: D, diesel; E, electric; G, gas engine; H, handoperated; T, tractor; W, windmill.
6. C, community; D, domestic; I, irrigation; N, not being used; P, public supply; S, stock; Sc, school.
7. Measured depths to water level are given in feet, tenths, and hundredths; reported depths to water level are given in feet.

LOGS OF TEST HOLES

Listed on the following pages are logs of 13 test holes drilled by the State Geological Survey. The locations of the test holes are shown on Plates 1 and 2. The test-hole-numbering system is described on page 13. The logs of 7 test holes along the Jewell-Republic County line including 1-5-18cc are given by Fishel (1948, pp. 154-164, Pls. 2, 5). The test holes extend along the county line from the northeastern corner of the county to the SE cor. sec. 1, T. 2 S., R. 6 W.

1-5-18cc. *Sample log of test hole in the SW cor. sec. 18, T. 1 S., R. 5 W., 8 feet north and 63 feet east of center of road intersection in Republic County; drilled by the State Geological Survey, 1942. Surface altitude, 1,595.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations		
Soil, clayey, brown-gray	2	2
Silt, yellow-gray	14	16
Silt, dark-brown	2	18
Silt, pink-buff grading downward to buff	12	30
Silt, buff, grading downward to light-brown	15	45
Silt, compact, gray	2	47
Silt, yellow-gray; contains some nodular caliche	23	70
Silt, brownish-gray grading downward to blue-gray and light yellow-gray; contains some sand	9	79
Gravel, medium to fine, and sand	11	90
CRETACEOUS—Gulfian		
Carlile shale		
Shale, calcareous, yellow and blue-black	1	91

1-6-14dd. *Sample log of test hole in the SE¼ SE¼ sec. 14, T. 1 S., R. 6 W., 84 feet east and 6 feet south of northeast corner of concrete culvert; drilled by the State Geological Survey, October 1944. Surface altitude 1,579.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations		
Soil, clayey, gray	1	1
Silt, clayey, gray-buff; contains some fine sand and caliche	11	11
Silt, clayey, light-tan	17	29
Silt, clayey, brown grading downward to light-gray; contains a little fine gravel and sand	4	33
Meade formation—Grand Island member		
Gravel, medium to fine, and sand; contains a little coarse gravel	7	40
Gravel, medium to fine, and some sand	10	50
Gravel, coarse to fine, and some sand	10	60
Gravel, medium to fine, and sand; contains a little coarse gravel	15	75
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, thin-bedded, gray-black	5	80

1-6-15dd. *Sample log of test hole at the SE cor. SE¼ SE¼ sec. 15, T. 1 S., R. 6 W., 3 feet south and 39 feet east of northeast corner of concrete culvert; drilled by the State Geological Survey, October 1944. Surface altitude, 1,609.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations		
Road fill and soil, gray	3	3
Silt, brown	4	7
Silt, buff	25	32
Silt, light yellow-gray, interbedded with much medium to fine gravel and sand	5	37
Meade formation—Grand Island member		
Gravel, coarse to fine, and sand	3	40
Gravel, medium to fine, and sand; contains some coarse gravel and a little light-gray clay	10	50
Gravel, medium to fine, and sand; contains some coarse gravel	20	70
Gravel, coarse to fine, and sand	10	80
Gravel, medium to fine, and sand contains a little coarse gravel and nonbedded yellow clay	10	90
Gravel, medium to fine, and sand	10	100
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, dark blue-gray	3	103

1-6-16dd. *Sample log of test hole at the SE cor. SE¼ SE¼ sec. 16, T. 1 S., R. 6 W., 51 feet west and 2 feet south of northwest corner of concrete culvert west of crossroads; drilled by the State Geological Survey, October 1944. Surface altitude, 1,629.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations		
Silt, clayey, gray	1	1
Silt, yellow-gray	5	6
Silt, blocky, brown	6	12
Silt, blocky, pink-buff	3	15
Silt, clayey, light-gray	2	17
Meade formation—Grand Island member		
Gravel, coarse to fine, and sand; contains some light yellow-gray clay and silt	33	50
Gravel, coarse to fine, and sand	10	60
Gravel, coarse to fine; contains some sand, a little silt, and nonbedded yellow clay	30	90
Gravel, coarse to fine; contains some yellow and light-gray clay and a little sand	9	99
Silt, clayey, pink-buff	2	101
Gravel, medium to fine, and coarse sand	11	112
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, dark blue-gray	2	114

1-6-19aa. *Sample log of test hole at the NE. cor. sec. 19, T. 1 S., R. 6 W., 54 feet south and 13 feet west of center of crossroads; drilled by the State Geological Survey, October 1944. Surface altitude, 1,680.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation and Meade formation—Sappa member		
Silt, blocky, dark gray-brown	6	6
Silt, soft, light yellow-gray; contains much very fine sand	24	30
Silt, light-buff; contains some coarse to fine sand	10	40
Sand, coarse to fine; contains a little medium to fine gravel and white silt	12	52
Clay, light gray-green	3	55
Meade formation—Grand Island member		
Sand, coarse to fine; contains a little coarse to fine gravel	5	60
Gravel, medium to fine, and sand; contains some gray-green silt at 65 feet	10	70
Gravel, medium to fine, and sand; contains some coarse gravel	10	80
Silt, dull gray-green and mottled yellow-brown; contains much fine to very fine sand	2	82
Sand, coarse to fine, grading downward to medium to fine gravel and sand	8	90
Gravel, medium to fine, and sand; contains a little coarse gravel	10	100
Sand, medium to fine	8	108
Gravel, medium to fine, and sand; contains some buff and gray silt	12	120
Gravel, coarse to fine, and sand	10	130
Gravel, medium to fine, and sand; contains some coarse gravel and some buff silt at 136 feet	10	140
Gravel, fine, and sand; contains some coarse to medium gravel and gray-buff silt	10	150
Gravel, fine; contains a little medium gravel and sand,	12	162
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, blue-gray	4	166

1-6-19bb. *Sample log of test hole at the NW cor. sec. 19, T. 1 S., R. 6 W., 51 feet east and 9 feet south of center of T road; drilled by the State Geological Survey, October 1944. Surface altitude, 1,631.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation and Meade formation—Sappa member		
Soil, light-brown	3	3
Silt, blocky, brown	4	7
Silt, yellow-gray; contains a little nodular caliche	3	10
Meade formation—Grand Island member		
Gravel, medium to fine, and sand; interbedded with buff silt	3	13

	Thickness, feet	Depth, feet
Gravel, medium to fine, and sand; contains a little coarse gravel	5	18
Silt, clayey, soft, gray-white	1	19
Gravel, coarse to fine, and sand	7	26
Silt, clayey, dull greenish-gray; contains much coarse to fine sand interbedded with coarse to fine gravel at 28 to 35 feet	14	40
Gravel, medium to fine, and sand; contains some coarse gravel	30	70
Gravel, coarse to medium, and a little fine gravel	3	73
Silt, clayey, light-buff	15	88
Silt, clayey, light greenish-gray; contains some fine gravel and sand	3	91
Gravel, fine, and sand	9	100
Gravel, medium to fine; contains some sand, a little coarse gravel, and light buff-gray silt	6.5	106.5
CRETACEOUS—Gulfian		
Carlile shale		
Shale, noncalcareous, gray	1.5	108

1-6-20aa. *Sample log of test hole at the NE cor. sec. 20, T. 1 S., R. 6 W., 54 feet south and 9 feet west of center of crossroads; drilled by the State Geological Survey, October 1944. Surface altitude, 1,646.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Meade formation		
Sappa member		
Soil, gray-brown	2.5	2.5
Silt, buff	2.5	5
Silt, buff; contains much fine and tubular caliche	2	7
Silt, dull yellow-gray; contains much fine to very fine sand	17	24
Silt, light greenish-gray and yellowish	3	27
Gravel, coarse to fine, and sand	1.5	28.5
Silt, soft, clayey, light blue-gray	4.5	33
Grand Island member		
Gravel, coarse to fine, and sand	7	40
Sand, coarse to fine; contains a little coarse to fine gravel	10	50
Sand, coarse to fine, grading downward to coarse to fine gravel and sand	6	56
Silt, soft, light-gray; contains much fine sand	7	63
Sand, coarse to fine; contains much medium to fine gravel and a little coarse gravel	17	80
Gravel, medium to fine, and sand; contains much coarse gravel	10	90
Gravel, coarse to fine, and sand	20	110
Gravel, fine, and sand; contains a little medium gravel and yellow and gray silt	10	120
Gravel, medium to fine, and sand; interbedded with light-gray silt	6	126

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, dark-gray	2	128

1-7-22bb. *Sample log of test hole at the NW cor. sec. 22, T. 1 S., R. 7 W., 42 feet east and 9 feet south of center of crossroads, drilled by the State Geological Survey, October 1944. Surface altitude, 1,713.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Meade formation		
Sappa member		
Soil, dark gray-brown	3	3
Silt, limonitic, compact, gray-green; contains much very fine sand	12	15
Clay, silty, light-gray	4	19
Silt, clayey, light brownish-gray and light greenish-gray	11	30
Silt, gray-green; contains some fine to very fine sand	48	78
Grand Island member		
Gravel, coarse to fine, and sand; contains much gray-green silt at 78 to 80 feet	4	82
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, dark-gray	4	86

1-7-24bb. *Sample log of test hole at the NW cor. sec. 24, T. 1 S., R. 7 W., 13 feet south and 4 feet west of telephone pole on section line east of road; drilled by the State Geological Survey, October 1944. Surface altitude, 1,730.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation and Meade formation—Sappa member		
Soil, dark gray-brown	2	2
Silt, yellow-gray	4	6
Silt, brown	3	9
Silt, clayey, dull-tan grading downward to gray-buff	9	18
Silt, clayey, light-gray	4	22
Silt, buff; contains some fine to very fine sand	18	40
Silt, yellow-buff; contains much very fine sand	38	78
Silt, clayey, light-gray and buff; contains much very fine sand	22	100
Silt, buff; contains much coarse to fine sand	2	102
Meade formation—Grand Island member		
Gravel, fine, and sand; contains some medium gravel and buff silt	6	108
Silt, buff grading downward to gray; contains some coarse to fine sand	6	114
Gravel, coarse to fine, and sand	6	120
Gravel, medium to fine, and sand	9	129
Silt, light-gray; contains much coarse to fine sand and a little caliche	9	138
Sand, coarse to fine; contains much medium to fine gravel and gray silt	12	150
Gravel, medium to fine, and sand	26	176

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, dark-gray	6	182

1-8-13cc. *Sample log of test hole in the SW¼ SW¼ sec. 13, T. 1 S., R. 8 W., 100 feet north and 30 feet east of center of road intersection; drilled by the State Geological Survey, January 1948. Surface altitude, 1,724.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Silt, dark-brown	9	9
Silt, clayey, tan to light-green	31	40
Silt, light-green	17	57
Silt, blue-gray	9	66
Silt, black; contains limestone pebbles	4	70
Silt, tan; contains limestone pebbles	15	85
Silt, brown	17	102
Silt and sand, very fine, brown	10	112
Clay, calcareous, yellow to green	8	120
Clay, calcareous, yellow to green; contains sand and limestone pebbles	10	130
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, blue-gray	12.5	142.5

1-8-19aa. *Sample log of test hole in the NE¼ NE¼ sec. 19, T. 1 S., R. 8 W., 75 feet south and 12 feet west of center of road intersection; drilled by the State Geological Survey, January and February, 1948. Surface altitude, 1,798.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations		
Road fill, dark-brown silt	1	1
Silt, tan	4	5
Silt, yellow-brown	7	12
Silt, dark-brown	5	17
Silt, brown	26	43
Silt, light-brown	11	54
Silt, brown	18	72
Silt, gritty, light-brown	28	100
Silt, light-brown	48	148
Silt, sandy, light-brown	2	150
Sand, fine to coarse; contains silt	20	170
Sand, fine to medium; contains silt	10	180
Sand, fine to coarse	18	198
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, weathered, yellow	6	204
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, blue-gray	14	218

1-9-19. *Sample log of test hole in the NW cor. lot 2, sec. 19, T. 1 S., R. 9 W., 21 feet south and 96 feet east of center of road intersection. Surface altitude, 1,860.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation and Meade formation—Sappa member		
Silt, dark-brown (soil)	1	1
Silt, brown	1	2
Silt, yellow-brown	7	9
Silt, brown	41	50
Silt, brown and white	32	82
Silt and lime concretions	16	98
Silt and very fine sand, light-tan	36	134
Silt and clay, light-tan	11	145
Meade formation—Grand Island member		
Sand, medium to coarse; contains fine gravel at 157 to 159 feet	14	159
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Chalk, weathered, yellow-brown	1	160
Shale, chalky, gray	10	170

2-6-27aa. *Sample log of test hole in the NE¼ NE¼ sec. 27, T. 2 S., R. 6 W., 0.09 mile west of NE corner of section, 45 feet west and 3 feet north of south end of concrete culvert; drilled by the State Geological Survey, October 1944. Surface altitude, 1,541.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation (?)		
Road fill and clayey soil, dark-gray	4	4
Silt, clayey, light-gray grading downward to buff	6	10
Silt, clayey, yellow-buff	5	15
Gravel, coarse to fine, and yellow-buff clayey silt	2	17
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, dark blue-gray; contains some gypsum at 17 to 19 feet	11	28

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AREAL GEOLOGY OF JEWELL CO., KANSAS

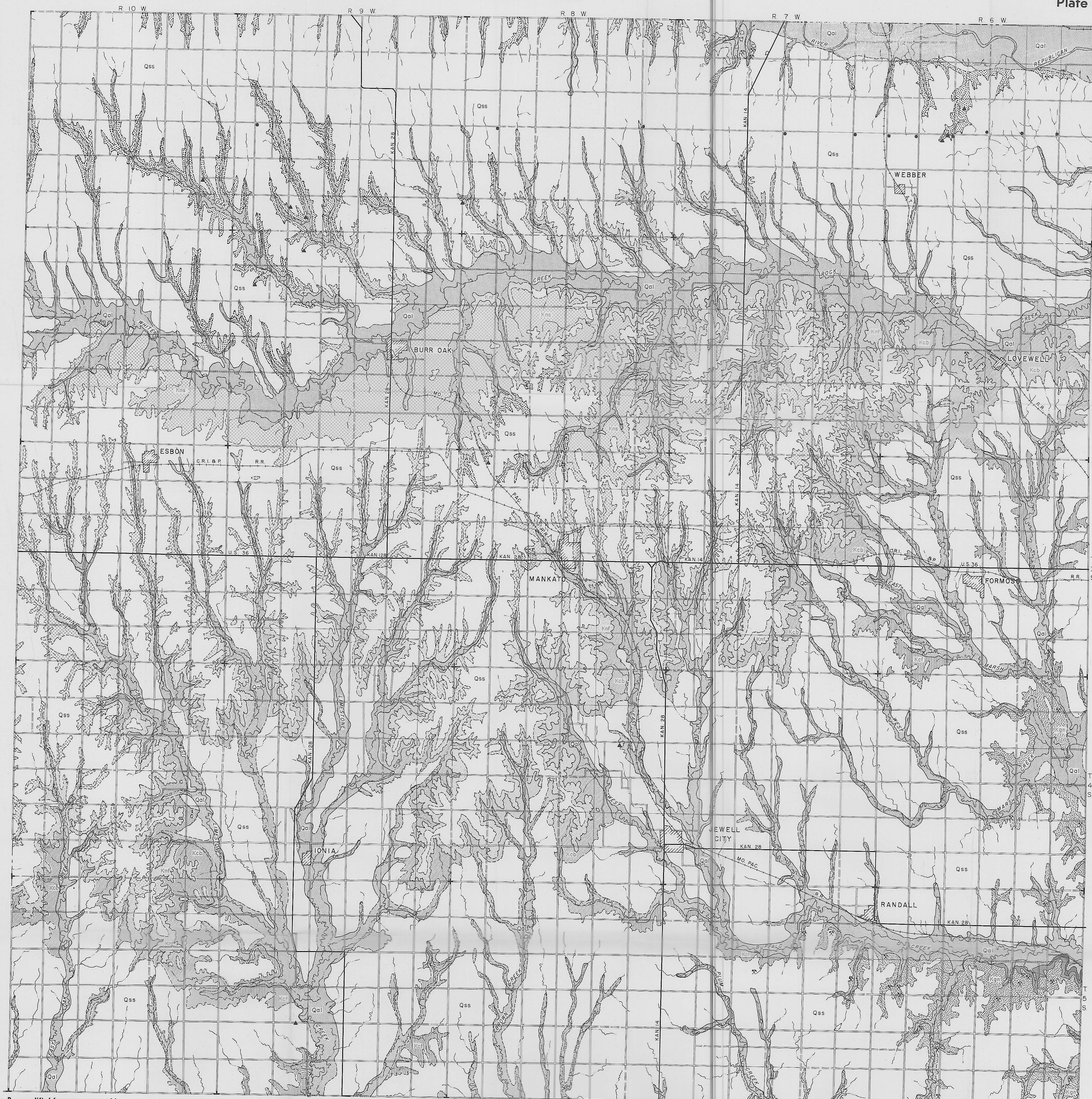
and a Geologic Cross Section

State Geological Survey
of Kansas

by A. R. Leonard

1953

Bulletin 115
Plate 1



Base modified from map prepared by State Highway Commission of Kansas

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

EXPLANATION

QUATERNARY — PLEISTOCENE

Qal — Alluvium

Unconsolidated silt, gravel, and sand. Yields small quantities of water in creek valleys, large quantities in Republican River Valley. Includes Recent alluvium and Late Wisconsinan terrace deposits. Dotted line indicates terrace scarp in Republican River Valley.

Qss — Sanborn formation

Massive eolian silt, sandy silt, limestone gravel, and sand and gravel. Locally includes slope deposits or underlying limestone gravel and Sappa member of the Meade formation where the Sappa Member is indistinguishable from the Loveland member of the Sanborn. Locally yields small supplies of water. Dotted line outlines upland edge of "terrace" along Republican River Valley.

Qm — Meade formation

Massive silt, stratified sandy silt, and cross-bedded sand and gravel. Locally contains the Pearlette ash lentil. Yields moderate supplies of water from basal gravel in northwestern part of area and smaller amount from silt in northwestern part.

CRETACEOUS — GULFIAN

Kns — Niobrara formation, Smoky Hill chalk member

Marine chalky shale and chalky limestone. Locally yields small supplies of water from fractures.

Knf — Niobrara formation, Fort Hays limestone member

Massive white chalky limestone. Yields little or no water to wells.

Kcb — Carlile shale, Blue Hill shale member

Gray fissile noncalcareous shale containing sandy zones at top and septarian and discoidal concretions. Yields little or no water to wells.

Kcf — Carlile shale, Fairport shale member

Gray, white, and buff calcareous shale and thin chalky limestone beds. Locally weathered zones yield small quantities of water to wells.

Kgn — Greenhorn limestone

Gray chalky shale alternating with chalky limestone in upper part and with dark crystalline limestone in lower part. Locally limestone in basal part yields meager quantties of water to wells and springs.

Kgs — Graneros shale

Dark-gray fissile noncalcareous shale; contains gypsum crystals, ochre, and locally sandy zones. Yields little or no water to wells.

Kd — Dakota formation

Massive fine-grained sandstone, structureless clay, and shale. Locally contains lignite in upper part. Yields moderate quantities of moderately mineralized water to a few wells in southeastern Jewell County, elsewhere contains highly mineralized water.

▲ Outcrop of pearlette volcanic ash of Meade formation.

⚒ Limestone quarry or gravel pit

● Test hole

Federal or State Highway

Graded road

Ungraded road

State line (no road)

County line (no road)

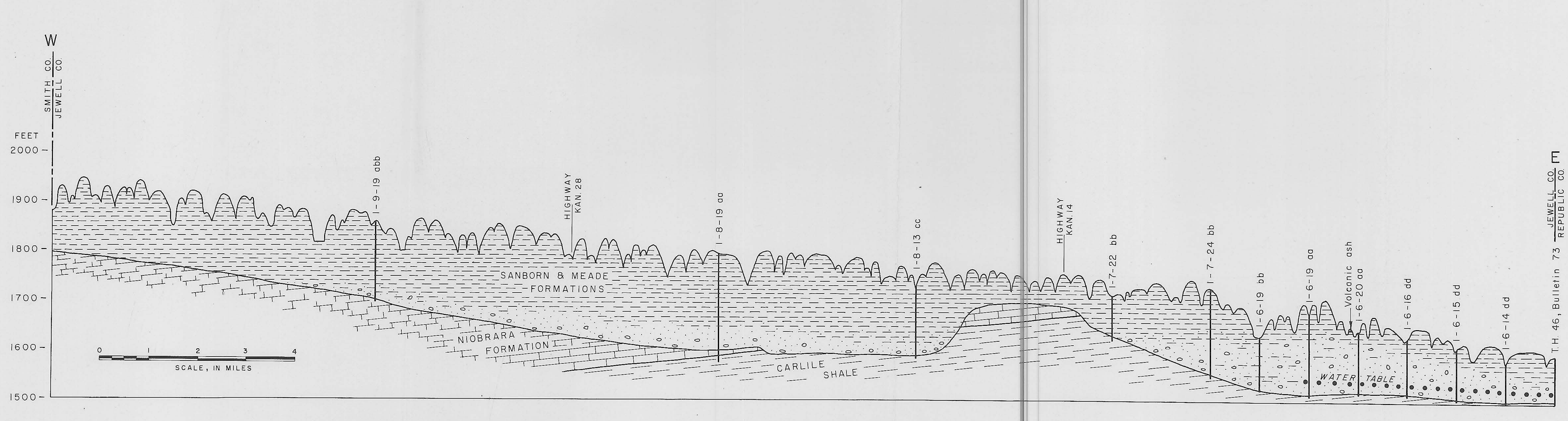
Township line (no road)

Section line (no road)

Railroad

Intermittent stream

0 1 2 3 4
SCALE, IN MILES



MAP OF JEWELL CO., KANSAS

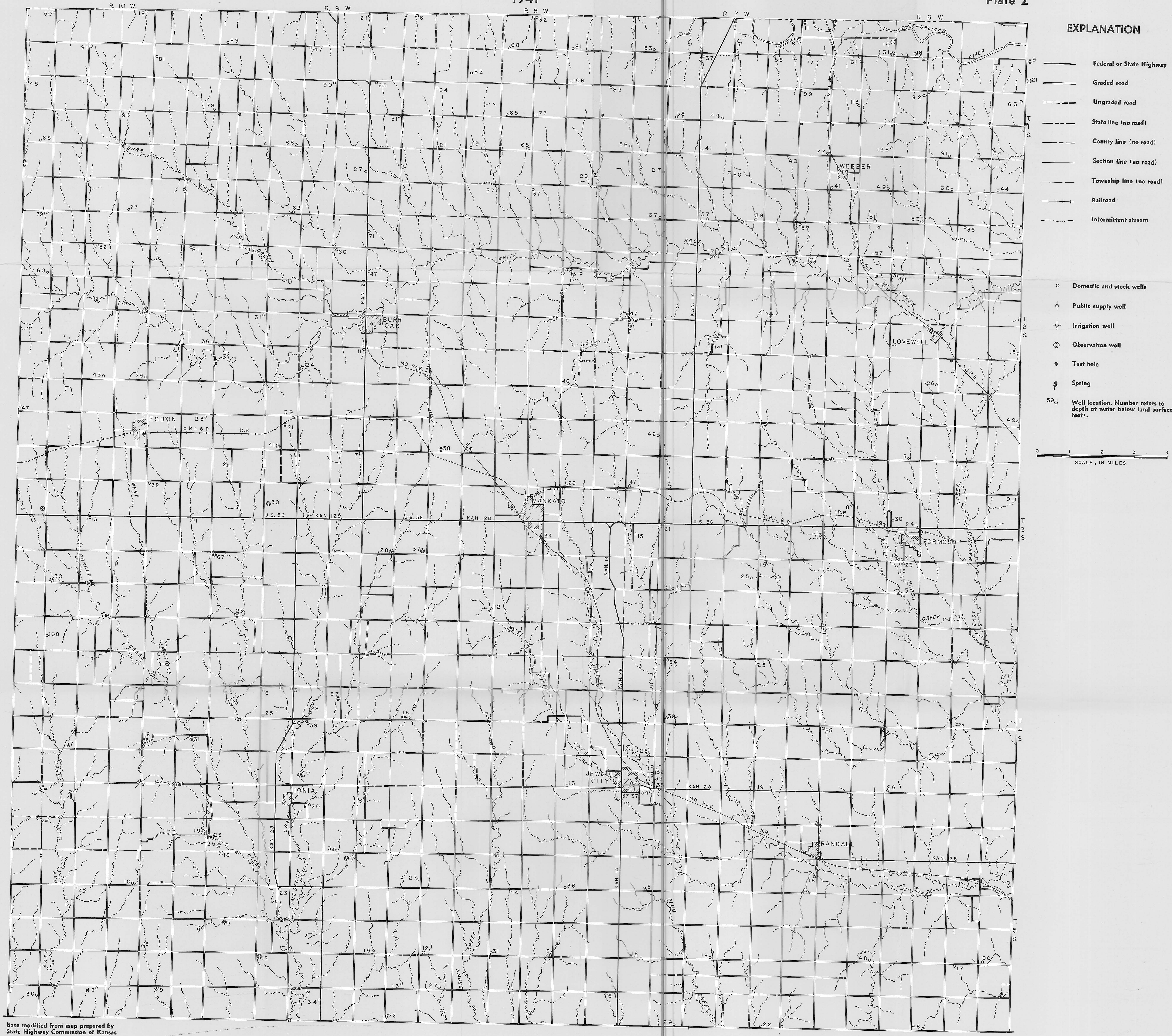
Showing the Depths to Water Level and the Location of Wells and Test Holes for Which Records are Given

by V. C. Fishel

1941

State Geological Survey of Kansas

Bulletin 115
Plate 2



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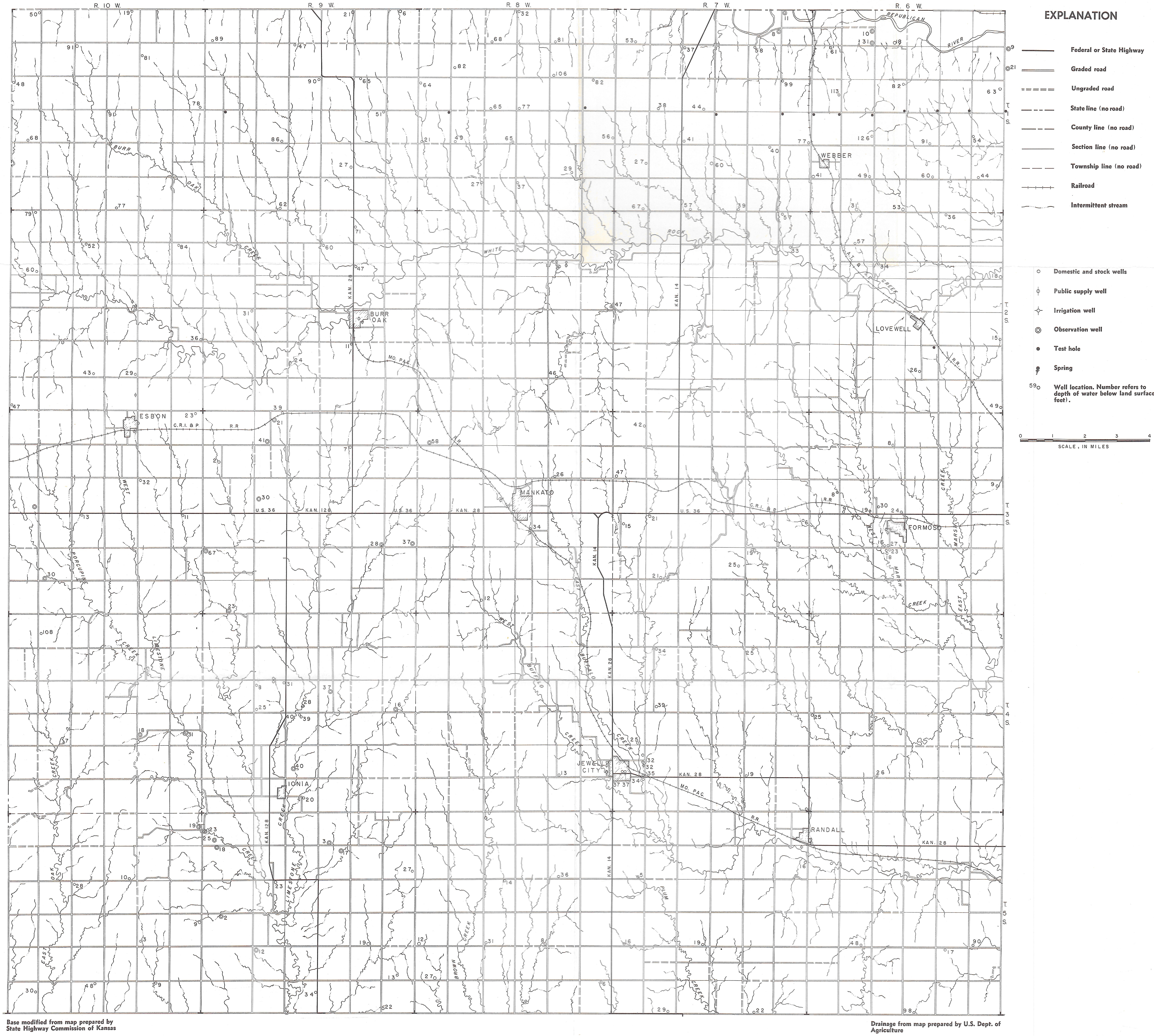

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AREAL GEOLOGY OF JEWELL CO., KANSAS

and a Geologic Cross Section

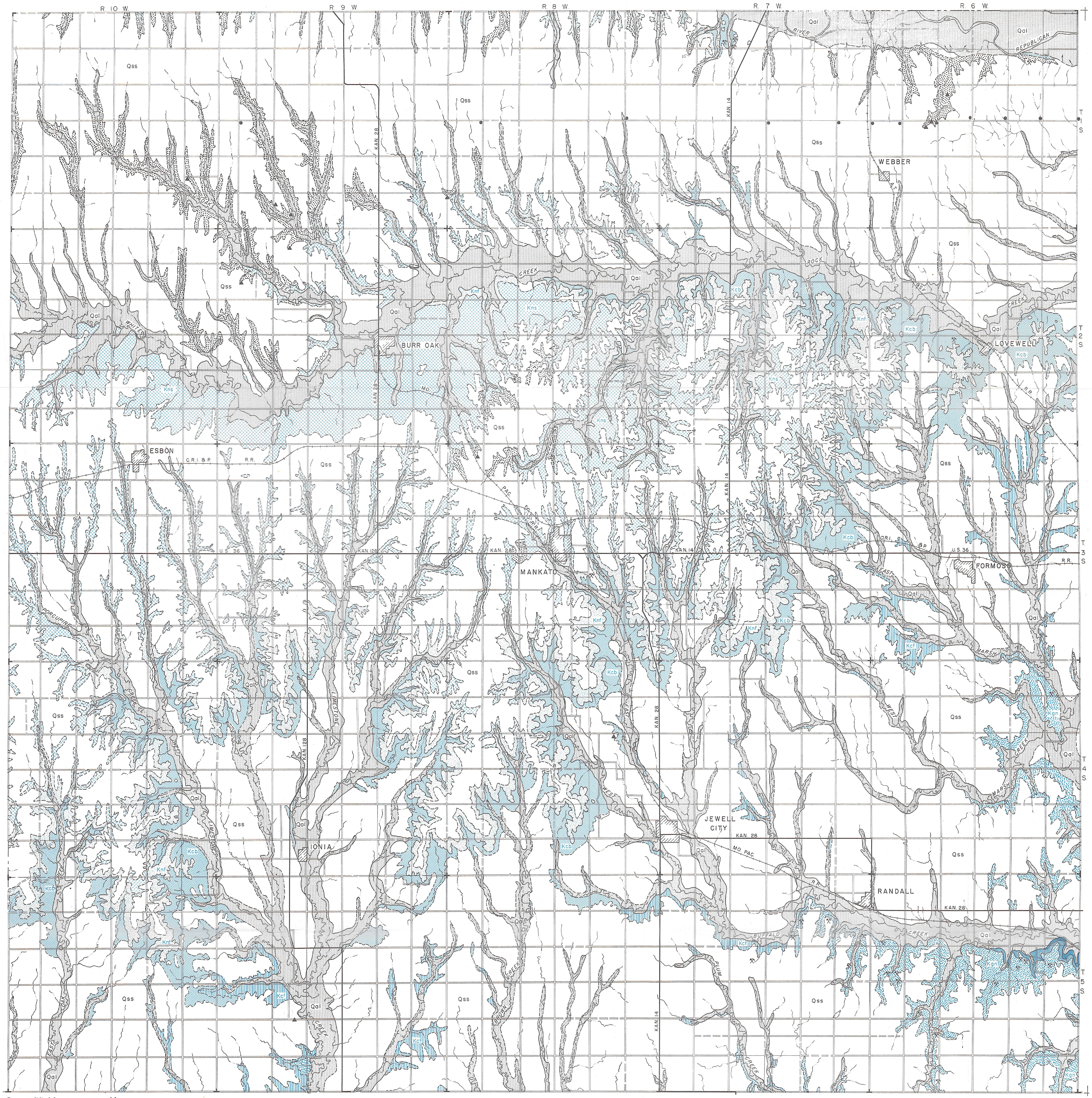
State Geological Survey of Kansas

by A. R. Leonard

1953

Bulletin 115

Plate 1



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

EXPLANATION

QUATERNARY — PLEISTOCENE

Alluvium (Qal)

Unconsolidated silt, gravel, and sand. Yields small quantities of water in creek valleys, large quantities in Republican River Valley. Includes Recent alluvium and Late Wisconsinan terrace deposits. Dotted line indicates terrace scarp in Republican River Valley.

Sanborn formation (Qss)

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Meade formation (Qm)

Massive silt, stratified sandy silt, and cross-bedded sand and gravel. Locally contains the Pearlette ash lentil. Yields moderate supplies of water from basal gravel in northwestern part of area and smaller amount from silt in northwestern part.

CRETACEOUS — GULFIAN

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Marine chalky shale and chalky limestone. Locally yields small supplies of water from fractures.

Niobrara formation, Fort Hays limestone member (Knf)

Massive white chalky limestone. Yields little or no water to wells.

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Carlile shale, Fairport shale member (Kcf)

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Graneros shale (Kgs)

Dark-gray fissile noncalcareous shale; contains gypsum crystals, ochre, and locally sandy zones. Yields little or no water to wells.

Dakota formation (Kd)

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0 1 2 3 4 SCALE, IN MILES