Geology and Ground-Water Resources of
RUSH COUNTY
Central Kansas

Jesse M. McNellis

Bulletin 207

State Geological Survey
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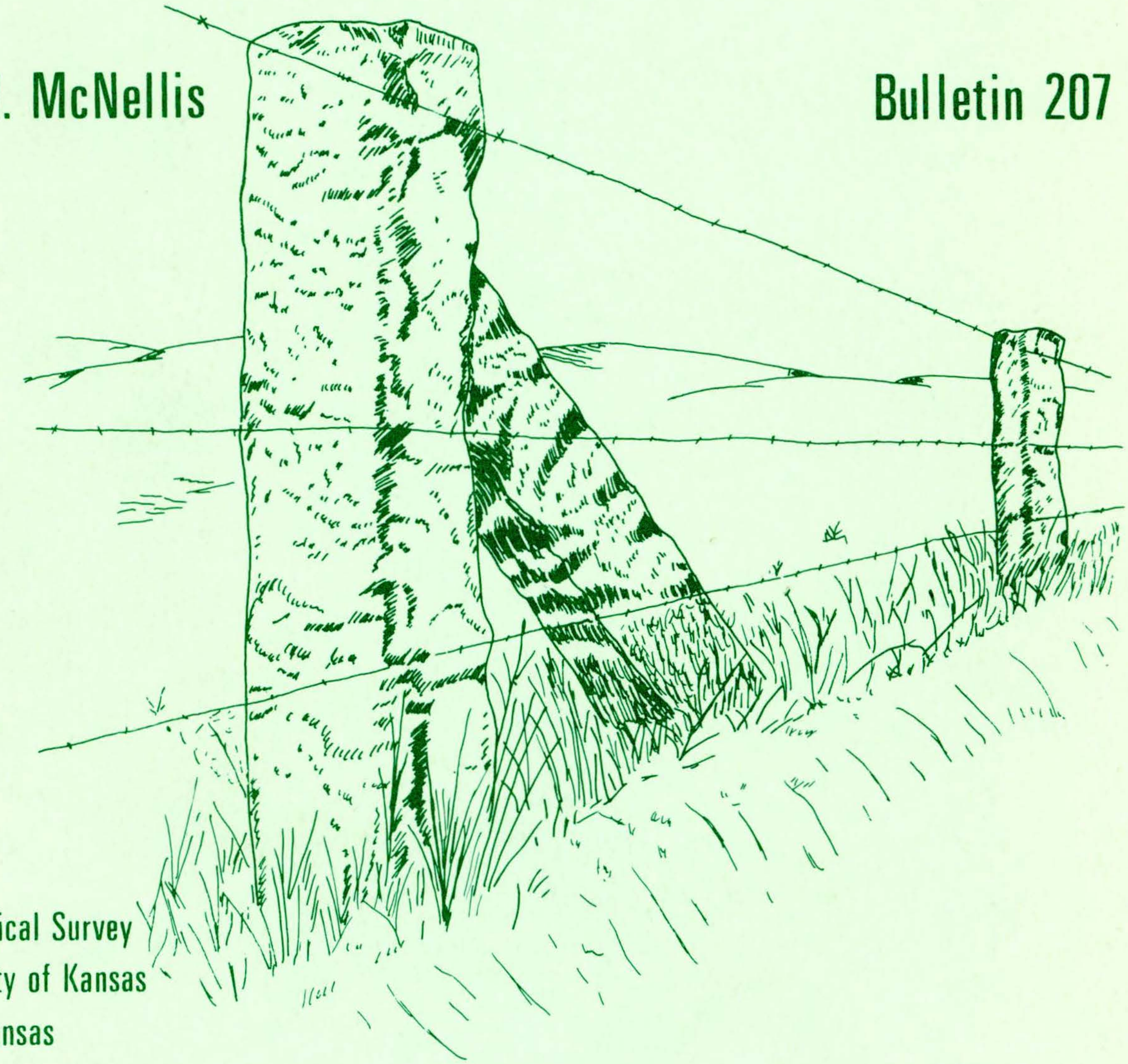

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Geology and Ground-Water Resources of Rush County, Central Kansas

By

Jesse M. McNellis

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

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Contents

Illustrations

Tables

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Geology and Ground-Water Resources of Rush County, Central Kansas

ABSTRACT

Rush County, which comprises an area of 724 square miles in central Kansas, is principally in the Smoky Hills section of the Great Plains physiographic province. The north third of the county is in the Smoky Hill River drainage basin and the rest is in the Arkansas River drainage basin. The average annual precipitation at Bison is 22.21 inches, and the average growing season is 174 days. The population of the county in 1970 was 5,117, of which 36.6 percent was rural. Agriculture is the dominant economic activity in the county and the chief mineral resources are ground water, oil and gas, and helium.

All rocks that crop out in Rush County are sedimentary. They include the Greenhorn Limestone, Carlile Shale, and Niobrara Chalk of Cretaceous age; the Ogallala Formation of Pliocene age; and eolian, fluvial, and colluvial deposits of Pleistocene age.

The principal aquifers are the Dakota Formation, which underlies the entire county, and the Pleistocene deposits in the stream valleys. Yields from wells in the Dakota generally are adequate for stock and domestic purposes, but the chemical quality of the water may be considered marginal for most uses. Wells obtaining water from the Dakota range in depth from 80 feet in the southeastern part of the county to a reported 530 feet in the northwestern part.

The Pleistocene aquifer in Walnut Creek valley yields 290 to 1,200 gallons per minute to wells for irrigation. Yields as great as 1,500 gallons per minute have been reported. Pleistocene deposits in other stream valleys yield adequate supplies for stock and domestic purposes. Water from Pleistocene deposits commonly is hard to very hard, but is satisfactory for most uses.

Recharge to the aquifers is principally from local precipitation. The aquifer in Walnut Creek valley receives sizeable amounts of recharge during periods of high flow in Walnut Creek; perhaps as much as 1⅓ feet of water per acre was recharged from a flood in 1959.

INTRODUCTION

Purpose and Scope

Irrigation by wells in Walnut Creek valley in Rush County during the dry 1950's demonstrated the economic importance of the ground-water resource. Because water supplies in the county are obtained principally from wells, ground water must be utilized in the best possible manner to ensure availability of this most important natural resource for future use.

This investigation was begun in August 1959 to determine the occurrence, availability, chemical characteristics, and geologic controls of ground water in Rush County. The study is part of a continuing program of geology and ground-water-resources investigations that was begun in Kansas in 1937 by the U.S. Geological Survey and the State Geological Survey of Kansas, in cooperation with the Division of Sanitation of the Kansas State Board of Health (now the Division of Environmental Health of the Kansas State Department of Health) and the Division of Water Resources of the Kansas State Board of Agriculture. The present status of the program is shown on figure 1.

Location and Extent of Area

Rush County, in central Kansas, is in the fourth tier of counties south of the Kansas-Nebraska border and is the sixth county east of the Kansas-Colorado border (fig. 1). The bordering counties are Ellis on the north, Barton on the east, Pawnee on the south, and Ness on the west. The county contains 20 town-

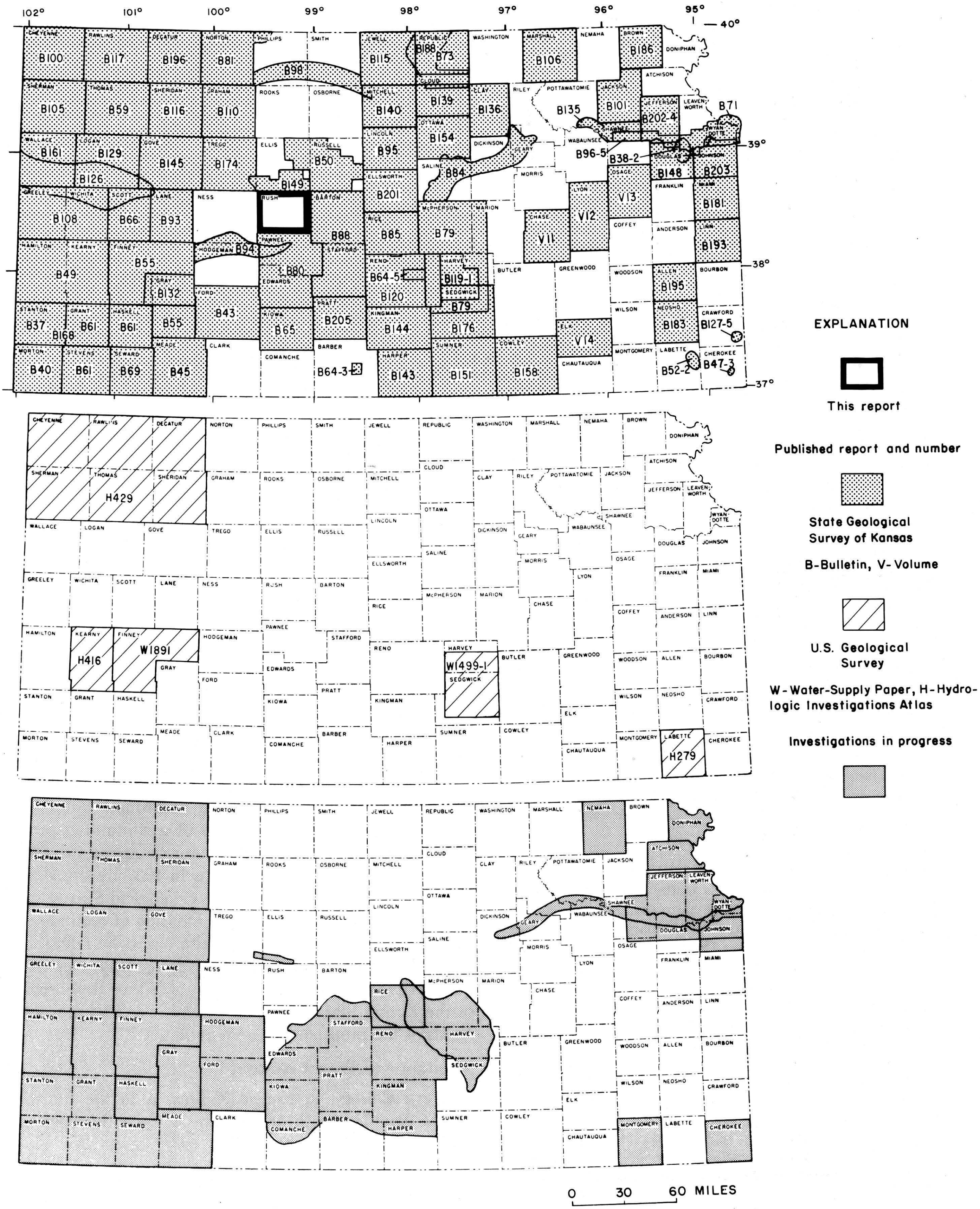


FIGURE 1.—Index maps showing area discussed in this report, and other areas for which ground-water reports have been published or are in preparation.

ships from T.16 S. to T.19 S. and from R.16 W. to R.20 W., and has an area of 724 square miles.

Previous Investigations

Rush County and the surrounding area have been investigated and studied previously by several workers. Reports by these investigators are listed in the Selected References.

Methods of Investigation

Field work for this report was done in the fall of 1959, the summer of 1960, and a short time in the spring of 1961. Data collected at 222 wells included depth of the well and depth to water in the well, if measurable. Other pertinent data available were obtained from well owners. A total of 161 test holes were drilled in the county by the U.S. Geological Survey and the State Geological Survey of Kansas. The test holes were drilled with a hydraulic rotary drilling machine (24 holes) and with a pickup-mounted power auger (137 holes). Drill cuttings were collected and examined. Water-well drillers in the area furnished test-hole logs. Several hundred oil-well logs on file at the State Geological Survey of Kansas were studied. In addition, a few thousand shot-hole logs from several oil and seismic survey companies were obtained and examined.

Wells and test holes were located by aerial photographs and automobile odometer readings. The altitudes of inventoried wells and Survey-drilled test holes were determined by plane table and alidade.

Samples of water were collected by the author and analyzed in the laboratory of the Division of Environmental Health of the Kansas State Department of Health. Chemical analyses of water from some of the municipal wells also were obtained from the Department of Health.

Water levels in available irrigation wells have been measured annually at least six times since 1960. Monthly or quarterly measurements are continuing on eight observation wells at the present time (1973).

Geology was mapped on aerial photographs obtained from the U.S. Department of Agriculture and transferred to a base map compiled from maps of the U.S. Soil Conservation Service and State Highway Commission of Kansas.

Well-Numbering System

Well and test-hole numbers in this report describe the location of wells and test holes according to General Land Office survey procedure as follows: first number, township; second number, range; third number, section; first letter, 160-acre tract (quarter section) within that section; second letter, 40-acre tract (quarter-quarter section) within that quarter section; third letter, 10-acre tract (quarter-quarter-quarter section) within that quarter-quarter section. The 160-acre, 40-acre, and 10-acre tracts are designated *a, b, c,* and *d* in a counterclockwise direction beginning in the northeast corner. For example, well 17-19W-27ddc is in the SW¼SE¼SE¼ sec. 27, T.17 S., R.19 W. (fig. 2). When two or more wells are located in the same 10-acre tract, the wells are numbered serially in the order they were inventoried.

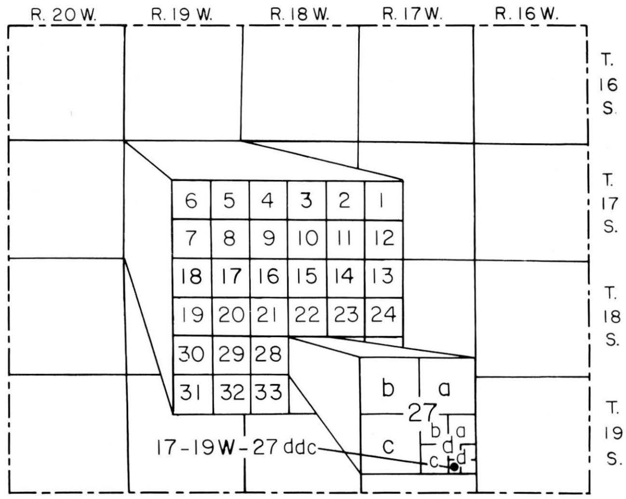


FIGURE 2.—Well-numbering system used in this report.

Acknowledgments

Thanks and appreciation are expressed to the many county residents who permitted access to their property and supplied information on their wells, to the municipal officials who provided information on city water supplies, to well drillers who supplied well and test-hole logs, and to oil and service companies that provided shot-hole logs. Special acknowledgment is made to the owners of the irrigation wells that were used in aquifer tests, and to Mr. Jerry Oborny for the copy of water-level measurements of several years duration for his irrigation well.

Topography and Drainage

Most of Rush County is in the Smoky Hills section of the Great Plains physiographic province (Frye and Schoewe, 1953). The southeast corner of the county is in the Great Bend Region, and the northwest corner is in the High Plains.

The altitude of land surface in Rush County ranges from slightly more than 2,300 feet above mean sea level in the northwest and southwest corners of the county to slightly less than 1,850 feet in the northeast corner. The maximum relief is somewhat more than 450 feet, but local relief seldom exceeds 100 feet.

Approximately the north third of Rush County is in Smoky Hill River drainage basin, but the Smoky Hill River occurs in Rush County only in secs. 5 and 6, T.16 S., R.17 W. Big Timber Creek is the largest tributary to the Smoky Hill River in Rush County; it heads in northeastern Ness County, enters Rush County in the vicinity of McCracken, and enters Ellis County northeast of Liebenthal. Other Smoky Hill tributaries in Rush County include Shelter Creek, Duck Creek, and Eagle Creek.

The south two-thirds of Rush County is in Arkansas River drainage basin. The major stream in this part of the county is Walnut Creek, which heads in western Lane County about 55 miles west of where it enters Rush County near Alexander. Walnut Creek flows eastward across Rush County and enters Barton County east of Shaffer. Major tributaries to Walnut Creek from the south include Old Maid Fork, Sandy Creek, and Otter Creek. Alexander Dry Creek and Sand Creek are the major tributaries to Walnut Creek from the north. Dry Walnut and Dry Creeks trend east-northeast in the southeast quarter of Rush County and enter Walnut Creek in Barton County. Along the south side of Rush County are headwater areas for some tributaries of Pawnee River.

Walnut Creek is an underfit stream; that is, it appears to be too small to have eroded the valley in which it flows. Walnut Creek valley ranges from about 1 to 3 miles in width across Rush County. Prior to the development of extensive irrigation from wells in the valley-fill deposits, Walnut Creek was a perennial stream through Rush County except after long droughts.

Climate

The climate of Rush County is characterized by abundant sunshine, moderate precipitation, high rates of evaporation, moderate to high wind velocities, and frequent and abrupt weather changes. Hot days and cool nights are typical in summer. During winter, temperatures are moderate to cold with occasional short periods of severe cold. Thundershowers are prevalent in spring and summer, and blizzards occur in winter.

The first precipitation records of the National Weather Service (formerly U.S. Weather Bureau) for Rush County date from 1891 to 1893. Precipitation records resume in 1902 and, with temperature records, continue to the present. The weather station was at La Crosse until 1923, when it was moved to Bison.

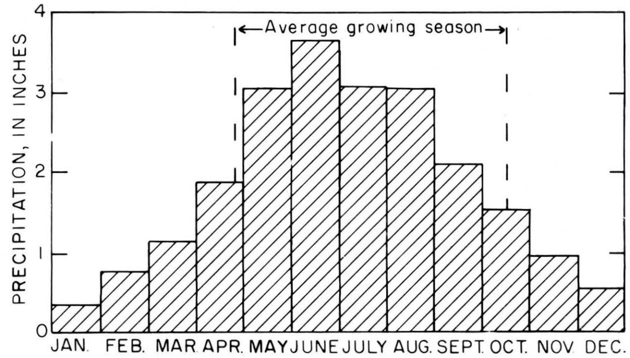


FIGURE 3.—Mean monthly precipitation 1891-93, 1902-70 and average growing season at Bison.

Three additional gages were installed at Alexander, Loretta, and McCracken in late 1940. Mean monthly precipitation through 1970 at Bison is shown on figure 3. Figure 4 shows the annual precipitation, the mean annual precipitation, and the cumulative departure from mean annual precipitation for the period of record at Bison (includes early record at La Crosse). Recorded annual precipitation in Rush County has ranged from 37.37 inches at Alexander in 1944 to 10.76 inches at Alexander in 1956.

Approximately three-quarters of the precipitation in Rush County occurs from April through September, which coincides with the growing season. The growing season at Bison has ranged from 140 to 207 days and averages 174 days.

The latest recorded date of a killing frost in the spring is May 27, 1907, and the average date is April 25. The earliest recorded date of a killing frost in the fall is September 17, 1903, and the average date is October 16. Recorded temperatures in Rush County have ranged from 116°F on July 13, 1934, to –25°F on January 12, 1912.

Population

The first settler in Rush County arrived in 1870 and the first family in 1871. Rush County was organized in 1874, and in 1875 counted 451 residents. In 1970 the county had a population of 5,117 (U.S. Bureau of the Census, 1971), of which 3,246 or 63.4 percent lived in incorporated cities and 1,871 or 36.6 percent lived on farms or in unincorporated communities. The population decreased 16.9 percent between 1960 and 1970. La Crosse, the largest city and the county seat, had a population of 1,583 in 1970. Other communities and their 1970 population were: McCracken, 333; Otis, 387; Bison, 285; Rush Center, 237; Liebenthal, 169; Alexander, 129; and Timken, 123. The average density of population in Rush County in 1970 was 7.1 per square mile as compared with 27.5 for the entire State.

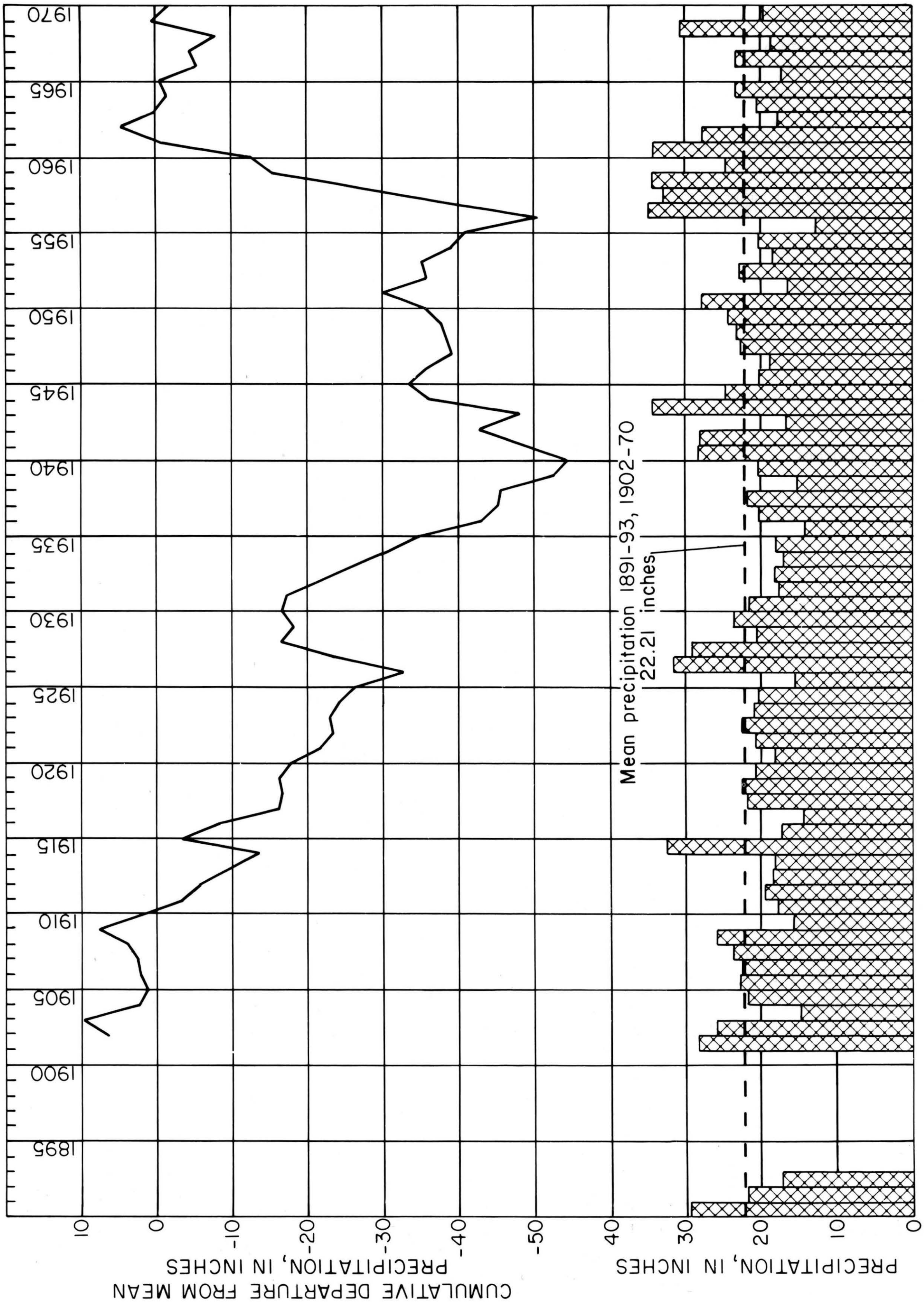


Figure 4.—Annual precipitation and cumulative departure from mean precipitation at Bison.

Agriculture

Agriculture is the dominant economic activity in Rush County. Crops valued at $6,996,960 and poultry and livestock valued at $5,017,220 were produced in Rush County in 1970 (Kansas State Board of Agriculture, 1971). The acreage and value of principal crops harvested in the county in 1970 are given in table 1.

TABLE 1.—Acreage and value of principal crops harvested in 1970 (Kansas State Board of Agriculture, 1971).

Crop	Acres	Value
Wheat	143,000	$5,300,000
Sorghum, all purposes	24,800	962,300
Corn, all purposes	2,900	333,100
Oats	280	6,300
Barley	360	8,900
Hay, all purposes	7,300	370,800
Other crops	210	15,560
Total	178,850	$6,996,960

Mineral Resources

The mineral resources of Rush County include oil and gas, helium, sand and gravel, "quartzite," and limestone, in addition to ground water. The U.S. Bureau of Mines (1971) lists petroleum products, helium, and sand and gravel, having a value of $6,749,354, as minerals produced commercially in Rush County in 1969.

OIL AND GAS

The first recorded drilling for petroleum products in Rush County was in 1903 when a dry hole in the southeast corner of sec. 33, T.17 S., R.17 W., reached a depth of 2,004 feet and another dry hole in the southwest corner of NW¼ sec. 34, T.17 S., R.17 W., reached 2,095 feet (Landes and Keroher, 1938). A third unsuccessful attempt was made in 1924 in the SW¼ sec. 3, T.16 S., R.16 W. In November 1928 the Danciger Oil and Refining Co. completed a gas well having a flow potential of 13 million cubic feet in the center of the NW¼ sec. 27, T.17 S., R.17 W., which was the beginning of successful petroleum operations in Rush County. The first oil well was completed on September 2, 1931, in the SW¼ sec. 17, T.19 S., R.16 W.

The most important producing field, the Otis-Albert gas and oil field, dates from March 1930 when the discovery gas well in sec. 11, T.18 S., R.16 W., was completed. The first oil in the field was discovered in 1934. Other important fields are the Ryan, discovered in 1945, the Rush Center, discovered in 1947, the Reichel, principally gas, discovered in 1953, and the Webs, discovered in 1954. Cumulative oil production in Rush County was 15,759,679 barrels through 1970. In addition to natural gas, helium gas has been extracted by a plant at Otis from 1943 to 1945 and from 1951 to the present time. The cumulative production, the number of wells, the producing zones, and other statistical data for all fields in the county are presented in annual reports by the Mineral Resources Section of the State Geological Survey of Kansas.

SAND AND GRAVEL

Deposits of sand and gravel are not extensive in Rush County. Remnants of Ogallala Formation provide sand and gravel in T.17 S., R.19 W., and in T.19 S., Rs.17-20 W. Pleistocene deposits in T. 16 S., Rs.16-18 W., have been used for road gravel, and a deposit of sand and gravel in sec. 3, T.18 S., R.20 W., was the source of part of the material used to build the asphalt-surfaced road between Alexander and McCracken. Small deposits of sand and gravel are present along stream courses within the county.

"QUARTZITE"

A silicified deposit of Ogallala crops out in the SW¼ sec. 6 and the NW¼ sec. 7, T. 16 S., R.20 W., and extends westward into Ness County. The quantity of material in the Rush County deposits is not large, but the material could have local use as aggregate or building stone.

LIMESTONE

The Fence-post limestone bed at the top of the Pfeifer Shale Member of the Greenhorn Limestone has been quarried extensively along the line of outcrop. No quarries are presently operating but reserves are very large. The limestone was and is used for fenceposts, as the name implies, over a wide area of central and north-central Kansas. In addition to fenceposts, the limestone has been used for foundations and buildings. The Catholic Church at Liebenthal is a fine example. The stone may be crushed and used as aggregate and for road material. Other limestone beds in the Greenhorn Limestone, and in the lowest part of the Carlile Shale, also have been quarried.

GENERAL GEOLOGY[1]

Distribution of Subsurface Rocks

PRECAMBRIAN ROCKS

Rocks of Precambrian age do not crop out in Kansas. Precambrian rocks in the State have been studied using well samples, logs, and geophysical methods

[1] The classification and nomenclature of rock units used in this report are those of the State Geological Survey of Kansas and differ somewhat from those used by the U.S. Geological Survey.

(Farquhar, 1957). The recorded number of wells penetrating Precambrian rocks in Rush County through 1964 totals 224 (Cole and others, 1961, 1965). The predominant types of Precambrian rocks reported from about 70 percent of the wells were granite or granite wash. Other Precambrian rock types include quartzite, quartz, porphyry, gneiss, schist, and diabase. A map of the configuration of the top of Precambrian rocks in Kansas by Cole (1962) shows an upthrown block of Precambrian rocks (fig. 5) trending southeastward from southwest Ellis County, across Rush County, to southwest Barton County. The depth to the top of the fault block ranges from 3,500 to 3,800 feet below land surface in Rush County.

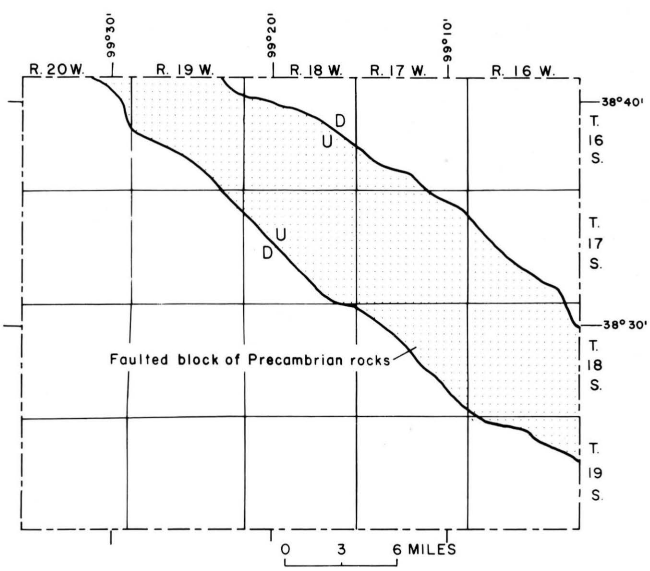


FIGURE 5.—Trend of faulted block of Precambrian rocks (from Cole, 1962).

Of probable interest are potassium-argon determinations made by J. Lawrence Kulp of Lamont Geological Observatory at Columbia University (Cole and Merriam, 1962) of the age of Precambrian rock samples from two wells in the county. Granite gneiss from the Skelly No. 1 Betz well in the NE¼SE¼SW¼ sec. 5, T.18 S., R.16 W., was dated at 1,260 million years and gray quartzite from the Skelly No. 4 Dyer in the NE¼SE¼NW¼ sec. 21, T.18 S., R.16 W., was dated at 1,200 million years.

PALEOZOIC ROCKS

Rocks of Paleozoic age do not crop out in Rush County. They have been studied using geophysical methods and well samples. The following maps issued by the State Geological Survey of Kansas reveal the general distribution and regional structure of Paleozoic rocks in Kansas: Arbuckle (Cambrian-Ordovician) rocks (Merriam and Smith, 1961), Silurian and Devonian rocks (Merriam and Kelly, 1960), Mississippian rocks (Merriam, 1960), and the Lansing Group of Pennsylvanian age (Merriam, Winchell, and Atkinson, 1958).

Briefly, distribution of Paleozoic rocks in Rush County is: Cambrian rocks are locally absent over the previously discussed upthrown Precambrian fault block (fig. 5) but are present beneath the rest of the county; Ordovician rocks are absent along the same general trend as the upthrown Precambrian fault block but are present elsewhere in the county; Silurian and Devonian rocks are absent throughout the county; Mississippian rocks are present in the southwest part of the county and absent elsewhere; Pennsylvanian and Permian rocks underlie the entire county.

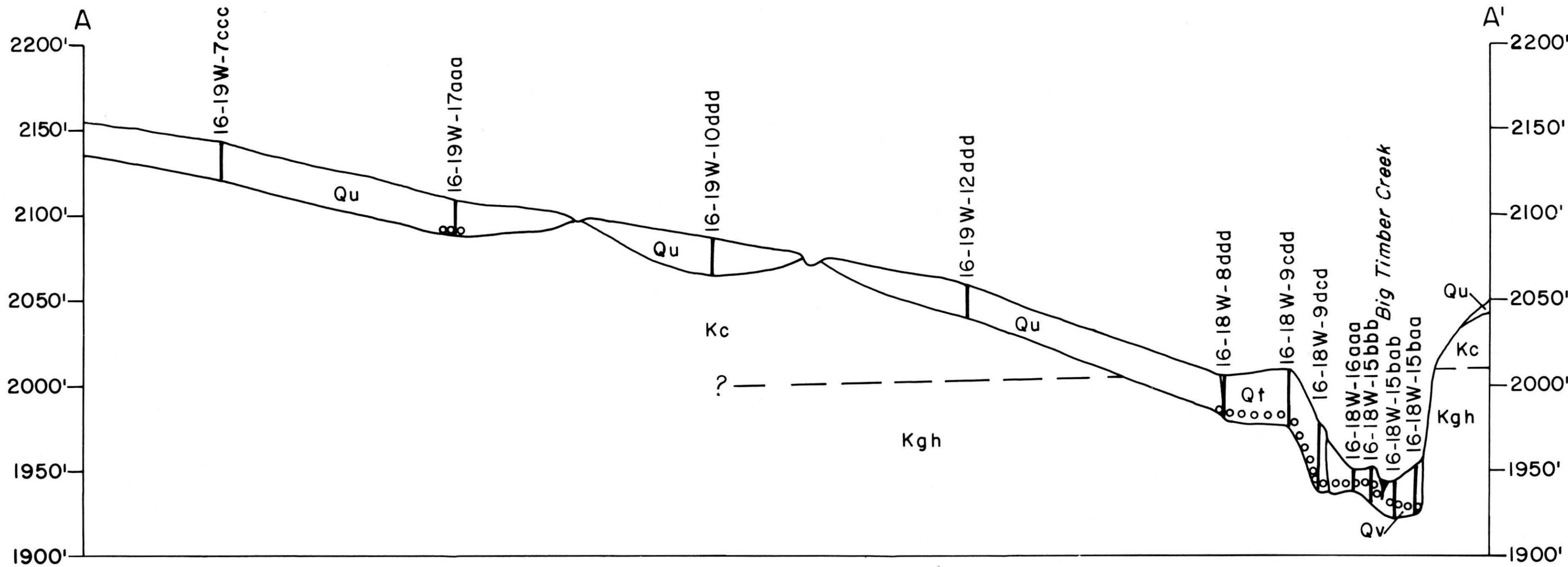
MESOZOIC ROCKS

Rocks of Mesozoic age in Rush County belong to the Cretaceous System. Cretaceous rocks unconformably overlie Paleozoic rocks and, in much of the county, are overlain unconformably by Cenozoic rocks. The Cretaceous units that underline the county but do not crop out include, in ascending order: Cheyenne Sandstone, Kiowa Formation, Dakota Formation, and Graneros Shale. These units are discussed in the section on geology and water supply.

Distribution of Exposed Rocks

Rock units exposed at the land surface, as shown on the geohydrologic map of Rush County (pl. 1), are sedimentary and range in age from Cretaceous to Pleistocene. Geologic relationships and the position of the water table are shown in selected geologic sections on figure 6.

The oldest rocks exposed in Rush County are marine deposits of Late Cretaceous age. The Greenhorn Limestone is the prominent rock cropping out along most stream valleys in all but the northwest quarter and the southwest eighth of the county. The Greenhorn underlies all but the deep valleys of Walnut Creek, the Smoky Hill River, and tributaries to Walnut Creek and the Smoky Hill River. The Graneros Shale or Dakota Formation underlies these valleys. Conformably overlying the Greenhorn is the Carlile Shale (Hattin, 1962, p. 24). The lower 20 to 35 feet of Carlile is relatively resistant; it crops out in stream valleys and closely resembles Greenhorn. The Carlile Shale is the bedrock formation in much of the upland area of the county. Above and unconformably overlying the Carlile Shale is the Fort Hays Limestone Member of the Niobrara Chalk (Hattin, 1962, p. 91), which is exposed in the extreme northwest corner of the county.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16-18W-9dcd
16-18W-16aaa
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Big Timber Creek
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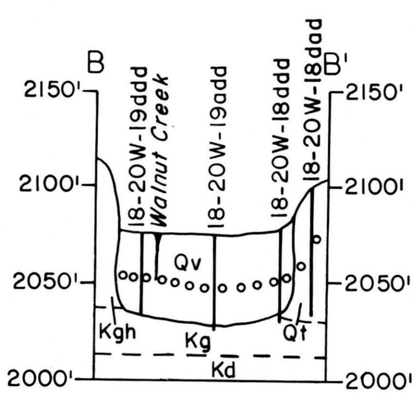
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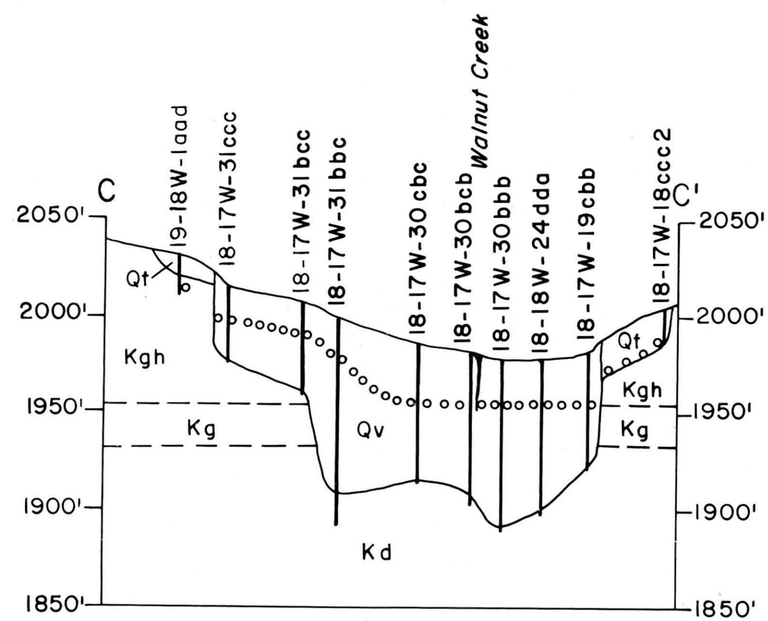
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18-17W-31bcc
18-17W-31bbc
18-17W-30cbc
18-17W-30bcb
Walnut Creek
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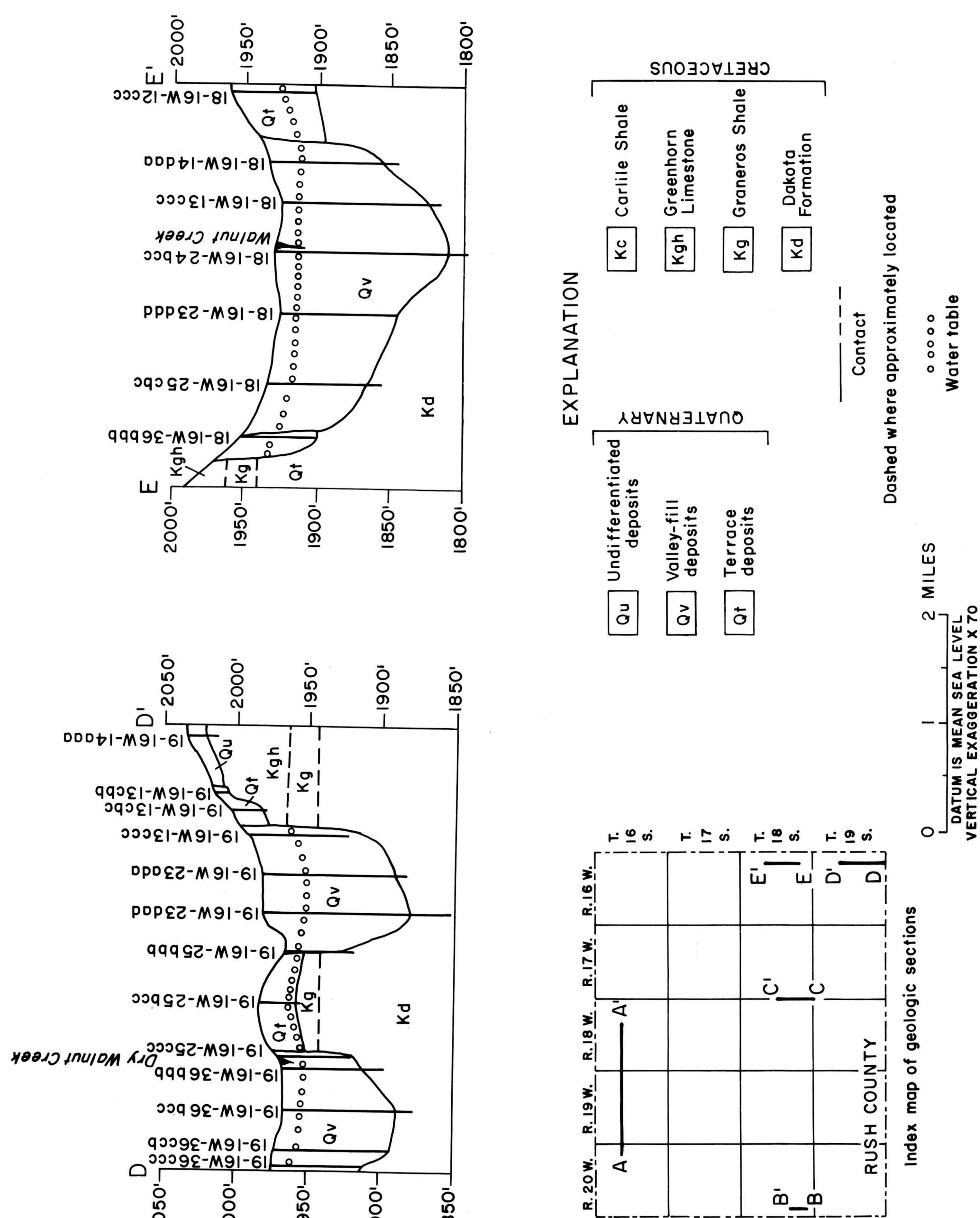

FIGURE 6.—Geologic sections.

TABLE 2.—Generalized section of geologic units and their water-bearing characteristics.

System	Series	Group	Formation or stratigraphic unit	Member	Thickness (feet)	Character	Water Supply[1]
Quaternary	Pleistocene		Undifferentiated deposits		0-56	Eolian, fluvial, and colluvial deposits; mostly silt that may overlie sand and some gravel.	May yield small to moderate quantities of water to wells.
			Valley-fill deposits		0-120	Fluvial and eolian deposits of gravel, sand, silt, and clay.	May yield moderate to large quantities of water to wells in Walnut Creek valley and small to moderate quantities of water to wells in other valleys.
			Terrace deposits		0-70	Fluvial and eolian deposits comprised of gravel, sand, silt, and clay.	May yield small to moderate quantities of water to wells.
Tertiary	Pliocene		Ogallala Formation	Kimball	0-44	Fluvial deposits of gravel, sand, silt, and clay; occurrences of soil caliche (referred to as "algal limestone") and quartzitic-appearing green conglomerate with an opaline matrix.	Occurs on divide areas and is not known to yield water to wells.
				Ash Hollow			
				Valentine			
Cretaceous	Upper Cretaceous	Colorado	Niobrara Chalk	Fort Hays Limestone	0-10	Marine deposits of massive chalky limestone.	Yields no water to wells.
			Carlile Shale	Codell Sandstone	0-300	Marine deposits of chalky limestone and chalky shale, overlain by virtually noncalcareous shale containing large concretions, overlain by friable silty sandstone. Contains numerous bentonite beds.	Not known to yield water to wells.
				Blue Hill Shale			
				Fairport Chalk			
			Greenhorn Limestone	Pfeifer Shale	0-100	Marine deposits of alternating chalky limestone and chalky shales; contains bentonite beds.	Not known to yield water to wells.
				Jetmore Chalk			
				Hartland Shale			
				Lincoln Limestone			
			Graneros Shale		0-40	Marine deposits of gray to black noncalcareous to slightly calcareous silty shale with sandstone lenses and bentonite beds.	Not known to yield water to wells.
			Dakota Formation	Janssen Clay	200-300	Some marine but primarily non-marine deposits of massive white to brown clay, silt, and shale. Contains interbedded lenticular sandstone and lignite.	Yields small to moderate quantities of water to wells.
	Lower Cretaceous			Terra Cotta Clay			
			Kiowa Formation		100-125	Marine deposits of thinly laminated gray to black shale with sandstone lenses and thin limestone beds in lower part.	Not known to yield water to wells.
			Cheyenne Sandstone		25-100	Some marine but primarily non-marine deposits of buff to gray sandstone with some shale.	Not known to yield water to wells.

Permian	Lower Permian	Nippewalla	Dog Creek Formation		600-700	Marine deposits of red siltstone and sandstone with some shale and gypsum.	Not known to yield water to wells.
			Blaine Formation				
			Flower-pot Shale				
			Cedar Hills Sandstone				
			Salt Plain Formation				
			Harper Sandstone				
		Sumner	Stone Corral Formation		20-30	Marine deposit of principally anhydrite.	Yields no water to wells.

[1] In this report, small quantities refers to yields generally less than 10 gpm, moderate quantities to 10 to 500 gpm, and large quantities to greater than 500 gpm.

Fluvial deposits of the Ogallala Formation of Pliocene age occur as erosional remnants unconformably overlying Greenhorn Limestone, Carlile Shale, and Fort Hays Limestone Member on the highest upland areas. Clay, silt, sand, and gravel of Pleistocene age unconformably overlie Cretaceous and Pliocene rocks in most of the county. Fluvial deposits are present on divide areas and in stream valleys. Most upland surfaces are thinly mantled with eolian silt or loess. Slope deposits or fluvial and colluvial deposits are present in headland areas of streams and on slopes along stream courses.

GEOLOGY AND WATER SUPPLY OF ROCK UNITS

Rocks that are significant to the water supply in Rush County range in age from Permian to Pleistocene. A generalized section of the rocks and their water-bearing characteristics is given in table 2.

The subsurface Permian and Cretaceous rocks are discussed because of their potential future utilization as aquifers or as confining beds below which brine and other liquid wastes might be disposed. When desalinization processes become more economical and more water is needed in central Kansas, the deeper aquifers could be utilized.

Permian System—Lower Permian Series

SUMNER GROUP

Stone Corral Formation

The Stone Corral Formation was named from exposures in and near sec. 11, T.20 S., R.6 W., Rice County, Kans., by Norton (1939, p. 1775). Many geologists refer to the Stone Corral as the "Cimarron anhydrite." The Stone Corral is the upper formation of the Sumner Group.

Lithology, distribution, and thickness.—At the type section in Rice County, the Stone Corral is a massive 6-foot ledge of cellular dolomite with some dolomitic shale that forms a prominent scarp (Norton, 1939, p. 1777). The amount of shale increases southward to such an extent that the formation is hardly recognizable in Kingman County (Merriam, 1963). The formation is represented by scattered dolomite rhombs in silty shale in Harper County (Swineford, 1955). The Stone Corral is present in the subsurface westward from Harper County on the south to Jewell County on the north. It is easily discernable with electric logs and is an important marker bed in petroleum exploration. The thickness of the formation in the subsurface is generally between 25 and 45 feet, but in

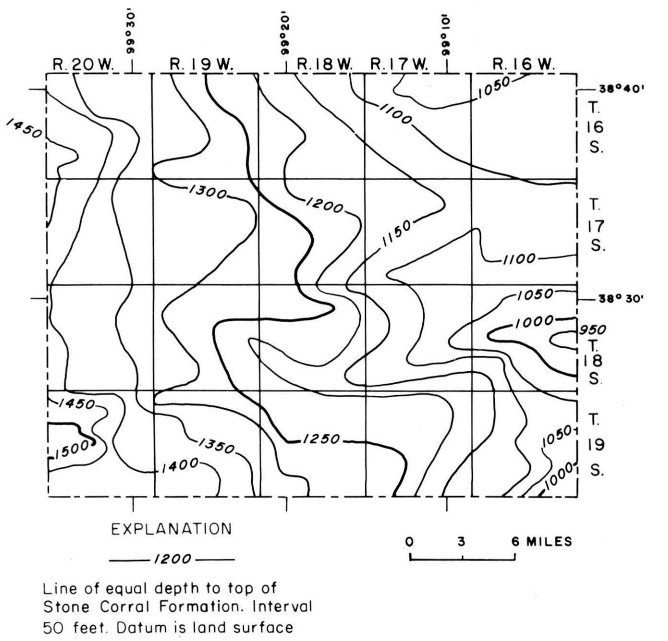

FIGURE 7.—Depth to top of Stone Corral Formation.

Scott County it is 100 feet thick (Norton, 1939, p. 1781). The Stone Corral in Rush County is between 20 and 30 feet thick. Depth to the Stone Corral in Rush County, as determined from electric and radioactive logs, ranges from about 900 to 1,550 feet. Figure 7 is a map showing the approximate depth to the top of the Stone Corral in Rush County.

Water supply.—The Stone Corral is not known to contain water in Rush County; rather, it is regarded as a barrier to the movement of water. Below the Stone Corral, brine and other wastes might be disposed with relatively little chance of leakage upward into higher formations.

NIPPEWALLA GROUP

The Nippewalla Group, which was named by Norton (1939, p. 1782), included several hundred feet of red beds between the Stone Corral and Blaine Formations. The State Geological Survey of Kansas (Zeller, 1968) now includes the following formations, in ascending order, in the Nippewalla Group: Harper Sandstone, Salt Plain Formation, Cedar Hills Sandstone, Flower-pot Shale, Blaine Formation, and Dog Creek Formation.

Lithology, distribution, and thickness.—The Nippewalla Group consists of siltstone and very fine grained sandstone, with minor quantities of silty shale and gypsum (Swineford, 1955). The group crops out in central and south-central Kansas and is in the subsurface in the western half of the State. The thickness of the Nippewalla in Kansas is reported to be approximately 930 feet by Moore and others (1951, p. 38), from 610 to 870 feet with an original thickness possibly greater than 1,000 feet by Lee (1953, p. 5), and through addition of formation thicknesses from 869 to 948 feet by Swineford (1955). In Rush County the thickness of the Nippewalla probably ranges from 600 to 700 feet.

A study of numerous electric and radioactive logs and some sample logs from Rush County and surrounding counties indicates that the Nippewalla is difficult to subdivide into the accepted stratigraphic sequence. The Harper Sandstone and Salt Plain Formation were not differentiated in this study. What is tentatively called Cedar Hills Sandstone in this report coincides with a subdivision picked as Cedar Hills by the Kansas Sample Log Service and described lithologically as "amber and orange-pink, rounded, polished, friable, fine to coarse, free-drilling sandstone, and shaly sandstone." Lee (1953) described the Cedar Hills in the subsurface as ". . . red sand and siltstone interstratified with silty shale. The sandstones, which are medium- to fine-grained, are in the main orange colored and include many polished subrounded grains slightly coarser than the more angular particles in which they are embedded. Because the sandstone crumbles easily, coherent fragments are rare in the cuttings." Figure 8 is a map showing the depth to the top of the Cedar Hills Sandstone in the county.

The Flower-pot Shale, Blaine Formation, and Dog Creek Formation, which are difficult to identify in the subsurface, were not differentiated in this study. The

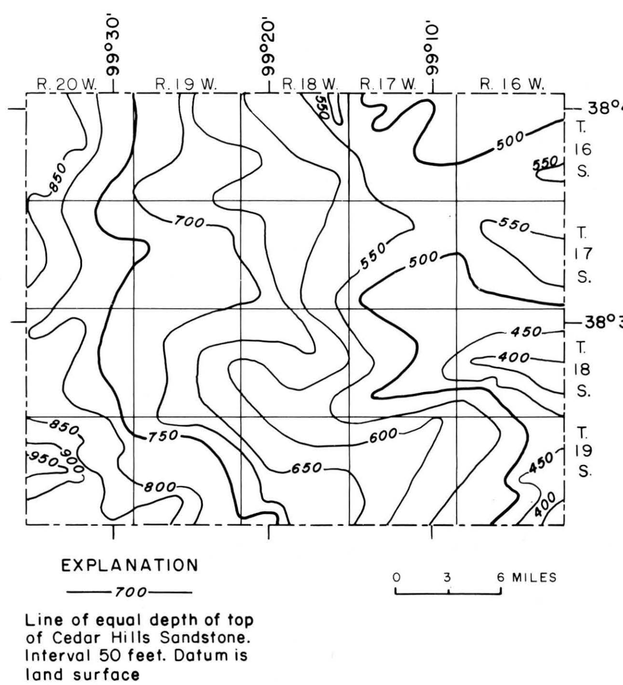

FIGURE 8.—Depth to top of Cedar Hills Sandstone.

part of the Nippewalla Group above the Cedar Hills Sandstone is about 100 feet thick, but may be considably thicker locally; it is relatively impermeable and retards movement of highly mineralized water from the Cedar Hills Sandstone to the overlying Cretaceous rocks.

Water supply.—Sandstone beds in the Nippewalla probably contain water. No data were obtained on the quantity or quality of water available from the Nippewalla in the county. Water from Permian rocks, probably the Nippewalla, was collected from six test holes in Russell County by Swineford and Williams (1945). The concentration of dissolved solids in the samples ranged from 31,000 to 71,000 mg/l (milligrams per liter).

Cretaceous System—Lower Cretaceous Series

CHEYENNE SANDSTONE

The Cheyenne Sandstone was named by Cragin (1889, p. 65) from Cheyenne Rock in sec. 8, T.30 S., R.16 W., which is a prominent ledge of sandstone on the north side of Medicine Lodge River valley about three-fourths of a mile west of Belvidere in southeast Kiowa County.

Lithology, distribution, and thickness.—The Cheyenne at the outcrop comprises chiefly light-colored friable cross-bedded fine- to medium-grained sandstone associated with lenses of sandy shale and conglomerate (Latta, 1946, p. 235). Swineford and Williams (1945) described the Cheyenne in the subsurface in Russell County as predominantly buff to light-gray sandstone containing small amounts of shale and siltstone. In the subsurface of Cheyenne County, Merriam and others (1959) describle the Cheyenne Sandstone as light-gray or brown fine- to medium-grained sandstone with some medium- to dark-gray noncalcareous shale. Exposures of Cheyenne Sandstone are confined to Barber, Kiowa, and Comanche Counties in south-central Kansas (Latta, 1946, p. 238), but the unit may be found in the subsurface in most of western Kansas.

The erosional surface on which the Cheyenne was deposited caused considerable range in thickness of the formation. In the type area the thickness of the Cheyenne ranges from 32.5 to 94 feet (Latta, 1946, p. 238), and in the subsurface the maximum thickness is 300 feet (Moore and others, 1951). In Rush County the thickness is estimated to range from 25 to 100 feet.

Water supply.—The Cheyenne is considered to be an aquifer, but is not known to have been tapped for water supplies in Rush County. To the northeast in Russell County, Swineford and Williams (1945) collected six samples of water from the Cheyenne that contained from 33,000 to 62,000 mg/l dissolved solids.

KIOWA FORMATION

The Kiowa Formation, which overlies the Cheyenne, was named by Cragin (1894, p. 49) from exposure in Kiowa County, Kans.

Lithology, distribution, and thickness.—The Kiowa Formation in the type area was described by Latta (1946) as consisting primarily of dark-gray to black thinly laminated shale grading upward into gray, tan, and brown clay and clay shale, but containing sandstone lenses throughout and thin beds of shell limestone in the lower part. In the subsurface in Russell County, the Kiowa consists of gray to black thinly laminated shale and interbedded thin white sandstone and siltstone (Swineford and Williams, 1945). In the subsurface in Cheyenne County the formation consists of medium- to dark-gray shale, some gray sandstone and siltstone, and a thin bed of impure limestone (Merriam and others, 1959). The Kiowa is exposed over a wide area in central Kansas (Plummer and Romary, 1942) and is in the subsurface in the western half of the state. Latta (1946) reports a maximum thickness of 293 feet of Kiowa in a test hole in the type area. Plummer and Romary (1942) report 100 to 125 feet over much of central Kansas; the range in thickness is assumed to be the same for Rush County.

Water supply.—The Kiowa is considered to be an aquifer but no wells are known to produce water from the formation in Rush County. Eight water samples from the Kiowa in Russell County contained from 33,000 to 59,000 mg/l dissolved solids (Swineford and Williams, 1945).

Cretaceous System—
Lower and Upper(?) Cretaceous Series

DAKOTA FORMATION

Meek and Hayden (1862) applied the name "Dakota Group" to the sandstone, various colored clay, and lignite beds that underline the "Benton Group" in eastern Nebraska. The name "Dakota Formation," as applied by the State Geological Survey of Kansas, is used in the sense described by Plummer and Romary (1942) and includes the continental and littoral beds occurring above the Kiowa Formation and below the Graneros Shale. The Dakota was subdivided by Plummer and Romary (1942) into the Terra Cotta Clay Member at the bottom and the Janssen Clay Member at the top.

The State Geological Survey of Kansas classifies the Dakota Formation in the Lower and Upper(?) Cretaceous Series; O'Connor (1968, p. 56) states that the boundary between Lower and Upper Cretaceous rocks "properly should be placed within the Dakota Formation".

Lithology, distribution, and thickness.—The following description of the lithology of the Dakota is taken from the description by Plummer and Romary (1947). The Terra Cotta Clay Member, which includes massive clay, silt, and sandstone, composes approximately the lower two-thirds of Dakota Formation. The Janssen Member includes beds of lignite, gray to dark-gray massive clay, silt, and some shale. Prominent sandstone layers and lenses are numerous but about three-fourths of the formation is clay, which is quantitatively the most important type of sedimentary material. The clay is dominantly kaolinite.

The Dakota crops out in Kansas from Washington County on the north, southwest to Kiowa County on the south, and in small patches in the southwest part of the State. Except in extreme south and southwest Kansas, it is found in the subsurface west of the outcrop. The Dakota does not crop out in Rush County. In the deep valleys of Walnut Creek and its tributaries in the east half of the county, and the Smoky Hill River and its tributaries in the northeast part of the county, the bedrock underlying the valley-fill deposits is Dakota. Study of electric and radioactive logs did not permit adequate delineation of the top or bottom of the Dakota in Rush County, and test-hole information is sparse. The thickness of Dakota ranges from 100 to 300 feet (Moore and others, 1951), although Merriam and others (1959) report 350 feet in the subsurface in Cheyenne County. In Rush County the thickness is estimated to range from 200 to 300 feet.

Water supply.—The Dakota is a principal aquifer, and dependable water supplies generally are available to wells throughout Rush County. Well yields range from a few gallons per minute for domestic supplies to a reported 500 gpm (gallons per minute) from a municipal well at La Crosse. Water from the Dakota is used extensively in the county except in Walnut Creek and Smoky Hill River valleys and their major tributaries. Reports from well drillers and land owners indicate that the depth to sandstone lenses in the Dakota is unpredictable. The quality of water in the Dakota is variable and generally is considered to be marginal for domestic use and irrigation. The dissolved-solids concentration ranged from 309 to 3,660 mg/l for 30 samples analyzed.

Cretaceous System—Upper Cretaceous Series

GRANEROS SHALE

The Graneros Shale was named by Gilbert (1896) from exposures at Graneros and on Graneros Creek in Pueblo County, Colo. The formation overlies the Dakota and is unconformably overlain by the Greenhorn Limestone in central Kansas (Hattin, 1965).

Lithology, distribution, and thickness.—The Graneros is composed primarily of gray to black noncalcareous to slightly calcareous silty shale; it contains some sandstone lenses and bentonite. One bentonite layer is an easily identifiable marker bed on electric logs in the western third of Kansas (Merriam, 1957).

Surface exposures of Graneros generally are poor, but it is exposed from Ford County on the southwest to Washington County on the northeast. The formation is in the subsurface west of the outcrop belt. No outcrop of Graneros was located in Rush County. The Graneros is present in the subsurface throughout the county, except beneath Walnut Creek and deep tributary valleys east of R.19 W.

Reported thicknesses of the Graneros range from 14 feet in Russell County (Swineford and Williams, 1945) to about 100 feet in Cheyenne County (Merriam and others, 1959). Hattin (1965) reports a range in thickness of the Graneros from 23.6 to 40.4 feet in central Kansas; this range in thickness is assumed to apply to Rush County where the Graneros is present.

Water supply.—The Graneros is not known to yield water to wells in Rush County.

GREENHORN LIMESTONE

The Greenhorn Limestone was named by Gilbert (1896) from exposures at Greenhorn Station and on Greenhorn Creek, south of Pueblo, Colo. Four members of the Greenhorn are recognized by the State Geological Survey of Kansas. In ascending order they are: Lincoln Limestone Member, Hartland Shale Member, Jetmore Chalk Member, and Pfeifer Shale Member. Rubey and Bass (1925) named the Lincoln and Jetmore, and Bass (1926) named the Hartland and Pfeifer. The Greenhorn lies unconformably on Graneros Shale and conformably underlies Carlile Shale.

Lithology, distribution, and thickness.—The Greenhorn comprises a sequence of alternating chalky limestone and chalky shale; it contains thin crystalline limestone beds in the basal member. The outcrop of the formation extends from Ford County on the south to Washington County on the north, with less extensive exposures in Hamilton and Kearny Counties in the southwest. In the subsurface the Greenhorn is found west and north of the outcrop and into adjacent states. Thickness of the formation ranges from 65 feet in Jewell County to 132 feet in Hamilton County. The thickness averages 100 feet in Rush County.

The Greenhorn Limestone is the oldest and most prominent rock unit that crops out in Rush County. The Greenhorn is not subdivided on plate 1.

Exposures of the Lincoln Limestone Member were not noted during field work, but some may be present in the northeastern part of the county. The Hartland Shale Member is exposed in stream banks, particularly in the northeastern part of the county.

The Jetmore Chalk Member is the most resistant member of the Greenhorn and the "shell" or "shellrock" bed at the top is diagnostic. The "shellrock" averages about 1 foot in thickness, may be unevenly bedded and appear to have a concretionary upper surface, and is composed chiefly of fossil clam shells. The top bed of the Jetmore has been quarried in the county.

The top bed of the Pfiefer Shale Member, the Fence-post limestone bed, has been extensively quarried. Other limestone beds in the Greenhorn and also in the lower part of the Carlile Shale occasionally have been quarried; thus, reliance on quarries alone to map the top of the Greenhorn is not recommended. Perhaps the best marker for mapping the top of the Greenhorn is the "sugar sand" (Moss, 1932). The "sugar sand" is about 6 feet below the top of the Fence-post Limestone, and about 15 feet above the "shellrock" or top of the Jetmore. White calcite prisms are found at the base of the "sugar sand," which is composed primarily of granular calcite with a silty clay binder. It is crumbly, averages 4 inches in thickness, and resembles white sugar when fresh and brown sugar when weathered. A similar sand about 2 inches thick associated with 2 inches of bentonite, which underlies a 6-inch limestone in the basal Carlile Shale, occurs about 5 feet above the top of the Fence-post bed. The occurrence of these insignificant-appearing sands are quite useful for locating the Greenhorn-Carlile contact.

Water supply.—The Greenhorn Limestone is not considered to be an aquifer in Rush County and no wells were inventoried that obtained water from the formation. Several dug wells in the county terminate in the Greenhorn but the water in the wells comes from overlying colluvial and fluvial material.

CARLILE SHALE

The Carlile Shale was named by Gilbert (1896) from exposures of gray shale near Carlile Station west of Pueblo, Colo., along the Arkansas River. Three members of the Carlile are recognized by the State Geological Survey of Kansas. In ascending order they are: the Fairport Chalk Member (Rubey and Bass, 1925), Blue Hill Shale Member (Logan, 1897), and Codell Sandstone Member (Bass, 1926).

Lithology, distribution, and thickness.—The lower 25 feet of Fairport is similar to the underlying Greenhorn and contains primarily chalky limestone beds and chalky limestone concretion zones intercalated with chalky shale. The rest of the Fairport contains chalky shale and some chalky limestone. Bentonite beds in the Fairport are usable markers and are persistent over much of the outcrop area (Hattin, 1962). The Fairport is distributed on the surface from Washington County in the northeast to Finney and Hamilton Counties in the southwest, and in the subsurface west of the outcrop. Thickness of the Fairport ranges from 90 feet along the Saline River in north Ellis County to 120 feet in Finney and Hodgeman Counties (Hattin, 1962).

Outcrops of the Fairport in Rush County, with a few exceptions, are confined to the lower 25 to 30 feet of the member. The exceptions are middle to upper Fairport, which is exposed along Big Timber Creek and along some of the other tributaries of the Smoky Hill River in northwestern Rush County.

The Blue Hill Shale Member is a dark-bluish-gray slightly silty, clayey shale. The member contains numerous large concretions. Hattin (1962, p. 64) states: "Three kinds occur: Calcareous septarian concretions (most abundant), non-calcareous clay-ironstone concretions, and sandstone concretions (least common)." Many of the concretions are found in traceable, widespread zones, but great numbers have no zonal distribution. The distribution of the Blue Hill in Kansas is similar to the Fairport, but offset to the west. Thickness of the member ranges from 72 feet in Hamilton County to 215 feet in Jewell County.

The Blue Hill probably is absent east of R.19 W. in Rush County because of erosion. It crops out in the northwest and southwest corners of the county. Examples of concretions or their remnants may be found in the SE¼ sec. 19, T.16 S., R.20 W., and the SW¼ sec. 20, T.16 S., R.20 W.

The Codell Sandstone Member is chiefly fine to very fine grained silty sandstone. It is distributed over the State in a manner similar to the rest of the Carlile, but farther west than the lower members. Thickness of the member ranges from half a foot in Jewell County to 31 feet in Ellis County (Hattin, 1962).

The Codell crops out in the SW¼ sec. 6, T.16 S., R.20 W., in Rush County and comprises 4 feet of rusty-orange friable silty sand; it overlies 2 feet of the Blue Hill Shale Member, and is overlain by about 5 feet of the Fort Hays Limestone Member of the Niobrara Chalk. No other Codell was noted in the county.

In Rush County, the maximum thickness of the Carlile Shale is estimated to be 300 feet.

Water supply.—No water supplies are known to be obtained from the Carlile in Rush County. In some circumstances the Carlile may serve as the container in a dug well but the water comes from overlying colluvial and fluvial material. The Carlile is not considered to be an aquifer in Rush County.

NIOBRARA CHALK

The Niobrara Chalk was named by Meek and Hayden (1862) from exposures in bluffs along the Missouri River in northern Nebraska. Two members of the Niobrara are recognized by the State Geological Survey of Kansas—the Smoky Hill Chalk Member above and the Fort Hays Limestone Member below. The Smoky Hill is not present in Rush County and only about 10 feet of the basal Fort Hays Member is present in the northwest corner of the county. The Niobrara Chalk is not an aquifer in Rush County.

Tertiary System—Pliocene Series

OGALLALA FORMATION

The Ogallala Formation was named by Darton (1899) from exposures that he later (Darton, 1920) designated as being near Ogallala Station in western Nebraska. Three members of the Ogallala are recognized by the State Geological Survey of Kansas: the Valentine Member at the base, the Ash Hollow Member in the middle, and the Kimball Member at the top (Zeller, 1968). A detailed discussion of the Ogallala is contained in Bulletin 118 of the State Geological Survey of Kansas (Frye, Leonard, and Swineford, 1956). The Ogallala was mapped as a single unit for this report, but in the following discussion the members are designated when applicable.

Lithology, distribution, and thickness.—The dominant types of lithology of the Ogallala in Rush County are (1) arkosic sand and gravel with associated clay balls that are sometimes poorly cemented with calcium carbonate, clay and silt beds, and some bentonite, (2) a quartzitic-appearing green conglomerate with an opaline cement matrix, and (3) a distinctive, discontinuous, very hard and dense white to pink limestone commonly referred to as "algal limestone." A study by Swineford, Leonard, and Frye (1958) indicates that development of the limestone was by soil-forming processes rather than by algae, and that pisolitic limestone is an accurate descriptive term for the bed. Common conversational usage is "algal limestone," which is used in this report. The "algal limestone" marks the stratigraphic top of the Ogallala Formation and the Kimball Member.

The Ogallala lies unconformably on Greenhorn, Carlile, and Niobrara in Rush County. Its areal distribution, shown on plate 1, generally is confined to the divide areas between Walnut Creek and the Smoky Hill River drainage in the north, and between Walnut Creek and the Pawnee River drainage in the south.

Frye, Leonard, and Swineford (1956, p. 73) describe the following measured section in the SW¼ sec. 1, T.16 S., R.21 W., Ness County:

	Thickness, feet
OGALLALA FORMATION	
Ash Hollow Member	
6. Silt, densely cemented, pale-gray to pinkish-gray; contains irregular opalized nodules	3
5. Sand and silt, loosely cemented, pinkish-tan, partly covered. At this stratigraphic position in the NW¼SW¼ sec. 21, T.15 S., R.21 W., Trego County, the following fossil seeds were collected: *Berrichloa conica, B. tuberculata, Biorbia fossilia, Celtis willistoni*	2.5
4. Sand, fine to coarse, some pebbles, cemented; weathers to smooth convex surfaces	7.5
3. Covered	7
Valentine Member(?)	
2. Conglomerate, densely cemented with opal; the opaline matrix has distinct green color and and is lenticular in distribution	10
1. Gravel and cobbles of Cretaceous Niobrara Chalk to 1 foot in diameter, in matrix of clay and chalk sand. Base rests on Niobrara Chalk	3
Total Ogallala measured	33

The Ogallala exposed in the northwestern part of Rush County (SW¼ sec. 6, and NW¼ sec. 7, T.16 S., R.20 S.) resembles bed 2, and is locally referred to as "green granite." Except for bed 2, the Ogallala north of Walnut Creek probably represents the Ash Hollow Member. About 20 feet of crossbedded, slightly consolidated arkosic sand and gravel, which rests on upper beds of the Fairport Chalk Member of the Carlile Shale in a gravel pit in the SE¼ sec. 16, T.17 S., R.19 W., is the most extensive exposure of Ash Hollow north of Walnut Creek. Test hole 17-19W-21aaa in the northeast corner of section 21 in the same township penetrated 28.0 feet of Ogallala. Another exposure of Ogallala in the north half of the county is in a trench silo in the NW¼ sec. 12, T.17 S., R.18 W., where about 6 to 8 feet of sand, gravel, and silt rests on the Fairport.

Test-hole logs and samples, shot-hole logs, gravel pits, and natural exposures document the occurrence of considerable Ogallala, predominantly Ash Hollow but with some Kimball, south of Walnut Creek. Gravel pits in the SW¼ sec. 8, T.19 S., R.20 W.; the SE¼ sec. 28, T.19 S., R.19 W.; and the SE¼ sec. 26 and the SW¼ sec. 25, T.19 S., R.18 W., contain slightly consolidated very fine to medium-grained crossbedded sand and some gravel of arkosic composition with associated balls of clay, and some local gravel composed of Cretaceous limestone fragments. The thickest Ogallala found in the county was about 44 feet in test hole 19-18W-33aba. The Kimball is recognized in numerous places south of Walnut Creek on the basis of "algal limestone" that caps topographic highs, including distinctive conical knolls. "Algal limestone" is exposed in the trail between the SE¼ sec. 36, T.18 S., R.16 W., and the NE¼ sec. 1, T.19 S., R.16 W.; in the south road ditch in the NE¼NW¼ sec. 16, T.19 S., R.16 W.; on top of the hill in the NW¼ sec. 25, T.19 S., R.18 W.; on top of the hill in the SE¼ sec. 28, T.19 S., R.18 W.; toward the top of two trench silos on the north side of the road in the SE¼SE¼SW¼ sec. 29, T.19 S., R.19 W.; on a small ridge south of the road in the NW¼ sec. 17, T.19 S., R.20 W.; along the road in the NW¼ sec. 26, T.19 S., R.20 W.; and in numerous other places in the south tier of townships. The lithology and thickness of the Ogallala are shown by logs at the end of this report.

Water supply.—The Ogallala is not an aquifer in Rush County because it is drained by streams that have eroded headward toward the divide areas. The drainage precludes water storage except in the most temporary sense. None of the wells inventoried obtained water from the Ogallala.

Quaternary System—Pleistocene Series

The Pleistocene Series has been divided into four glacial stages (Nebraskan, Kansan, Illinoisan, Wisconsinan) and four interglacial stages (Aftonian, Yarmouthian, Sanagmonian, Recent) by the State Geological Survey of Kansas (Bayne and O'Connor, 1968). Most of these stages are thought to be represented in Rush County. Topographic position, fauna, and lithology of deposits in relation to adjoining or very similar deposits in adjacent counties form the basis for this belief. Three categories of Pleistocene deposits were mapped in the county (pl. 1). Two of the three mapped units are unconsolidated, principally fluvial, deposits conveniently separated by their relative topographic position. The deposits in terrace position, herein called terrace deposits, and the deposits in valleys, herein called valley-fill deposits, may be of Kansan, Illinoisan, Wisconsinan, or Recent age. The third mapped unit is primarily an unconsolidated eolian deposit but contains some fluvial and colluvial material. These deposits, herein called undifferentiated deposits, may be as old as Nebraskan but commonly are Wisconsinan and Recent in age.

TERRACE DEPOSITS

Lithology, distribution, and thickness.—Fluvial deposits with some eolian and colluvial components are found in terrace position along the valleys of the major streams and their tributaries. These deposits of clay, silt, sand, and gravel primarily are arkosic, but often include some limestone pebbles. Thickness of the deposits may be as much as 70 feet bordering Walnut Creek valley, 50 feet bordering Big Timber Creek valley, and 40 feet bordering Dry Walnut Creek valley.

Water supply.—The terrace deposits yield small to moderate supplies of water to wells. Two irrigation wells in Walnut Creek valley and one in Dry Walnut Creek valley obtain all or part of their water from these deposits; yields range from 290 to a reported 400 gpm. Numerous stock and domestic wells also obtain their water from these deposits. Water from the terrace deposits is hard, but otherwise is of satisfactory chemical quality for the uses mentioned.

VALLEY-FILL DEPOSITS

Lithology, distribution, and thickness.—Fluvial clay, silt, sand, and gravel compose the valley-fill deposits. The upper 20 to 40 feet of the fill is predominantly silt with some clay that overlies a thick deposit of sand and gravel in Walnut Creek valley. In Dry Walnut Creek valley, the fill is principally silt with minor amounts of sand and gravel. The fill in Big Timber Creek valley is not as thick as the fill in Walnut Creek valley, but the lithology is similar. Thickness of the fill may be as much as 120 feet in Walnut Creek valley, slightly more than 100 feet in Dry Walnut Creek valley, and more than 40 feet in Big Timber Creek valley. The valley fill is as much as 2 miles wide in Walnut Creek valley and three-fourths of a mile wide in Dry Walnut and Big Timber Creek valleys.

About 30 different forms of snails and several forms of clams were noted in the samples from test holes drilled across Walnut Creek valley. Samples from test hole 18-17W-31bbc were particularly abundant in number of shells and in number of forms. The precise depths from which the different shells came are not known, but, between 30 and 75 feet, shells were so numerous as to appear to be the major part of the return from the drilling operation.

The drill cuttings containing the shells were blue to gray silty clay, fine to coarse arkosic sand, and medium to coarse, predominantly limestone, gravel. Although the volume of material returned in the 30-to 75-foot interval was normal, only 10 small sacks of sample material were collected. Each sack of the material was then split into one small sample-cuttings envelope in the office. In light of the sampling procedure just described, the number of shells and forms recovered is remarkable.

The following fossil mollusks were recovered from the sample cuttings from test hole 18-17W-31bbc, Rush County, Kans. The shells were identified by the author.

	NUMBER OF SPECIMENS
FRESH-WATER SNAILS	
Amnicola limosa parva Lea	44
Ferissia parallela (Haldeman)	3
Gyraulus labiatus Leonard	112
Helisoma antrosa (Conrad)	7
Lymnaea SP	6
Menetus pearlettei Leonard	2
Pomatiopsis cincinnatiensis (Lea)	2
Valvata tricarinata (Say)	177
LAND SNAILS	
Carychium perexiguum Baker	6
Gastrocopta proarmifera Leonard	5
Gastrocopta procera (Gould)	1
Gastrocopta tappaniana (C.B. Adams)	2
Helicodiscus parallelus (Say)	2
Pupilla muscorum sinistra Franzen	1
Pupoides albilabris (C. B. Adams)	2
Retinella electrina (Gould)	12
Succinea SP	17
Vallonia gracilicosta Reinhardt	72
Vertigo millium (Gould)	4
Vertigo ovata Say	2
Zonitoides arboreus (Say)	3
AT LEAST TWO FORMS OF CLAMS	

The fauna indicates that the summers were not as hot as they are in Rush County at the present time, but winters may not have been cooler. Precipitation probably was greater and a generally more humid condition prevailed. Permanent bodies of cool water are indicated. In terms of age, the list above appears to fit well in the assemblage of fossils of Kansan age described by Leonard (1950) and Frye and Leonard (1952).

Water supply.—Yields ranging from 400 to 1,200 gpm are obtained from the valley-fill deposits by irrigation wells in Walnut Creek valley, and yields as large as 1,500 gpm have been reported. No irrigation wells obtain water from these deposits in Big Timber and Dry Walnut Creek valleys; however, small to moderate supplies are obtained by stock and domestic wells. The water is hard but suitable for most uses. The dissolved-solids concentration for 17 water samples analyzed ranged from 369 to 789 mg/1.

UNDIFFERENTIATED DEPOSITS

Lithology, distribution, and thickness.—Eolian deposits, with some fluvial and colluvial components that are predominantly silt containing some sand and some gravel, compose the undifferentiated deposits. The silt probably is loess of Wisconsinan age; it commonly overlies sand and some gravel. In the northwestern part of the county, the lower part of the undifferentiated deposits may be of Nebraskan age because of their topographic position and relation to similar deposits in Ellis County. The greatest thickness of these deposits, as much as 56 feet, was found in Tps. 17 and 18 S., R.20 W. Other areas with thick undifferentiated deposits are in T.16 S., R.20 W., and T.17 S., R.16 W. These thick deposits definitely are fluvial in origin, except for the overlying loess, and may represent buried channels of Nebraskan age.

Water supply.—Small to moderate yields are obtained from these deposits by some stock and domestic wells in the county where the deposits are relatively thick. However, such a favorable circumstance is not widespread. The water is very hard, but otherwise is satisfactory for stock and domestic uses.

GROUND WATER

The following discussion of ground water in Rush County is devoted principally to the aquifer in Walnut Creek valley, which comprises the valley-fill and terrace deposits. Definitions of the terms used in the discussion are given in the Glossary of Terms.

Source

The primary source of ground water in Rush County is local precipitation. For example, the ground water in the valley-fill deposits of Walnut Valley is derived from the rain and snow on the entire watershed of Walnut Creek. Water in the Dakota Formation, on the other hand, is derived from rain and snow on the outcrop of the formation east of Rush County, and from unconsolidated water-saturated deposits, such as those in Walnut and Dry Walnut Creek valleys, that overlie the Dakota. Ground water, thus, consists of water that falls in the form of rain or snow and then percolates through the soil materials to the water table. Figure 9 illustrates the relationship between precipitation, ground-water levels in selected wells, and streamflow in Rush County.

Occurrence and Movement

Water in the unconsolidated deposits occurs in the interstices between the rock particles. The rate at which water will move through these aquifers depends on the hydraulic gradient and on the shape, size, and interconnection of the contained interstices. The quantity of ground water available to wells also depends on the areal extent and the saturated thickness of the aquifer. Interstices in sand and gravel are larger and better connected than interstices in silt and clay. Thus, water will move freely through a coarse gravel under a low hydraulic gradient, but will move with extreme slowness through clay even under a high hydraulic gradient.

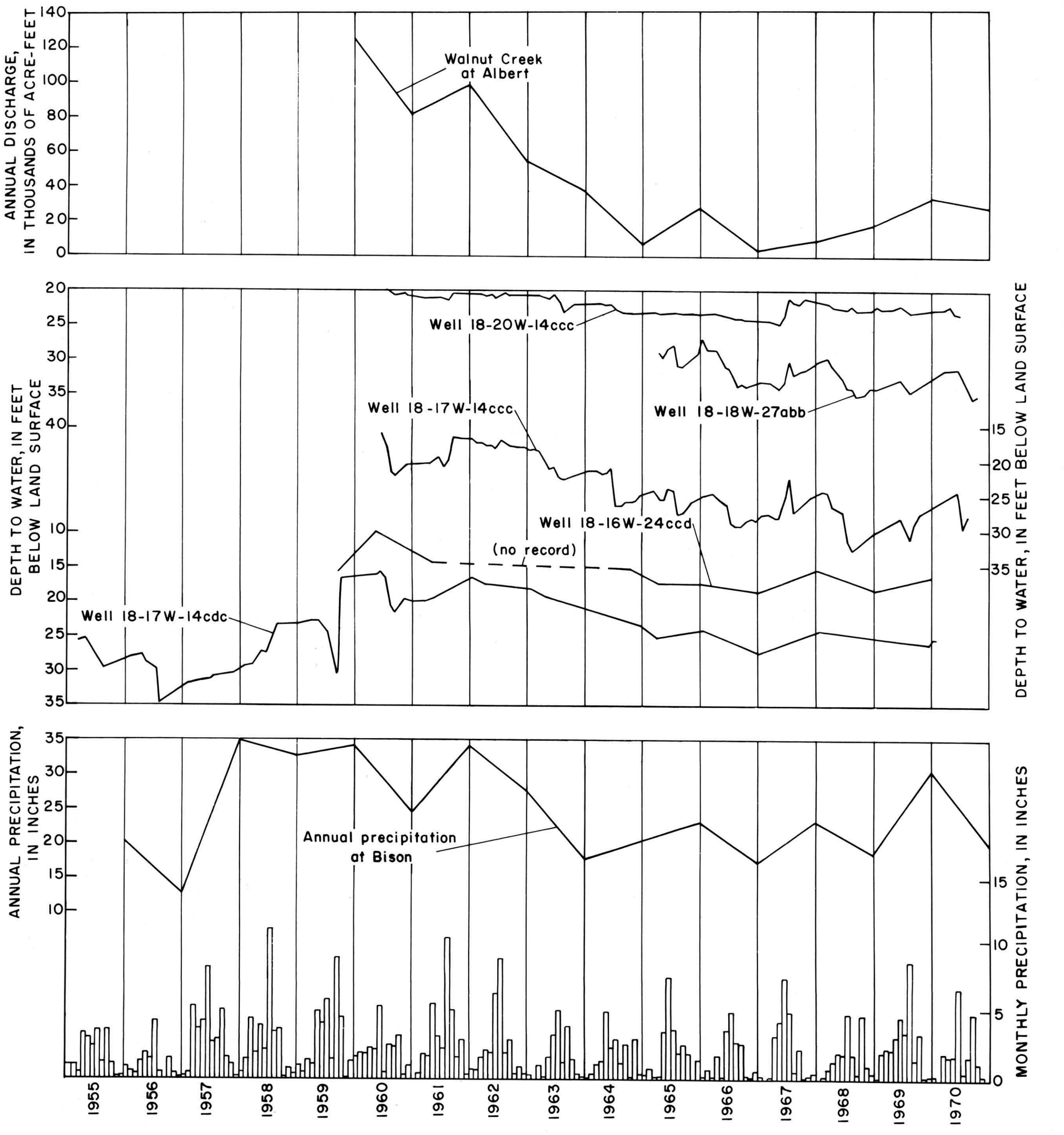

FIGURE 9.—Change in water level in five wells in Walnut Creek valley, monthly precipitation at Bison, and annual discharge of Walnut Creek at Albert.

The shape and slope of the water table in 1960 in Walnut Creek valley are shown on plate 1 by contours drawn through points of equal altitude of the water table. Ground water moves downgradient at right angles to the contours. The contours indicate that ground water was moving toward Walnut Creek from both sides of the valley and was discharging into the creek in 1960. The spacing of contours in Walnut Creek valley indicate a hydraulic gradient of about 5 feet per mile at the west boundary of Rush County to 3 feet per mile at the east boundary.

The quantity of water flowing through a given cross-sectional area of an aquifer can be computed by the formula:

TABLE 3.—Calculated velocity and quantity of water moving through the aquifer at the west and east ends of Walnut Creek valley.

	Average aquifer saturated thickness (feet)	Assumed porosity (percent)	Average aquifer width (miles)	Hydraulic gradient (feet per mile)	Hydraulic conductivity (feet per day)	Velocity (feet per day)	Quantity of water (Cubic feet per day)	Quantity of water (Acre-feet per year)
West end	20	30	1	5	382	1.2	38,200	320
East end	70	30	2.5	3	221	.4	116,000	970

$$Q = pAv = KIA$$

where Q is the quantity of water,
p is the porosity of the aquifer material,
A is the cross-sectional area,
v is the average velocity of ground water,
K is the hydraulic conductivity, and
I is the hydraulic gradient.

The approximate rate of movement of ground water through an aquifer is obtained by transposition of the above formula to:

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

and for the units of feet, days, and miles to:

$$v = \frac{KI}{53\,p}$$

In the case of the aquifer in Walnut Creek valley, the amount of water entering Rush County as subsurface inflow at the Ness County line and the amount leaving as subsurface outflow at the Barton County line can be calculated. Additionally, the velocity of the ground water can be calculated. The results of these calculations are given in table 3.

Storage

The amount of recoverable water stored in an aquifer is a function of the volume of the aquifer and its storage coefficient (S).

Maps showing the configuration of the bedrock surface and the saturated thickness of the valley-fill and terrace deposits of Walnut Creek valley in 1960 are shown on plate 2. On the saturated thickness map the area between each pair of contours was planimetered and multiplied by the average saturated thickness to determine the volume of saturated material. The volume of saturated deposits was calculated to be 1,610,000 acre-feet. Based on an assumed storage coefficient of 0.15, the volume of water available for pumping in 1960 was determined to be 241,500 acre-feet. From a practical point of view, much less would be available for irrigation. Yields from wells would diminish substantially when less than half this quantity of water was pumped from storage.

Changes in Storage

One method of assessing changes in the amount of ground water in an aquifer involves periodic water-level measurements, construction of water-level-change maps from the measurements, and computation of the volume of material and water involved in the change. Unless outside influences such as heavy pumping upset natural conditions, the changes in storage in an aquifer reflect seasonal changes in precipitation and evapotranspiration. Water-level-change maps would illustrate, by minor fluctuations and trends, the essentially static conditions in an undisturbed aquifer. The aquifer in Walnut Creek valley is heavily pumped, and the change maps reveal the effect of large withdrawals of ground water for irrigation.

Changes in storage in the aquifer in Walnut Creek valley are documented by six water-level-change maps (pl. 2). Water-level measurements made in the spring of 1965 and each January from 1966 through 1970 are compared with the base measurements made in the spring of 1960. The maps were planimetered and the changes in volume of saturated material and volume of water were computed (table 4). The changes are

TABLE 4.—Changes in volume of saturated material and water in storage in Walnut Creek valley from 1960 to indicated year. [Plus (+) and minus (−) indicate increase or decrease in storage, respectively.]

From 1960 to	Decrease in volume of saturated material (acre-feet)	Decrease in volume of water S = 0.15 (acre-feet)	Change in volume of water between successive years (acre-feet)
1965	257,000	38,550	
			− 300
1966	259,000	38,850	
			−12,150
1967	340,000	51,000	
			+16,650
1968	229,000	34,350	
			−17,250
1969	344,000	51,600	
			+10,950
1970	271,000	40,650	

all declines when related to the 1960 measurements, but when successive changes are compared, there are 3 years of declines and 2 years of gains.

The volume of water in storage during the time from the spring of 1965 through January 1970 ranged from 189,900 to 207,150 acre-feet.

Discharge

Ground water in Walnut Creek valley is discharged from the aquifer by pumping by wells, evapotranspiration, subsurface outflow, and inflow to streams. In the section on movement of water, the subsurface outflow from the valley was estimated to be about 970 acre-feet per year.

PUMPING BY WELLS

Pumpage from irrigation wells is reported to the Kansas State Board of Agriculture by irrigators. A summary of the estimated annual pumpage from the aquifer in Walnut Creek valley for the years 1958-67, based on the amounts reported, is given in table 5. The average annual pumpage during this period was 14,100 acre-feet.

TABLE 5.—Estimated annual pumpage in Walnut Creek valley, 1958-67.

Year	Pumpage (acre-feet)	Year	Pumpage (acre-feet)
1958	5,800	1963	16,800
1959	13,300	1964	18,900
1960	9,900	1965	16,000
1961	9,700	1966	21,700
1962	7,300	1967	21,400

EVAPOTRANSPIRATION

Direct evaporation is limited to areas where the water table is near the land surface, such as along stream banks and in streambeds. This condition is restricted to a small part of the valley, and discharge by evaporation probably is not large.

Transpiration by plants from the saturated zone is not confined to the water courses where willow, cottonwood, and other trees are concentrated. Alfalfa may transpire considerable quantities of water from the aquifer. No quantitative estimate of evapotranspiration was made.

INFLOW TO STREAMS

Prior to the development of irrigation, Walnut Creek probably was a gaining stream through Rush County except during times of flooding. Examination of streamflow records at Albert, in Barton County 1 mile east of Rush County, indicates an alternating sequence of gaining and losing flow that reflects precipitation and pumping by wells. Streamflow at Albert, which is summarized in table 6, does not all come from ground water. The recorded flow represents two components: (1) overland flow directly from precipitation, and (2) inflow from ground water. No quantitative estimate of inflow to streams was made.

TABLE 6.—Summary of streamflow of Walnut Creek at Albert.[1]

Year	Mean daily streamflow (cubic feet per second)			Annual streamflow (acre-feet)
	Maximum	Minimum	Mean	
1959	10,300	0.2	174	126,000
1960	3,850	.5	113	81,860
1961	3,450	0	136	98,360
1962	1,770	9.6	75.2	54,480
1963	1,520	0	50.3	36,400
1964	251	0	9.24	6,700
1965	1,090	0	36.7	26,540
1966	232	0	3.3	2,390
1967	2,600	0	134	96,890
1968	1,830	0	23.7	17,190
1969	1,690	0	43.9	31,750
1970	2,820	0	36.0	26,090

[1] From U.S. Geological Survey (1962, 1969, 1967-72)

Recharge

The aquifer in Walnut Creek valley is recharged by subsurface inflow from the west and tributary valleys on the north and south, and by seepage losses from Walnut Creek and tributary creeks during periods of high flow. These two increments of recharge result from local precipitation within Walnut Creek basin.

SUBSURFACE INFLOW

In the section on movement of water, subsurface inflow to the aquifer in Walnut Creek valley from the west was estimated to be 38,200 cubic feet per day, or 320 acre-feet per year. The combined subsurface inflow from Sandy, Otter, and Dry Creek valleys and Old Maid Fork valley on the south and Sand Creek valley on the north probably is at least an equivalent amount, although no formal quantitative determination of inflow from tributary valleys was made.

SEEPAGE LOSSES FROM STREAMS

The drainage system of Walnut Creek basin carries large amounts of surface water into the valley. For this water to percolate to the saturated zone, the surface of the stream must be above the water table, and the sediments between the stream channel and the water table must be permeable. The sediments in

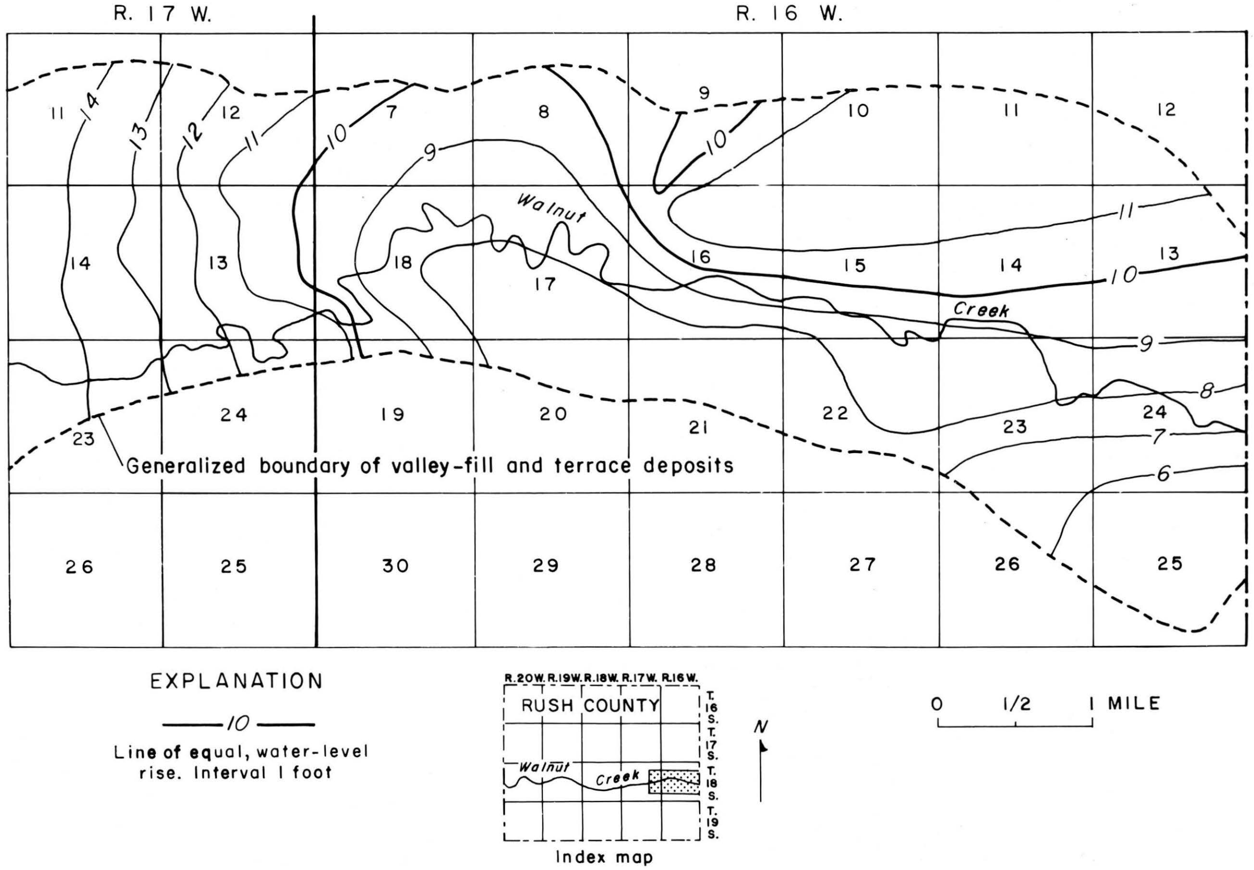

FIGURE 10.—Water-level rise in valley-fill and terrace deposits in Walnut Creek valley, eastern Rush County, September 1959 to May-June 1960.

Walnut Creek valley are permeable and the water table is below stream level after or during the irrigation season, after or during drought, or during some combination of these conditions. When a major flood occurs, the circumstances for recharge are enhanced because the stream may leave its bank and spread completely across the valley.

A large amount of recharge occurred during the flood of September 1959. This flood, which was the largest of record for Walnut Creek, spread water completely over the valley. The author had measured water levels in 21 wells in the first half of September 1959. The same wells were remeasured in the spring of 1960. A map showing change in water level for part of the valley in eastern Rush County (fig. 10) was constructed and analyzed. The volume of saturated material and the volume of water in storage increased by 104,000 and 15,600 acre-feet, respectively. The surface area of the valley included on the map was about 11,700 acres. Thus, about $1\frac{1}{3}$ feet of water was recharged by the flood of September 1959 to each acre of valley in the mapped area. If this amount of recharge is applied to the entire area of the valley inundated by the flood in Rush County, the total increase in storage would be about 50,000 acre-feet.

The changes in volume of water between successive years (table 4), when combined with the estimated annual pumpage (table 5), also indicate large amounts of recharge to the aquifer (table 7). Table 7 gives the change in volume of water in the aquifer, the estimated volume of water pumped from the aquifer, and the estimated volume of recharge to the aquifer. The volume of recharge is calculated by adding algebraically the volume of change to the volume pumped.

This approach to determination of recharge is dependent on estimated pumpage based on reported

TABLE 7.—Change in volume of water in, volume of water pumped from, and volume of water recharged to the aquifer in Walnut Creek valley for 1965-69.

Year	Change (acre-feet)	Pumpage (acre-feet)	Recharge (acre-feet)
1965	− 300	16,000	15,700
1966	−12,150	21,700	9,550
1967	+16,650	21,400	38,050
1968	−17,250	[1]20,000	2,750
1969	+10,950	[1]20,000	30,950
Cumulative Total	− 2,100	99,100	97,000

[1] Assumed values

usage, an estimated storage coefficient, and the assumption that the stream was losing and not gaining during periods of high flow. The principal evidence for a losing stream is the extensive periods of no flow at Albert.

TABLE 8.—Decrease in volume of saturated material in Walnut Creek valley, 1960-70.

Year	Volume of saturated material (acre-feet)	Percent of 1960 volume of saturated material	Percent decrease in 1960 volume of saturated material	Percent change in volume of saturated material between successive years
1960	1,610,000	----	----	
1965	1,353,000	84	16	—
1966	1,351,000	84	16	0
1967	1,270,000	79	21	−5
1968	1,381,000	86	14	+7
1969	1,266,000	79	21	−7
1970	1,339,000	83	17	+4

Even if the estimates for pumpage and storage coefficient are not considered to be of the right order of magnitude, the changes in volume of saturated material are real. The cumulative change in volume of saturated material for the 5-year period 1965-69 is a decline of only 14,000 acre-feet (2,100 acre-feet of water ÷ 0.15 storage coefficient). Table 8 expresses the change in volume of saturated material in percent of volume of saturated material in 1960. Beginning in 1965 the volume of saturated material has changed by as much as 7 percent of the 1960 total in 1 year. This indicates that significant recharge occurs, and occurs rapidly. The drainage network of Walnut Creek, which funnels runoff into the valley, thus concentrating precipitation, is the most effective recharge mechanism to the aquifer.

HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS IN WALNUT CREEK VALLEY

The quantity of water available from an aquifer depends on the ability of the aquifer to store and to transmit water. The ability of an aquifer to store water is measured by its storage coefficient and the ability to transmit water by its transmissivity. These hydraulic properties are in turn dependent upon the dimensional and geological parameters of the aquifer.

Three aquifer tests were made to determine the storage coefficient, the transmissivity, and the hydraulic conductivity of the valley-fill deposits in Walnut Creek valley. The test data were analyzed by methods referred to as the Thiem method, the Theis nonequilibrium method, and the Jacob modified nonequilibrium method (Ferris and others, 1962; Stramel, Lane, and Hodson, 1958). Each test was analyzed by all or some of the preceding methods in an attempt to arrive at aquifer coefficients judged to be most nearly correct. The theory and mathematical derivations of the methods are presented in the references noted.

Results of analysis of the tests are presented in table 9. Under the heading of hydrologic properties both the terms previously used by the U.S. Geological Survey, coefficient of transmissibility and field coefficient of permeability, and the terms currently used, transmissivity and hydraulic conductivity (Lohman and others, 1972), are listed.

The storage coefficients determined by the three aquifer tests range from 1.4 x 10^{-1} (unconfined aquifer) to 2.6 x 10^{-4} (confined aquifer). The disparities in storage coefficients could result from partial penetration of the aquifer by the pumping well or the observation wells, localized confining layers in the aquifer, insufficient length of aquifer tests, or some combination of these or other factors. The aquifer is considered to be generally unconfined in Walnut Creek valley and to be similar to aquifers in other stream valleys where storage coefficients of 0.15 and 0.20 have been used.

TABLE 9.—Aquifer-test results.

			Hydrologic properties					
Well number and owner	Date of test (1960)	Duration of test (minutes)	Coefficient of transmissibility (gal per day per ft)	Transmissivity (ft^2 per day)	Field coefficient of permeability (gal per day per ft^2)	Hydraulic conductivity (ft per day)	Storage coefficient (dimensionless)	Yield (gpm)
18-16W-16bbb (Glantz)	August 3-5	2,733	100,000	13,400	1,650	221.1	2.6×10^{-4} 3.6×10^{-2}	1,000
18-17W-28bcc (Oborny)	August 15-22	10,095	70,000	9,380	1,750	234.5	3.1×10^{-2} 4.4×10^{-3}	740
18-19W-21cdb (Webs)	July 16-17	1,840	100,000	13,400	2,850	381.9	1.2×10^{-2} 1.4×10^{-1}	450

Table 10.—Chemical analyses of water from selected wells, Walnut Creek, and one seep[1]
[Dissolved constituents and hardness given in milligrams per liter.[2]]

Well number	Sample number (figs. 11-13, 18)	Depth (feet)	Geologic source[3]	Date of collection	Temperature (°C)	Dissolved solids (evaporated at 180 °C)	Silica (SiO_2)	Total iron (Fe)	Total manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium[4]	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate[5] (NO_3)	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Non carbonate	Specific conductance (micromhos at 25 °C)	pH	Sodium-adsorption ratio
16-16W-32ccb	1	266	Kd	5-12-60	16.0	1,440	9.5	.21	0.00	19	13	510	332	210	510	3.3	3.4	100	0	2,650	----	22
16-17W-16dcd	2	370	Kd	5-12-60	15.5	1,270	5.0	.32	.00	11	11	460	277	200	440	3.4	.4	72	0	2,170	----	23
22aaa	3	320	Kd	10- 6-60	16.5	1,410	8.0	.56	.00	13	9.6	510	274	190	540	3.4	1.6	72	0	2,680	----	26
16-18W- 6dac	4	230	Kd	5-13-60	15.5	2,090	8.5	.02	.00	14	19	760	307	260	880	3.7	2.8	110	0	3,870	----	31
6dac2	5	seep	----	5-13-60	13.0	17,400	----	----	----	2,000	360	4,000	190	1,400	9,600	----	----	6,500	6,300	29,800	----	----
27cdd	6	209	Kd	5-12-60	14.0	1,870	8.0	.42	.00	19	11	680	356	270	700	4.4	3.8	92	0	3,430	----	31
16-19W-17bab	7	400	Kd	5-13-60	18.5	1,030	8.0	.39	.00	8.3	16	360	398	180	240	5.6	2.9	86	0	1,800	----	16
16-20W-5bbd	8	530	Kd	5-13-60	18.0	1,300	8.5	.07	.00	8.3	9.6	480	431	220	360	5.2	3.8	60	0	2,320	----	28
21ddc	9	54	Qu	5-13-60	14.5	412	46	.01	.00	89	20	20	290	37	39	.5	18	300	66	700	----	.5
17-16W-20aaa	10	315	Kd	10-13-60	----	1,000	6.0	.54	.00	7.4	1.3	390	442	88	290	4.4	2.1	24	0	1,870	----	35
17-17W-28dcd	11	230	Kd	5-12-60	15.5	1,790	7.0	.16	.00	18	22	640	321	240	700	3.6	4.9	140	0	3,320	----	24
17-18W-20daa	12	300	Kd	10-12-60	----	1,360	8.0	.09	.07	10	5.1	500	273	190	500	3.8	1.9	46	0	2,370	----	32
28aad	13	335	Kd	5-12-60	16.5	3,660	8.0	.30	.00	38	29	1,300	249	290	1,800	3.2	7.1	210	10	6,740	----	38
33acd	14	300	Kd	4- 1-60	----	1,300	6.0	.17	.00	13	11	460	294	220	430	3.6	1.9	78	0	2,370	8.0	23
33dbc	15	300	Kd	5- 5-59	----	1,320	7.5	.14	.00	14	5.1	480	284	220	440	3.7	1.2	56	0	2,370	7.8	28
34bbd	16	302	Kd	5- 8-61	----	1,300	9.0	1.2	.05	31	9.4	450	307	210	430	3.2	.9	120	0	2,400	7.8	18
17-19W-27ddc	17	320	Kd	5-16-60	16.5	1,950	6.0	.08	.00	100	46	550	432	450	580	4.1	.4	440	87	3,370	----	11
17-20W-29cdd	18	285	Kd	5-13-60	17.0	1,200	10	.10	.00	49	36	340	298	360	260	2.8	3.8	270	26	1,900	----	9.0
36abb	19	325	Kd	10-12-60	----	884	6.0	2.7	.00	9.1	3.3	320	268	160	240	3.2	1.3	36	0	1,640	----	23
18-16W-16bbb	20	86	Qv	8- 5-60	15.0	374	47	.18	.00	94	9.1	19	304	30	19	.2	5.8	270	22	590	----	.5
19bba	21	55	Qv	8-19-60	13.0	789	34	.27	.55	160	19	84	458	190	57	.7	7.1	490	110	1,270	----	1.7
23aaa	22	75	Qv	5-25-61	----	444	31	.01	.00	110	11	28	346	48	38	.2	2.9	330	46	760	7.6	.6
23add	23	stream	----	8-24-60	22.0	441	28	3.2	.62	95	10	45	296	80	31	.5	6.2	280	36	730	----	1.2
28cdc	24	168	Kd	5-17-60	14.5	773	8.0	.36	.00	9.1	15	270	554	140	46	4.5	1.3	84	0	1,310	----	13
18-17W-11cda	25	86	Qv	8-17-60	13.0	420	50	.27	.00	100	11	24	271	17	76	.4	5.8	300	78	690	----	.6
14cdc	26	70	Qv	8-19-60	12.0	487	36	1.8	.70	100	12	46	337	93	24	.3	4.9	310	36	790	----	1.2
18ccc	27	224	Kd	10- 7-60	----	1,270	9.0	.46	.00	21	10	460	336	140	460	3.0	.4	94	0	2,360	----	21
27aba	28	59	Qv	8-24-60	12.0	369	43	.20	.00	93	8.8	18	288	40	15	.3	9.3	270	32	590	----	.5
28bcc	29	63	Qv	8-11-60	12.0	446	41	2.2	.31	100	10	31	300	85	22	.2	4.2	300	57	720	----	.8
34bca	30	175	Kd	10-11-60	----	650	8.0	.38	.00	18	9.5	220	407	120	70	2.6	1.9	84	0	1,160	----	10
18-18W- 9aab	31	265	Kd	10-12-60	----	1,320	8.0	1.1	.00	14	5.6	480	298	230	440	4.2	1.8	58	0	2,470	----	27
25bcb	32	67	Qv	8-22-60	12.0	568	35	1.5	.47	120	11	62	378	99	46	.4	6.2	350	40	930	----	1.5
26dda	33	187	Kd	10-12-60	----	500	8.0	.36	.00	29	10	150	329	52	84	1.6	.4	110	0	920	----	6.1
28aac	34	83	Qv	7-22-61	----	415	26	.62	.12	114	11	19	351	53	19	.2	.4	330	42	630	7.8	.5
30ddc	35	70	Qv	8-11-60	12.0	420	35	.18	.42	100	7.3	28	300	47	27	.3	23	290	46	700	----	.7
31dda	36	150	Kd	10-11-60	14.5	644	9.0	1.1	.00	10	2.7	240	354	95	110	2.8	1.8	36	0	1,160	----	17
34bbb	37	59	Qv	8-22-60	12.0	665	33	.18	.00	140	12	66	340	180	49	.5	18	400	120	1,050	----	1.4
36dca	38	54	Qt	8-19-60	12.0	414	31	.18	.00	120	9.0	13	316	40	17	.2	34	320	66	710	----	.3
18-19W-21cdb	39	58	Qv	8-11-60	13.0	488	45	.18	.00	120	11	29	334	90	23	.2	6.2	340	68	740	----	.7
27aaa	40	64	Qv	8-11-60	12.0	549	36	.29	.00	140	10	32	293	140	34	.2	23	380	140	850	----	.7

18-20W-14ccb	41	44	Qv	8-11-60	12.0	463	52	.20	.00	120	11	19	322	63	21	.3	15	340	68	710	---	.5
15ccb	42	63	Qv	8-11-60	13.0	465	50	.20	.00	120	12	20	310	79	22	.3	14	340	82	730	---	.5
19acc	43	54	Qv	8-11-60	12.0	479	50	.20	.35	110	13	28	356	79	14	.3	5.8	340	46	780	---	.7
19ccb	44	stream	---	8-22-60	21.0	418	33	1.4	.00	89	12	36	277	83	22	.5	5.8	270	45	680	---	1.0
20dca	45	47	Qv	2- 6-61	---	535	33	.10	.00	150	10	20	424	89	14	.2	7.1	420	74	920	7.5	.4
36abb	46	214	Kd	10-11-60	14.0	1,220	8.0	.55	.00	13	4.8	450	361	220	340	5.6	1.0	52	0	2,220	---	27
19-16W-23ddb	47	80	Qv,Kd	10- 7-60	12.0	657	20	.53	.00	170	16	32	316	74	100	.1	88	480	230	1,170	---	.6
19-17W-27add	48	185	Kd	5-17-60	15.5	309	11	.06	.00	37	17	59	292	19	20	.6	1.9	160	0	570	---	2.0
19-18W- 3aca	49	140	Qt,Kd	8-15-60	12.0	469	33	.18	.00	120	11	21	312	77	40	.2	9.7	350	98	790	---	.5
27ccb	50	390	Kd	5-16-60	16.0	448	8.0	.71	.00	20	13	140	299	28	90	.9	1.7	100	0	800	---	6.0
19-19W-24ccb	51	290	Kd	5-16-60	16.0	591	11	.71	.00	19	8.9	190	278	120	93	3.0	2.7	84	0	1,050	---	9.0
19-20W- 4bbb	52	284	Kd	10-11-60	13.5	861	7.0	.15	.00	10	5.1	310	327	200	160	5.4	.8	46	0	1,550	---	20
17ddc	53	360	Kd	5-13-60	14.5	1,130	14	.22	.00	6.6	7.2	420	442	200	250	5.2	4.4	46	0	1,970	---	27
26baa	54	410	Kd	5-13-60	19.0	745	9.5	3.0	.00	6.6	7.7	260	317	170	120	4.9	3.6	48	0	1,190	---	16

[1] Samples analyzed by Kansas State Department of Health.
[2] One milligram per liter is equivalent to 8.33 pounds of substance per million gallons of water.
[3] Kd, Dakota Formation; Qt, terrace deposits; Qu, undifferentiated Pleistocene deposits; Qv, valley-fill deposits.
[4] Sodium and potassium expressed as sodium.
[5] In areas where the nitrate content of water is known to exceed 45 mg/l, the public should be warned of the potential dangers of using the water for infant feeding (U.S. Public Health Service, 1962, p. 7).

Thus, a storage coefficient of 0.15 was assigned to the valley-fill deposits.

CHEMICAL CHARACTER OF GROUND WATER

Chemical character of ground water in Rush County is indicated by analyses of samples of water collected from 51 wells and a seep. The analyses of two water samples from Walnut Creek also are included. Results of the chemical analyses are given in milligrams per liter in table 10, but many of the data were examined using units of milliequivalents per liter. Milligrams per liter can be converted to milliequivalents per liter (meq/l) by multiplying milligrams per liter by the factors given in table 11.

TABLE 11.—Factors for converting milligrams per liter to milliequivalents per liter.

Mineral constituents	Chemical symbol	Multiply by
CATIONS		
Calcium	Ca^{++}	0.04990
Magnesium	Mg^{++}	.08226
Sodium	Na^{+}	.04350
Potassium	K^{+}	.02558
ANIONS		
Carbonate	CO_3^{--}	.03333
Bicarbonate	HCO_3^{-}	.01639
Sulfate	SO_4^{--}	.02082
Chloride	Cl^{-}	.02821
Fluoride	F^{-}	.05264
Nitrate	NO_3^{-}	.01613

Water from the seep, which is near an abandoned oil well, had unusually large concentrations of dissolved constituents. The sample is not considered to be representative of water from aquifers of Cretaceous or younger age: therefore, the analysis is shown only in table 10 and on figures 11-13, and is not included in the discussion of ranges in concentration of chemical constituents in ground water.

Chemical Constituents in Relation to Use

The following discussion of the chemical constituents of ground water in relation to use has been adapted in part from publications of the U.S. Geological Survey and the State Geological Survey of Kansas. The recommended maximum concentration of chemical constituents in water used for domestic purposes (U.S. Public Health Service, 1962) are summarized in table 12.

Dissolved solids.—When water evaporates, the residue consists of the mineral constituents listed in table 10 and may contain some organic matter and water of crystallization. Water containing more than 1,000 mg/l of dissolved solids is generally objection-

TABLE 12.—Recommended maximum concentrations of chemical constituents in water used for domestic purposes (adapted from U.S. Public Health Service, 1962).

Constituent	Concentration (milligrams per liter)
Chloride (Cl)	250
Fluoride (F)	1.2
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

able for domestic and municipal use; however, in various sections of the country, and in Rush County, water that contains more than 1,000 mg/l dissolved solids is used with no apparent adverse effect. More than 60 percent of the water samples from the Dakota Formation in Rush County contained more than 1,000 mg/l dissolved solids. The dissolved-solids concentration of water samples ranged from 309 to 3,660 mg/l. Of 53 samples, 19 contained less than 500 mg/l, 14 contained 500 to 1,000 mg/l, and 20 contained 1,000 or more mg/l dissolved solids.

Hardness.—Hardness in water may be recognized by the increased quantity of soap required to produce lather; it is a major contributor to scale formation in boilers, radiators, water heaters, and pipes. Akaline earths, mainly calcium and magnesium, commonly cause hardness in water, but iron and manganese may also contribute when they are present in high concentrations.

Carbonate hardness, or temporary hardness, is that part of the hardness that is equivalent to the carbonate and bicarbonate present in water; it can be removed for household use almost completely by boiling the water. Noncarbonate hardness, or permanent hardness, is the remainder of the hardness; it cannot be removed by boiling.

Water that has 60 mg/l or less of hardness is usually considered to be soft and suitable for most purposes without further softening. Moderate hardness, which ranges from 61 to 120 mg/l, does not seriously interfere with the use of water for most purposes, but it does increase the amount of soap required. Water with hardness ranging from 121 to 180 mg/l is considered to be hard, and laundries and industries may profitably soften such supplies. Water with hardness of more than 180 mg/l is very hard and generally requires softening before use. The preceding ranges in hardness are from Durfor and Becker (1964).

The calcium and magnesium hardness of water samples collected in Rush County ranged from 24 to 490 mg/l. Of 53 samples, 26 were very hard, 2 were hard, 14 were moderately hard, and 11 were soft.

Iron.—Some iron is present in most ground water. The quantity present may vary significantly from place to place, even within the same aquifer. When water contains 0.1 to 0.3 mg/l or more of iron in solution, the iron upon oxidation may precipitate as a red sediment. Iron may give a disagreeable taste to water, it may stain clothing, cooking utensils, and plumbing fixtures, and it may be objectionable in the preparation of foods and beverages. Iron can be removed from most water by aeration and filtration, but chemical treatment also may be required.

The concentration of total iron in water samples collected from wells in Rush County ranged from 0.01 to 3.0 mg/l. The sample from Walnut Creek near the east side of the county had a concentration of 3.2 mg/l. Of 53 samples, 28 contained less than 0.30 mg/l, and 25 contained 0.30 mg/l or more of iron.

Manganese.—Manganese has properties similar to iron and is considered with iron when evaluating the usefulness of water. Only 10 samples of water collected in Rush County contained measurable amounts of manganese and the concentration present ranged from 0.05 to 0.70 mg/l.

Chloride.—Chloride is widely distributed in nature; it is an abundant constituent of sea water, oilfield brines, and streams and lakes in arid or semiarid regions. In ground water the concentration of chloride may range from a few to more than 100,000 mg/l. Small quantities of chloride may be dissolved from most rock materials. Chloride has little effect on the suitability of water for ordinary use unless concentrations are high enough to make the water impotable or corrosive. The removal of chloride from water is costly and uneconomic for most present-day uses. Water containing 200 to 300 mg/l of chloride, and an equivalent amount of sodium, may have a salty taste.

The chloride content of water samples collected in Rush County ranged from 14 to 1,800 mg/l. Of 53 samples, 35 contained 250 mg/l or less, and 18 contained more than 250 mg/l of chloride.

Fluoride.—Fluoride generally is present in ground water in small quantities. Knowledge of the concentration of fluoride in water used by children is quite important, as concentrations of about 1 mg/l in drinking water lessens the incidence of tooth decay (Dean and others, 1941). The use of water containing more than 1.5 mg/l fluoride during the time of formation of permanent teeth may cause mottled tooth enamel (Dean, 1936).

The fluoride concentration of samples of water from Rush County ranged from 0.1 to 5.6 mg/l. Of 53 samples, 25 contained 1.2 mg/l or less and 28 contained more than 1.2 mg/l of fluoride.

Sulfate.—Sulfate in ground water is derived chiefly from solution of gypsum and anhydrite, or by oxidation of sulfides of iron. Water containing more than 250 mg/l sulfate will have a laxative effect on some of those who drink it.

The sulfate content of water samples in Rush County ranged from 17 to 450 mg/l. Of 53 samples, 48 contained less than 250 mg/l and 5 contained more than 250 mg/l of sulfate.

Sodium.—Sodium commonly is present in ground water and its concentration may range from a few milligrams per liter in water in some aquifers to more than 100,000 mg/l in brines. Water containing 130 to 200 mg/l of sodium, and an equivalent amount of chloride, may have a salty taste.

A large percentage concentration of sodium in water to be used for irrigation is undesirable because of its effect on soils. The concentration of sodium in water in relation to its use for irrigation is discussed in a later section.

The concentration of sodium in water samples in Rush County ranged from 13 to 1,300 mg/l. Of 53 samples, 29 contained less than 250 mg/l and 24 con-

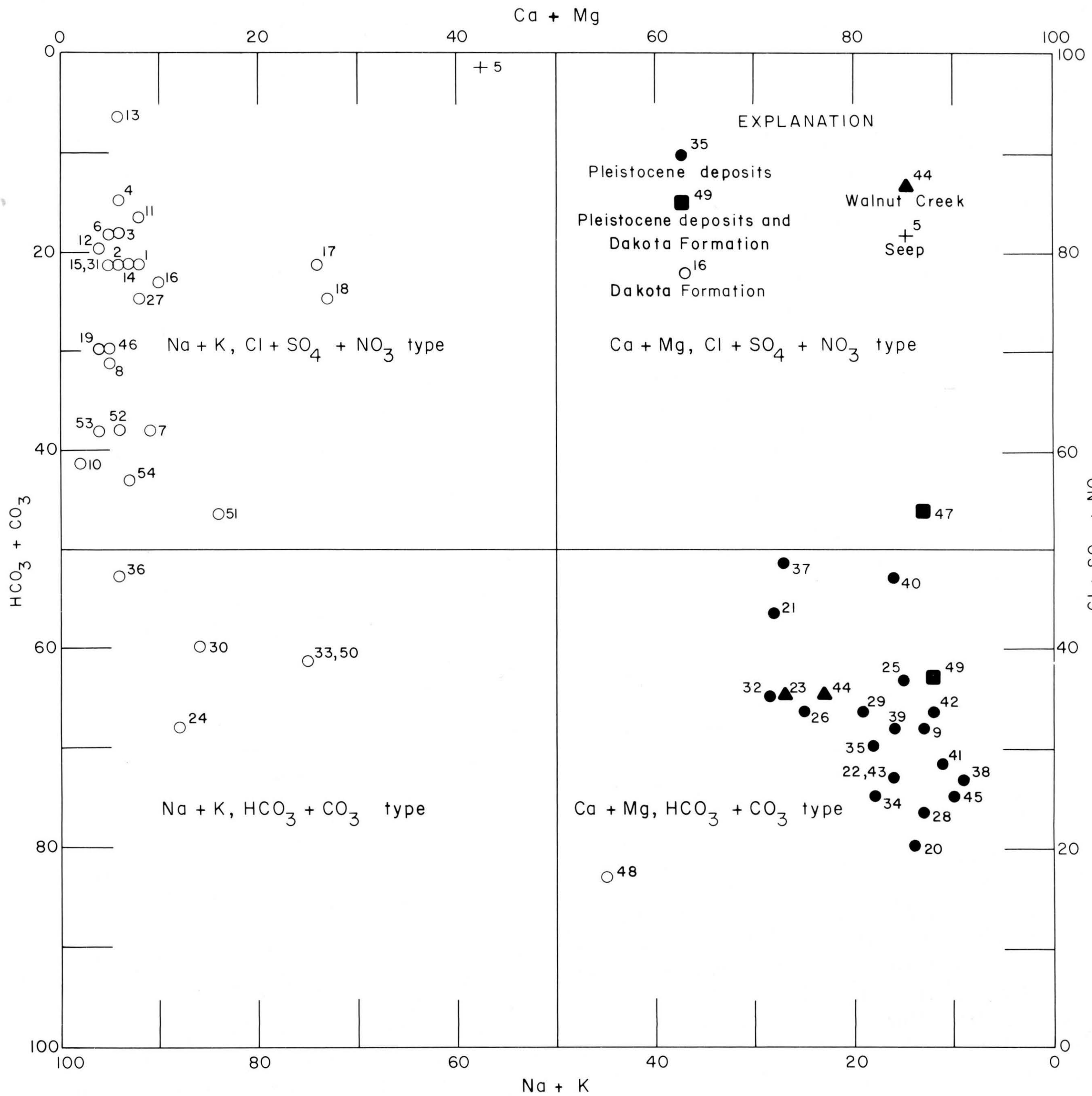

FIGURE 11.—Modified Piper diagram of percent milliequivalents per liter of cations and anions for water samples. Numbers by symbols are sample-identification numbers from table 10.

tained more than 250 mg/l of sodium.

Nitrate.—In 1954, a physician in Iowa reported cyanosis, or methemeglobinemia, in infants whose feeding formulas were mixed with water containing high concentrations of nitrate (Comly, 1945). This so-called blue-baby disease appears to be a hazard when waters containing more than 45 mg/l of nitrate are used for infant feeding (Hem, 1970). Older children and adults seemingly are not harmed by moderate concentrations of nitrate in water. Boiling or softening of water for household use will not remove or decrease the nitrate content.

The concentration of nitrate in water samples collected from Rush County ranged from 0.4 to 88 mg/l. Only one sample exceeded 45 mg/l nitrate; all other samples contained less than 35 mg/l. In a recent study by the county agent, 748 wells were sampled and 201 were found to contain water with 45 mg/l or more nitrate (E. L. VanMeter, written commun., 1971). The high concentrations of nitrate were commonly found to result from surface contamination due to improper location and sealing of the well.

Silica.—Silica is present in most water and may be deposited with other scale-forming minerals in steam boilers, but it has little effect on the use of water for other purposes.

The concentration of silica in water samples in Rush County ranged from 5.0 to 52 mg/l. Of 53 samples, 31 contained 20 mg/l or less and 22 contained more than 20 mg/l of silica.

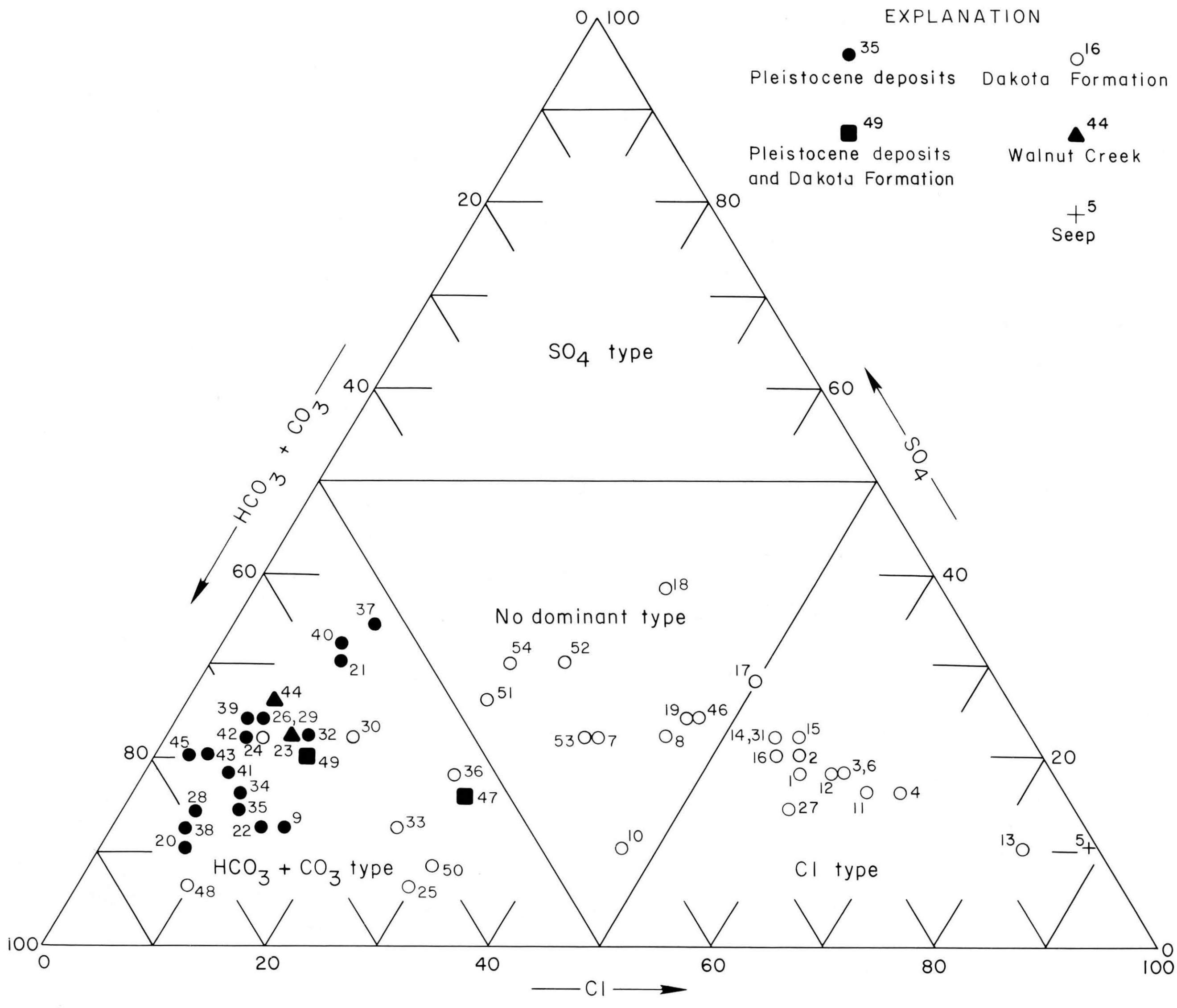

FIGURE 12.—Trilinear diagram of percent milliequivalents per liter of anions for water samples. Numbers by symbols are sample-identification numbers from table 10.

Chemical Constituents in Relation to Location and Aquifer

Samples of ground water were collected from 51 wells in Rush County; 30 samples were from the Dakota Formation of Cretaceous age, 19 samples were from aquifers of Pleistocene age, and two samples were from Pleistocene and Dakota deposits. Surface-water samples were collected from Walnut Creek near the east and west county lines.

AQUIFER DELINEATION AND WATER TYPE

Figures 11, 12, and 13 are diagrams modified from those proposed by Piper (1944), in which milliequivalents per liter of cations and (or) anions are plotted as percentages of total milliequivalents per liter of cations or anions. The diagrams are useful for comparing the chemical relations of water from different sources and for classifying the water by chemical type. For example, by examination of the values plotted on the diagrams, water from the Dakota Formation can be distinguished readily from water from the Pleistocene deposits. Most of the analyses for water samples from the Dakota indicate water of the sodium chloride type and most of those for samples from the Pleistocene deposits indicate water of the calcium bicarbonate type.

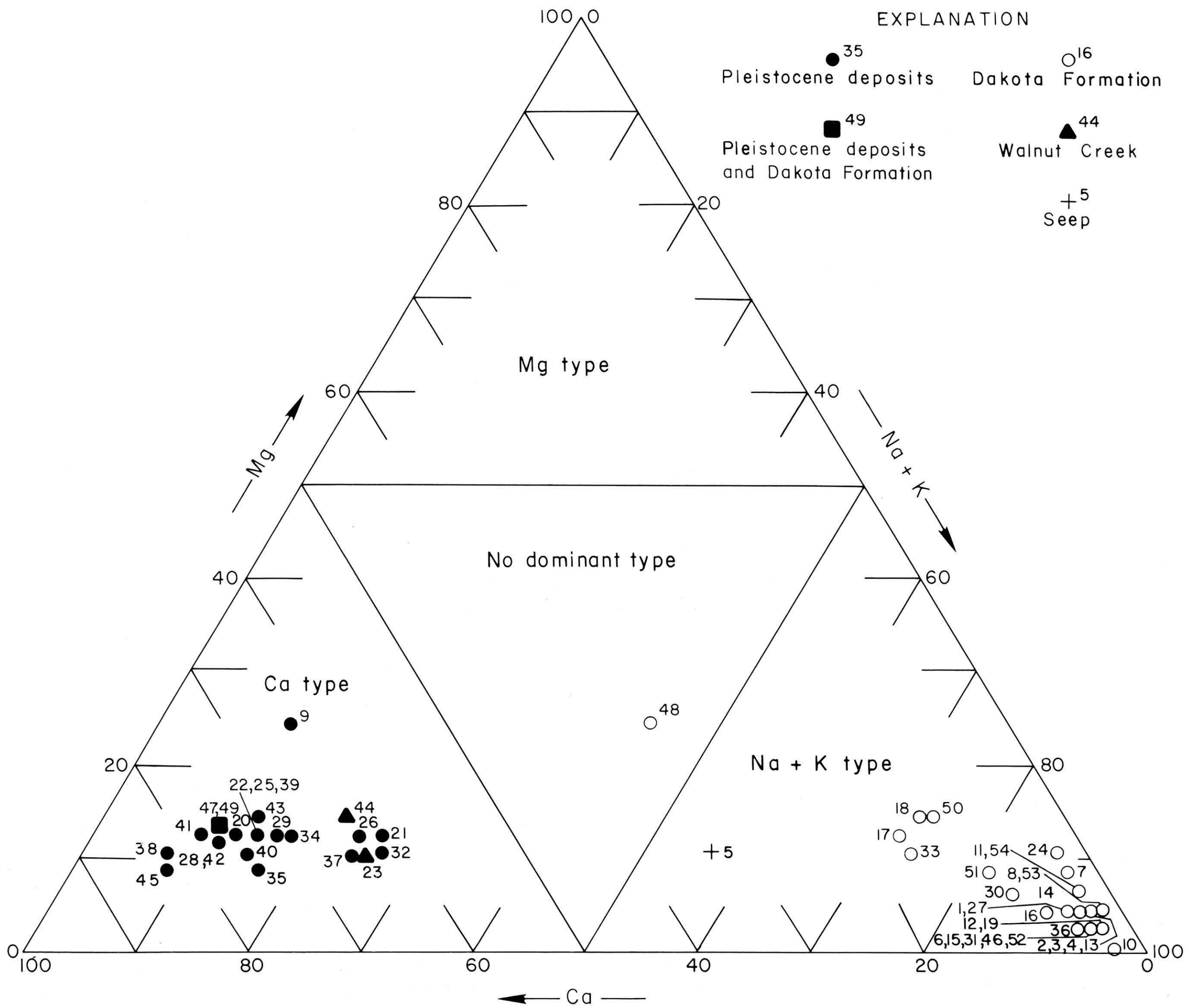

FIGURE 13.—Trilinear diagram of percent milliequivalents per liter of cations for water samples. Numbers by symbols are sample-identification numbers from table 10.

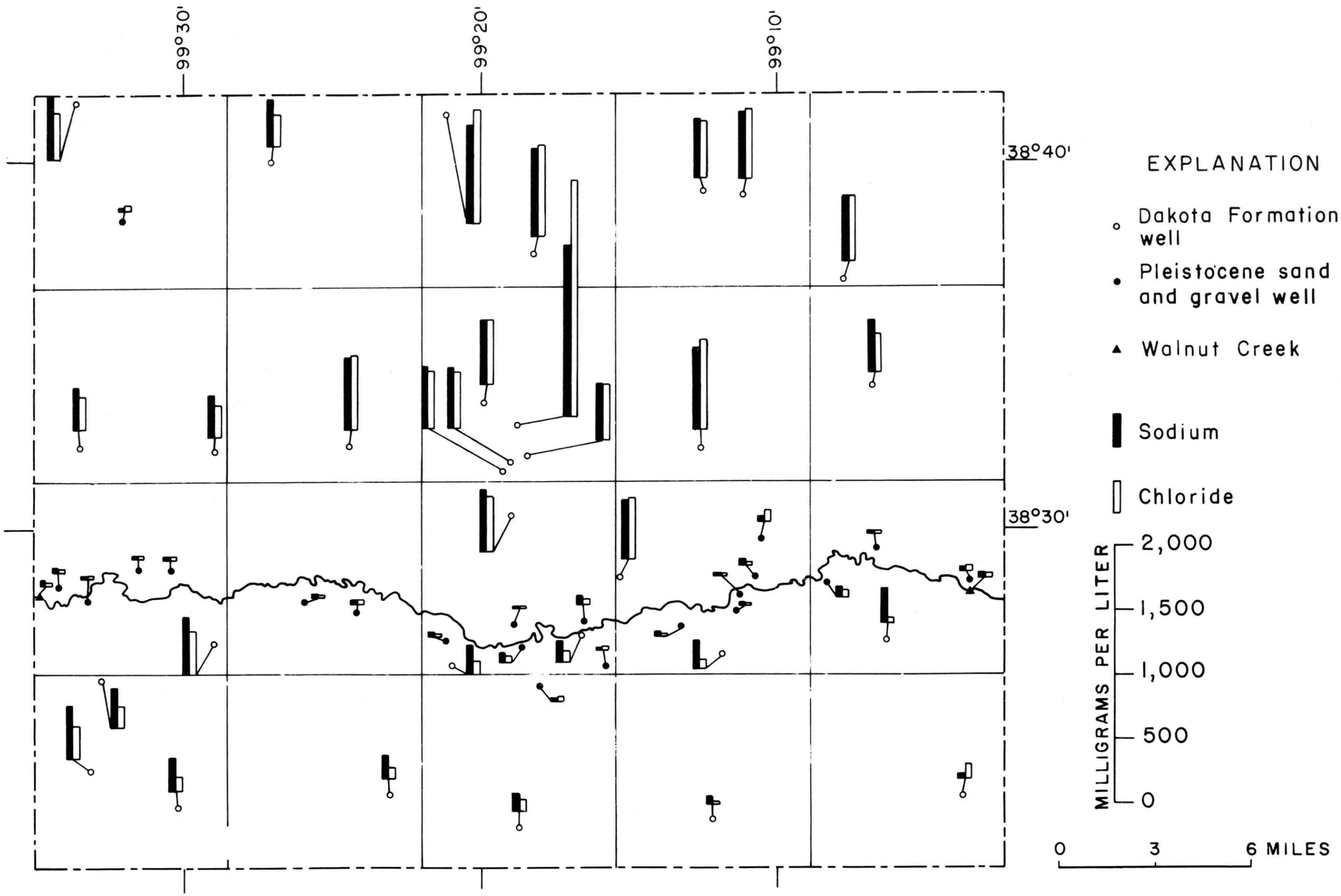

FIGURE 14.—Concentrations of sodium and chloride in water samples.

SODIUM AND CHLORIDE

The large range in concentration of sodium and of chloride by location and aquifer is illustrated on figure 14. A significant decrease in chloride concentration relative to sodium concentration, as well as a noticeable decrease in total sodium and chloride, in water from the Dakota is apparent on the south side of Walnut Creek in Rs.16-19 W. The reduction in sodium and chloride concentration may have resulted from recharge and dilution of water in the Dakota by water from the sand and gravel of Pleistocene age where the two aquifers are in contact in the valley of Walnut Creek. The area of contact begins somewhere in R.19 W. and continues eastward through the county.

HARDNESS AS $CACO_3$ AND SULFATE

The locations where water samples were collected and the range in concentration of hardness and of sulfate in the water are shown on figure 15. In general, Pleistocene deposits contain water with higher concentrations of hardness and lower concentrations of sulfate than the Dakota. Water from the Dakota has a wide range in concentration of hardness and of sulfate. Figure 15 also indicates a possibility of some recharge and dilution of water in the Dakota by water from Pleistocene deposits, as there is some decrease in sulfate concentration in water from the Dakota on the south side of Walnut Creek.

FLUORIDE, IRON, AND MANGANESE

The locations where water samples were collected and the fluoride, iron, and manganese concentrations in the water are shown on figure 16. The large fluoride concentrations in all but three of the Dakota water samples and the smaller concentrations of fluoride in the water from the Pleistocene aquifers are readily apparent. Concentrations of iron differ greatly in water samples from both aquifers, and no pattern for amount of iron or location of sample is apparent. Manganese was found in 10 of the samples analyzed. Two samples of Dakota water contained small concentrations of manganese, and the sample from Walnut Creek on the east side of the county contained a relatively large concentration. Manganese was contained in seven other samples from the Pleistocene aquifer, but no pattern of concentration or location of samples is discernable.

SILICA

Inspection of the chemical analyses of water samples from Rush County reveals large differences in concentration of silica in water from the Dakota and in water from the Pleistocene aquifers. None of the 30 samples of water from the Dakota had concentrations that exceeded 14 mg/l of silica, and no samples of water from the Pleistocene deposits had concentrations less than 26 mg/l of silica. Thus, a concentration of 14 mg/l or less of silica for a water sample from an unknown aquifer would indicate a probable source of Dakota Formation for that sample. Figure 17 shows the locations and concentrations of silica for the water samples.

Chemical Constituents in Relation to Use of Water for Irrigation

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

The development and maintenance of successful irrigation projects involves controlling the salinity and alkalinity of soils as well as supplying irrigation water to the land. Irrigation water quality, irrigation practices, and soil-drainage conditions are involved in saline and alkali soil control. Inadequate soil drainage and soil management or improper irrigation practices may cause soil to become unproductive through the accumulation of excess soluble salts or exchangeable sodium.

In areas where rainfall is sufficient and soil conditions are ideal, the soluble salts present in the soil are carried downward by percolating water and ultimately reach the water table. The process of dissolving and transporting soluble salts by the downward movement of water through the soil is termed leaching. The amount of water applied to the soil must be in excess of the amount needed by plants, or water will not percolate below the root zone, and mineral matter will accumulate at that point. Zones of impermeable soil near the surface can retard the downward movement of water, the soil may become waterlogged, and salts may be deposited. Unless soil drainage is adequate, leaching operations may not be successful, because leaching requires the passage of water through and away from the root zone.

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

Diagnosis and classification of the total concentra-

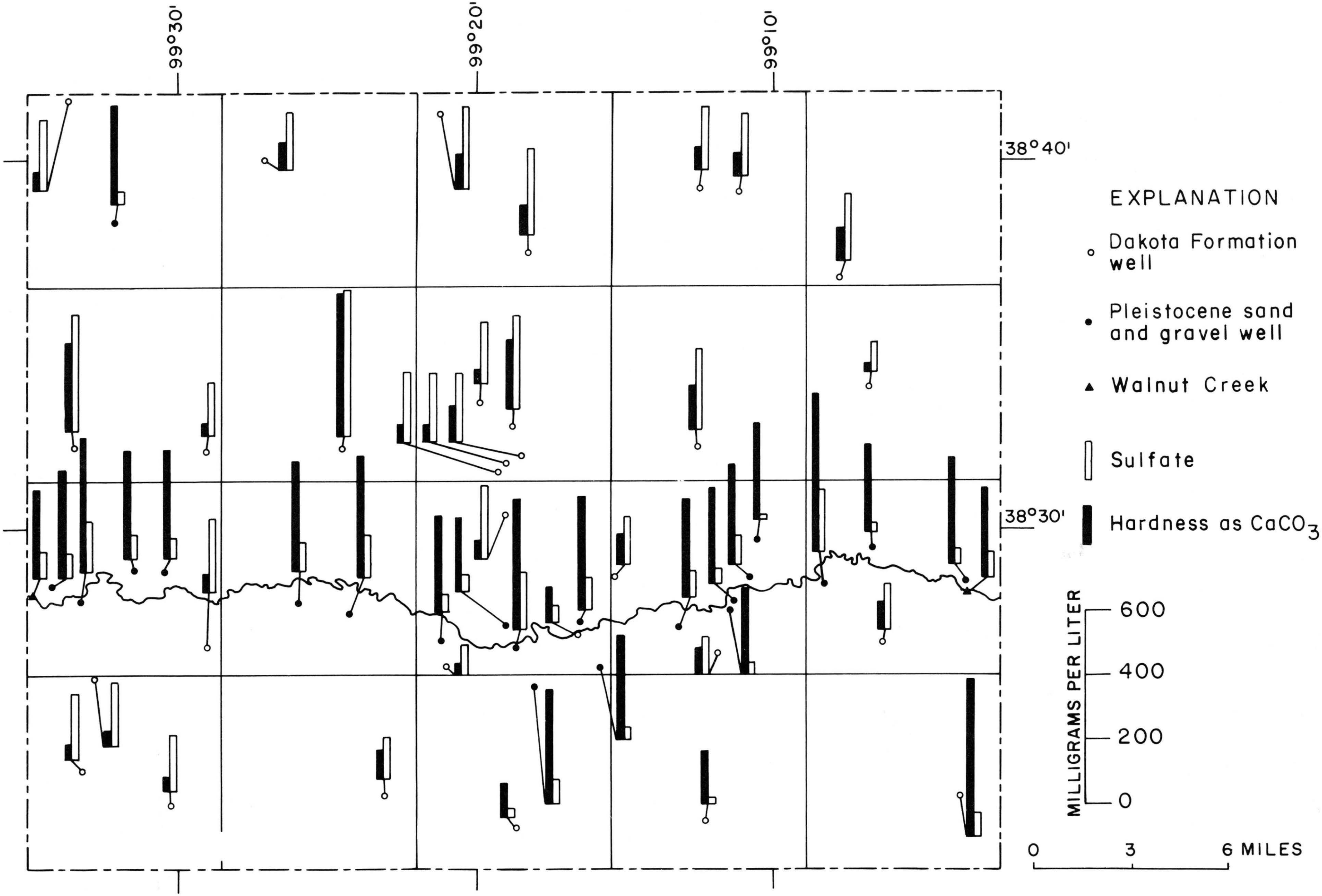

FIGURE 15.—Concentrations of hardness and sulfate in water samples.

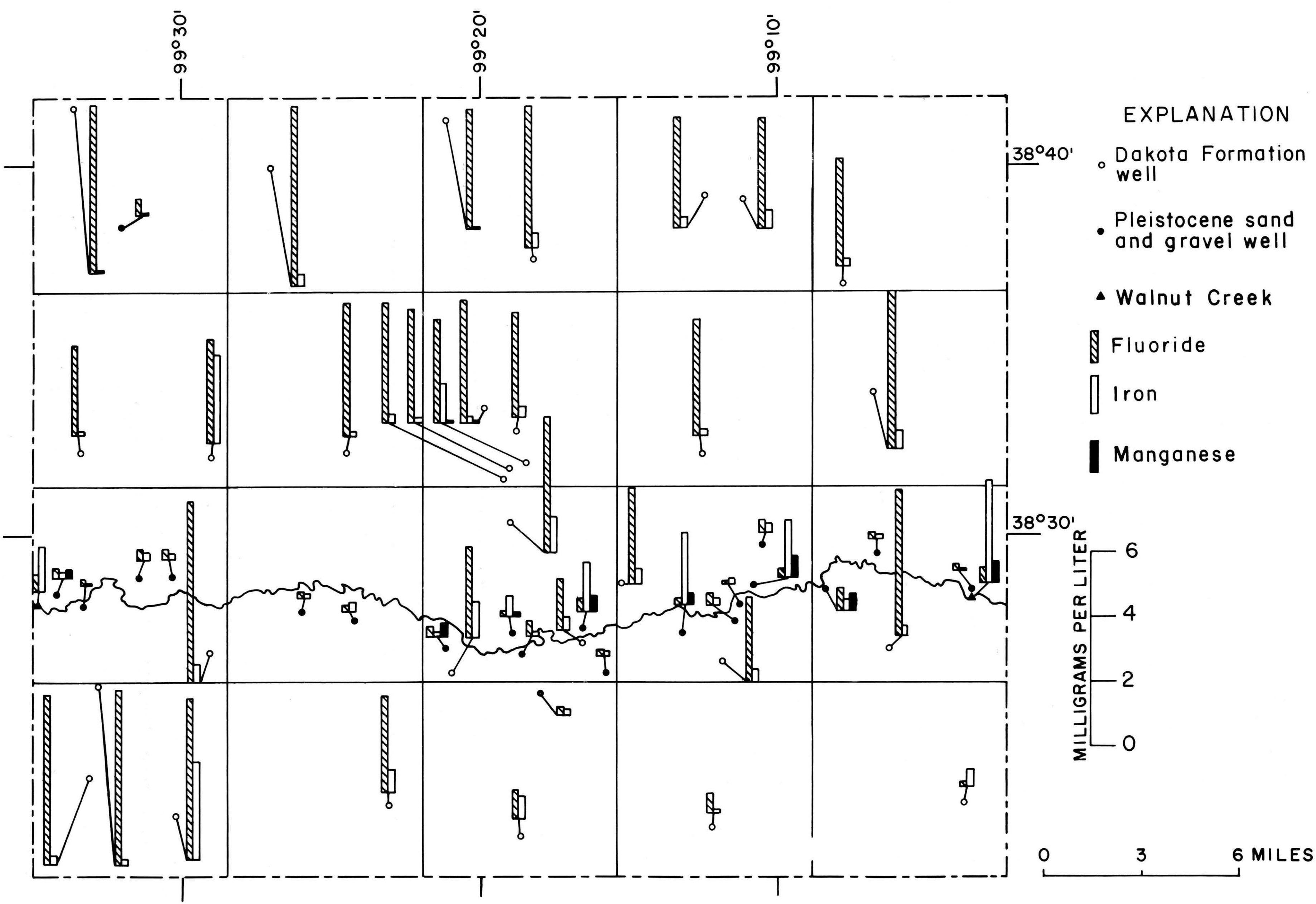

FIGURE 16.—Concentrations of fluoride, iron, and manganese in water samples.

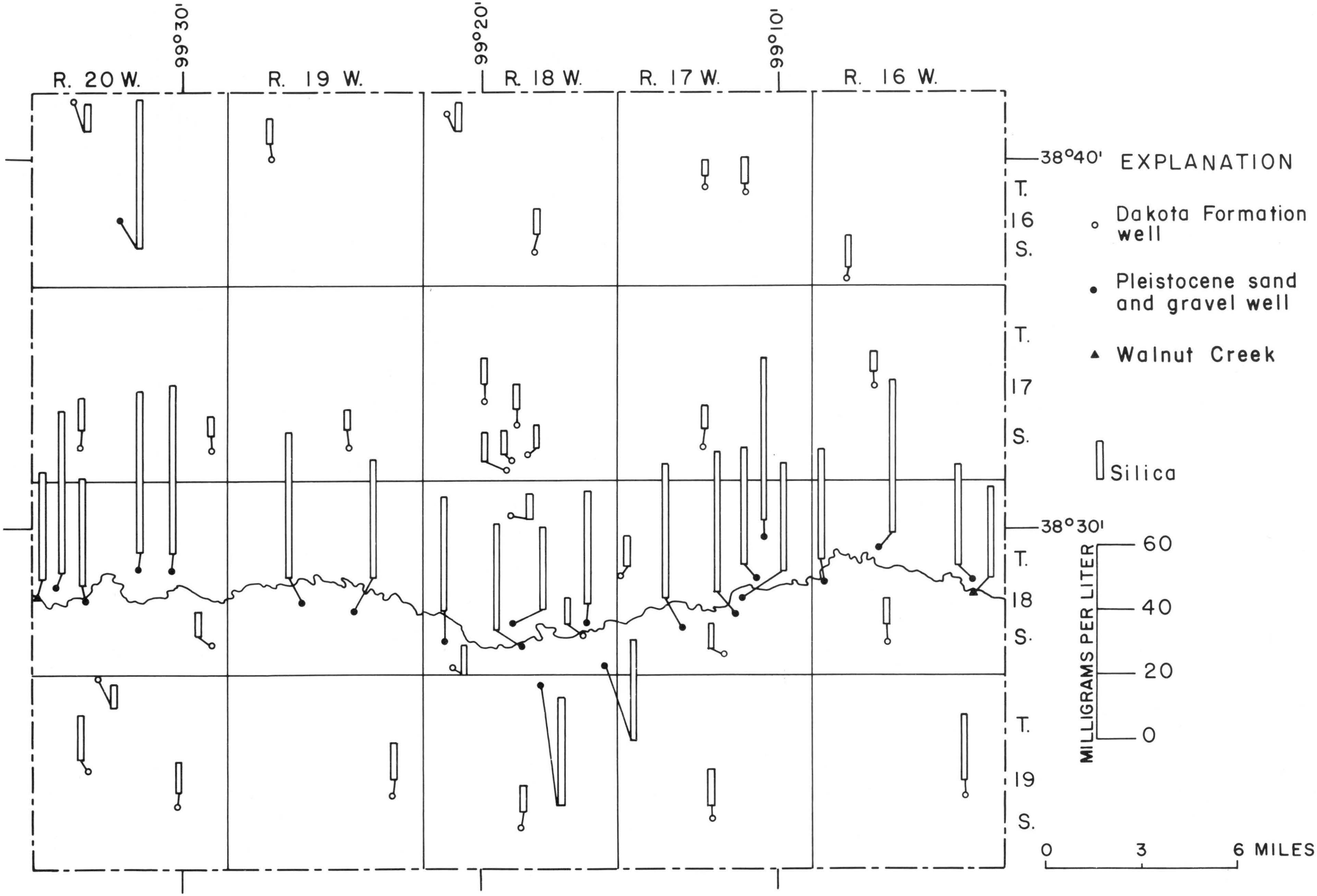

FIGURE 17.—Concentrations of silica in water samples.

tion of soluble salts in irrigation water can be expressed in terms of electrical conductivity (specific conductance). Electrical conductivity is a measure of the capacity of ionized inorganic salts in solution to conduct an electrical current; it is generally expressed in micromhos per centimeter at 25°C. The electrical conductivity can be determined accurately in the laboratory, or an approximation of the electrical conductivity can be obtained by multiplying the total milliequivalents per liter of calcium, magnesium, sodium, and potassium by 100, or by dividing the dissolved solids in milligrams per liter by a factor that averages 0.64. However, in Rush County, only eight of the 53 analyses would be close to 0.64. The factor for most of the analyses in Rush County is about 0.60. Water with conductivity values below 750 micromhos per centimeter is satisfactory for irrigation insofar as salt content is concerned, although crops sensitive to salt may be adversely affected by irrigation water with conductivity values in the range 250 to 750 micromhos per centimeter. Water in the range 750 to 2,250 micromhos per centimeter is widely used, and satisfactory crop growth is obtained under favorable soil-drainage conditions and good management, but saline soil conditions will develop when leaching is incomplete. Very few instances are known where water with conductivity values greater than 2,250 micromhos per centimeter has been used successfully. The use of copious quantities of such water on soils and subsoils with excellent drainage may allow the more salt-tolerant crops to be grown.

The alkali hazard of an irrigation water is determined by the absolute and relative concentrations of sodium, potassium, calcium, and magnesium. In the past the relative proportion of sodium to the other principal cations in irrigation water generally was expressed as the percentage of sodium, expressed as milliequivalents, among the principal cations (referred to as the percent sodium). The sodium-adsorption ratio (SAR), used to express the relative activity of sodium ions in exchange reactions with soil, is a better measure of suitability of water for irrigation with respect to the sodium (alkali) hazard. The sodium-adsorption ratio may be determined by the formula

$$SAR = \frac{Na^{+1}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

with ionic concentrations expressed in milliequivalents per liter. If the sodium-adsorption ratio and the electrical conductivity of a water are known, the suitability of the water for irrigation can be determined by plotting these values on the diagram shown on figure 18.

The significance and interpretation of the diagram for the classification of irrigation waters is as follows:

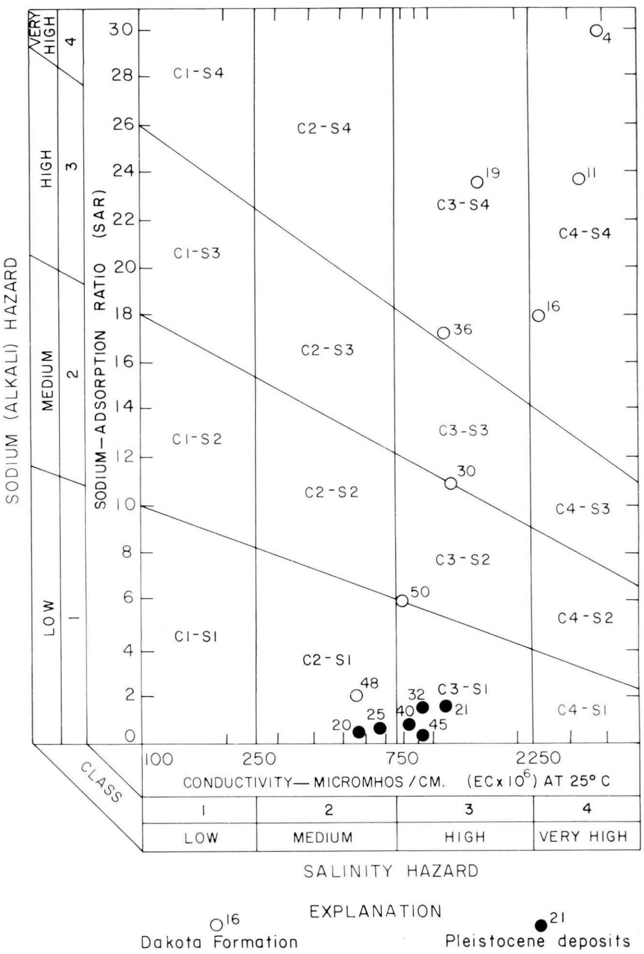

FIGURE 18.—Diagram showing suitability of water for irrigation. Numbers by symbols are sample-identification numbers from table 10.

Low-salinity water (C1) can be used for irrigation with most crops on most soils with small probability that soil salinity will develop. A minimum of leaching is required; minimum leaching generally occurs under normal irrigation practices, except in soils of very low permeability.

Medium-salinity water (C2) can be used if moderate leaching occurs. Moderately salt-tolerant plants generally can be grown without special salinity-control practices.

High-salinity water (C3) cannot be used on soils of restricted drainage. Special management for salinity control may be required and plants with good salt tolerance should be grown, even on soils with adequate drainage.

Very high salinity water (C4) may be used occasionally under special circumstances. The soil must be permeable and have excellent drainage, irrigation water must be applied in excess to provide maximum leaching, and extremely salt-tolerant crops must be selected.

Low-sodium water (S1) can be used on most soils with scant danger of the development of harmful levels of exchangeable sodium.

Medium-sodium water (S2) present an alkali hazard in fine-textured soils under low-leaching conditions, unless gypsum is present in the soil. This water is usuable on coarse-textured or organic soils of high permeability.

High-sodium water (S3) produces harmful levels of exchangeable sodium in most soils and requires special soil management for successful use. The soil must have good drainage, a high leaching rate, and organic matter additions. Chemical amendments such as calcium chloride, gypsum, sulfur, sulfuric acid, crushed limestone, and others may be required for replacement of exchangeable sodium. Harmful levels of exchangeable sodium may not develop in gypsiferous soils.

Very high sodium water (S4) generally is unsatisfactory for irrigation except at low to medium salinity, where solution of calcium from the soil or the use of a chemical amendment may make these waters usable.

All water samples from the Pleistocene aquifers in Rush County have a low alkali hazard and medium to high salinity hazard. Irrigation is successful in Rush County with water of this quality, which implies acceptable soil drainage with adequate leaching and good soil-management practices. Water from the Dakota is much less acceptable for irrigation. Water from the Dakota cannot be used to irrigate lawns and domestic gardens satisfactorily in much of the county. If the reader will note the position of Dakota water samples on figure 18, he will have a clearer understanding of why water from most of the wells in the Dakota cannot be used for irrigation, even for a garden plot, without careful management.

An appraisal of the quality of irrigation water should be concerned first with the determination of the salinity and alkali hazards by reference to figure 18. Consideration then may be given to independent characteristics, such as boron, other toxic elements, and bicarbonate, any one of which may change the quality rating. Soil-drainage characteristics and management, as well as water quality, must be considered also before water-use recommendations are made. The interested reader is referred to Agricultural Handbook 60 (U.S. Salinity Laboratory Staff, 1954) for a more complete discussion of the suitability of water for irrigation.

Sanitary Quality

The analyses of water listed in table 10 show only the amounts of dissolved mineral matter in the water and do not indicate the sanitary quality of the water. However, high concentrations of certain minerals, such as nitrate or chloride, may indicate pollution of the water supply.

The municipal supplies in Rush County are obtained from properly constructed wells, which meet the requirements of and are periodically examined by the Division of Environmental Health of the Kansas State Department of Health. Many of the people of the county, however, have private water supplies, and precautions should be taken to protect these supplies from pollution. Possible sources of pollution, such as barnyards, privies, and cesspools, should be as far as possible from well locations, and well casings should be sealed to a level below the water table. In general, dug wells are more vulnerable to contamination from the surface than drilled and cased wells, because they often are not effectively cased or sealed at the surface.

UTILIZATION OF GROUND WATER

Ground water in Rush County is used for domestic, stock, municipal, industrial, and irrigation supplies. The largest use is for irrigation of about 10,000 acres in Walnut Creek valley. Table 13 contains information pertaining to 222 wells in Rush County. The number of wells given according to principal use is: 60 domestic and stock wells, 10 public supply wells, and 152 irrigation wells.

SUMMARY

Ground water in Rush County is obtained principally from deposits of Pleistocene age and from the Dakota Formation of Cretaceous age. Maximum yields from irrigation wells tapping Pleistocene deposits in Walnut Creek valley have been measured as 1,200 gpm and reported as 1,500 gpm. The maximum reported yield from the Dakota was 500 gpm from a municipal well at La Crosse.

Water in storage in the Pleistocene deposits in Walnut Creek valley provides water for intensive irrigation. Recharge to the Pleistocene aquifer in the valley occurs quickly and in large amounts during periods of high flow in Walnut Creek. About 50,000 acre-feet of water may have been recharged in September 1959 by the maximum flood of record on Walnut Creek.

Water from Pleistocene deposits is hard to very hard, but otherwise is suitable for most uses. Dissolved-solids concentrations of water samples from Pleistocene deposits ranged from 369 to 789 mg/l. Water from the Dakota Formation is variable in chemical quality and generally is considered to be marginal for domestic use and for irrigation. Dissolved-solids concentrations of water samples from the Dakota ranged from 309 to 3,660 mg/l.

TABLE 13.—Records of wells.

Well number[1,2]	Owner or user	Depth of well[3] (feet)	Diameter of well (inches)	Type of casing[4]	Principal water-bearing unit: Character of material[5]	Principal water-bearing unit: Geologic source[6]	Method of lift,[7] type of power[8]	Use[9]	Water level: Depth below land surface[3] (feet)	Water level: Date of measurement	Altitude of land surface above mean sea level (feet)	Yield[3] (gallons per minute)
16-16W- 8bcc	J. Kisner	10	5	G	Sd, St	Qv	Cy, W	S	8.7	10-60	1,911	
10ddd	E. Hopkins	9		R	Sd, St	Qv	Cy, H	S	3.8	10-60	1,877	
28aba	Jacob Wegele	21			Sh, St	Qu, Kc	N	S	12.3	10-60	1,947	
32ccb*	Jeff Allen	266 R	2	G	Ss	Kd	Cy, E	D, S			2,005	
16-17W-16dcd*	Mary Basgall	370 R	2	G	Ss	Kd	Cy, E	D, S				
22aaa*	St. Mary Church	320 R			Ss	Kd	T, E	PS				
16-18W- 3cdc	J. Werth	10	36	R	Sd, St	Qt	Cy, W	S	7.7	9-60	1,932	
6dac*	C. N. Bieker	230 R	2	G	Ss	Kd	Cy, E, W	D, S				
7bcc	W. Kreutzer	18	36	R	Sd, St	Qu, Kc	Cy, W	S	6.1	9-59	2,032	
9bad	M. Bahr	33	48	R	Sd, Gr, St	Qt	Cy, W	S	27.5	9-60	1,970	
18ccd	John P. Enslinger	22	48	R	Sd, St	Qu	N	S	7.0	9-59	2,032	
20bbb	Schuckman	16		R	Sd, St	Qu	Cy, H, W	S	10.1	9-60	2,008	
27cdd*	Noel Mellick	209 R	5	G	Ss	Kd	Cy, E	D, S			2,035	
28aba	B. Legleiter	15		R	Sd, St	Qv	Cy, W	S	7.8	9-60	1,973	
29add	W. R. Jefferies	23	72	R	Sd, St	Qv	Cy, W	S	16.3	9-60	1,984	
30ccd	Leonard Kreutzer	28	48	R	Sd, Gr, St	Qv	C, E	D, S	22.6	9-60	2,012	
16-19W- 6daa	G. E. Schutte	12	36	R	Sd, St	Qv	Cy, W	S	8.6	8-59	2,039	
11bba	Albert Zimmerman	27	36	R	Sd, St	Qu, Kc	Cy, W	S	7.0	9-59	2,029	
17bab*	Mrs. M. B. Close	400 R	2	G	Ss	Kd	Cy, E, W	D, S				
19ddd	John Oelkers	30	36	R	Sd, St	Qu	C, E	D, S	24.4	8-59	2,083	
25abb	Rudolph Schoendaller	22	48	R	Sd, St	Qt	Cy, E	S	14.9	9-59	2,016	
25dad	J. H. Kreutzer	23	36	R	Sd, St	Qv	Cy, W	S	17.6	9-60	2,008	
27ada	L. Mosher	30			Sd, St	Qv	Cy, W	S	19.5	9-60	2,034	
27bcb	Harry Saunders Estate	16	36	R	Sd, St	Qt	Cy, W	S	5.5	9-59	2,033	
29aaa	M. F. Littler	22	6	G	Sd, Gr, St	Qu	Cy, W	D	13.3	9-60	2,063	
30bbb	Cemetery	37	6	G	Sd, Gr, St	Qu	Cy, H	PS	27.7	9-60	2,102	
32dbd	F. M. Hardwick	30	7	G	Sd, Gr, St	Qt	J, E	D	21.6	9-59	2,051	
34bcb	G. J. Huber	30	53	R	Sd, Gr, St	Qv	Cy, W	S	16.6	9-60	2,040	
35aba	F. Komerak	18	36	R	Sd, St	Qv	Cy, W	S	9.5	9-60	2,023	
16-20W- 2dac	A. H. Foster	16	72	R	Sd, St	Qu, Kc	Cy, W	S	8.9	8-59	2,080	
5bbd*	Fred Black	530 R	2	G	Ss	Kd	Cy, E, W	D, S				
6dcc	V. Jarvis	30	6	G	Sd, St	Qv	C, E	D, S	20.3	8-59	2,230	
21ddc*	Alvin Janke	54	6	G		Qu	J, E	D, S	16.1	8-59	2,147	11
17-16W-20aaa*	A. Ochs	315 R	2	G	Ss	Kd	Cy, E	D, S			2,065	
17-17W-19ddd	Orland Scheuerman	24	36	R	Sd, St	Qv	Cy, E, W	D, S	12.2	8-59	2,028	
28dcd*	Emma Schwartzkopf	230 R	2	G	Ss	Kd	Cy, E	D			2,015	
32dcd	School District	57	6	G	Sd, Gr, St	Qt	Cy, H	PS	26.4	9-60	2,012	
17-18W-20daa*	W. Weber	300 R			Ss	Kd	Cy, W	D, S			2,131	
26abb	H. J. Kleihege	18	36	R	Sd, St	Qu	Cy, W	S	10.2	8-59	2,050	
28aad*	L. V. Mellick	335 R	2		Ss	Kd	Cy, W	D, S			2,095	
33acd*	City of La Crosse	300 R	10		Ss	Kd	T, E	PS	160 R	10-54	2,065	500 R
33dbc*	do	300 R	10	S	Ss	Kd	T, E	PS	157 R	5-53	2,060	300 R
34bbd*	do	302 R		S	Ss	Kd	T, E	PS			2,060	
17-19W-27ddc*	Ray Weiser	320 R	2	G	Ss	Kd	Cy, W	D, S			2,132	
17-20W- 1bab	K. House	39	6	G	Sd, Gr, St	Qt	Cy, W	S	24.7	9-60	2,089	

TABLE 13.—Records of wells—continued.

Well number[1,2]	Owner or user	Depth of well[3] (feet)	Diameter of well (inches)	type of casing[4]	Principal water-bearing unit: Character of material[5]	Principal water-bearing unit: Geologic source[6]	Method of lift,[7] type of power[8]	Use[9]	Water level: Depth below land surface[3] (feet)	Water level: Date of measurement	Altitude of land surface above mean sea level (feet)	Yield[3] (gallons per minute)
1ddc	V. Huxol	34	6	G	Sd, Gr, St	Qv	Cy, H	S	16.3	9-60	2,070	
27add	School District	11	36	R	Sd, St	Qu	N	PS	9.5	9-60	2,134	
29cdd*	O. S. Bellport	285 R			Ss	Kd	Cy, W	D, S			2,175	
36abb*	H. L. Baker	325 R			Ss	Kd	Cy, W	D, S			2,130	
18-16W- 8ddc	John Luft	99	16	I	Sd, Gr	Qv	T	I	16.9	5-60	1,944	660
9ccd	I. B. Pearson	79			Sd, Gr	Qv	T	I	16.9	5-60	1,942	
14bcc	Willis C. Mohr	73	16	G	Sd, Gr	Qv	T	I	5.9	5-60	1,929	1,080
15adb	do		19		Sd, Gr	Qv	T	I	18 R	39	1,936	650 R
15cbc	Harry Herbel	77 R	24		Sd, Gr	Qv	T, T	I	10.9	5-60	1,935	
15daa	Ed Mohr	81 R			Sd, Gr	Qv	T	I	9.1	5-60	1,933	
16adc	Morris Brack	84 R	24	I	Sd, Gr	Qv	T, T	I	9.9	5-60	1,935	1,500 R
16bac	do	88 R			Sd, Gr	Qv	T, T	I	12.0	5-60	1,937	700
16bbb*	H. E. Glantz	86	19		Sd, Gr	Qv	T	I	16.3	5-60	1,942	1,000
16dbd	Adolph Schroat	78 R			Sd, Gr	Qv	T	I	12.6	5-60	1,936	
17abb	do	73			Sd, Gr	Qv	T	I	12.3	5-60	1,939	660
18acb	Henry J. Pechanec	85	19		Sd, Gr	Qv	T, T	I	16.5	5-60	1,947	1,000 R
18cbd	do	71	19	I	Sd, Gr	Qv	T, T	I	15.2	5-60	1,947	800 R
18cdc	do	51	16	I	Sd, Gr	Qv	T	I	13.7	5-60	1,947	550 R
18dab	Adam Huenergardt	78	16		Sd, Gr	Qv	T, T	I	11.6	5-60	1,940	1,250 R
19bba*	Lloyd Rodie	55	16		Sd, Gr	Qv	T, T	I	15.4	5-60	1,950	670
21aab	H. E. Glantz	79			Sd, Gr	Qv	T	I	7.6	5-60	1,932	720
22cad	Francis Schneider	62			Sd, Gr	Qv	T	I	18.3	5-60	1,942	
23aaa*	City of Otis	75	24	S	Sd, Gr	Qv	T	PS	7.6	5-60	1,926	100 R
23bbb	Joe Koochel	87 R	16		Sd, Gr	Qv	T	I			1,929	
23bca	do	78 R	19		Sd, Gr	Qv	T, LPG	I	6.4	5-60	1,928	900 E
24ccd	Elmer Brack	48	15		Sd, Gr	Qv	T, T	I	9.9	5-60	1,927	
25bbc	Glenn Moore	33			Sd, Gr	Qv	T, T	I	15.4	5-60	1,934	
28cdc*	Dale Wagner	168 R			Ss	Kd	Cy, W	D, S			2,043	
18-17W- 6dda	Mrs. Mary Ficken	33	36		Sd, Gr, St	Qv	Cy, W	S	23.7	9-60	2,005	
11cda*	C. H. Hardy	86 R	19		Sd, Gr	Qv	T	I	19.6	5-60	1,958	800
12cdc	S. A. Crotinger	79	16	I	Sd, Gr	Qv	T, T	I	15.6	5-60	1,952	800 E
13bbc	Andy Schuetz	70	16	I	Sd, Gr	Qv	T	I	14.6	5-60	1,952	1,350 R
13cad	B. F. Pechanec	56	24	G	Sd, Gr	Qv	T, T	I	14.6	5-60	1,951	
13ccb	do	71	16		Sd, Gr	Qv	T, T	I	15.1	5-60	1,953	1,100 R
13ccc	W. R. Pechanec		16		Sd, Gr	Qv	T	I			1,955	650 R
13dab	Henry J. Pechanec	74	16	I	Sd, Gr	Qv	T, T	I			1,949	1,200 R
13dcc	B. F. Pechanec	51	16	I	Sd, Gr	Qv	T, T	I	16.8	5-60	1,952	
14abd	Robert Kraisinger	89	19	S	Sd, Gr	Qv	T, T	I	17.0	5-60	1,955	1,400 R
14adb	Lester Dirks	79 R			Sd, Gr	Qv	T, T	I	15.6	5-60	1,954	
14bcc	do	71	16		Sd, Gr	Qv	T	I	18.3	5-60	1,958	
18-17W-14cdc*	Jerry Oborny	70	16		Sd, Gr	Qv	T, E	I	16.2	5-60	1,956	890
15adc	Louis E. Oborny	85 R	16		Sd, Gr	Qv	T	I	19.8	5-60	1,960	
15dca	Jean Oborny	76	19	I	Sd, Gr	Qv	T, E	I	19.5	5-60	1,961	700
16ddd	E. F. Pechanec	50 R	19		Sd, Gr	Qv	T, E	I	19.4	5-60	1,962	350 R
18ccc*	E. O. Serpan	224 R	2		Ss	Kd	Cy, E	D, S			2,015	

19add	Clarence Gisick	74	19		Sd, Gr	Qv	T, T	I	24.8	5-60	1,978	350 R
19cbc	B. E. Seuser	70	14		Sd, Gr	Qv	T, T	I	23.0	5-60	1,983	700 E
19ccc	do	66	19		Sd, Gr	Qv	T, T	I	21.3	5-60	1,980	1,000 R
20adc	Ralph Pivonka	74 R	16		Sd, Gr	Qv	T	I	18.7	5-60	1,968	
20bcd	R. E. Gisick	65 R	19		Sd, Gr	Qv	T, T	I	19.2	5-60	1,972	600 R
20dcc	C. A. Pivonka	88	16		Sd, Gr	Qv	T, T	I	20.2	5-60	1,971	1,200 R
20ddb	Blanche Holopirek				Sd, Gr	Qv	T	I			1,971	
21acb	F. J. Pechanec	72	19		Sd, Gr	Qv	T, T	I	20.2	5-60	1,963	
21adc	do	70 R	19		Sd, Gr	Qv	T, T	I	21.2	5-60	1,965	
21bbb	do	64	14		Sd, Gr	Qv	T, T	I	20.8	5-60	1,968	
21bdc	Frank Vondracek	70 R	19		Sd, Gr	Qv	T, T	I	20.4	5-60	1,965	800 R
21cbc	L. A. Renner	69			Sd, Gr	Qv	T, T	I	19.9	5-60	1,968	
21cdc	James Jecha	61 R	10		Sd, Gr	Qv	T	I	20.1	5-60	1,968	
21dbc	do				Sd, Gr	Qv	T	I	21.7	5-60	1,967	1,200 R
21ddc	J. A. Vondracek	72	16		Sd, Gr	Qv	T	I	20.0	5-60	1,965	1,000 R
22cdb	Charles B. Besperat	70	17		Sd, Gr	Qv	T, T	I	21.0	5-60	1,964	650 R
22dba	W. Smrcka	73	19	I	Sd, Gr	Qv	T, T	I	23.7	5-60	1,966	
23abb	V. Kraisinger	57			Sd, Gr	Qv	T	I	16.4	5-60	1,956	1,200 R
23bbd	S. Vecesky	71			Sd, Gr	Qv	T, T	I	18.3	5-60	1,959	
27aba*	Ed Richter	59	16	I	Sd, Gr	Qv	T, T	I	23.4	5-60	1,972	580
27bba	Ernest Bucl	55			Sd, Gr	Qv	T, T	I	20.2	5-60	1,965	
28abc	Al Holopirek	54	19		Sd, Gr	Qv	T	I	16.1	5-60	1,964	
28aca	Ed Juno	62	19		Sd, Gr	Qv	T, T	I	19.9	5-60	1,968	550 R
28bbc	E. J. Oborny	66	16		Sd, Gr	Qv	T, T	I	17.1	5-60	1,968	
28bcc*	do	63	19	I	Sd, Gr	Qv	T, E	I	18.2	5-60	1,969	740
28cba	Otto Serpan	63	16	I	Sd, Gr	Qv	T, NG	I	21.2	5-60	1,972	
30abb	Dr. J. H. Baker	75 R			Sd, Gr	Qv	T	I	22.0	5-60	1,978	
30bab	James Stejskal	69	16		Sd, Gr	Qv	T	I	22.2	5-60	1,979	
34bca*	Mary Horacek	175 R			Ss	Kd	Cy, W	D, S			2,005	
18-18W- 2ada	H. L. and E. W. Ficken	32	6	G	Sd, Gr, St	Qv	Cy, W	S	11.0	9-60	2,011	
9aab*	V. Zetko	265 R			Ss	Kd	Cy, W	D, S			2,092	
19ada	D. E. Bailey	26	6	G	Sd, Gr, St	Qv	Cy, W	S	9.8	8-60	2,020	
22ccd	F. H. Kirks	66			Sd, Gr	Qv	T	I	20.4	5-60	1,995	
23ccd	Rush County Farm	73	16		Sd, Gr	Qv	T	I	24.2	5-60	1,991	1,100 R
24bcc	Rudolph Oborny	73	19	I	Sd, Gr	Qv	T, T	I	24.8	5-60	1,987	800 R
24cbc	Joe Haberman	71	19		Sd, Gr	Qv	T, T	I	22.5	5-60	1,986	
24dcc	Rudolph Oborny	81 R	19		Sd, Gr	Qv	T, E	I	21.9	5-60	1,982	1,100 R
25bcb*	Frank Oborny	67	16		Sd, Gr	Qv	T, T	I	21.9	5-60	1,983	1,000
26aba	C. O. Dighton	72 R			Sd, Gr	Qv	T	I	21.8	5-60	1,986	975
26adb	Dr. J. H. Baker				Sd, Gr	Qv	T	I	21.1	5-60	1,984	
26bab	C. T. Oborny	71 R	19		Sd, Gr	Qv	T, T	I	23.7	5-60	1,990	1,200 R
26dbb	Joe Jira	54	16		Sd, Gr	Qv	T	I	19.2	5-60	1,984	600 R
26dcb	T. D. Barron	56	14		Sd, Gr	Qv	T	I	22.8	5-60	1,991	545
26dda*	Ted Barron	187 R	4	G	Ss	Kd	S, E	D			2,005	
27aab	Frank Jira	72 R	16	I	Sd, Gr	Qv	T, T	I	22.6	5-60	1,995	700 R
27bac	Frank Stejskal	69 R	19		Sd, Gr	Qv	T, T	I	21.6	5-60	1,996	1,200 R
27ccb	Frank Oborny	67			Sd, Gr	Qv	T	I	21.0	5-60	2,000	1,000 R
27dac	J. Flamik	81 R	16		Sd, Gr	Qv	T	I	21.0	6-60	1,996	
27ddc	B. L. Moore	68 R	16		Sd, Gr	Qv	T	I	19.6	5-60	1,996	800 R
28aac*	City of Rush Center	83 R	10	S	Sd, Gr	Qv	T, E	PS	20.1	9-60	1,996	300 R
28ccd	Ernest Hallett	64	16	I	Sd, Gr	Qv	T	I	22.3	5-60	2,003	1,000 R
28dbb	Frank Oborny	65			Sd, Gr	Qv	T, T	I	18.1	5-60	1,999	
28ddd	L. V. Reynolds	59	16		Sd, Gr	Qv	T, E	I	22.6	5-60	2,002	
29acc	J. and B. Reynolds	68 R	18		Sd, Gr	Qv	T, E	I			2,005	1,100 R
29bdb	Everett Reynolds	80 R	16	I	Sd, Gr	Qv	T, T	I	22.7	5-60	2,009	1,000 R

TABLE 13.—Records of wells—concluded.

Well number[1,2]	Owner or user	Depth of well[3] (feet)	Diameter of well (inches)	Type of casing[4]	Principal water-bearing unit: Character of material[5]	Principal water-bearing unit: Geologic source[6]	Method of lift,[7] type of power[8]	Use[9]	Water level: Depth below land surface[3] (feet)	Water level: Date of measurement	Altitude of land surface above mean sea level (feet)	Yield[3] (gallons per minute)
30adc	D. E. Bailey	69			Sd, Gr	Qv	T	I	16.7	5-60	2,007	1,000 R
30bbc	B. and K. Schneidemind	60	19		Sd, Gr	Qv	T	I	19.5	6-60	2,012	900 R
30cac	W. L. Bailey	85 R	19		Sd, Gr	Qv	T, LPG	I	22.3	5-60	2,014	1,000 R
30cdb	Ken Button	72	19		Sd, Gr	Qv	T, T	I	25.0	5-60	2,017	1,000 R
30ddc*	Henry Howe	70			Sd, Gr	Qv	T, E	I	27.2	5-60	2,017	890
31bda	Roy Button	63 R	19		Sd, Gr	Qv	T, E	I	33.5	5-60	2,024	1,000 R
31dda*	Mrs. E. Jilg	150 R			Ss	Kd	Cy, E	D, S			2,070	
32aba	W. C. Martin	57			Sd, Gr	Qv	T	I	22.8	5-60	2,005	
33abb	L. V. Reynolds	56			Sd, Gr	Qv	T, T	I	22.9	6-60	2,004	
34acb	T. T. House Estate	105 R	16		Ss, Gr	Qu, Kd	T, E	I	21.0	6-60	1,997	
34bbb*	do	59	16		Sd, Gr	Qv	T, E	I	21.1	5-60	2,000	
34bbc	do	54	16		Sd, Gr	Qv	T, E	I	19.6	5-60	1,999	
36dca*	J. S. Oliverus	54	14		Sd, Gr	Qt	T	I	26.2	5-60	2,024	400 R
18-19W-15ccc	H. W. Grass Estate	59	18		Sd, Gr	Qv	T	I	22.2	6-60	2,031	
15ccd	do	56			Sd, Gr	Qv	T	I	19.9	6-60	2,029	400
18ccc	George Kershner	53	19		Sd, Gr	Qv	T	I	24.6	6-60	2,048	400 R
19abc	T. Baldwin	55	25	I	Sd, Gr	Qv	T	I	25.6	6-60	2,043	500 R
20abc	N. Kirby				Sd, Gr	Qv	T, NG	I	24.4	6-60	2,039	
20bbc	C. Williams	49			Sd, Gr	Qv	T, T	I	25.2	6-60	2,041	450 R
20cbc	Andy Felder	57			Sd, Gr	Qv	T	I	24.3	6-60	2,041	500 R
20dbc	Dan W. Phillips	44	48		Sd, Gr	Qv	T	I	23.1	6-60	2,038	600 R
21acc	H. W. Grass Estate	61 R	16		Sd, Gr	Qv	T	I	19.1	6-60	2,031	
21cca	Leroy Seaman	60 R			Sd, Gr	Qv	T, T	I	26.4	6-60	2,038	
21cdb*	J. H. Webs	58	16		Sd, Gr	Qv	T	I	25.7	6-60	2,036	450
21dca	Lloyd West	60 R	19		Sd, Gr	Qv	T	I	24.9	5-60	2,034	
18-19W-21ddc	do	58	16		Sd, Gr	Qv	T	I	24.6	5-60	2,035	
22acb	H. J. Ford	54	19		Sd, Gr	Qv	T, E	I	23.7	5-60	2,029	
22bcb	H. O. Jones	60			Sd, Gr	Qv	T, E	I	20.0	6-60	2,029	
22cbb	Charles Collins	54	20	I	Sd, Gr	Qv	T, E	I	20.3	5-60	2,029	500 R
22ccc	do	54	16	G	Sd, Gr	Qv	T, E	I	27.0	5-60	2,035	500 R
22dba	L. J. Ford	70	19		Sd, Gr	Qv	T, T	I	19.8	5-60	2,025	
22ddb	Frank Kershner	78 R			Sd, Gr	Qv	T, E	I	21.5	6-60	2,026	
23cbc	John Weitzel	75			Sd, Gr	Qv	T, E	I	22.0	5-60	2,027	
23ccd	Vera Bitters	77	19		Sd, Gr	Qv	T, T	I	23.8	5-60	2,027	450 R
24bcd	D. Brown	81 R	19		Sd, Gr	Qv	T, T	I	23.0	5-60	2,021	
24cdb	do	63 R	19		Sd, Gr	Qv	T, E	I	21.9	5-60	2,018	500
24dbc	Bertha Weltmer	65 R	19		Sd, Gr	Qv	T, T	I	24.1	6-60	2,019	
25aba	Robert Trout	62 R	16		Sd, Gr	Qv	T, E	I	20.8	5-60	2,014	600
25acb	do	60	18		Sd, Gr	Qv	T	I	21.3	5-60	2,014	850 R
25cbd	D. Brown	54	19		Sd, Gr	Qv	T, E	I	25.5	5-60	2,021	900
26aab	M. West	58	19		Sd, Gr	Qv	T, T	I	18.9	5-60	2,019	600 R
26add	do	84 R	19		Sd, Gr	Qv	T, E	I	21.4	5-60	2,019	700 R
26bbb	Frank West	52 R	19		Sd, Gr	Qv	T, E	I	24.0	5-60	2,029	
27aaa*	Charles Collins	64	20	I	Sd, Gr	Qv	T, E	I	24.6	5-60	2,028	1,200
18-20W-13dad	Ralph Dome	64 R	19		Sd, Gr	Qv	T	I	35.7	6-60	2,060	650 R

13dbc	do	61	19		Sd, Gr	Qv	T		I	26.7	6-60	2,052	700 R
13dcc	do	61 R	26		Sd, Gr	Qv	T		I	24.9	6-60	2,051	450 R
14ccb*	John Georg	44	16		Sd, Gr	Qv	T		I	26.0	6-60	2,056	450
15ccb*	Clyde Bryant	63 R	12		Sd, Gr	Qv	T, NG		I	25.4	6-60	2,064	600 R
17dcc	Harry Jones	53			Sd, Gr	Qv	T, LPG		I	29.7	6-60	2,074	
19aab	Fred Pabst	47	18		Sd, Gr	Qv	T		I	25.3	6-60	2,078	600 R
19aac	do	50 R	16		Sd, Gr	Qv	T		I	26.4	6-60	2,080	
19acc*	L. C. Young	54 R	72		Sd, Gr	Qv	C, NG		I	32.4	6-60	2,084	400 R
19daa	V. Huxol	58			Sd, Gr	Qv	T		I	26.8	6-60	2,077	
20acc	W. R. Olson	52			Sd, Gr	Qv	T		I	26.5	6-60	2,073	
20bcd	Mrs. J. G. Bott	55	16		Sd, Gr	Qv	T		I	26.4	6-60	2,076	500 R
20cbc	do	52 R	18		Sd, Gr	Qv	T		I	29.0	6-60	2,079	
20dca*	City of Alexander	47			Sd, Gr	Qv	T, E		PS	28.9	10-60	2,074	
20ddc	Unknown				Sd, Gr	Qv	N		I	29.0	6-60	2,078	
21acc	Clyde Bryant	43	12		Sd, Gr	Qv	T		I	25.7	6-60	2,066	400 R
21caa	G. W. Geckles	47	53	R	Sd, Gr	Qv	C, NG		I	24.9	6-60	2,066	
21cbc	do		53	R	Sd, Gr	Qv	C, LPG		I	24.3	6-60	2,070	
22cbb	John C. Seltman	49	16		Sd, Gr	Qv	T, E		I	27.5	6-60	2,063	500 R
22dba	George Miller	51 R	84		Sd, Gr	Qv	C, LPG		I	27.0	6-60	2,061	450 R
23cda	G. Wilson	50	5	G	Sd, Gr	Qv	N		S	31.8	10-59	2,065	
24aab	George Kershner	52	30		Sd, Gr	Qv	T		I	24.2	6-60	2,049	400
24abc	Lynn Fox	53 R	18	S	Sd, Gr	Qv	T, LPG		I			2,052	600 R
36abb*	Kenneth Almquist	214 R			Ss	Kd	Cy, W		D, S			2,125	
19-16W-23ddb*	Herman Hemken	80	6		Ss	Qv, Kd	Cy, E, W		D, S			1,982	
36dab	Wm. F. Werhan	140 R	14		Ss, Sd	Qt, Kd	T		I	22.1	7-60	1,975	
19-17W-27add*	Les Brannon	185 R	3	G	Ss	Kd	Cy, E		D, S				
19-18W- 3aca*	Ed Holopirek	140 R	14		Ss, Gr	Qt, Kd	T, T		I	23.6	5-60	2,020	290
27ccb*	Martin Hemken	390 R			Ss	Kd	Cy, E, W		D, S				
19-19W-24ccb*	A. Eilts	290 R	6		Ss	Kd	Cy, W		D, S			2,205	
19-20W- 4bbb*	B. Frank	284 R			Ss	Kd	Cy, E		S			2,145	
17ddc*	Elsie Lebsack	360 R			Ss	Kd	Cy, E, W		D, S			2,295	
26baa*	Claude Huddleston	410 R	5	S	Ss	Kd	Cy, W		S			2,235	

[1] Well-numbering system described in text.
[2] Asterisk following well number indicates analysis of water is given in table 10.
[3] R, reported; E, estimated.
[4] G, galvanized; I, black iron; R, rock; S, steel.
[5] Gr, gravel; Sd, sand; Sh, shale; Ss, sandstone; St, silt.
[6] Kc, Carlile Shale; Kd, Dakota Formation; Qt, terrace deposits; Qu, undifferentiated Pleistocene deposits; Qv, valley-fill deposits.
[7] C, centrifugal; Cy, cylinder; J, jet; N, none; S, submersible; T, turbine.
[8] E, electric; H, hand; LPG, liquefied petroleum gas; NG, natural gas; T, tractor; W, wind.
[9] D, domestic; I, irrigation; PS, public supply; S, stock.

LOGS OF TEST HOLES

The logs of 6 test holes drilled or augered by the U.S. Geological Survey and the State Geological Survey of Kansas and one test hole drilled by Dal Wells are given on the following pages. Logs of additional test holes are on file at the state and U.S. Geological Survey offices, Lawrence, Kans., and may be examined there.

17-19W-21aaa.—Sample log of test hole in the NE¼NE¼NE¼ sec. 21, T.17 S., R.19 W., in trail into field about 13 feet east and 7 feet south of stone cornerpost in NE corner of section; augered August 2, 1960. Altitude of land surface, 2,222.6 feet. Depth to water, 23.5 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Soil	3.5	3.5
Silt with caliche nodules	2.5	6
Silt and clay; some sand	2.5	8.5
Sand, very fine to coarse	10	18.5
Sand and gravel, fine to coarse	9.5	28
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Colorado Group		
Carlile Shale		
Shale, weathered	.5	28.5

18-16W-24bcc.—Sample log of test hole in the SW¼SW¼NW¼ sec. 24, T.18 S., R.16 W., about 60 yards east of Otis blacktop in north track of trail going east just south of bridge over Walnut Creek; drilled September 28, 1960. Altitude of land surface, 1,930.7 feet. Depth to water, 17.1 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Valley-fill deposits		
Roadfill and soil	10	10
Silt and clay, brown	19	29
Clay, silty grayish-white; some sand, very fine; some mollusk shells	4	33
Sand, fine to coarse	7	40
Sand, fine to coarse; gravel, fine; some clay	10	50
Sand, fine to coarse; gravel, fine to medium	5	55
Sand, fine to coarse; strip of clay at 75 feet; few mollusk shells	35	90
Sand, very fine; some clay	8	98
Sand, fine to coarse; gravel, fine	17	115
Sand, fine; some gravel	5	120
CRETACEOUS SYSTEM		
Lower and Upper(?) Cretaceous Series		
Dakota Formation		
Sand, fine to coarse (cemented with iron oxide); some clay, red and gray	10	130
Sand, fine (cemented with iron oxide)	20	150

18-17W-31bbc.—Sample log of test hole in the SW¼NW¼NW¼ sec. 31, T.18 S., R.17 W., in east road shoulder about 21 yards south of sign for narrow bridge across Walnut Creek tributary or about 80 yards north of bridge; drilled September 22 to 26, 1960. Altitude of land surface, 2,000.1 feet. Depth to water, 21.0 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Valley-fill deposits		
Roadfill	4	4
Silt and clay, tan to brown	16	20
Clay and silt, brown to black	8	28
Clay, silty, bluish-gray; some sand, very fine	2	30
Clay, silty, buish-gray; sand, coarse, quartz; many fossil mollusks	2	32
Silt and clay, bluish-gray; sand, coarse, quartz; gravel, fine limestone	6	38
Clay, gray; sand, fine, quartz; many fossil mollusks	4	42
Sand, coarse, quartz; gravel, fine to medium, limestone, angular, some quartz, rounded	8	50
Sand, very fine to coarse, quartz; gravel, fine to coarse, limestone, rounded, some arkosic material; many fossil mollusks; some clay, brown to black	25	75
Sand, fine to coarse; gravel, fine to coarse composed of limestone; clay, silty, gray	17	92
CRETACEOUS SYSTEM		
Lower and Upper(?) Cretaceous Series		
Dakota Formation		
Clay, silty, sandy, gray to ochre	18	110

18-18W-28aac.—Sample log of test hole in the SW¼NE¼NE¼ sec. 28, T.18 S., R.18 W., two blocks south of Kans. Hwy. 96 and two blocks west of U.S. Hwy. 182, 14 yards north and 144 yards west of SW corner of vacant lot NW of school in Rush Center. Site of Rush Center city well; drilled by Dal Wells for Rush Center September 15, 1960. Altitude of land surface, 1,996.0 feet. Depth of water, 20.0 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Valley-fill deposits		
Soil	3	3
Silt and clay, brown	18	21
Silt and clay, brown; some sand, fine	3	24
Sand, fine; some silt, brown	2	26
Sand, fine to coarse	6	32
Sand, fine to coarse; gravel, fine	3	35
Clay and sand	1	36
Sand, fine to coarse; gravel, fine	3	39
Sand, fine to coarse; gravel, fine; clay streaks	15	54
Sand, fine to coarse; gravel, fine to medium	11	65
Clay streak and sand	1	66
Sand, fine to coarse; gravel, fine to medium	6	72
Sand, very fine; clay, reddish-brown	11	83
Sand, fine to coarse; gravel, fine to medium	6	89
Sand with clay	3	92
Sand, fine to coarse; gravel, fine to medium	9	101
CRETACEOUS SYSTEM		
Lower and Upper(?) Cretaceous Series		
Dakota Formation		
Shale, red; some sand	3	104

18-20W-19add.—Sample log of test hole in the SE¼SE¼NE¼ sec. 19, T.18 S., R.20 W., about 100 yards north of half-mile line in west barpit; drilled September 22, 1960. Altitude of land surface, 2,075.3 feet. Depth to water 27.3 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Valley-fill deposits		
Silt, light-brown	10	10
Silt and clay, light-brown; caliche zone at 13 feet about 0.2 foot thick	10	20
Silt and clay, tan to light-brown	8	28
Sand, very fine to fine	7	35
Sand, very fine to fine with some clay, bluish-black	8	43
Sand, fine to coarse; gravel, fine to medium; some clay	4	47
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Colorado Group		
Graneros Shale		
Shale, platy, hard, blackish-gray	3	50

19-16W-23dad.—Sample log of test hole in the SE¼NE¼SE¼ sec. 23, T.19 S., R.16 W., in west road shoulder directly east of first line pole north of drive into farmstead; drilled September 29, 1960. Altitude of land surface, 1,980.8 feet. Depth to water, 28.9 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Valley-fill deposits		
Roadfill and silt, reddish-brown	10	10
Silt and clay, reddish-brown	40	50
Silt and clay, tan, soft, with caliche	6	56
Silt and clay, reddish-brown	4	60
Clay and silt, soft to hard, tannish-red to reddish-brown, with caliche	16	76
Clay and silt, black	4	80
Clay, black; gravel, fine to medium, limestone, angular; many mollusk shells	10	90
Clay, soft, silty, tan	5	95
Gravel, fine, limestone, angular	6	101
CRETACEOUS SYSTEM		
Lower and Upper(?) Cretaceous Series		
Dakota Formation		
Clay, black, gray, and green	9	110
Rock chips; sand, fine; clay, varigated red	10	120
Sand, fine, limonitic cement; some clay	10	130

19-18W-33aba.—Sample log of test hole in the NE¼NW¼NE¼ sec. 33, T.18 S., R.18 W., in the south road shoulder about 500 yards west of U.S. Hwy. 183; augered June 27, 1960. Altitude of land surface, 2,214.1 feet. Depth to water, 34.0 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pliocene Series		
Ogallala Formation		
Roadfill	3.5	3.5
Silt, some sand	5	8.5
Sand, very fine, "flour like," pink	8	16.5
Sand, fine, pink	4	20.5
Sand, fine, grayish-pink	7	27.5
Sand, fine to medium, gray	10	37.5
Clay, tan; some sand	6	43.5
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Colorado Group		
Carlile Shale		
Shale, dark-grey	.5	44

GLOSSARY OF TERMS

Many of the county reports of ground-water investigations in Kansas contain summaries of the principles of occurrence and movement of ground water as discussed by Meinzer (1923a) and Moore and others (1940); the reader is referred to Lane (1960, p. 25-39), Bayne (1960, p. 25-30), or Hodson and Wahl (1960, p. 28-32) for a discussion of the subject. Most of the following definitions of technical terms commonly used in a discussion of ground water are from Leonard and Berry (1961, p. 58-61), as adapted from Meinzer (1923b); however, some are from Lohman and others (1972).

Aquifer.—A rock formation, bed, or zone that contains water that is available to wells. An aquifer is sometimes referred to as a water-bearing rock, or water-bearing bed.

Artesian water.—Ground water under sufficient hydraulic pressure to rise above the level at which the water-bearing rock is tapped in drilling a well. Equivalent to confined ground water. The pressure is sometimes called artesian pressure and the rock containing artesian water is an artesian aquifer or confined aquifer.

Colluvial.—Of or relating to gravitational processes. Colluvial deposits result from action of gravity pulling loose material downhill.

Confining bed.—A less permeable rock layer that overlies or underlies an aquifer and retards vertical movement of water.

Eolian.—Of or relating to wind or wind action. Eolian deposits result from deposition of wind-carried sediment.

Evapotranspiration.—The combined total water evaporated by heat energy and transpired by plants into the atmosphere.

Fluvial.—Of or relating to streams or running water. Fluvial deposits result from deposition of water-carried sediment.

Gaining stream.—A stream or reach of a stream whose flow is being increased by inflow of ground water. Replaces the term "effluent stream."

Ground water.—Water in the saturated zone or water below the water table.

Hydraulic conductivity.—A measure of the rate of flow of water through an aquifer, which is dependent primarily on the nature of the interstices within the aquifer. Expressed in units of length per units of time that are consistent and suitable to the problem involved. Replaces the term "field coefficient of permeability." To convert a value of hydraulic conductivity to a value for coefficient of permeability, multiply by 7.48.

Hydraulic gradient.—Gradient of the water table measured in the direction of the greatest slope, generally expressed in feet per mile.

Impermeable rock.—An impervious rock, through which movement of water under common subsurface pressure differentials is negligible.

Inflow.—Movement of ground water into an area in response to a hydraulic gradient.

Interstice.—An opening or void in a rock. Interstices may be filled with air, gas, oil, water, or some other material. The interstices in an aquifer are filled with water.

Losing stream.—A stream or reach of a stream that is losing water to the ground. Replaces the term "influent stream."

Outflow.—Movement of ground water from an area in response to a hydraulic gradient.

Percolate.—The movement of water through soil and rock to the saturated zone.

Permeable rock.—Pervious rock, or a rock that has a texture permitting water to move through it readily under ordinary pressure differentials.

Permeability.—The capacity of water-bearing rock to transmit water, which is related to the size and interconnection of interstices. The *field coefficient of permeability,* is expressed as the rate of flow of water at the prevailing temperature, in gallons per day, through each mile of width and for each foot of thickness of an aquifer under a hydraulic gradient of 1 foot per mile; replaced by the term "hydraulic conductivity." To convert a value for field coefficient of permeability to the equivalent value of hydraulic conductivity, multiply by 0.134.

Porosity.—The porosity of a rock is its property of containing openings or interstices. Quantitatively, the porosity of a rock is the ratio (usually expressed as a percentage) of the volume of openings in the rock to the total volume of the rock.

Recharge.—The process by which water is absorbed and added to the saturated zone. Also used to designate the quantity of water added to the ground-water reservoir.

Runoff.—The discharge of water through surface streams. It includes both surface-water runoff and ground-water runoff. Also used to designate the quantity of water discharged as runoff.

Saturated zone.—The zone of porous rocks saturated with water. Ground water is contained in this zone.

Storage.—Water stored in openings in the saturated zone is said to be in storage. Discharge of water from an aquifer not replaced by recharge is said to be from storage.

Storage coefficient.—The volume of water released from or taken into storage per unit surface area of an aquifer per unit change in the component of head normal to that surface.

Transmissibility.—The transmissibility of a rock is its capacity to transmit water under pressure. The *coefficient of transmissibility* is the *field coefficient of permeability* multiplied by the saturated thickness, in feet, of the aquifer; replaced by the term "transmissivity." To convert a value of transmissivity to a value for coefficient of transmissibility, multiply by 7.48.

Transmissivity.—The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Expressed in units of length squared per units of time. Replaces the term "coefficient of transmissibility." To convert a value for coefficient of transmissibility to an equivalent value of transmissivity, multiply by 0.134.

Water table.—The upper surface of the saturated zone where the pressure is atmospheric. The water table is not a plane surface, but has irregularities much like the land surface.

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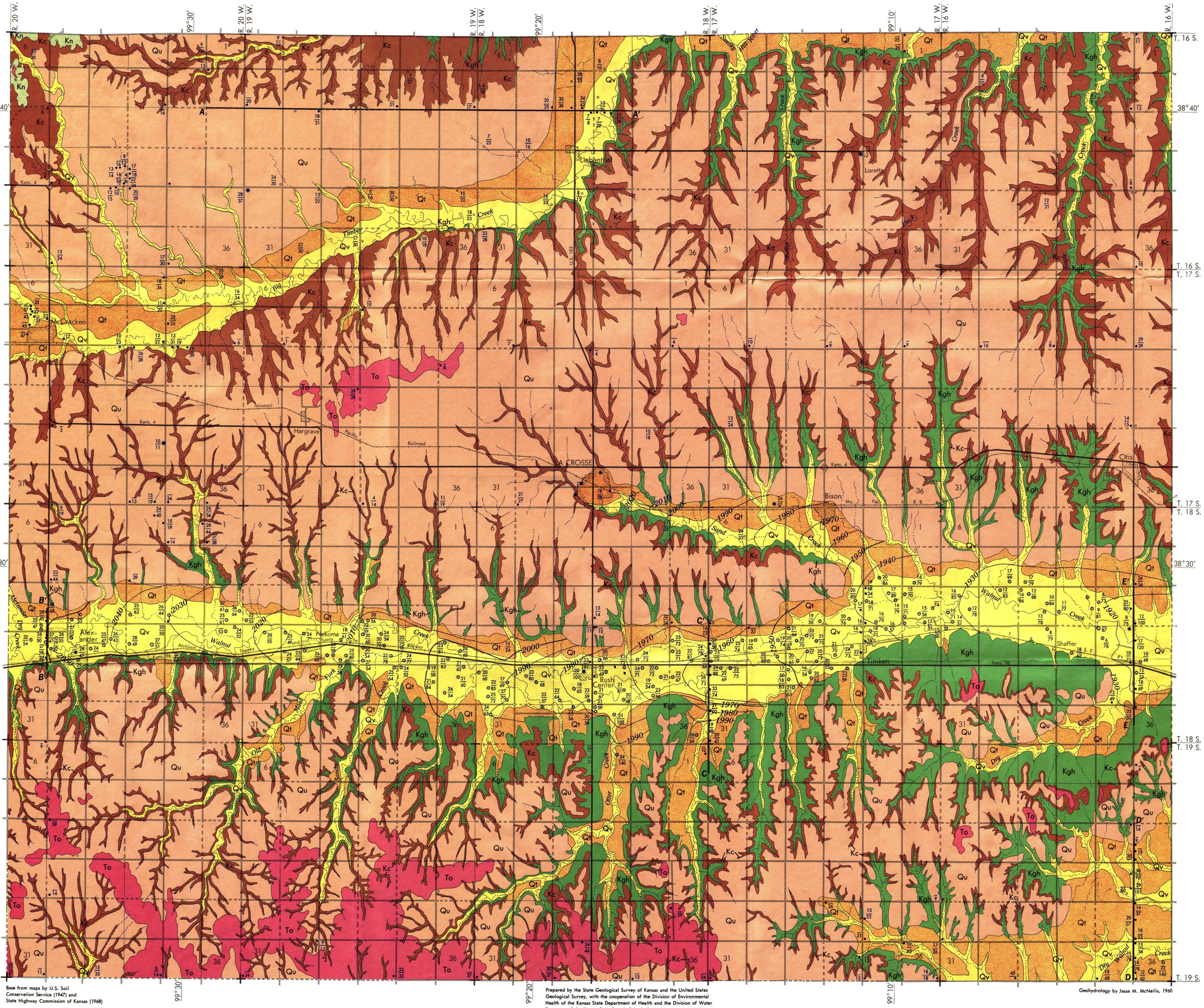
State Geological Survey
of Kansas

GEOHYDROLOGIC MAP OF RUSH COUNTY, KANSAS

Bulletin 207
Plate 1



EXPLANATION

QUATERNARY

Pleistocene

Qu

Undifferentiated deposits

Eolian, fluvial, and colluvial deposits of mostly silt, which may overlie sand and some gravel. May yield small to moderate quantities of water to wells.

Qv

Valley-fill deposits

Fluvial and eolian deposits of gravel, sand, silt, and clay. May yield moderate to large quantities of water to wells in Walnut Creek valley and small to moderate quantities of water to wells in other stream valleys.

Qt

Terrace deposits

Fluvial and eolian deposits of gravel, sand, silt, and clay in terrace position to stream courses. May yield small to moderate quantities of water to wells.

TERTIARY

Pliocene

To

Ogallala Formation

Fluvial deposits of gravel, sand, silt, and clay; soil caliche (referred to as "algal limestone"); and quartzitic-appearing green conglomerate with an opaline matrix. Occurs on divide areas. Not known to yield water to wells.

CRETACEOUS

Upper Cretaceous

Kn

Fort Hays Limestone Member of the Niobrara Chalk

Marine deposits of massive chalky limestone. Only lowest part present. Yields no water to wells.

Kc

Carlile Shale

Marine deposits of chalky limestone, noncalcareous to chalky shale containing large concretions and thin bentonite beds, and friable silty sandstone. Not known to yield water to wells.

Kgh

Greenhorn Limestone

Marine deposits of alternating chalky limestone and chalky shale containing thin bentonite beds. Not known to yield water to wells.

Contact

A —— A'

Trace of geologic section

Sections shown on figure 6

—— 1940 - - -

Water-table contour

Shows altitude of water-table, 1960. Dashed where approximately located. Contour interval 10 feet. Datum is mean sea level

Domestic or stock well

Public supply well

Irrigation well

Test hole

Observation well

$\frac{34}{56}$

Upper number is depth to water and lower number is depth to bedrock, if known, or depth of well, in feet below land surface

10°

True North

Magnetic North

APPROXIMATE MEAN
DECLINATION, 1972

Scale 1: 84 480

1 ½ 0 1 2 3 MILES

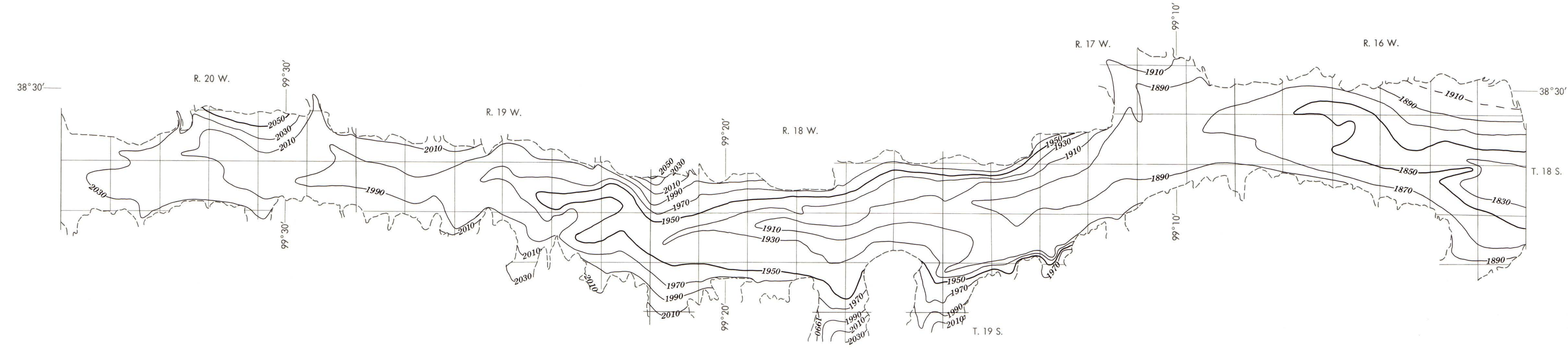
Base from maps by U.S. Soil Conservation Service (1947) and State Highway Commission of Kansas (1968)

Prepared by the State Geological Survey of Kansas and the United States Geological Survey, with the cooperation of the Division of Environmental Health of the Kansas State Department of Health and the Division of Water Resources of the Kansas State Board of Agriculture

Geohydrology by Jesse M. McNellis, 1960

MAPS OF WALNUT CREEK VALLEY, RUSH COUNTY, KANSAS

showing configuration of bedrock surface, saturated thickness (1960), and decline in water level (1960-70)



CONFIGURATION OF BEDROCK SURFACE

EXPLANATION

—1890— —

Bedrock contour

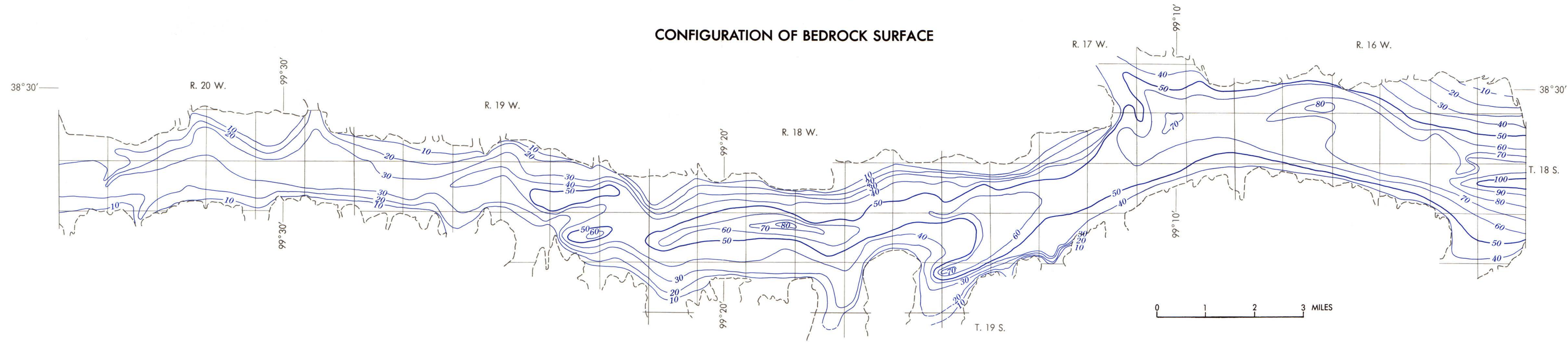
Shows altitude of bedrock surface. Dashed where approximately located. Contour interval 20 feet. Datum is mean sea level

Approximate limit of valley-fill and terrace deposits

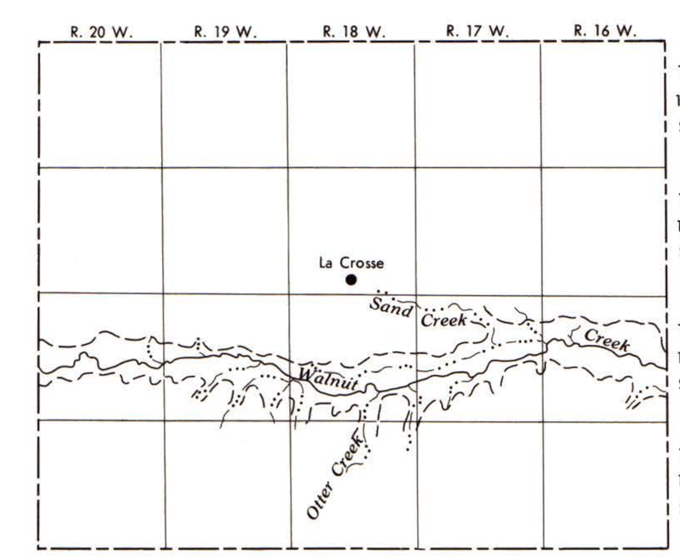
—50— —

Line of equal thickness of saturated material, 1960

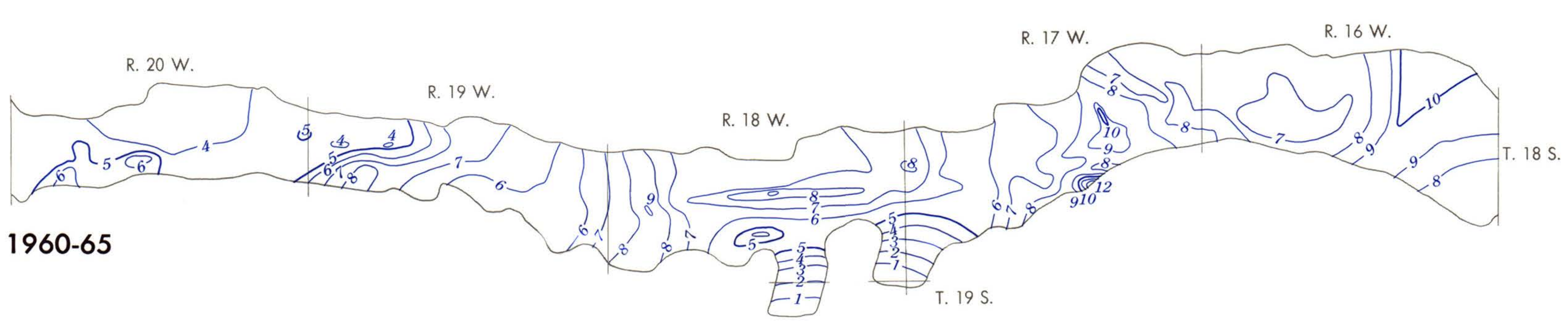
Dashed where approximately located. Interval 10 feet



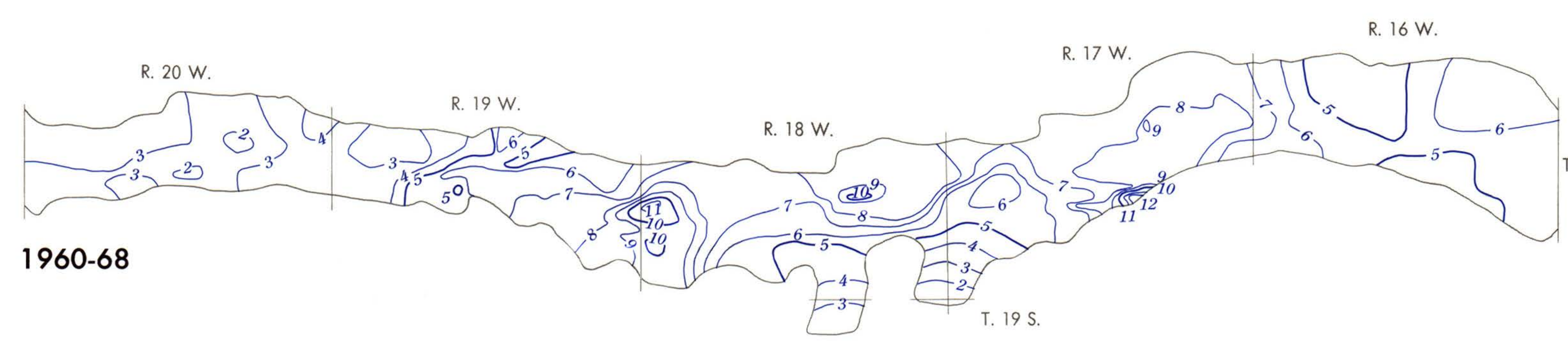
SATURATED THICKNESS, 1960



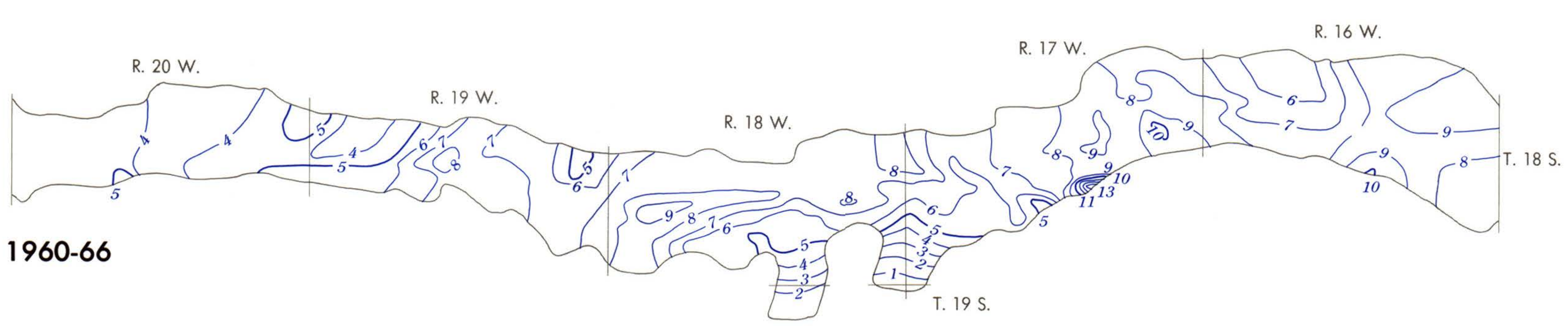
Index map



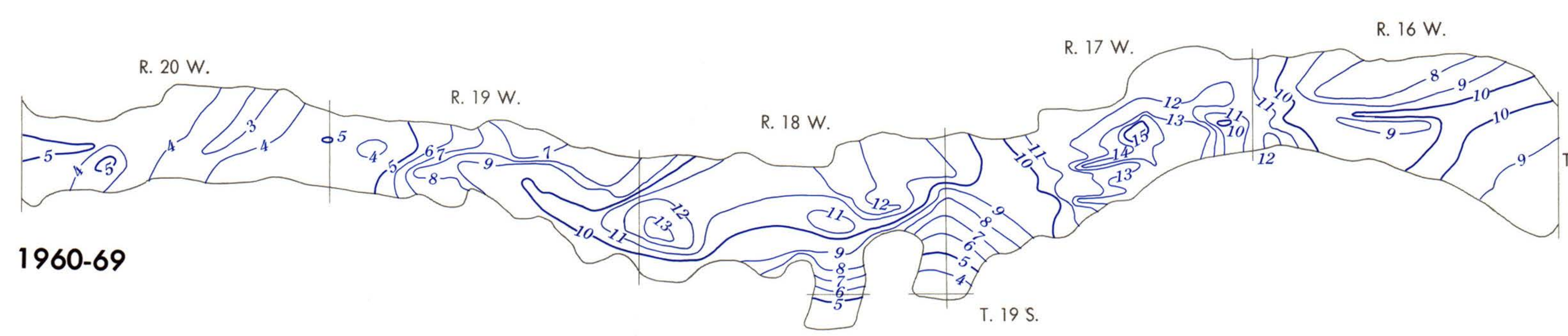
1960-65



1960-68



1960-66



1960-69

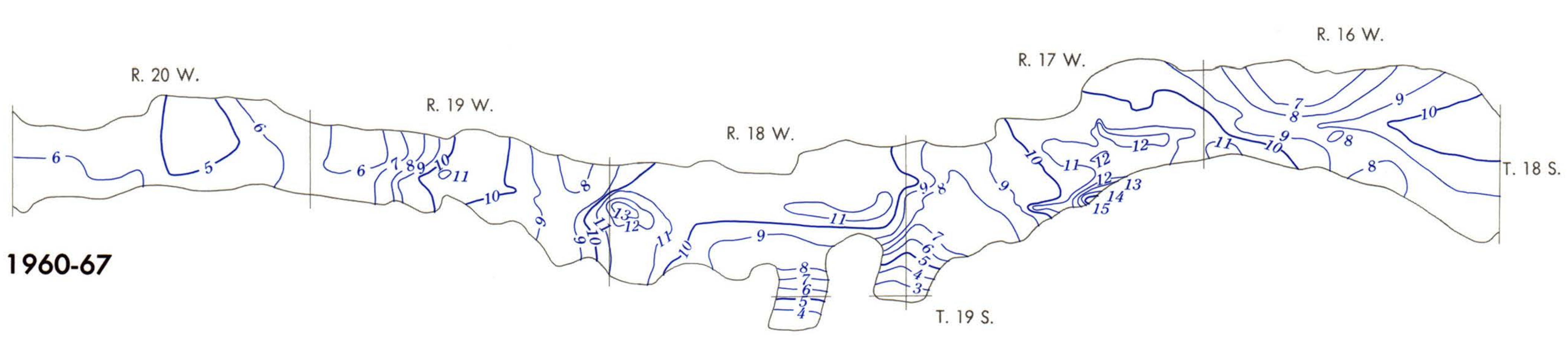
EXPLANATION

—8—

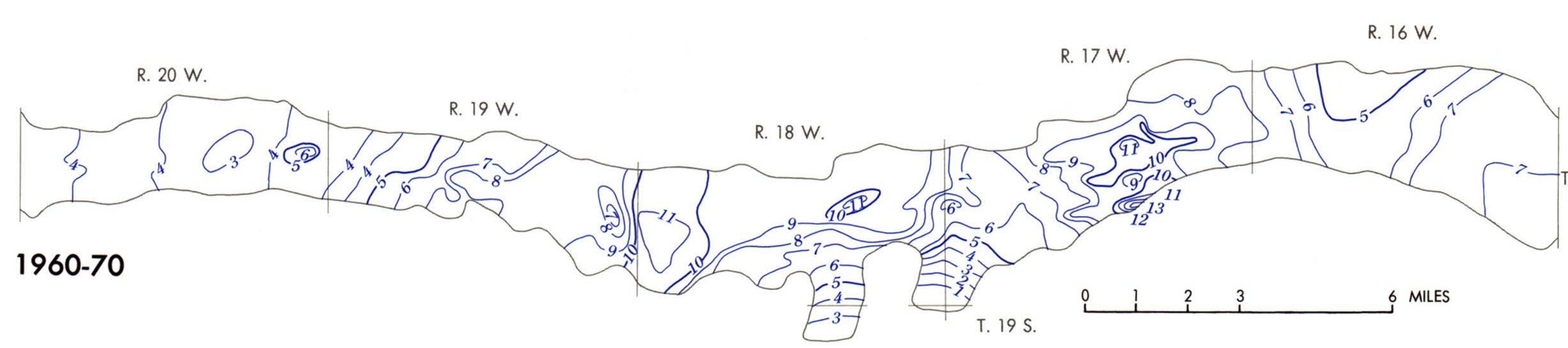
Line of equal water-level decline

Interval 1 foot

Limit of area used for determining changes in water level and volume of saturated material in Walnut Creek valley



1960-67



1960-70

DECLINE IN WATER LEVEL