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GEOHYDROLOGY OF SOUTHWESTERN KANSAS

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Geohydrology of Southwestern Kansas

SUMMARY

The study area includes about 8,900 square miles* in Finney, Grant, Gray, Hamilton, Haskell, Kearny, Meade, Morton, Seward, Stanton, and Stevens Counties, Kansas.

Geologic formations considered in the study range in age from the Lower Permian Blaine Formation, used as a structural marker bed, to the Quaternary alluvium. The main structural feature in the area is a broad northeastward plunging syncline. This feature is cut by the Bear Creek Fault in the northwestern part of the area and the Crooked Creek-Fowler Fault in the southeastern part. Both faults have as much as 250 feet of vertical displacement.

The surface of the Permian rocks defines the lower limit of generally usable ground water. The surface of the bedrock, which may be on Permian, Jurassic, or Cretaceous rocks, defines the lower limit of the principal aquifer in the unconsolidated deposits. The topographic surface, which is part of the High Plains section of the Great Plains physiographic province, has a typically flat to gently rolling surface. Two through-flowing streams, the Arkansas and Cimarron Rivers, have cut valleys and dissected the adjacent land surface.

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* A conversion table of metric units and abbreviations is given on page 17.

Mean annual precipitation at Sublette is 19.45 inches, very little of which contributes recharge to the aquifer. Total potential evaporation near Garden City was measured at 66.13 inches per year. The streams in southwestern Kansas generally lie above the water table and contribute recharge to the aquifer during periods of flow. The lower reaches of Crooked Creek and the Arkansas and Cimarron Rivers, however, have been cut below the water table, and water is discharged from the aquifer to the stream.

Annual recharge to the unconsolidated aquifer is estimated to be 210,000 acre-feet from precipitation, 163,500 acre-feet from streamflow, and 8,400 acre-feet from subsurface inflow. Annual discharge from the aquifer is about 53,500 acre-feet to streamflow, 15,300 acre-feet to subsurface outflow, and pumpage from wells. The net withdrawal of ground water from wells during the 1974 irrigation season was estimated to be between 1.7 and 2.2 million acre-feet.

Minor amounts of water for irrigation use are obtained from bedrock aquifers. These include the gypsum aquifer (in the Upper Permian Day Creek Dolomite), the sandstone aquifer (in undifferentiated Upper Jurassic rocks and Lower Cretaceous rocks), and the chalk aquifer (in the Upper Cretaceous Niobrara Chalk). Most of the water used for irrigation is obtained from sand and gravel layers in the unconsolidated aquifer, which consists largely of the undifferentiated Pleistocene deposits and the Pliocene Ogallala Formation and relatively minor amounts of Quaternary alluvium in the stream valleys. Yields of 1,000 to 1,500 gallons per minute commonly are obtained from the aquifer.

The potentiometric surface shows the result of concentrated pumping as well as natural gradient changes caused by differences in lithology and thickness of the aquifer. Potentiometric contours near stream valleys, except in the lower reaches of Crooked Creek and the Arkansas and Cimarron Rivers, indicate that there is no contribution to streamflow from the aquifer.

The main part of the unconsolidated aquifer underlies 75 percent of southwestern Kansas. The saturated thickness of this aquifer ranges from less than 50 feet to about 630 feet. There is about 105 million acre-feet of water available for pumping. Potential yields to wells, based on driller's tests, may range from less than 100 to as much as 3,000 gallons per minute. In southeastern Seward and southwestern Meade Counties where highly mineralized water occurs in the lower part of the unconsolidated aquifer, irrigation wells generally are constructed to utilize only the upper, freshwater part of the aquifer. In some areas, bedrock aquifers may yield additional water for irrigation.

Most of the water used for irrigation in southwestern Kansas is of the calcium bicarbonate type and presents a medium to high salinity hazard and a low alkali hazard. Water in the unconsolidated aquifer ranges from a calcium bicarbonate type to a sodium chloride type.

The number of irrigation wells increased from about 420 in 1945 to about 7,000 in 1975. Following the same upward trend, 124,000 acres were irrigated in 1950, and 1,400,000 acres were irrigated in 1975. During the three years from 1972 to 1975, there was a rapid increase in sprinkler irrigation.

About 14 million acre-feet of water have been removed from storage since 1940, which has resulted in water-level declines ranging from 0 to 135 feet. The greatest declines (more than 50 percent) have occurred in the earliest developed and most heavily pumped areas. Water levels in wells outside the immediate area of pumping also have declined as a result of the heavy withdrawals.

Since 1940, the saturated thickness in the main part of the unconsolidated aquifer in southwestern Kansas has decreased a median of 8 percent. Decreases in saturated thickness range from 0 in some undeveloped areas to almost 60 percent of the 1940 value in other areas.

INTRODUCTION

Purpose and Scope of Investigation

Southwestern Kansas is one of the principal areas of ground-water development for irrigation in the State, and many reports are available concerning ground-water conditions in the area. The purposes of this investigation were to consolidate and update data, to determine the extent and effects of irrigation development on the ground-water resource, to determine the chemical quality of the ground water in relation to irrigation use, to describe the general operation of the hydrologic system, and to identify problem areas where intensive quantitative studies will be needed by State and local agencies for planning and management of the resource. This study began in 1972 as part of a cooperative program of ground-water investigations between the Kansas Geological Survey and the U.S. Geological Survey. Support in this study was provided by the Division of Water Resources of the Kansas State Board of Agriculture and the Division of Environment of the Kansas Department of Health and Environment.

Location and Extent of the Area

The study area (fig. 1) includes Finney, Grant, Gray, Hamilton, Haskell, Kearny, Meade, Morton, Seward, Stanton, and Stevens Counties in southwestern Kansas. The total area is about 8,900 square miles (Institute for Social and Environmental Studies, 1971).

Figure 1.--Maps showing location of report area.

Previous Investigations

There are many studies dealing with geology and water resources in the study area. Early studies from 1897 to 1940 are listed by Smith (1940).

The historical data for this report were obtained from studies of the ground-water resources that began in 1937 in cooperation with the Kansas Geological Survey. These studies were reported as follows: Seward County by Bryne and McLaughlin (1948); Meade County by Frye (1942); Stanton County by Latta (1941); Finney and Gray Counties by Latta (1944); Morton County by McLaughlin (1942); Hamilton and Kearny Counties by McLaughlin (1943); and Grant, Haskell, and Stevens Counties by McLaughlin (1946).

Additional cooperative studies were made in southwestern Kansas after irrigation development. These studies were made as follows: Grant and Stanton Counties by Fader and others (1964); Finney County by Meyer and others (1970) and by Gutentag and others (1972); Kearny County by Gutentag and others (1972); Haskell County by Gutentag and Stullken (1974); Hamilton County by Lobmeyer and Sauer (1974); and Gray County by McGovern and Long (1974).

Well-Numbering System

The well numbers in this report give the location of wells and test holes according to the Bureau of Land Management's system of land subdivision. This method of well and test-hole location is shown in figure 2. The first number indicates the township; the second number indicates the range west of the sixth principal meridian; and the third indicates the section in which the well or test hole is situated. Letters following the section number locate the well within the section. The first letter denotes the quarter section or 160-acre tract; the second letter, the quarter-quarter section or 40-acre tract; the third letter, the quarter-quarter-quarter section or 10-acre tract. These tracts are designated A, B, C, and D in a counterclockwise direction beginning in the northeast quadrant. Where two or more wells are located in a 10-acre tract, wells are numbered serially, beginning with 2, according to the order in which they were recorded. For example, 28-37W-10BCD2 indicates that this is the second well or test hole recorded in the SE1/4SW1/4NW1/4 sec.10, T.28 S., R.37 W., Grant County.

Figure 2.--System of numbering wells and test holes in Kansas.

Metric Units

The inch-pound units of measurement given in this report are listed with equivalent International System (SI) of units using the following abbreviations and conversion factors:

Inch-pound unit	Multiply by	SI unit
Length		
inch (in)	2.54	centimeter (cm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square foot (ft^2)	.0929	square meter (m^2)
acre	.4047	square hectometer (hm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	.02832	cubic meter (m^3)
acre-foot (acre-ft)	.001233	cubic hectometer (hm^3)
Flow		
gallon per minute (gal/min)	.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
Hydraulic conductivity		
foot per day (ft/d)	.3048	meter per day (m/d)
Specific capacity		
gallon per minute per foot [(gal/min)/ft]	.207	liter per second per meter [(L/s)/m]
Gradient		
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)

Acknowledgments

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GEOLOGIC FRAMEWORK

Stratigraphy

A primary consideration in a geohydrologic study is the stratigraphic relation of beds that are water bearing to beds that are not water bearing (see table 1).

The oldest beds considered in the study are those of the Lower Permian Blaine Formation, which are easily identified on geophysical logs and are usable in the interpretation of regional structure. The relation of Upper Permian rocks to the geohydrology is significant because they contain highly mineralized water. Upper Jurassic and Lower Cretaceous rocks underlying most of the area contain water-yielding zones and are in hydraulic connection with younger deposits. Upper Cretaceous rocks in the northern part of the area yield little water and retard the movement of vertical flow. Tertiary and Quaternary deposits underlie most of the area and are the principal water-yielding beds in southwestern Kansas.

ble 1.--Generalized section of geologic formations and their water-bearing properties*

System	Series	Stratigraphic unit	Thickness, feet	Physical character	Water supply
		Alluvium	0-80	Stream-laid deposits ranging from silt and clay to sand and gravel that occur along principal stream valleys.	Yields to wells range from 500 to more than 1,000 gal/min in the Arkansas River valley, 50 to 500 gal/min in the Pawnee River valley, and 50 to 1,000 gal/min in the Cimarron River valley.
aternary	Pleistocene	Dune sand	0-75	Fine to medium quartzose sand with small amounts of clay, silt, and coarse sand formed into mounds and ridges by the wind.	Lies above the water table and does not yield water to wells. The sand has a high infiltration rate and is important as area of ground-water recharge.
		Loess	0-45	Silt with subordinate amounts of very fine sand and clay deposited as windblown dust.	Lies above the water table and does not yield water to wells. Serves as minor area of ground-water recharge.
		Undifferentiated deposits	0-550	Sand, gravel, silt, clay, and caliche overly the Ogallala Formation when both formations are present, composite of stream-lain and windblown deposits.	The sand and gravel of the undifferentiated Pleistocene deposits and the Ogallala Formation are the principal water-bearing deposits in the area. Yields range from 100 to 3,100 gal/min.
rtiary	Pliocene	Ogallala Formation	0-500	Poorly sorted clay, silt, sand, and gravel generally calcareous; when cemented by calcium carbonate, forms caliche layers or mortar beds.	
		Niobrara Chalk	0-250	Upper unit (Smoky Hill Chalk Member)--yellow to orange-yellow chalk and light- to dark-gray beds of chalky shale. Lower unit (Fort Hays Limestone Member)--consists of a white to yellow massive chalky limestone; contains thin beds of dark-gray chalky shale.	Initially (1968-72), yielded 500 to 2,500 gal/min to wells in northern Finney and eastern Kearny Counties where the Fort Hays Limestone Member has been honeycombed by fractures and solution openings. Because of increased irrigation development, yields have been reduced by 100 to as much as 2,000 gal/min.
	Upper Cretaceous	Carlile Shale	0-330	Upper part consists of a dark-gray to blue-black noncalcareous to slightly calcareous shale that locally is interbedded with calcareous silty very fine-grained sandstone. Lower part consists of very calcareous dark-gray shale and thin gray interbedded limestone layers.	Sandstone in upper part may yield 5 to 10 gal/min to wells.
etaceous		Greenhorn Limestone	0-200	Chalky light yellow-brown shale with thin-bedded limestone. Dark-gray calcareous shale and light-gray thin-bedded limestone, contains layers of bentonite.	Not known to yield water to wells in southwestern Kansas.
		Graneros Shale	0-130	Dark-gray calcareous shale interbedded with black calcareous shale, contains thin beds of bentonite. Also contains thin-bedded gray limestone and fine-grained silty sandstone layers.	Not known to yield water to wells in southwestern Kansas.
	Lower Cretaceous	Undifferentiated rocks	0-450	Upper unit (Dakota Formation)--brown to gray fine- to medium-grained sandstone; interbedded with gray sandy shale and varicolored shale; contains lignite lenses (0-160 feet). Middle unit (Kiowa Formation) --dark-gray to black shale; interbedded with light yellow-brown and gray sandstone (0-150 feet). Lower unit (Cheyenne Sandstone)--gray and brown very fine- to medium-grained sandstone; interbedded with dark-gray shale (0-125 feet).	The sandstone units commonly yield from 50 to 500 gal/min to wells. Yields of more than 1,000 gal/min are reported in a few areas. Water may be more mineralized in the lower unit than in the upper unit.
ırassic	Upper Jurassic	Undifferentiated rocks	0-350	Dark-gray shale; interbedded with grayish-green and bluish-green calcareous shale. Contains very fine- to medium-grained silty sandstone and some thin limestone beds at the base.	In Morton and Stanton Counties, sandstone beds are yielding in combination with the overlying Lower Cretaceous units. In the northernmost counties where the aquifer is deepest, the water may be mineralized.
		Big Basin Formation	0-160	Brick-red to maroon siltstone and shale; contains very fine-grained sandstone.	Where not highly mineralized, may yield small quantities of usable water for domestic and stock purposes.
	Upper Permian	Day Creek Dolomite	0-80	White to pink anhydrite and gypsum; contains interbedded dark-red shale.	Solution cavities have yielded large quantites (300 to 1,000 gal/min) of high sulfate water to wells in Morton County.
ermian		Whitehorse Formation	100-350	Red to maroon fine-grained silty sandstone, siltstone, and shale.	Fresh to highly mineralized water. Not known to yield significant amounts of water to wells in southwestern Kansas.
	Lower Permian	Dog Creek Formation	15-60	Maroon silty shale, siltstone, very fine sandstone, and thin layers of dolomite and gypsum.	Not known to yield significant amounts of water to wells in southwestern Kansas. Water probably highly mineralized.
		Blaine Formation	20-150	Generally consists of four gypsum and anhydrite beds separated by red shale; contains bedded halite at some sites.	

The classification and nomenclature of the stratigraphic units used in this report are those of the Kansas Geological Survey and differ somewhat from those of the U.S. Geological Survey.

Geologic Structure

Southwestern Kansas lies in a broad marginal syncline on the east side of the Las Animas Arch (Merriam, 1963). The syncline plunges to the northeast away from the Sierra Grande uplift in southeastern Colorado. The top of the Blaine Formation, as shown by a structure map (pl. 1), slopes 14.5 feet per mile from the southwestern corner of Morton County to the north-central part of Finney County. The regional structure is cut by two faults that define the northwestern and southeastern limits of the principal aquifer in the unconsolidated deposits. These faults (the Bear Creek Fault in Hamilton, Stanton, Grant, and Kearny Counties and the Crooked Creek-Fowler Fault in Meade County), which are the result of the dissolution and removal by ground water of evaporites within and just below the Blaine Formation, have a vertical displacement of as much as 250 feet. The Crooked Creek and Fowler Faults previously have been considered separately as individual faults (Frye and Schoff, 1942). Present data indicate that the Fowler Fault and the Crooked Creek Fault are part of the same zone of dissolution and collapse. Therefore, it is recommended here that the fault be named the Crooked Creek-Fowler Fault. The Bear Creek and Crooked Creek-Fowler Faults are partially defined on the present land surface by a line of sinkholes and filled sinks.

Plate 1.--Map showing configuration of top of the Blaine Formation, southwestern Kansas.

Numerous other structural features are evident on the Blaine surface. A syncline in northwest Kearny County may be traced for about 15 miles. Small, poorly defined structural features, which may be minor faults, also occur in northwestern Haskell and southwestern Finney Counties. Some of these structural features may have influenced the drainage system during erosion of the bedrock surface and subsequent deposition of the overlying unconsolidated deposits.

Permian Surface

The configuration of the Permian surface (pl. 2) shows general patterns of folding, faulting, and sculpturing by post-depositional events. The general slope of the Permian surface is 15.4 feet per mile in a northeasterly direction. A period of erosion occurred prior to the deposition of the Upper Jurassic and Lower Cretaceous rocks upon the Permian surface. In parts of Haskell, Meade, Morton, Seward, and Stevens Counties, the Permian surface underwent additional erosion prior to deposition of Tertiary and Quaternary deposits. Thus, the Permian surface converges toward the top of the Blaine Formation, and the distance between these surfaces varies from slightly over 600 feet in southwestern Morton County to less than 150 feet in northeastern Finney County and south-central Meade County. The Permian surface is formed on the Whitehorse Formation, Day Creek Dolomite, and the Big Basin Formation.

Plate 2.--Map showing configuration of top of the Permian surface, southwestern Kansas.

Bedrock Surface

Consolidated rocks of Late Permian to Late Cretaceous age, which underlie the unconsolidated deposits of Tertiary and Quaternary age, are referred to as bedrock in this report. The bedrock surface (pl. 3) is an erosional surface influenced and modified by structure, with an average slope of 13.7 feet per mile toward the southeast. The local relief, which may be as much as 250 feet, is the result of erosion in Seward and Stevens Counties and of subsidence along the Bear Creek and Crooked Creek-Fowler Faults. In contrast, the bedrock surface in central Haskell County is nearly flat.

The bedrock surface in the southern part of the area is formed on Permian rocks and is coincident with the Permian surface. In the central part, the bedrock surface is formed on stratigraphically younger undifferentiated rocks of Late Jurassic and Early Cretaceous age. The bedrock surface in the northern part of the study area is formed on rocks of Late Cretaceous age. The comparative altitudes of the various formations as they subcrop on this bedrock surface generally indicate a northeast dip of the bedrock units.

Plate 3.--Map showing bedrock geology and configuration of the bedrock surface, southwestern Kansas.

Surface Topography

Southwestern Kansas lies in the High Plains section of the Great Plains physiographic province (Fenneman 1931), and is part of the broad treeless plain that slopes gently eastward from the Rocky Mountain front. In the study area, altitudes of the land surface (pl. 4) range from about 3,850 feet in the northwestern corner of Hamilton County to 2,150 feet along the Cimarron River in the southeastern corner of Meade County. The prevailing slope shown on the topographic map is about 12.5 feet per mile in a southeasterly direction. The topographic map is included in this report as an aid in determining the depth from land surface to the various surfaces at a given location.

Plate 4.--Map showing surface topography, southwestern Kansas.

HYDROLOGY

Ground-Water Occurrence

Bedrock Aquifers

The bedrock aquifers are the gypsum aquifer in Upper Permian rocks, the sandstone aquifer in the Upper Jurassic and Lower Cretaceous rocks, and the chalk aquifer in Upper Cretaceous rocks. The bedrock aquifers differ from the unconsolidated aquifer in that they generally lie at a greater depth, are more difficult to drill, contain water that generally is under artesian head, commonly contain more highly mineralized water, and generally will not sustain large yields.

Gypsum Aquifer.--The gypsum aquifer is defined here as the highly permeable zones within the Upper Permian Day Creek Dolomite. In Morton County, the gypsum aquifer consists of locally cavernous white to pink anhydrite and gypsum that are interbedded with dark-red shale. The presence of cavities commonly is indicated by a sudden drop of the drill stem and a loss in circulation of fluid during drilling. Stock and irrigation wells, which tap the Day Creek, pump from water-filled solution cavities in the evaporite deposits. Depth of the Day Creek below land surfaces ranges from about 200 feet in the southwestern part of Morton County near the Cimarron River to about 800 feet in northeastern Morton County. The gypsum aquifer has been tapped only in central Morton County, where solution cavities yield 300 to 1,000 gal/min. Because water from wells in the Day Creek is highly mineralized, utilization of this water for irrigation is limited (see section on Quality of Water for Irrigation).

Sandstone Aquifer.--The sandstone aquifer, as used in this report, refers to the permeable sandstone beds contained throughout the Upper Jurassic and Lower Cretaceous rocks in southwestern Kansas. The sandstone beds within the two rock units are discontinuous and differ greatly from one area to another. Because the sandstones are unpredictable, only the depth to and thickness of the two major rock units are given.

Upper Jurassic rocks consist chiefly of red siltstone interbedded with buff, green, and white sandstone. The rocks are similar in lithology and probably are equivalent to the Entrada Sandstone and Morrison Formation of southeastern Colorado (Voegeli and Hershey, 1965).

Lower Cretaceous rocks, which contain the sandstone aquifer, are comprised of the Cheyenne Sandstone, Kiowa Formation, and Dakota Formation. The Cheyenne Sandstone consists of a white to rust-colored fine- to coarse-grained quartzose sandstone. The Kiowa Formation generally consists of a dark-gray to black silty shale containing calcareous shale lenses and interbedded sandy siltstone, fine sandstone, and tan calcareous shale. Where the Kiowa Formation consists predominantly of sandstone beds, it is difficult to distinguish from the underlying Cheyenne Sandstone or the overlying sandstone beds of the Dakota Formation. The Dakota Formation in most areas consists of fine- to medium-grained reddish-brown to yellowish-brown ferruginous sandstone, containing yellow and gray silty shale beds.

In areas where the bedrock surface is formed on the undifferentiated Upper Jurassic and Lower Cretaceous rocks (pl. 3), the depth to and thickness of the interval containing the sandstone aquifer may be estimated from the included maps. The depth to the interval is obtained by subtracting the altitude of the bedrock surface (pl. 3) from that of the land surface (pl. 4); the thickness is obtained by subtracting the altitude of the Permian surface (pl. 2) from that of the bedrock surface. For example, altitudes at a site in the southeast corner of the city of Ulysses are about 3,050 feet for the land surface, 2,655 feet for the bedrock surface, and 2,485 feet for the Permian surface. Thus, the depth to the interval is about 395 feet, and the thickness is about 170 feet.

In areas where the bedrock surface is formed on undifferentiated Upper Cretaceous rocks (pl. 3), the depth to and thickness of the interval containing the sandstone aquifer may be determined from generalized maps in U.S. Geological Survey, Hydrologic Investigation Atlases (see Selected References).

Only the loose to slightly cemented sandstone beds in the sandstone aquifer contain significant amounts of recoverable water. Locally, the silty or tightly cemented sandstone beds yield only enough water to wells in the aquifer for domestic or stock supplies. In areas where the sandstone beds are loosely cemented, such as northeastern Finney County, yields of more than 1,000 gal/min have been obtained from the aquifer by irrigation wells. In other areas of Grant, Morton, and Stanton Counties, many multiple-aquifer wells obtain part of their yield from the sandstone aquifer.

Chalk Aquifer.--The chalk aquifer is defined as that part of the Niobrara Chalk that contains saturated fractures and solution openings. Because the occurrences of fractures and solution openings are irregular, it is difficult to predict the occurrence of water. A well drilled in limestone or chalk must penetrate a sufficient amount of water-filled fractures or solution openings to provide an adequate yield. Therefore, it is commonly necessary to drill several test holes to locate a well that will yield enough water for the intended use.

In northern Finney County and eastern Kearny County, about 45 irrigation wells produce water, solely or in part, from several zones of fractures and solution openings in the Fort Hays Limestone Member (lower unit of the Niobrara Chalk). In the area where the zones of fractures and solution openings are productive, the Fort Hays subcrops beneath the Tertiary and Quaternary deposits. These 1- to 2-foot zones occur approximately 20 feet and 40 feet above the contact with the underlying Carlile Shale. It is possible that similar saturated fractures and solution openings in the Fort Hays Limestone Member also may be found near the Fort Hays-Carlile contact in northern Hamilton and Kearny Counties. However, the potential for large yields is not indicated in these areas.

Initial yields (1968-72) of 500 to 2,500 gal/min were available to wells from the Fort Hays Limestone Member in northern Finney and eastern Kearny Counties. Because of irrigation development and lowering water levels, well yields (1976) have been reduced 100 to 2,000 gal/min.

It is the authors' opinion that the fractures and solution openings in the Niobrara Chalk are limited both in thickness and in areal extent and that water is transported only short distances. The fractures and solution openings are hydraulically connected and obtain their water supply from the overlying thinly saturated (less than 10 feet) Ogallala and undifferentiated Pleistocene deposits.

Unconsolidated Aquifer

The saturated part of the Ogallala Formation of Pliocene age, the undifferentiated Pleistocene deposits, and the Quaternary alluvium are defined here as the unconsolidated aquifer. These unconsolidated deposits, which comprise the aquifer in southwestern Kansas, consist of a heterogeneous assortment of alluvial sediments. Individual beds of silt, clay, sand, gravel, and caliche may be correlated with confidence only for short distances.

Yields differ from one area to another owing to the water-producing zones within the aquifer. Coarse sand and gravel deposits, which probably represent channel-fill of a large stream, commonly yield 1,000 to 2,500 gal/min to wells, and yields of as much as 3,000 gal/min have been measured. Coarse sand and gravel interbedded with silt and clay probably represent deposits of numerous streams as they migrated laterally across an ancient flood plain. Yields to wells from these deposits may range from about 100 to 1,000 gal/min. In the Arkansas and Cimarron River valleys, very coarse gravel and cobbles interbedded with silt and clay layers yield about 500 to 1,000 gal/min. In the Pawnee River valley, medium to coarse gravel interbedded with silt and clay layers yield about 50 to 500 gal/min to wells.

Potentiometric Surface.--The configuration of the potentiometric surface, which may reflect water levels in unconfined or confined layers of the aquifer, is shown on plate 5. Data on water levels were obtained during the winter (January 1975) when effects of seasonal pumping for irrigation were at a minimum. Many hydrologic features are shown by the shape and slope indicated by contours on this surface. Contours are not shown in areas where water levels are at or near the bedrock surface or are isolated from the main part of the unconsolidated aquifer.

Ground water in the unconsolidated aquifer occurs predominantly under unconfined conditions, although confined conditions may occur locally. When water is withdrawn from a confined layer in the aquifer during the irrigation season, the head declines. Owing to the differences in head, water leaks through the confining layer and results in a water-level decline in the overlying unconfined layer of the aquifer (Gutentag and others, 1972). In the nonirrigation season, the head in the confined layer of the aquifer is increased as water moves into the pumped area from surrounding areas of little or no pumping. In response to the increase in head, water levels rise in the unconfined layer of the aquifer. The difference in heads in the two aquifer layers can be indirectly related to the intensity of withdrawal during the previous pumping season, the vertical hydraulic conductivity and extent of the confining layer, and the duration of time available for recovery during the nonpumping season.

Plate 5.--Map showing configuration of potentiometric surface in the unconsolidated aquifer, southwestern Kansas, January 1975.

In much of southwestern Kansas, the alluvial deposits are lenticular and heterogeneous. The potentiometric surfaces have not been differentiated with respect to individual aquifer layers because most wells tap all the water-yielding material at a given location. In some areas, wells also may have a contribution from the underlying sandstone aquifer where it is in contact with the unconsolidated aquifer. Water-level data from multiple-aquifer wells used in this study tend to indicate trends in the unconsolidated aquifer because most of the yields are from the unconsolidated aquifer.

The water surface slopes generally eastward across the study area at about 10.5 feet per mile, and the water movement is in that direction. Flattening of the gradient, as indicated by widely spaced contours, probably results from a high hydraulic conductivity of the material through which the water is moving and an increased thickness of water-bearing materials. Areas defined by widely spaced contours, such as southeastern Haskell County, generally are well suited for development of large-capacity wells. An area of apparently flat gradient north of Garden City, however, is the result of a distorted flow pattern caused by very intensive pumping in a localized area.

Closely spaced contours in the study area indicate a steep slope of the potentiometric surface caused by low hydraulic conductivity and reduced thickness of water-bearing materials. A belt of closely spaced contours extends across parts of Grant, Haskell, Seward, and Stevens Counties. Water-well drillers report that fine-grained deposits of low hydraulic conductivity commonly occur in the same areas as those shown by closely spaced contours.

The Cimarron River from U.S. Highway 83 bridge to the Kansas-Oklahoma State line and the Arkansas River in Gray County are examples of gaining streams because they intercept the water table. Thus, the upstream flexures of the contours show flow toward the streams. The lack of upstream flexures in other areas where contour lines cross stream valleys indicates that the water table lies below the streambed and that the streams receive no contribution from ground water in those reaches.

Saturated Thickness.--The area of the unconsolidated aquifer underlain by sufficient saturated material to support irrigation is about 6,600 square miles, or about 75 percent of the total 8,900 square miles in southwestern Kansas. This area of saturated material is referred to as the main part of the unconsolidated aquifer, as shown on plate 5. In other parts of the area, the unconsolidated aquifer is extremely thin or absent.

The saturated thickness of the unconsolidated deposits is shown on plate 6. Within the main part of the unconsolidated aquifer, the saturated thickness ranges from less than 50 feet to about 630 feet, with a median saturated thickness of 284 feet. Generally, the areas of greatest saturated thickness coincide with areas where unconsolidated deposits overlie the deepest channels in the bedrock surface. An example is the area in southwest Seward County.

Plate 6.--Map showing saturated thickness of the unconsolidated aquifer, southwestern Kansas, January 1975.

Saturated thickness may be used as an approximation in locating a possible well site. However, the collective thickness, degree of sorting, and hydraulic conductivity of water-yielding materials within the saturated section are important considerations in developing an irrigation supply. In test drilling for a well site, contractors commonly estimate discharge from the well by assigning arbitrary values of yield per foot of water-yielding material.

The unconsolidated aquifer, in general, has a specific yield (storage coefficient) that reflects unconfined conditions. Results of aquifer tests in Finney County (Meyers and others, 1970) indicate a range in specific yield of 0.05 to 0.22, and in Haskell County (Gutentag and Stullken, 1976) indicate a range of 0.15 to 0.20.

In some areas of relatively great saturated thickness, the water-yielding layers are separated by numerous fine-grained layers, which result in confined conditions. Early in the development of irrigation in Grant and Stanton Counties, aquifer tests in the principal water-yielding layers indicated storage coefficients that ranged from 0.001 to 0.0001 (Fader and others, 1964). As pumpage for irrigation greatly increased, however, water-level declines reduced the confining effects of the upper layers. Subsequent tests probably would indicate a storage coefficient nearly equal to that of an unconfined aquifer.

It is estimated that the specific yield for the principal water-yielding zones ranges from 0.15 to 0.20 and the weighted average for the unconsolidated aquifer would be about 0.15.

The amount of ground water stored in the unconsolidated aquifer in southwestern Kansas was determined by computing the area of each saturated thickness interval shown on plate 6, multiplying by the average thickness of each interval, summing the products, and multiplying their summation (total volume) by the specific yield. Assuming that the average specific yield is 0.15 for the whole saturated thickness, the total volume of water in storage in southwestern Kansas is computed to be about 150 million acre-feet as of January 1975. Assuming that only 70 percent of the total volume of water is economically recoverable by wells, approximately 105 million acre-feet is available for pumping.

Potential Yield.--The potential yield, as used in this report, is the calculated quantity that could be pumped from a well when the water-level drawdown is equivalent to 70 percent of the effective thickness of the unconsolidated aquifer. The effective thickness, or aggregate thickness of water-yielding material in the saturated part of the aquifer, probably is the most important factor in estimating well yield.

The map (pl. 7) showing the potential yield to wells was drawn on the basis of driller's well-production tests where drawdowns were measured at different stages of increasing discharge. The computed potential yield to irrigation wells in the unconsolidated aquifer ranges from less than 100 gal/min to as much as 3,000 gal/min. Potential yields of more than 1,000 gal/min are very speculative, owing to a deficiency in the data available and the method of computing values from well-production tests. The actual yield of an individual well depends on many factors including well construction, method of completion, density of well development in the surrounding area (mutual interference), and transmissivity of the water-yielding deposits at the well site. Because wells normally are designed for irrigation requirements and pump efficiency rather than aquifer potential, the estimated yields are useful chiefly as a general guide in planning. Before selecting a site for installation of a large-capacity well, test drilling is a requisite to ensure the greatest yield for the least pumping lift.

Plate 7.--Map showing potential yield of the unconsolidated aquifer, southwestern Kansas, January 1975.

The area delineated as the shallow alluvial aquifer along the Arkansas River indicates the location of Quaternary alluvium where large quantities of ground water may be obtained in addition to the quantities indicated for the principal part of the unconsolidated aquifer.

In southwestern Meade and southeastern Seward Counties, the potential yield ranges for 500 to 3,000 gal/min. However, it may be necessary to restrict irrigation-well yields from the unconsolidated aquifer because mineralized water commonly is present in the deep water-yielding layers. In these areas, extreme caution should be used in developing the potential yield of water. It is suggested that test drilling be done and electric logs be run to determine the probable water quality in the deep parts of the aquifer. At some sites, it may be desirable to install test wells and collect water samples to determine the water quality.

QUALITY OF WATER FOR IRRIGATION

The chemical quality of water in southwestern Kansas, generally is the result of conditions within the hydrologic system. The quality of surface-water inflow, as shown by the analyses listed in table 2, is largely controlled by the effects of stream regulation and return flow from irrigation use occurring outside the study area. The quality of surface-water outflow, which is contributed mostly from ground-water storage, is dependent on geohydrologic conditions within the area. The quality of ground water in the various geologic formations, as shown by the analyses listed in table 3, is a result of the quantity and quality of recharge and the interaction with chemical constituents in each aquifer system.

In this report, water is classified by type according to the principal constituents and by general categories in terms of dissolved-solids concentrations in mg/L (milligrams per liter). Freshwater is defined as having less than 1,000 mg/L dissolved solids; saline water is 1,000 to 10,000 mg/L; brackish water is 10,000 to 35,000 mg/L; and saltwater or brine is more than 35,000 mg/L.

Table 2.--Chemical analyses of surface water in southwestern Kansas

[Concentrations in milligrams per liter]

Location	Site number	Date of collection	Discharge (ft^3/s)	Temperature (°C)	Dissolved silica (SiO_2)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Dissolved potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)
Arkansas River gaging stations											
Near Coolidge	-	01/08/76	21	1.0	15	440	180	640	12	0	329
At Dodge City	-	01/06/76	2.2	1.0	14	130	42	96	6.8	0	320
Cimarron River sampling sites											
32 33W 21CCA	2	11/14/74	.01	3.0	20	94	31	61	5.0	0	390
32 33W 36BDA	3	11/14/74	.35	6.0	15	78	30	36	5.5	0	300
33 32W 20ACD	4	11/14/74	11.5	8.5	20	77	24	43	3.8	0	260
33 32W 25ACC	5	11/14/74	19.1	10.0	20	83	23	50	4.0	0	240
34 30W 31BBC	7	11/14/74	41.9	11.5	20	93	34	120	---	0	240
34 31W 15CBA	6	11/14/74	39.6	10.5	19	88	27	86	4.5	0	260
35 29W 08DDC	10	11/14/74	57.7	11.0	20	93	37	380	5.8	0	230
35 29W 10BCD	11	11/14/74	56.5	6.0	20	94	42	410	5.8	0	240
35 30W 09CCB	8	11/14/74	56.3	6.0	21	86	32	140	5.2	0	240
35 30W 13BBB	9	11/14/74	55.7	9.0	21	96	38	370	5.2	0	250

Location	Site number	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
Arkansas River gaging stations											
Near Coolidge	-	2,500	200	0.6	10.2	4,510	1,800	1,600	6.5	5,000	8.8
At Dodge City	-	370	43	.8	30.5	903	500	240	1.9	1,320	7.6
Cimarron River sampling sites											
32 33W 21CCA	2	140	23	.8	0.2	566	360	42	1.4	900	7.8
32 33W 36BDA	3	120	19	.8	0.4	452	320	72	0.9	720	7.9
33 32W 20ACD	4	140	21	.8	5.4	461	290	74	1.1	730	7.9
33 32W 25ACC	5	150	40	.8	6.2	492	300	110	1.3	780	7.6
34 30W 31BBC	7	150	190	.8	5.2	739	370	170	2.7	1,260	8.1
34 31W 15CBA	6	150	98	.8	4.8	608	330	120	2.1	1,010	7.9
35 29W 08DDC	10	180	620	.8	4.6	1,460	380	190	8.4	2,590	7.9
35 29W 10BCD	11	180	650	.8	4.2	1,520	410	210	8.9	2,650	7.9
35 30W 09CCB	8	150	220	.8	4.4	772	350	150	3.3	1,340	7.8
35 30W 13BBB	9	170	580	.8	4.0	1,400	400	190	8.1	2,460	8.0

Table 3.--Chemical analyses of ground water in southwestern Kansas

[Concentrations in milligrams per liter]

FINNEY COUNTY

Local well number	Well depth (ft)	Geologic source[1/]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
21 32W 20CB	203	QU,TO	10/12/60	....	31	0.01	0.00	38	36	61	....
22 27W 14BD	485	KD	07/15/70	18.0	6.1	.06	.02	11	1.1	176	5.4
23 32W 20DC	261	QU,TO	11/19/60	....	24	.01	.00	73	34	34	....
23 34W 26CCC	309	QU,TO	05/19/69	14.5	....	.10	.00	248	91	121	12
24 32W 18CC	280	TO	03/10/61	....	17	.01	....	83	21	46	....
24 33W 12CB	45	QA	05/07/64	14.5	17	.00	.00	360	134	351	17
25 31W 02A	300	QU,TO	07/31/70	15.5	....	1.5	.05	107	34	73	7.1
26 32W 26CD	205	QU,TO	04/29/63	....	17	.09	.00	50	9.0	12	3.2
26 33W 19DAC	200	QU,TO	04/10/68	16.0	19	.02	.00	61	6.8	9.3	3.2

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
21 32W 20CB	0	261	109	27	3.6	0.0	434	243	29	1.7	760	...
22 27W 14BD	0	244	106	77	2.3	1.8	508	32	0	14	820	7.8
23 32W 20DC	0	239	138	31	1.0	12	465	322	126	.8	790	...
23 34W 26CCC	0	181	912	117	.8	10	1,680	993	845	1.7	2,100	7.5
24 32W 18CC	0	183	199	20	.7	6.6	484	294	144	1.2	790	7.9
24 33W 12CB	0	334	1,620	168	1.8	38	2,870	1,450	1,170	4.0	3,530	...
25 31W 02A	0	224	308	38	1.0	15	728	406	222	1.6	1,030	7.7
26 32W 26CD	0	185	20	7.0	.3	4.9	214	162	10	.4	370	...
26 33W 19DAC	0	200	16	11	.3	7.1	232	180	16	.3	380	7.6

GRANT COUNTY

Local well number	Well depth (ft)	Geologic source[1/]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
27 37W 11AB	340	QU,TO	05/07/64	....	23	0.00	0.00	70	35	75	5.5
28 35W 15BB	220	QU,TO	10/28/41	16.5	....	.68	.00	55	12	45	....
28 36W 13AC	438	QU,TO	05/04/64	....	19	.00	.00	67	28	46	4.4
28 37W 21DAA	300	QU,TO	03/20/68	....	22	.16	.00	67	30	54	4.8
28 38W 04CC	285	QU,TO	07/20/59	15.5	25	.09	.00	89	58	86	....
29 35W 15AB	460	QU,TO	05/25/60	18.5	23	.03	.00	75	27	51	....
29 36W 04BAB	645	TO,KJ	08/14/75	....	25	.13	.00	51	23	102	4.8
29 36W 04BCC	380	QU,TO	08/14/75	....	22	.19	.00	74	27	32	4.0
30 38W 05BB	310	QU,TO	05/14/64	....	15	.01	.00	60	19	35	3.3
30 38W 13CC	560	QU,TO	05/14/64	....	17	.00	.00	54	24	46	3.8

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
27 37W 11AB	0	288	193	24	2.0	26	596	318	82	1.8	850	7.5
28 35W 15BB	0	190	104	11	.5	4.1	327	186	30	1.4	...	...
28 36W 13AC	0	254	137	15	1.2	18	461	282	74	1.2	670	7.6
28 37W 21DAA	0	205	191	24	1.5	19	514	290	122	1.4	780	7.8
28 38W 04CC	0	227	349	57	2.1	15	793	460	274	1.7	1,220	...
29 35W 15AB	0	242	171	16	1.2	8.0	491	298	100	1.3	790	...
29 36W 04BAB	0	217	210	30	1.2	3.3	557	222	44	3.0	870	7.6
29 36W 04BCC	0	193	107	67	1.1	9.2	438	296	138	.8	760	7.6
30 38W 05BB	0	190	110	26	.9	7.5	371	228	72	1.0	570	7.7
30 38W 13CC	0	217	129	13	1.0	13	408	233	55	1.3	600	7.7

1/ Geologic source: QA, Quaternary alluvium; QU, undifferentiated Pleistocene deposits; TO, Ogallala Formation; KN, Niobrara Chalk; KD, Dakota Formation, KJ, Upper Jurassic-Lower Cretaceous rocks, PW, Whitehorse Formation; PD, Day Creek Dolomite.

Table 3.--Chemical analyses of ground water in southwestern Kansas--Continued

[Concentrations in milligrams per liter]

GRAY COUNTY

Local well number	Well depth (ft)	Geologic source[1]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
24 29W 23BAA2	200	QU,TO	06/07/67	16.5	36	0.05	0.00	53	25	22	5.2
24 30W 01BCB	170	QU,TO	05/07/70	15.0	45	.11	.00	58	25	30	6.3
26 28W 06D	80	QA	07/06/70	14.5	21	.02	.00	130	40	45	7.6
26 29W 08B	246	QU,TO	05/12/70	15.5	16	.05	.00	56	11	19	3.8
27 27W 10DCB	100	QU,TO	07/28/64	....	20	.00	.00	60	9.8	17	4.1
29 28W 28CDC	204	QU,TO	05/08/64	....	19	.04	.00	57	11	16	3.0
29 30W 36C	...	QU,TO	05/21/70	16.0	18	.04	.00	45	7.7	14	3.0

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (μmhos/cm at 25°C)	pH
24 29W 23BAA2	0	217	65	22	1.2	20	356	235	57	0.6	550	7.6
24 30W 01BCB	0	215	84	22	2.7	15	396	248	72	.8	600	7.7
26 28W 06D	0	278	284	35	.8	26	740	489	261	.9	1,060	7.5
26 29W 08B	0	215	26	9.0	.4	12	270	184	8	.6	430	7.6
27 27W 10DCB	0	232	17	7.0	.3	9.3	259	190	0	.6	410	7.4
29 28W 28CDC	0	210	26	10	.5	10	256	187	15	.5	172	7.7
29 30W 36C	0	183	14	4.0	.3	11	206	144	0	.5	340	7.7

HAMILTON COUNTY

Local well number	Well depth (ft)	Geologic source[1]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
21 42W 03CB	...	KD	06/21/72	....	15	1.1	0.00	4.8	2.0	220	5.2
23 42W 26DCA	70	QA	04/30/64	....	25	.00	.00	472	127	505	21
23 43W 26BCC	22	QA	09/02/60	....	22	.20	.00	276	116	352	....
24 43W 10DD	60	QU,TO	11/26/40	14.5	....	.7	....	167	48	37	....
26 41W 36CCD	...	QU,TO	04/29/64	16.0	25	.13	.00	105	39	54	7.7
24 39W 35CBA	90	QU,TO	04/23/62	....	25	.01	.00	200	35	140	7.2

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (μmhos/cm at 25°C)	pH
21 42W 03CB	0	398	121	38	2.8	0.4	598	20	0	21	960	8.2
23 42W 26DCA	0	295	2,040	311	1.0	10	3,660	1,700	1,460	5.3	4,500	7.4
23 43W 26BCC	0	254	1,480	122	1.4	16	2,510	1,170	958	4.5	3,310	...
24 43W 10DD	0	320	215	56	.7	159	843	616	354	.7	....	...
26 41W 36CCD	0	234	291	25	1.5	14	678	422	230	1.1	970	...
24 39W 35CBA	0	220	620	84	.5	19	1,250	650	470	2.4	1,800	...

Table 3.--Chemical analyses of ground water in southwestern Kansas--Continued

[Concentrations in milligrams per liter]

HASKELL COUNTY

Local well number	Well depth (ft)	Geologic source[1/]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
27 31W 11CBB	250	QU,TO	05/04/66	16.0	18	0.00	0.00	53	7.8	20	3.4
28 33W 04A	620	QU,TO	04/30/70	17.0	18	.08	.00	53	5.9	16	2.4
28 33W 36D	590	QU,TO	04/30/70	....	18	.09	.00	43	11	24	2.8
28 34W 15DAB	408	QU,TO	04/30/70	17.0	19	.12	.00	51	13	19	2.8
29 32W 26CB2	384	QU,TO	08/04/64	....	16	.00	.00	48	11	27	3.2
30 31W 14DB	270	QU,TO	05/05/64	....	17	.00	.00	51	11	20	2.7
30 34W 28ABB	532	QU,TO	04/30/70	18.0	25	.13	.00	62	30	41	5.2

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
27 31W 11CBB	0	205	23	8.0	0.4	14	249	164	0	0.7	400	7.7
28 33W 04A	0	176	26	10	.4	12	230	156	12	.6	360	7.7
28 33W 36D	0	185	36	8.0	.6	6.2	245	152	0	.9	380	7.7
28 34W 15DAB	0	181	31	20	.8	11	258	180	32	.6	420	7.8
29 32W 26CB2	0	198	47	14	.6	1.8	266	165	3	.9	430	7.4
30 31W 14DB	0	200	36	7.0	.6	4.3	248	172	8	.7	390	7.8
30 34W 28ABB	0	210	154	20	1.1	9.7	465	278	106	1.1	690	7.7

KEARNY COUNTY

Local well number	Well depth (ft)	Geologic source[1/]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
21 35W 27CCA	163	KN	05/22/67	....	28	1.4	0.00	51	27	42	6.8
22 37W 34DD	154	QU,TO	11/07/40	15.0	....	2.4	....	64	22	43	....
23 35W 25BBB2	320	QU,TO	05/08/64	15.0	18	.01	.00	251	49	95	11
24 35W 22CCC	65	QA	05/07/64	14.5	13	.0	.00	354	101	362	17
24 36W 23CBB2	280	QA,TO	04/26/63	16.0	19	.07	.18	210	100	164	13
25 36W 03CCD	40	QA	09/21/60	14.5	12	.02	.00	346	115	416	....
25 36W 18ACC	150	QU,TO	09/21/60	14.5	10	.01	.00	367	94	401	....
26 37W 21DDD	330	QU,TO	04/26/63	16.5	19	.07	....	56	24	35	5.0
26 38W 06BCC	300	KD	04/26/63	18.0	18	.12	.00	29	26	41	5.5

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
21 35W 27CCA	0	234	76	28	1.4	23	399	238	46	1.2	610	8.0
22 37W 34DD	0	185	144	20	.9	13	402	255	103	1.2	....	...
23 35W 25BBB2	0	200	678	110	.5	15	1,330	828	664	1.5	1,800	7.2
24 35W 22CCC	0	256	1,660	116	1.1	17	2,770	1,300	1,090	4.4	3,330	7.2
24 36W 23CBB2	0	246	922	92	1.0	8.4	1,650	935	733	2.3	2,180	...
25 36W 03CCD	0	268	1,750	131	1.4	11	2,920	1,340	1,120	5.0	3,810	7.3
25 36W 18ACC	0	166	1,760	139	.8	10	2,870	1,300	1,170	4.8	3,810	7.2
26 37W 21DDD	0	251	74	16	.9	10	363	238	32	1.0	590	...
26 38W 06BCC	22	200	35	15	2.4	5.3	298	180	0	1.3	480	...

Table 3.--Chemical analyses of ground water in southwestern Kansas--Continued

[Concentrations in milligrams per liter]

MEADE COUNTY

Local well number	Well depth (ft)	Geologic source[1]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
31 28W 23AC	290	QU,TO	09/10/64	....	19	0.00	0.00	58	14	15	3.2
32 29W 27AAB	583	PW	12/17/74	....	8.3	.86	.22	320	120	87	10
32 29W 27AAB2	468	TO	11/22/74	....	22	1.6	.00	59	15	27	4.8
33 28W 29BC	120	TO	07/28/64	....	21	.00	.00	58	15	63	4.2
34 30W 27BBB	720	PW	11/21/74	....	10	.88	.00	1,500	470	10,800	38
34 30W 27BBB2	504	TO	11/20/74	....	20	.36	.00	83	21	48	4.5
35 30W 09ABC	260	QU,TO	05/11/66	17.0	22	.01	.00	59	20	38	4.2

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (μmhos/cm at 25°C)	pH
31 28W 23AC	0	222	30	9.0	0.8	12	271	202	20	0.5	430	7.4
32 29W 27AAB	0	66	1,400	16	.9	1.4	1,960	1,300	54	1.1	2,300	7.4
32 29W 27AAB2	0	200	73	18	.8	3.5	319	210	48	.8	500	8.0
33 28W 29BC	0	220	52	79	.8	3.5	405	206	26	1.9	670	7.4
34 30W 27BBB	0	78	2,800	18,200	1.0	.3	33,800	5,800	5,600	62	57,300	7.6
34 30W 27BBB2	0	190	200	21	.9	6.3	494	290	140	1.2	750	7.9
35 30W 09ABC	0	212	85	29	1.0	5.8	369	229	55	1.1	580	7.7

MORTON COUNTY

Local well number	Well depth (ft)	Geologic source[1]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
31 43W 20CBB	157	QU,TO	04/25/63	13.0	18	0.05	0.00	62	30	30	3.6
32 39W 18AA	170	QU,TO	10/13/39	15.5	....	1.5	....	74	47	67	....
32 41W 28DB	600	PD	04/09/62	19.0	25	.03	.00	597	97	58	5.0
32 42W 14CCC	187	QU,TO	04/24/63	16.5	25	.05	.00	38	40	44	4.2
33 39W 16ABB	422	QU,TO	04/25/63	14.5	25	1.8	.00	61	37	48	5.5
33 43W 15AAC	260	QU,TO	04/25/63	18.0	25	1.5	.00	39	38	49	6.6
34 42W 05BDC	75	QU	04/04/62	....	25	.02	.00	450	95	83	5.2
35 40W 03BBB	385	QU,TO	04/25/63	....	25	.17	.00	114	42	56	4.2
35 43W 24AA	270	QU,TO	04/12/65	....	23	.00	.00	64	28	59	5.8

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (μmhos/cm at 25°C)	pH
31 43W 20CBB	0	205	98	44	1.3	11	399	278	110	0.8	670	...
32 39W 18AA	0	242	270	24	1.9	6.2	613	380	182	1.5	....	...
32 41W 28DB	0	163	1,780	10	2.3	8.0	2,670	1,890	1,750	.6	2,920	...
32 42W 14CCC	0	244	118	12	3.6	9.7	415	260	60	1.2	660	...
33 39W 16ABB	0	229	183	24	.6	.4	498	304	116	1.2	790	...
33 43W 15AAC	0	259	114	13	2.8	11	426	254	42	1.4	670	...
34 42W 05BDC	0	159	1,480	11	2.2	8.0	2,230	1,510	1,380	.9	2,520	...
35 40W 03BBB	0	217	367	16	.5	6.6	738	457	279	1.2	1,050	...
35 43W 24AA	0	349	99	14	.6	5.8	471	274	0	1.6	740	7.4

[Concentrations in milligrams per liter]

SEWARD COUNTY

Local well number	Well depth (ft)	Geologic source[1]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
31 32W 03DAD	412	QU,TO	05/07/74	....	23	0.20	0.00	66	15	33	3.8
31 33W 06CBD	347	QU,TO	05/08/74	....	24	.00	.00	66	25	40	4.4
31 34W 18BBB	375	QU,TO	05/07/74	....	23	.02	.00	59	31	58	5.6
32 31W 26CAA	341	QU,TO	05/07/74	....	22	.05	.00	56	18	33	4.2
32 31W 31ACC	386	QU,TO	05/07/74	....	24	.11	.00	69	26	52	4.6
32 34W 10DA	350	QU,TO	05/07/74	....	23	.08	.00	51	26	33	4.4
32 34W 17DCC	335	QU,TO	05/07/74	....	26	.03	.00	62	26	36	4.0
33 32W 28CDD	465	PW	10/10/74	....	14	1.8	.00	3,600	1,800	6,100	680
33 32W 28CDD2	205	QU	10/10/74	....	23	1.5	.00	80	25	82	4.5
34 31W 30BBB	705	PW	10/18/74	....	33	1.0	.00	1,300	640	5,000	320
34 31W 30BBB2	460	TO	10/22/74	....	11	.81	.00	150	50	670	12
34 31W 30BBB3	250	QU	07/22/75	16.0	25	.05	.00	70	17	41	3.2
34 34W 16DAA	458	QU,TO	05/07/74	....	31	.02	.00	77	17	24	3.2
34 34W 17DDD	562	JU	10/16/74	....	29	1.3	.00	70	23	32	3.2
35 33W 16BCA	383	QU,TO	05/07/74	....	33	.03	.00	53	24	27	3.2

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
31 32W 03DAD	0	220	78	23	0.9	12	363	230	46	1.0	570	7.8
31 33W 06CBD	0	220	108	37	.9	21	432	270	92	1.1	690	7.6
31 34W 18BBB	0	259	158	19	1.1	5.8	488	270	62	1.5	740	7.7
32 31W 26CAA	0	210	87	15	.8	7.3	345	210	44	1.0	540	7.7
32 31W 31ACC	0	220	171	20	.8	12	48	280	99	1.4	730	7.6
32 34W 10DA	0	220	98	15	1.1	9.1	370	230	52	1.0	570	7.8
32 34W 17DCC	0	220	116	23	.8	8.0	411	260	80	1.0	630	7.6
33 32W 28CDD	0	156	1,260	20,300	.1	.2	33,800	16,380	6,300	21	....	7.9
33 32W 28CDD2	0	220	150	96	.7	9.3	577	300	120	2.1	950	8.0
34 31W 30BBB	0	140	1,100	11,000	.4	1.0	19,500	5,800	5,700	28	....	7.7
34 31W 30BBB2	0	95	200	1,300	1.1	2.9	2,420	580	510	12	4,500	8.1
34 31W 30BBB3	0	212	77	55	.4	9.6	403	244	70	1.1	700	7.7
34 34W 16DAA	0	190	120	17	.4	12	396	260	107	.6	580	7.6
34 34W 17DDD	0	190	140	15	.5	15	423	270	120	.9	660	8.4
35 33W 16BCA	0	220	67	22	.7	10	350	230	46	.8	530	7.7

STANTON COUNTY

Local well number	Well depth (ft)	Geologic source[1]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
27 39W 13AC	508	KD	04/22/64	....	24	0.00	0.00	86	39	51	6.1
27 40W 26BA	343	QU,TO	04/22/64	....	17	.00	.00	69	17	29	4.2
27 42W 11DBD	252	QU	07/08/64	....	14	.00	.00	69	18	26	4.1
27 42W 31CCC	400	TO,KJ	04/27/64	....	14	.00	.00	54	13	30	3.3
28 39W 08BC	290	QU	04/24/60	....	18	.11	.00	70	19	28	4.0
29 42W 24CC	515	KJ	08/26/60	16.5	27	.24	.00	55	23	54	....
30 39W 23BB	405	QU,TO	04/26/64	....	16	.00	.00	44	19	29	3.1

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
27 39W 13AC	0	256	237	21	1.2	4.9	596	375	165	1.2	870	7.5
27 40W 26BA	0	185	132	15	.8	6.6	382	242	90	.8	570	7.7
27 42W 11DBD	0	190	124	12	.8	5.8	367	246	90	.7	550	7.2
27 42W 31CCC	0	178	84	11	.7	6.2	304	188	42	1.0	470	7.8
28 39W 08BC	0	190	130	16	1.0	9.7	389	252	96	.8	590	7.6
29 42W 24CC	0	240	118	15	1.6	7.1	419	232	35	1.5	690	...
30 39W 23BB	0	207	62	13	1.3	7.5	297	188	18	.9	480	7.7

Table 3.--Chemical analyses of ground water in southwestern Kansas--Continued

[Concentrations in milligrams per liter]

STEVENS COUNTY

Local well number	Well depth (ft)	Geologic source[1/]	Date of collection	Temperature (°C)	Dissolved silica (SiO_2)	Total iron (Fe)	Dissolved manganese (Mn)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Sodium (Na)	Potassium (K)
31 35W 26DCC	420	QU,TO	05/09/74	....	23	0.08	0.00	54	29	37	4.8
31 36W 27BCB	450	QU,TO	05/09/74	....	23	.02	.00	43	25	40	4.0
31 38W 17CDA	400	QU,TO	05/10/74	....	28	.00	.00	70	49	54	5.2
32 35W 08DDD	495	QU,TO	05/09/74	....	23	.02	.00	46	29	42	4.4
32 37W 10DCC	480	QU,TO	05/10/74	....	34	.08	.00	50	19	22	3.8
33 38W 20DDB	405	QU,TO	05/09/74	....	29	.02	.00	62	19	28	3.0
34 35W 07BCC	456	QU,TO	05/09/74	....	30	.02	.00	77	14	19	3.2
34 35W 18BCA	470	TO	10/09/74	....	8.7	1.8	.00	40	13	26	3.0
34 39W 14DDD	540	TO	08/08/74	....	25	2.2	.00	74	25	28	4.3
35 36W 01AAA	...	QU,TO	05/08/74	....	32	.00	.00	66	19	20	3.0
35 39W 10CAD	530	QU,TO	05/09/74	....	31	.03	.00	83	18	26	2.8

Local well number	Carbonate (CO_3)	Bicarbonate (HCO_3)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness (Ca,Mg)	Hardness Noncarbonate	Sodium adsorption ratio	Specific conductance (µmhos/cm at 25°C)	pH
31 35W 26DCC	0	220	107	27	1.1	10	401	250	74	1.0	640	7.7
31 36W 27BCB	0	220	97	13	1.3	4.0	356	210	34	1.2	570	7.6
31 38W 17CDA	0	220	242	32	1.6	12	600	380	200	1.2	880	7.7
32 35W 08DDD	0	222	114	16	.9	10	394	230	52	1.2	620	7.7
32 37W 10DCC	0	220	46	17	.5	5.1	307	200	21	.7	480	7.7
33 38W 20DDB	0	180	100	19	.3	26	376	230	82	.8	550	7.7
34 35W 07BCC	0	193	79	32	.3	10	360	250	92	.5	560	7.6
34 35W 18BCA	0	120	65	26	.7	4.5	246	150	56	.9	400	7.9
34 39W 14DDD	0	190	170	12	.4	8.6	437	288	130	.7	660	7.5
35 36W 01AAA	0	193	90	20	.4	11	357	240	84	.6	550	7.5
35 39W 10CAD	0	180	155	17	.4	9.8	431	280	135	.7	630	7.6

Surface Water

Most of the streamflow into the area is diverted for irrigation use or percolates to the underlying aquifer. Surface-water outflow generally represents ground-water contributions to the stream from the unconsolidated aquifer.

Arkansas River

The quality of surface water entering the area during medium to low flow commonly is saline. Analyses of samples collected from the Arkansas River at Coolidge, Kansas, show that the water contains dissolved solids ranging from 2,000 to 5,000 mg/L and is a mixed type containing sodium, calcium, magnesium, and sulfate. Monthly streamflow records indicate that the water in Hamilton County "...moves from the river to the alluvium during periods of high flow and moves from the alluvium to the river during periods of low flow..." (Lobmeyer and Sauer, 1974). Thus, the chemical quality of surface water and ground water in the river valley are similar in the reach where streamflow normally occurs in Hamilton and western Kearny Counties.

During years of normal to above-normal precipitation, ground-water contributes flow to the Arkansas River downstream from the Finney-Gray County line. The quantity of inflow to the stream is greatest during the nongrowing season and decreases as irrigation use and evapotranspiration increase. The analysis of samples collected from the Arkansas River at Dodge City, Kansas (about 10 miles east of the Gray County line), indicates that the quality of surface water leaving the area is fresh (dissolved solids range from about 500 to 1,000 mg/L), and is a mixed type containing calcium, magnesium, sulfate, and bicarbonate.

Cimarron River

Miscellaneous discharge and chemical-quality measurements were made, during November 1974, on a reach of the river from a site near the point where flow began (between sites 1 and 2) to about 4 miles upstream from the Oklahoma-Kansas State line (site 11). The locations of measurement sites are shown on plate 8, and the data are listed in table 4. Site 10, included in the list of measurements, is the U.S. Geological Survey gage on the Cimarron River near Forgan, Oklahoma (Station No. 07156900). The measurements were made after a killing frost to reduce the effects of evapotranspiration on ground-water inflow and during a period when there was no surface-water inflow to the river between sites.

The relation of stream discharge to distance in river miles is shown graphically (fig. 3). The discharge increases progressively from site 3 (sec.36, T.32 S., R.33 W.) to site 8 (sec.9, T.35 S., R.30 W.) and becomes relatively steady from site 8 to site 11 (sec.10, T.35 S., R.29 W.). Thus, most of the ground-water inflow from the aquifer to the river occurs upstream from site 8.

Plate 8.--Map showing locations of selected sampling sites and diagrams of chemical characteristics of water in the unconsolidated aquifer, southwestern Kansas.

Table 4.--Miscellaneous discharge and chemical-quality measurements on Cimarron River, Meade and Seward Counties, Kansas

Location	Site number	Date 1974	Discharge (ft^3/s)	Time (c.s.t.)	Temperature (°C)	Specific conductance (µmhos/cm at 25°C)	Dissolved chloride (mg/L)
32 33W 18AAA	1	Nov. 14	0	0900	---	---	--
32 33W 21CCA	2	Nov. 14	.01	0925	3.0	900	23
32 33W 36BDA	3	Nov. 14	.35	1025	6.0	735	19
33 32W 20ACD	4	Nov. 14	11.5	1025	8.5	730	21
33 32W 25ACC	5	Nov. 14	19.1	1145	10.0	760	40
34 31W 15CBA	6	Nov. 14	39.6	1230	10.5	1010	98
34 30W 31BBC	7	Nov. 14	41.9	1535	11.0	1200	186
35 30W 09CCB	8	Nov. 14	56.3	1100	6.0	1340	215
35 30W 13BBB	9	Nov. 14	55.7	1330	9.0	2400	580
35 29W 08DDC	10	Nov. 14	57.7	1410	11.0	2600	620
35 29W 10BCD	11	Nov. 14	56.5	1610	10.0	2650	650

Figure 3.--Relation of distance in miles along Cimarron River to (A) discharge and (B) dissolved chloride on November 14, 1974.

A water sample was collected at each measurement site for analysis and for an indication of changes in the chemical quality of ground-water inflow to the river. The quality of water being discharged from the study area by the river is saline (about 1,400 mg/L) and is a sodium chloride type.

The concentration of chloride also is related to distance in river miles (fig. 3B). Chloride concentrations increased gradually from site 3 to site 8 and increased rapidly between sites 8 and 9. Thus, most of the ground-water inflow was contributed upstream from site 8, but the greatest increase in chlorides occurred between sites 8 and 9. Much of the chloride increase probably is attributable to a spring that yields salty water to the river in the NE1/4 sec.16, T.35 S., R.30 W. The chloride concentration of the spring water is not known, but water samples from nearby wells in the Whitehorse Formation show concentrations ranging from 10,000 to 20,000 mg/L.

Unconsolidated Aquifers

Water quality in the unconsolidated deposits differs chiefly as a result of the source, quantity, and quality of recharge and by association with water in other geologic formations in the subsurface. In general, the chemical quality of water in the unconsolidated aquifer, listed in table 3 and shown by plate 8, improves from west to east.

Quaternary Alluvium

The quality of water in the alluvium of the Arkansas River valley is the cumulative result of saline-water recharge and the concentration of dissolved solids by evapotranspiration. Most soils in the valley are saline because they have been affected by flooding, a shallow water table, and by surface- and ground-water irrigation. Thus, chemical constituents in water percolating to the aquifer are the result of selective precipitation of salts. The concentration of salts in the aquifer also are increased by evaporation from the shallow water table and transpiration by abundant vegetation, such as cottonwood and salt cedar.

Ground water in the alluvium from Coolidge to Garden City contains high concentrations of calcium, magnesium, sodium, and sulfate (pl. 8) and dissolved solids decrease downgradient from about 3,700 to 2,900 mg/L. In Gray County, water in the alluvium contains increased concentrations of calcium and bicarbonate and decreased concentrations of magnesium, sodium, and sulfate. According to McGovern and Long (1974), dissolved solids in the alluvial aquifer "...decrease from 1,600 mg/L at the western county line to about 500 mg/L at the eastern county line."

Ogallala Formation and Undifferentiated Pleistocene Deposits

The quality of water in the unconsolidated deposits commonly is fresh (dissolved solids range from 200 to 600 mg/L), and may be either a calcium bicarbonate type or a mixed type containing calcium, magnesium, sodium, bicarbonate, and sulfate. The chemical quality of water differs from area to area and may differ significantly with depth. These differences probably result from the source and quality of recharge, the depth, thickness, and character of sediments in the aquifer, and the association with water or soluble minerals in the bedrock formations.

In the eastern part of the unconsolidated aquifer (pl. 8), water is a calcium bicarbonate type. In the western and southern parts, magnesium, sodium, and sulfate also are principal constituents. Because precipitation is the major source of recharge within the study area, the chemical constituents in ground water probably were derived from dissolution of minerals within the aquifer and from adjacent bedrock formations. The abundance of calcium carbonate in the unconsolidated deposits provides an ample source for these constituents throughout the area. Jurassic and Cretaceous rocks that underlie the western part of the aquifer, as well as some of the unconsolidated deposits derived from these formations, provide increased percentages of sodium, magnesium, and sulfate.

In parts of northern Kearny and Finney Counties, the chemical quality of water in the aquifer has been affected by the addition of dissolved minerals derived from Upper Cretaceous rocks. The water is fresh (200 to 500 mg/L) and commonly contains sodium, magnesium, and sulfate in combination with calcium bicarbonate. Water in the aquifer north of the Arkansas River valley (pl. 8) also shows the result of extensive surface-water irrigation. Because diversions from the river have been used for many years, this source of saline water has become a significant part of the recharge. Thus, water in the aquifer, especially at shallow depths, may contain dissolved solids as high as 1,000 to 2,000 mg/L.

In some parts of southern Meade and Seward Counties, saline water occurs near the base of the unconsolidated aquifer. Water samples from three wells, located in the same 10-acre tract of sec.30, T.34 S., R. 30 W., indicate that the chemical quality in the aquifer has been affected by highly mineralized water from the underlying Whitehorse Formation. As shown by the diagrams in figure 4, the chemical characteristics of the saline water in the lower part of the aquifer are different from those of the freshwater in the upper part, but are similar to those of the brackish water in the bedrock formation.

Figure 4.--Chemical characteristics in water from three wells in sec.30, T.34 S., R.30 W. in Seward County.

Bedrock Aquifers

Whitehorse Formation

Near the Cimarron River in southwestern Meade County and southeastern Seward County, wells in the Whitehorse Formation yield brackish water with concentrations of dissolved solids as high as 33,900 mg/L. Analyses of samples (table 3) show the water to be a mixed sodium calcium magnesium chloride in central Seward County and a sodium chloride in southwestern Meade County. Water from wells in these areas is not usable for most purposes. Electric logs indicate that the water in the Whitehorse may not be as highly mineralized in northwestern Meade County.

Day Creek Dolomite

The oldest formation in southwestern Kansas that yields usable supplies of water is the Day Creek Dolomite. Water from permeable zones in the formation (gypsum aquifer) is saline, with dissolved solids of about 2,700 mg/L, and is a calcium sulfate. Water from the formation has been used for irrigation in Morton County, although continued use tends to accumulate gypsum in the soil and to rapidly corrode aluminum distribution pipe.

Undifferentiated Upper Jurassic and Lower Cretaceous Rocks

Wells in southern Hamilton County and in Stanton and Morton Counties commonly are screened in all available water-producing sandstones in the undifferentiated Upper Jurassic and Lower Cretaceous rocks and in the unconsolidated deposits. Therefore, the quality of water from those wells is similar to that from wells screened only in the unconsolidated aquifer in the same general area. Where well yields are obtained only from the sandstones, the water has a slightly higher concentration of sodium and sulfate than water from nearby wells in the unconsolidated aquifer.

In northeastern Finney County, the upper part of the sandstone aquifer (Dakota Formation) yields water that is fresh, with dissolved solids ranging from 400 to 600 mg/L, and that is a mixed sodium bicarbonate sulfate. Geophysical logs from oil tests in this area indicate that water in the lower part of the sandstone aquifer (Cheyenne Sandstone) is highly mineralized.

Niobrara Chalk

An analysis of water from the Niobrara Chalk by Latta (1944) shows that the chalk aquifer yields a mixed calcium magnesium bicarbonate water similar to that in the overlying unconsolidated aquifer. The composition of water and concentration of dissolved solids generally may be correlated with surficial conditions rather than with the mineralogical composition of the aquifer. In Finney County, Hill and others (1967) show the constituents in water from the Fort Hays Limestone Member to be almost entirely calcium carbonate.

Suitability of Water for Irrigation

When irrigation water is applied to the land, it is necessary to consider the effects on the salinity and alkalinity of the soils. The most important chemical characteristics in evaluating the suitability of water for irrigation are the total concentration of soluble salts, expressed in terms of electrical conductivity (EC), and the relative proportion of sodium to other principal cations, expressed as the sodium-adsorption-ratio (SAR). The suitability of water from various geologic formations is shown in the diagram (fig. 5) and described according to the classification of the U.S. Salinity Laboratory Staff (1954).

Water from the Ogallala Formation and the undifferentiated Pleistocene deposits generally has a low-sodium and medium-salinity hazard. Water from undifferentiated Jurassic rocks, Lower Cretaceous rocks, and the Niobrara Chalk, which probably is derived indirectly from the unconsolidated aquifer, has similar characteristics. This type of water may be used on most soils and with crops that tolerate moderate amounts of salt.

Water from the Quaternary alluvium and from the Day Creek Dolomite have medium- and low-sodium hazards, respectively, and a very high salinity hazard. These types of water may be used on salt tolerant crops grown in permeable, coarse-textured soils, but only by utilizing additives and special farming practices.

In the northern part of the area, water from the Dakota Formation has a high-sodium and high-salinity hazard. This water may produce harmful levels of exchangeable sodium in most soils and will require good drainage, leaching and special additives.

Figure 5.--Classification of irrigation water.

HYDROLOGIC CYCLE

The natural geohydrologic cycle in southwestern Kansas is depicted by the generalized block diagram (fig. 6). Water enters the aquifers by underflow from the west, by seepage from streams especially in times of high flow, and by recharge of precipitation within the area. Water is discharged to the east and south by underflow, by seepage to perennial streams, and by evapotranspiration where the water table is shallow. This natural cycle has been modified by man's activities to include discharge from the aquifer by pumpage from wells and recharge to the aquifer from deep percolation of applied irrigation water.

Precipitation

The mean annual precipitation ranges from 15.82 inches, at Johnson in Stanton County, to 22.53 inches at Cimarron in Gray County, according to the records of the National Weather Service (U.S. Dept. of Commerce, 1975). Mean annual precipitation near the center of the area at Sublette is 19.45 inches. About three-fourths of the total annual precipitation falls during the growing season (April-October). Showers and thunderstorms in southwestern Kansas are often of high intensity and short duration and vary in areal distribution so that significant amounts fall in one area while nearby areas receive little or no rainfall.

Owing to summer heat, low humidity, and high wind movement, most precipitation returns rapidly to the atmosphere through evaporation and transpiration by plants. A total potential evaporation of 66.13 inches was measured at the Garden City Experiment Station from May through October 1974. Potential transpiration probably averages 0.70 times the total potential evaporation or about 46 inches (Crippen, 1965).

Figure 6.--Natural geohydrologic features.

Recharge

As reported in the Finney County study (Meyer and others, 1970), recharge from precipitation on irrigated areas is significantly greater than from precipitation on nonirrigated areas. In irrigated areas, it is common practice to pump sufficient ground water to maintain soil moisture for crop use and for leaching of salts. Therefore, precipitation that is in excess of the amount needed to overcome soil-moisture deficiencies can percolate to the water table. In nonirrigated areas, vegetation generally utilizes all precipitation supplied to the soil so that excess water for percolation below the root zone is available only during periods of abnormally high rainfall. For this report, estimates of recharge from precipitation during the growing season (April-October) are assumed to be 10 percent of precipitation on irrigated land and 1 percent of the precipitation on nonirrigated land (Gutentag and Stullken, 1976).

Recharge to the aquifer is calculated for 6,600 square-miles, which is the part of the area that is underlain by sufficient saturated material to support irrigation. From the following section on "Annual Withdrawals," records for 1975 show that about 1,400,000 acres were irrigated; the remaining 2,824,000 acres were not irrigated. Annual recharge to the aquifer, based on about 15 inches of precipitation during the growing season, is computed to be 210,000 acre-feet (175,000 acre-feet in the irrigated area and 35,000 acre-feet in the nonirrigated area).

Runoff of precipitation to streams also is a source of recharge to the aquifer in southwestern Kansas. The streams generally have sandy channels and are underlain by permeable deposits of sand and gravel. Water infiltrates the channel sides and bottom during periods of flow after heavy rains, and much of this water percolates to the water table. Some of the runoff that collects in shallow depressions of the land surface also percolates to the water table and recharges the ground-water reservoir. However, the bottoms of the depressions often are filled with clayey soils that retard infiltration; consequently, most of the water evaporates. The amount of annual recharge from runoff into surface depressions and streams is assumed to be included with the total estimate of recharge from precipitation.

An additional 163,500 acre-feet per year enters the area as streamflow in the Arkansas and Cimarron Rivers (U.S. Geological Survey, 1975).

Water also enters the area as subsurface inflow from the north and west. Based on the hydraulic gradient, the cross-sectional area of saturated deposits, and an average hydraulic conductivity, the inflow is calculated to be about 8,400 acre-feet per year.

Discharge

Outflow through the subsurface and seepage to streams comprise the primary modes of natural discharge of ground water from the area. Subsurface outflow, which is principally to the east, is calculated in a manner similar to that of subsurface inflow to be about 15,300 acre-feet per year.

The ground-water contribution to streamflow is considered as ground-water discharge. Parts of three streams in the area, the Arkansas River, the Cimarron River, and Crooked Creek, receive flow from ground-water seepage. As reported by Busby and Armentrout (1965), the 20-year average base flow (ground-water contribution) of the Cimarron River at Mocane, Okla. (Station No. 07157000), is 46.1 ft^3/s or 33,400 acre-feet per year, and the base flow of Crooked Creek near Nye, Kans. (Station No. 07157500), is 12.2 ft^3/s or 8,800 acre-feet per year. Figures reported in Meyer and others (1970) and McGovern and Long (1974) indicate that about 11,300 acre-feet per year of ground water leaves the area as base flow in the Arkansas River.

Discharge from the unconsolidated aquifer by evapotranspiration is negligible in southwestern Kansas because the water table in most of the area is too far below the land surface to be affected by evaporation and transpiration.

Annual Withdrawal

Withdrawals by wells far exceed all other discharges of ground water in southwestern Kansas. Based on records of the U.S. Department of Agriculture, as discussed in the section "Ground-Water Development," it was estimated that pumpage for irrigation of 1,400,000 acres in 1975 was between 2.1 and 2.8 million acre-feet.

Some of the water withdrawn by wells and applied for irrigation is returned to the aquifer. Figures experimentally derived by Meyer and others (1970) for irrigated land in Finney County show that about 20 percent of the water applied to irrigated land in southwestern Kansas is returned to the aquifer by percolation below the root zone. Based on the average annual withdrawal by wells for irrigation of 2.1 to 2.8 million acre-feet, calculations suggest that about 420,000 to 560,000 acre-feet per year returns to the ground-water reservoir. On the basis of 1975 data, the net withdrawal of water by wells for irrigation in southwestern Kansas is estimated to be 1.7 to 2.2 million acre-feet annually.

Measurements of natural-gas consumption of 119 wells show that an average of 7,000 cubic feet of gas is required to pump 1 acre-foot of water. Based on this figure, the volume of natural gas required to pump the estimated total withdrawal of 2.1 to 2.8 million acre-feet of water would amount to 1.5×10^{10} to 2.0×10^{10} cubic feet. Data from the Kansas Corporation Commission in 1974 show that the 5,768 natural gas wells in southwestern Kansas produced 7.95×10^{11} cubic feet of natural gas or 1.38×10^{8} cubic feet per well. Therefore, the natural gas consumed for withdrawal of ground water in southwestern Kansas in 1974 was about 2 to 2.5 percent of the total natural gas production, or the production from 116 to 152 gas wells.

GROUND-WATER DEVELOPMENT

The number of irrigation wells in southwestern Kansas, as indicated by the records of the Division of Water Resources, Kansas State Board of Agriculture (fig. 7), increased from about 420 in January 1946 to about 7,000 in January 1975. The rate at which wells were installed increased in the mid-1950's and again in the mid-1960's, primarily in response to periods of below normal precipitation. Irrigators have continued to install wells as a means of providing an additional water supply during future dry periods, assuring a maximum crop production, and increasing production of milo and corn for use in cattle feeding.

Records from the Agricultural Stabilization and Conservation Service and the Soil Conservation Service, U.S. Department of Agriculture, show that about 1,400,000 acres were irrigated by ground water in 1975. If it is assumed that the application rate ranged from 1.5 to 2.0 feet per acre, as commonly reported by irrigators in the area, the total pumpage would be between 2.1 and 2.8 million acre-feet per year.

Records from the Division of Water Resources, Kansas State Board of Agriculture, also show that about 150,000 acre-feet, or an additional 5 percent of the water withdrawn in southwestern Kansas, were pumped by municipalities, feed lots, and industries.

The locations of all large-capacity wells (yielding more than 100 gal/min) in southwestern Kansas, March 1975, are shown on plate 9.

Figure 7.--Cumulative number of applications to appropriate ground water.

Plate 9.--Map showing location of large-capacity wells, southwestern Kansas, March 1975.

EFFECTS OF DEVELOPMENT

Water-Level Declines

Water-level declines in the unconsolidated aquifer since 1940 (pl. 10), which have resulted principally from irrigation withdrawals, range from a few feet to about 135 feet. The greatest declines of about 130 to 135 feet have occurred in Grant County near Ulysses in T.30 S., R.37 W., and T.28 S., R.37 W. Declines of greater than 50 feet also have occurred in Finney, Haskell, and Stanton Counties. At the example site in the southeast corner of the city of Ulysses, the water-level decline has been about 100 feet. About 10 percent of the study area has experienced 50 feet or more of water-level decline. The median water-level decline for the entire study area is 13 feet.

Plate 10.--Map showing water-level decline in the unconsolidated aquifer, in feet, southwestern Kansas, 1940-75.

Water in most of the unconsolidated aquifer in southwestern Kansas is unconfined. Thus, water-level generally declines represent actual dewatering of part of the aquifer. In some of the deep zones, confined aquifer conditions were indicated by previous tests (Fader and others, 1964). However, continued pumping from these zones has lowered the head and reduced the confining effect of the upper layers.

The amount of water removed from storage in the unconsolidated aquifer can be estimated by determining the volume of aquifer dewatered, from plate 10, and multiplying by the average specific yield of the aquifer. An average specific yield of 15 percent was assumed for the aquifer; including those areas where confinement still prevails. The volume of ground water in storage was reduced by about 14 million acre-feet during 1940-75. The net withdrawal in the 1974 irrigation season, based on 1975 data, was estimated to be 1.7 to 2.2 million acre-feet.

Hydrographs from four wells, constructed from data provided by the Division of Water Resources, Kansas State Board of Agriculture, are shown on figures 8 through 11. The hydrograph of well 27-37W-4DA (fig. 8) illustrates the long-term effects of increasingly heavy development on water levels in an unconfined aquifer. This well is screened only in the upper part of the unconsolidated aquifer. The water level during 1941-51 was stable, which is indicative of minimal early development in an area where recharge to and discharge from the aquifer were about equal. Increased development is shown by a net decline in water-level during 1951-64. The water level has continued to decline at a fairly steady rate from 1964 through 1975.

Wells 27-38W-32BCC (fig. 9) and 29-38W-35CCD (fig. 10), located in the same highly developed area as well 27-37W-4DA (fig. 8), are screened opposite all water-bearing materials in the unconsolidated aquifer, including the lower confined beds. Similar water-level declines in the three wells from 1969 to 1975 indicate that nearly equal changes have occurred over broad areas as a result of irrigation withdrawals from different parts of the aquifer.

Figure 8.--Hydrograph of observation well 27-37W-4DA.

Figure 9.--Hydrograph of observation well 27-38W-32BCC.

Figure 10.--Hydrograph of observation well 29-38W-35CCD.

Well 27-38W-15BBB (fig. 11), located outside the boundary of the unconsolidated aquifer, produces water only from the sandstone aquifer. However, a hydraulic connection between the two aquifers is indicated because the hydrograph of water levels in the sandstone aquifer shows the effect of pumping from the adjacent unconsolidated aquifers.

A comparison of the well-location map (pl. 9) and the water-level decline map (pl. 10) suggests the cause and effect relationship between well density and water-level changes. The areas of greatest well density generally correspond to the areas of greatest withdrawals and water-level declines.

Figure 11.--Hydrograph of observation well 27-38W-15BBB.

Depletion of Ground Water in Storage

Depletion of ground water in storage or ground-water mining is indicated by water-level declines resulting from irrigation development. The relation of long-term irrigation withdrawals to changes in ground-water storage (1940-75) also may be shown (see plate 11) as a percentage decrease in saturated thickness.

The reduction in saturated thickness between 1940 and 1975 ranged from less than 10 percent to almost 60 percent, with a median of 8 percent. In about 5 percent of the area encompassed within the unconsolidated aquifer, the saturated thickness has decreased 40 percent or more since 1940. At the example site in the southeast corner of the city of Ulysses, the decrease in saturated thickness since 1940 is about 35 percent.

Plate 11.--Map showing percentage decrease in saturated thickness of the unconsolidated aquifer, southwestern Kansas, 1940-75.

Water levels in well 27-37W-4DA and well 27-38W-32BCC have declined about 70 feet and 90 feet, respectively, since 1940. The decrease in saturated thickness of the aquifer from 1940 to 1975 at both locations (pl. 11) is about 30 percent. During the same period, the water level in well 29-38W-35CCD declined about 80 feet, and the saturated thickness decreased about 20 percent. Although areas of greatest declines generally coincide with areas of greatest pumping, these examples indicate that similar amounts of water-level decline in different areas may not represent similar percentages of ground-water depletion. The most significant changes since 1940 are in northern Finney and northern Morton Counties where water-level declines of less than 50 feet have reduced saturated thickness by as much as 50 percent.

Further increases in the rate of withdrawals may significantly shorten the economic life of the aquifer. Those areas that have declines of 40 percent or more have already experienced a large reduction in well yields and a large increase in the cost of pumping.

FUTURE OUTLOOK FOR IRRIGATION

Economic Factors

Irrigation is a principal factor in the economy of southwestern Kansas. Some of the major problems that have greatest economic significance to the irrigator are crop prices, fuel and power costs, dependability of fuel supplies, and the efficient use of available water and power. As government control and farm programs tend to regulate prices and fuel supplies, the individual irrigator probably can gain the most benefit by increasing the efficiency of water and power use.

Additional water may be made available by utilizing potholes and tail-water pits to collect excess runoff from precipitation or waste water from irrigation. Portable pumps and lines could be used to convey the additional water to the crops as needed.

Declining water levels may result in lower well yields, which could necessitate changes in the engineering of the pumping plants. It might be beneficial to lower some pump bowls in order to achieve the maximum yield of the well even if the additional lift required a larger power unit. The condition of the well casing, pumping unit, and distribution system need to be analyzed for the conservation of water and energy.

FUTURE STUDIES

The present study has defined a number of areas that need additional study. Measurements are needed to monitor the rate and areal increase of the water-level declines. Continued analysis is necessary to determine the effects of new well development and to observe possible changes in well yields. Changes in chemical quality of water, which may become evident with declines in water level, need to be continually monitored and evaluated.

Predictive models of ground-water and surface-water relationships with the aquifer system may be used to aid in management planning. Management policies probably will depend on some way of controlling withdrawal from the ground-water reservoir by limiting (1) the amount that can be pumped per well, (2) the number of wells, or (3) the irrigated acreage.

A number of problems of limited areal extent may need further study. The The sandstone aquifer needs study in order to evaluate its potential use to supplement declining yields of the unconsolidated aquifer. The relationship of the chalk aquifer to the unconsolidated aquifer needs to be studied. The relative merits of various allocation techniques need to be tested in areas critically affected by excessive drawdowns. Studies are needed to determine the source and extent of saline water in southwestern Meade and southeastern Seward Counties. Point sources of pollution, such as urban areas, water-disposal areas, and cattle-feeding operations, need monitoring so that remedial action may be adopted.

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GLOSSARY OF GEOHYDROLOGIC TERMS

Most of the definitions of geohydrologic terms given below are taken from Lohman and others (1972).

Acre-foot - The amount of water needed to cover 1 acre to a depth of 1 foot, equals 325,851 gallons.

Aquifer - Formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Caliche - A deposit of clay, silt, sand, or gravel cemented by porous calcium carbonate to form a concrete-like deposit (mortar beds).

Confining bed - A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

Confined ground water - Ground water that is under pressure significantly greater than atmospheric and that has as its upper limit the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the confined water occurs.

Head - When used alone, head is understood to mean static head, which is the height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point (see potentiometric surface).

Hydraulic conductivity - The volume of water at the existing kinematic viscosity that will move through an isotropic porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic gradient - The change in static head per unit of distance in a given direction.

Lenticular - Describes deposits shaped like lenses when viewed in cross section.

Percolation - Laminar flow of water, moving by the force of gravity or hydrostatic pressure, through a porous material.

Potentiometric surface - A surface that represents the hydrostatic head. In a confined (artesian) aquifer, the water is under a pressure significantly greater than atmospheric, and the surface is defined by the levels to which water stands in wells above the water body tapped. In an unconfined aquifer, the surface coincides with the water table.

Reentrant - A transverse valley extending into an escarpment.

Saturated thickness - The amount (thickness) of aquifer material that is saturated.

Specific capacity - The rate of discharge of water from the well divided by the drawdown of water level within the well.

Specific conductance - A measure of the ability of water to conduct an electrical current and is related to the concentration of specfic chemcial ions in solution.

Specific yield - The ratio of (1) the volume of water which the rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock or soil. The definition implies that gravity drainage is complete.

Storage coefficient - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined water body, the storage coefficient is virtually equal to the specific yield.

Transmissivity - The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Unconfined ground water - Ground water in an aquifer that has a water table.

Water table - That surface in an unconfined ground-water body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body enough to hold standing water. The water table is a particular potentiometric surface.

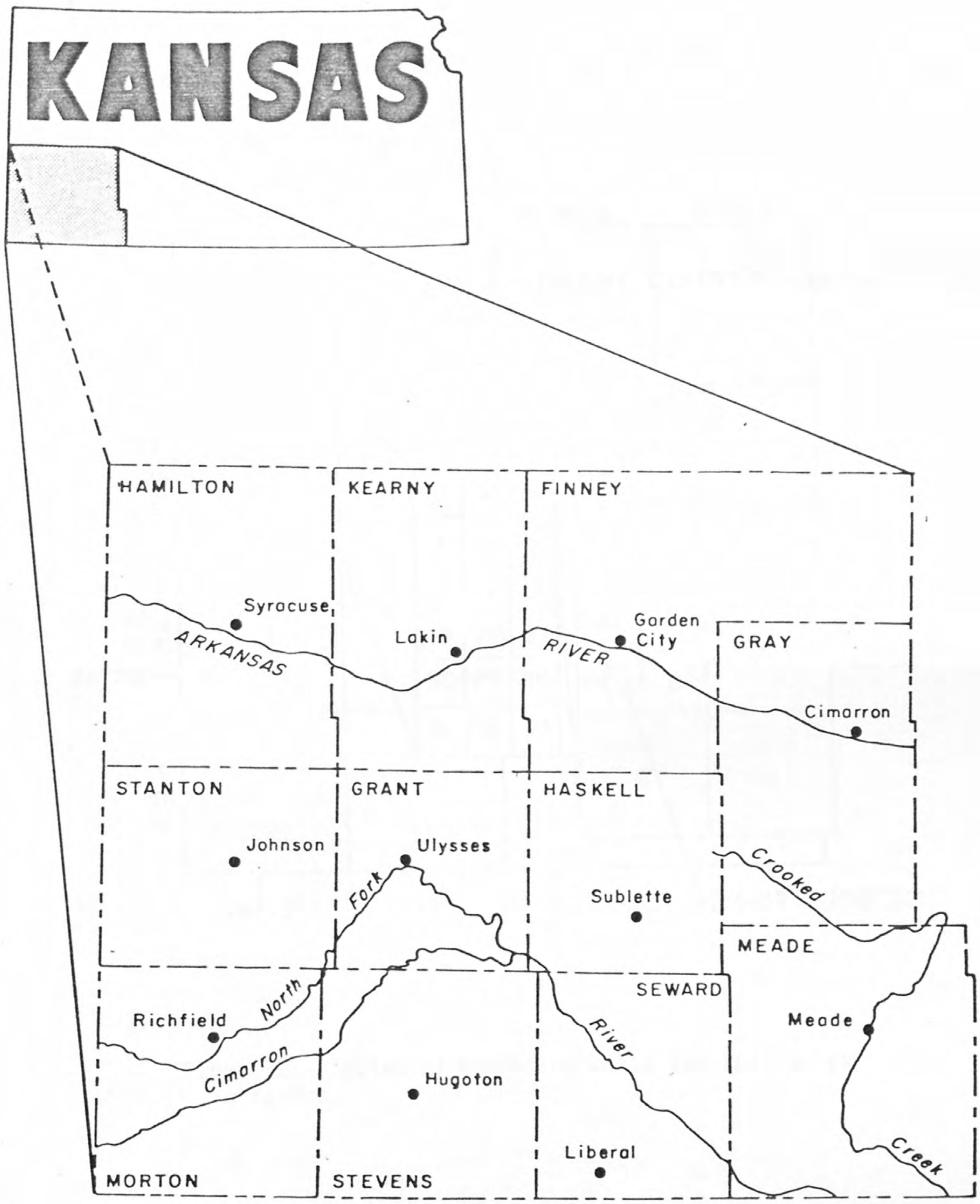

Figure 1.--Maps showing location of report area.

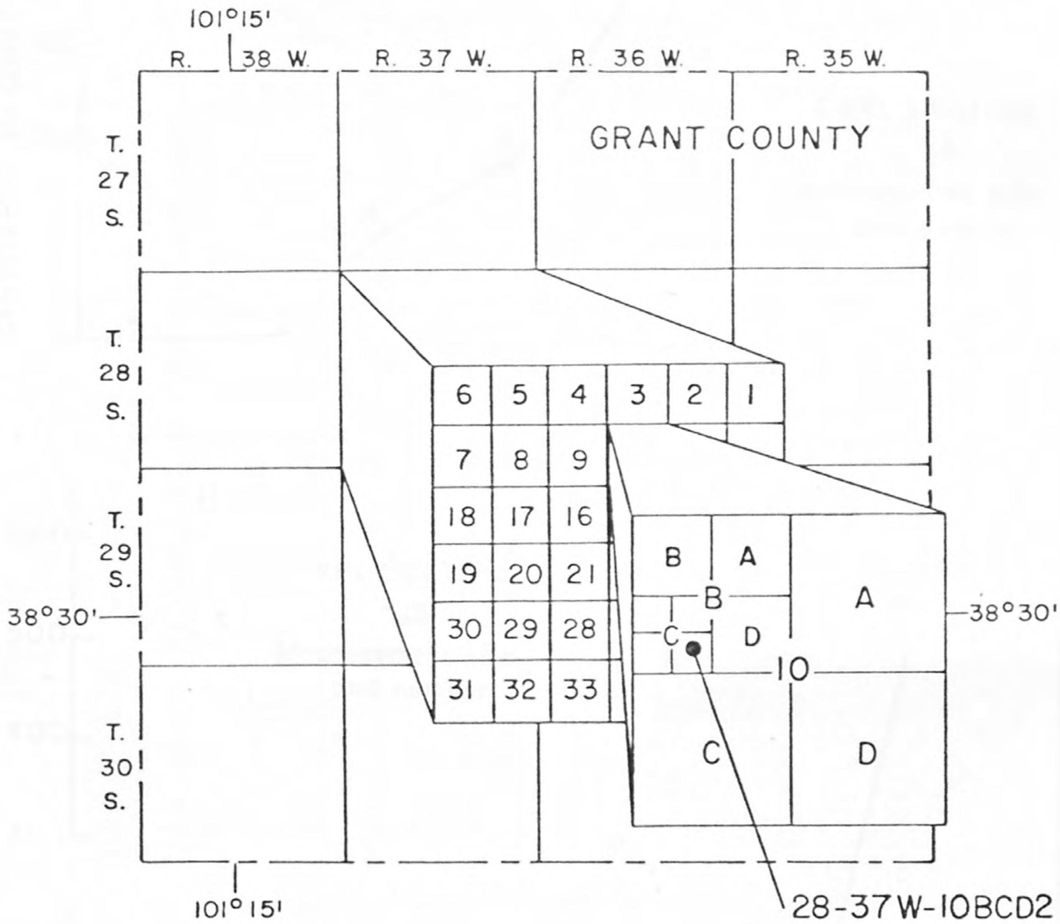

Figure 2.--System of numbering wells and test holes in Kansas.

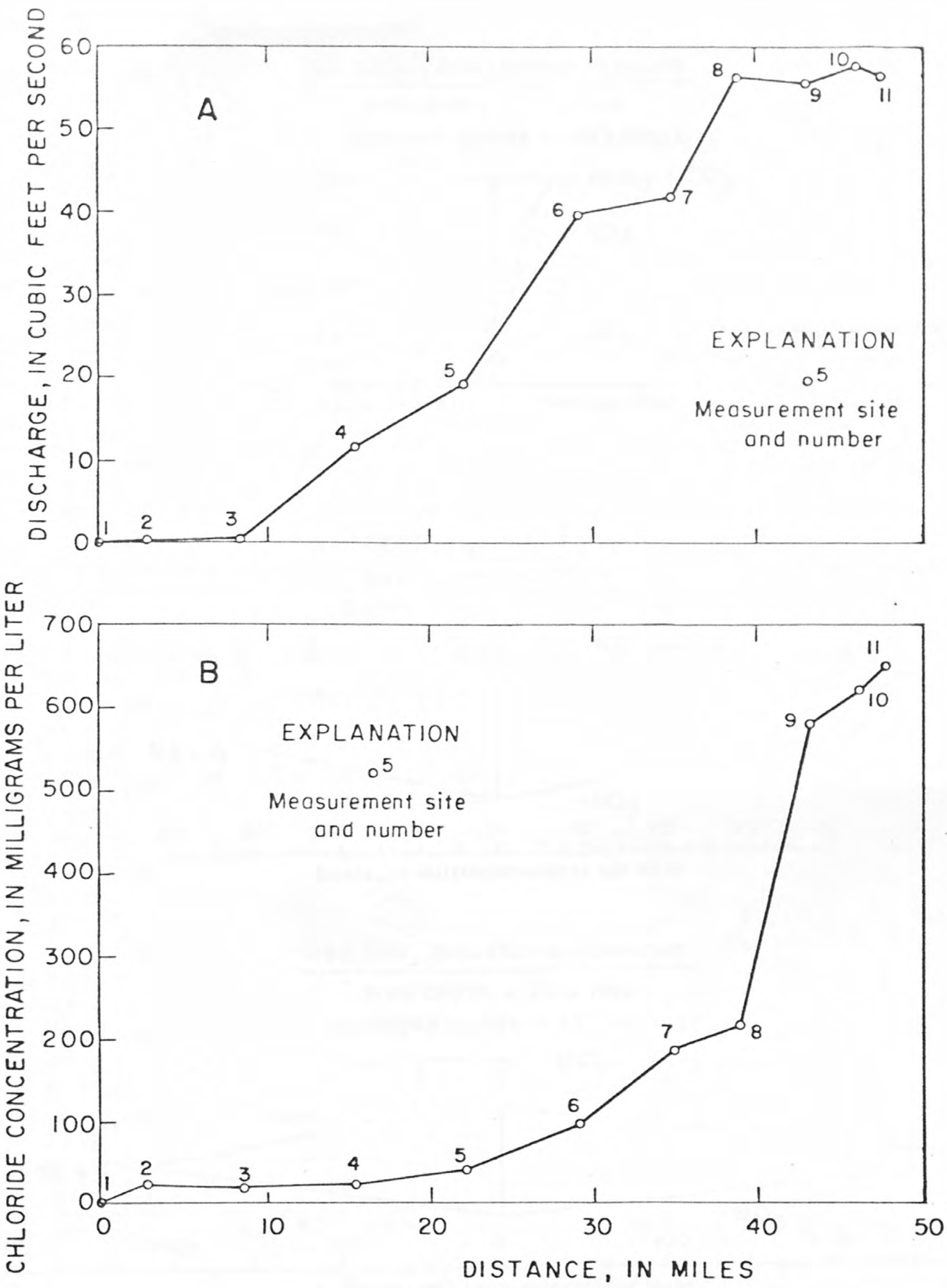

Figure 3.--Relation of distance in miles along Cimarron River to (A) discharge and (B) dissolved chloride on November 14, 1974.

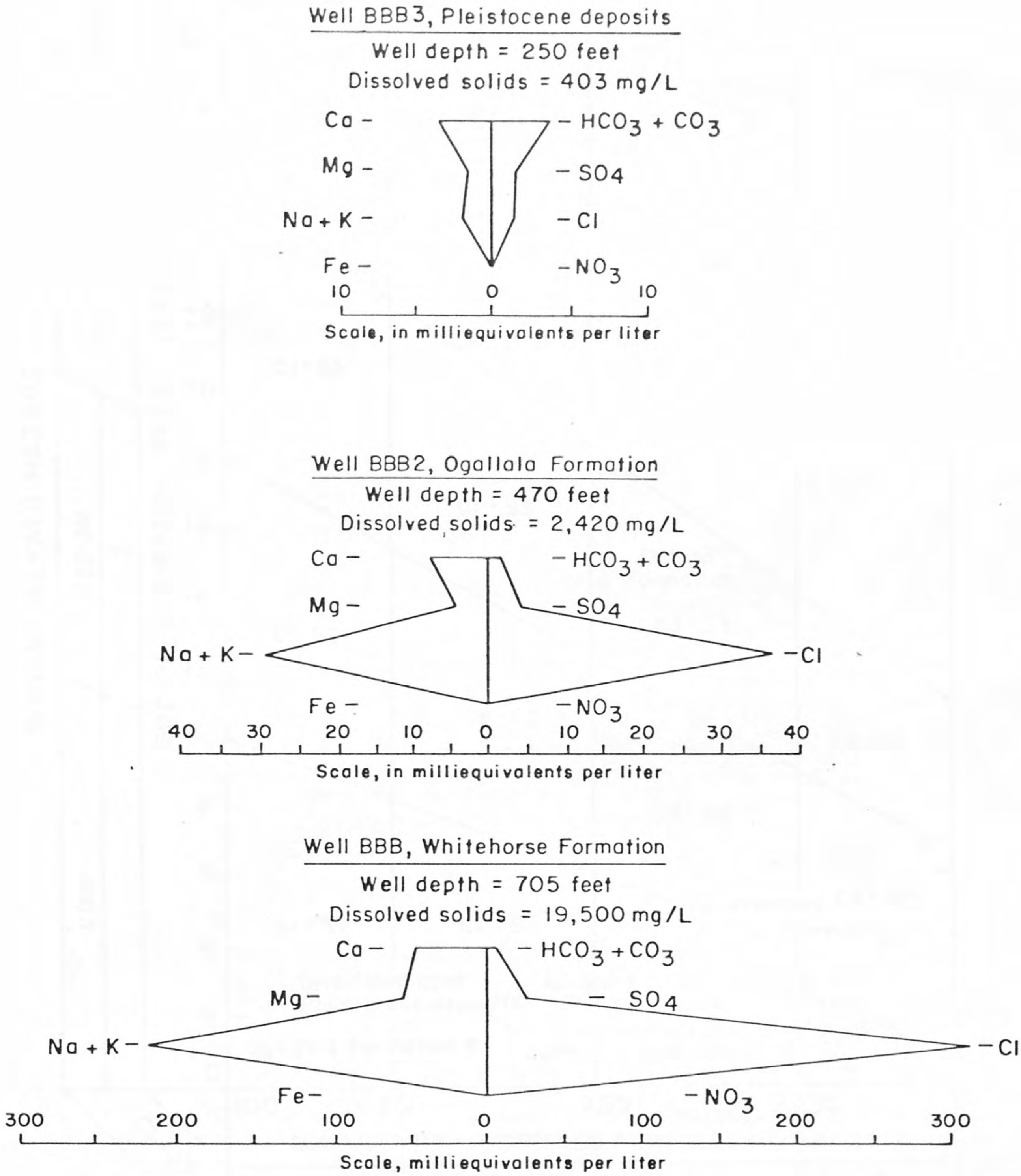

Figure 4.--Chemical characteristics of water from three wells in sec. 30, T. 34 S., R. 30 W. in Seward County.

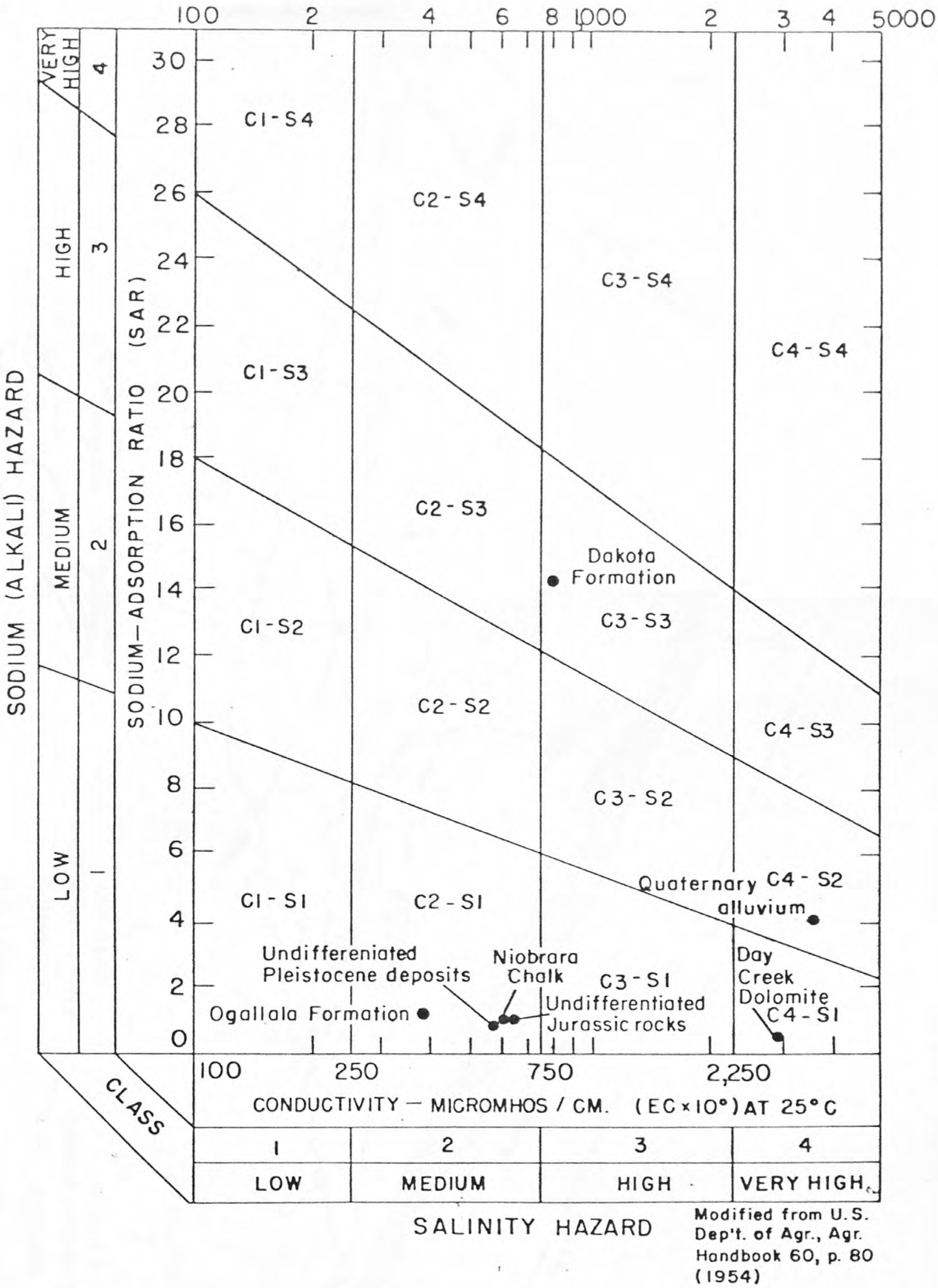

Figure 5.--Classification of irrigation water.

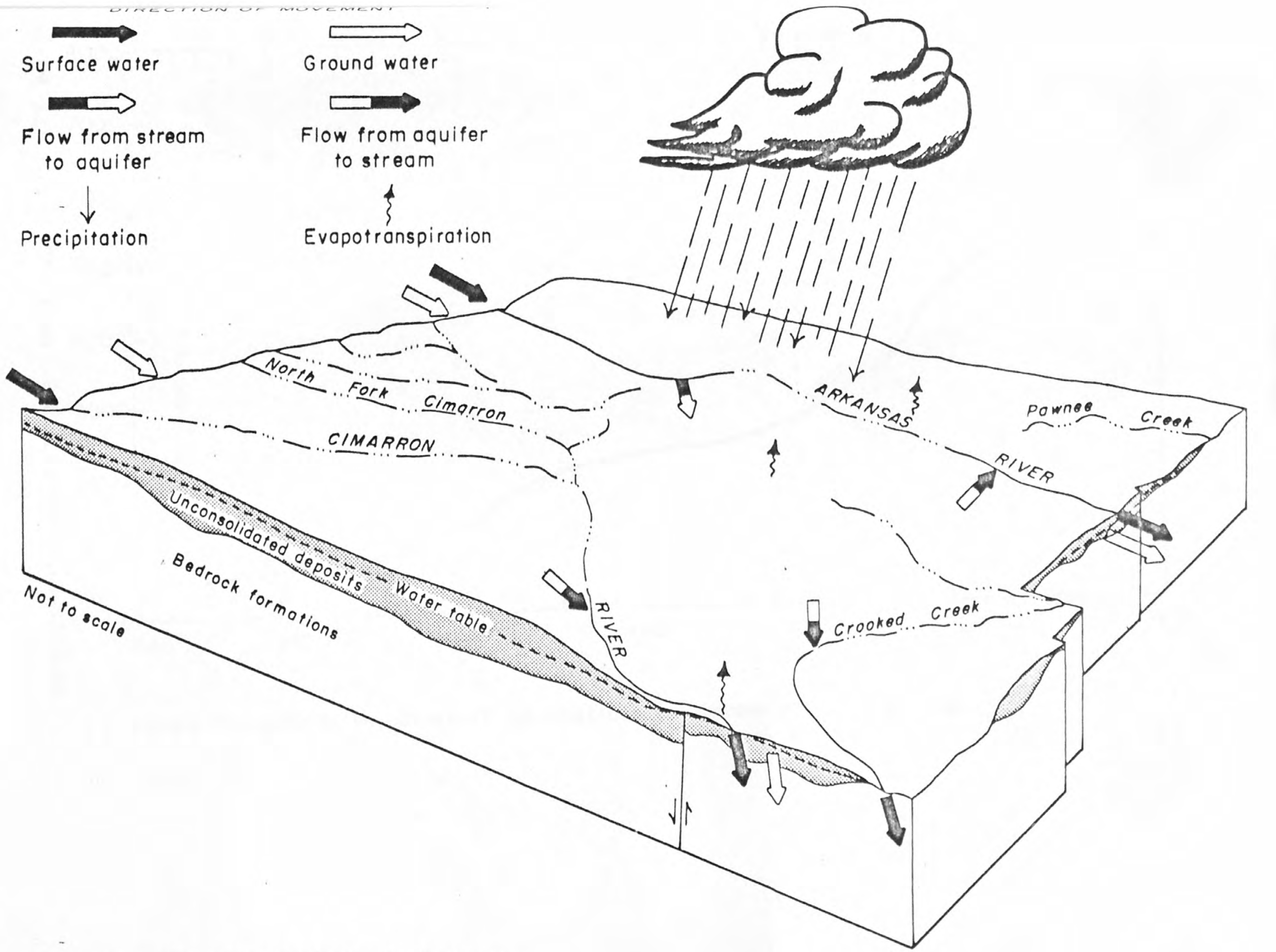

Figure 6.--Natural geohydrologic features.

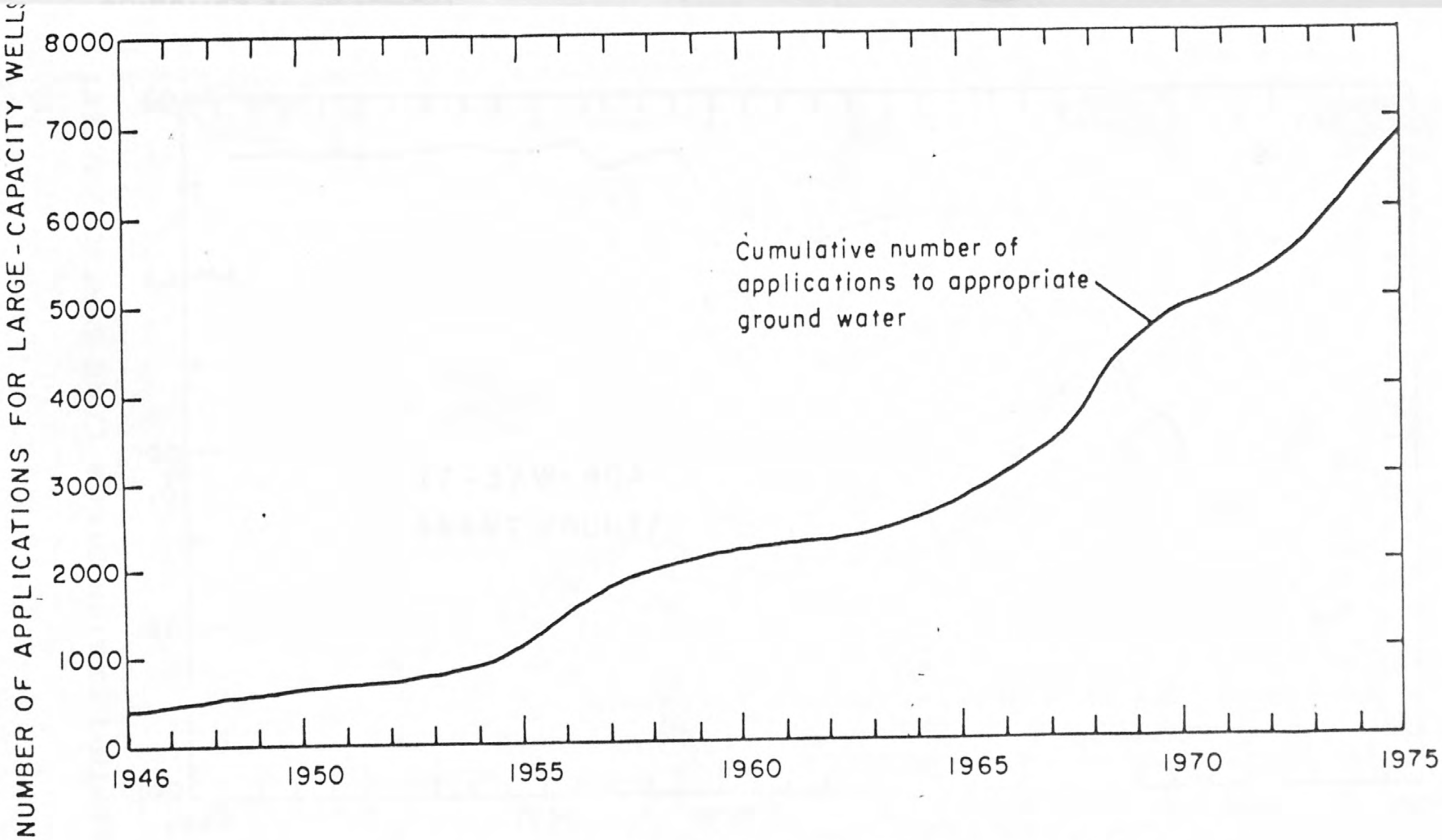

Figure 7.--Cumulative number of applications to appropriate ground water.

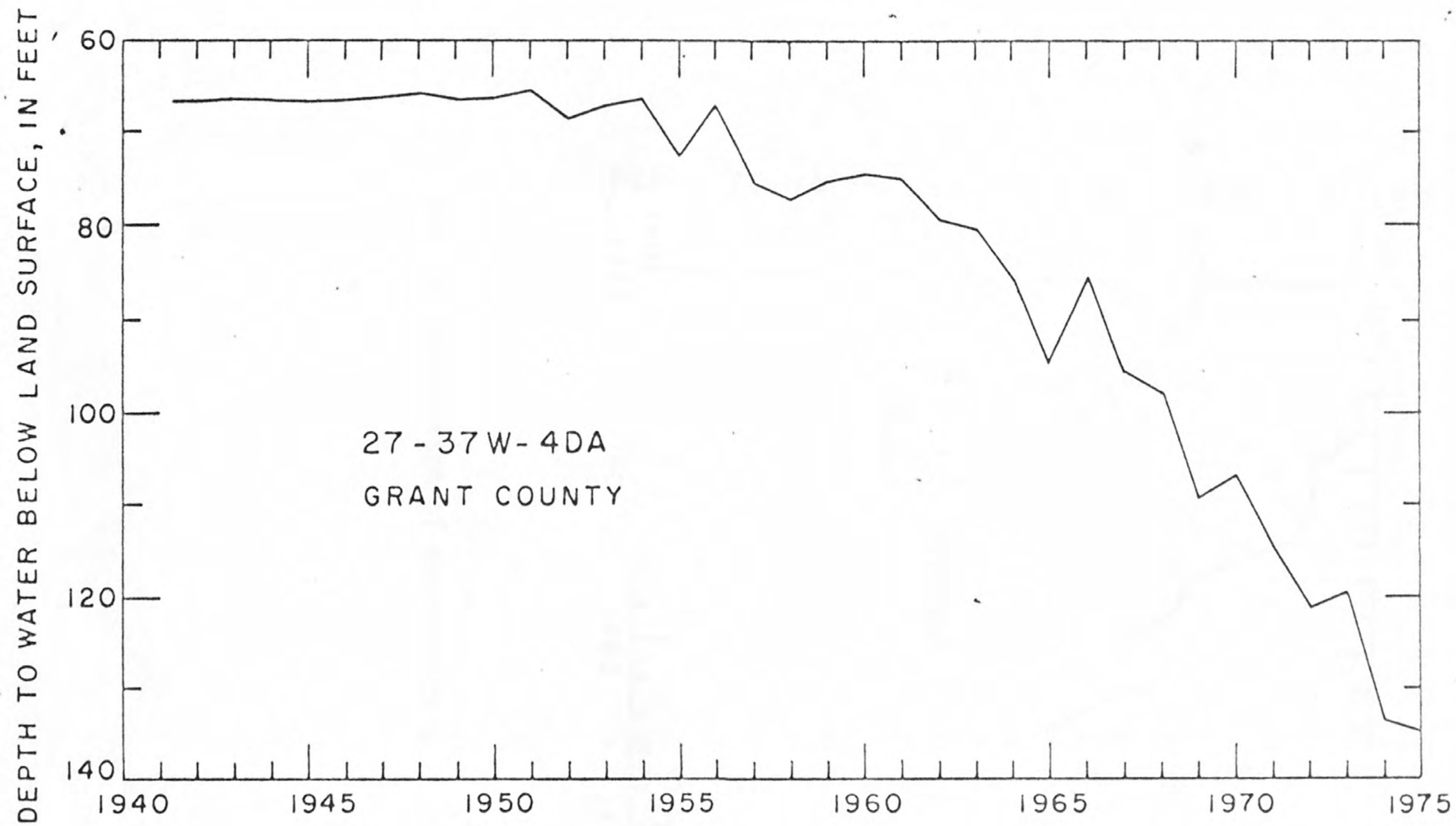

Figure 8.--Hydrograph of observation well 27-37W-4DA.

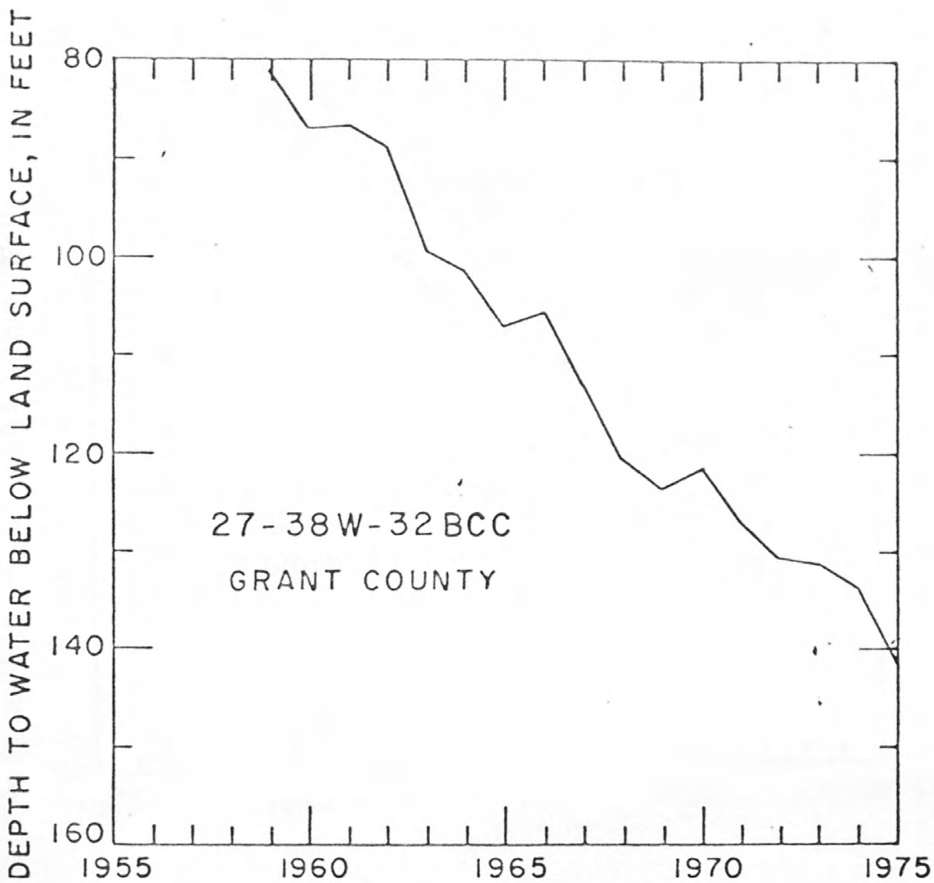

Figure 9.--Hydrograph of observation well 27-38W-32BCC.

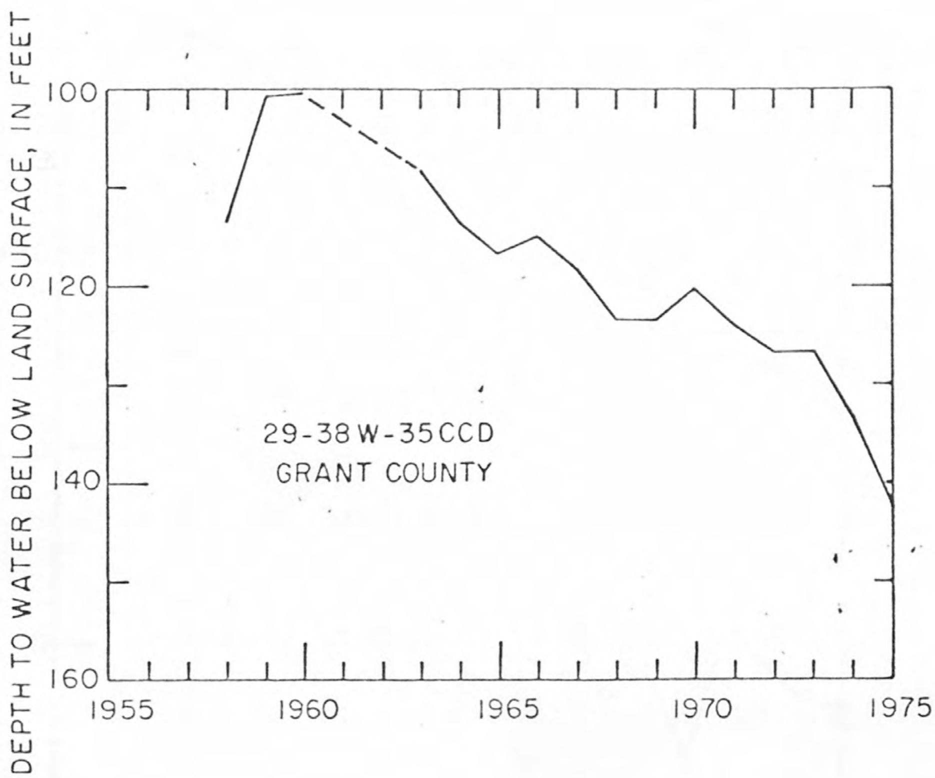

Figure 10.--Hydrograph of observation well 29-38W-35CCD.

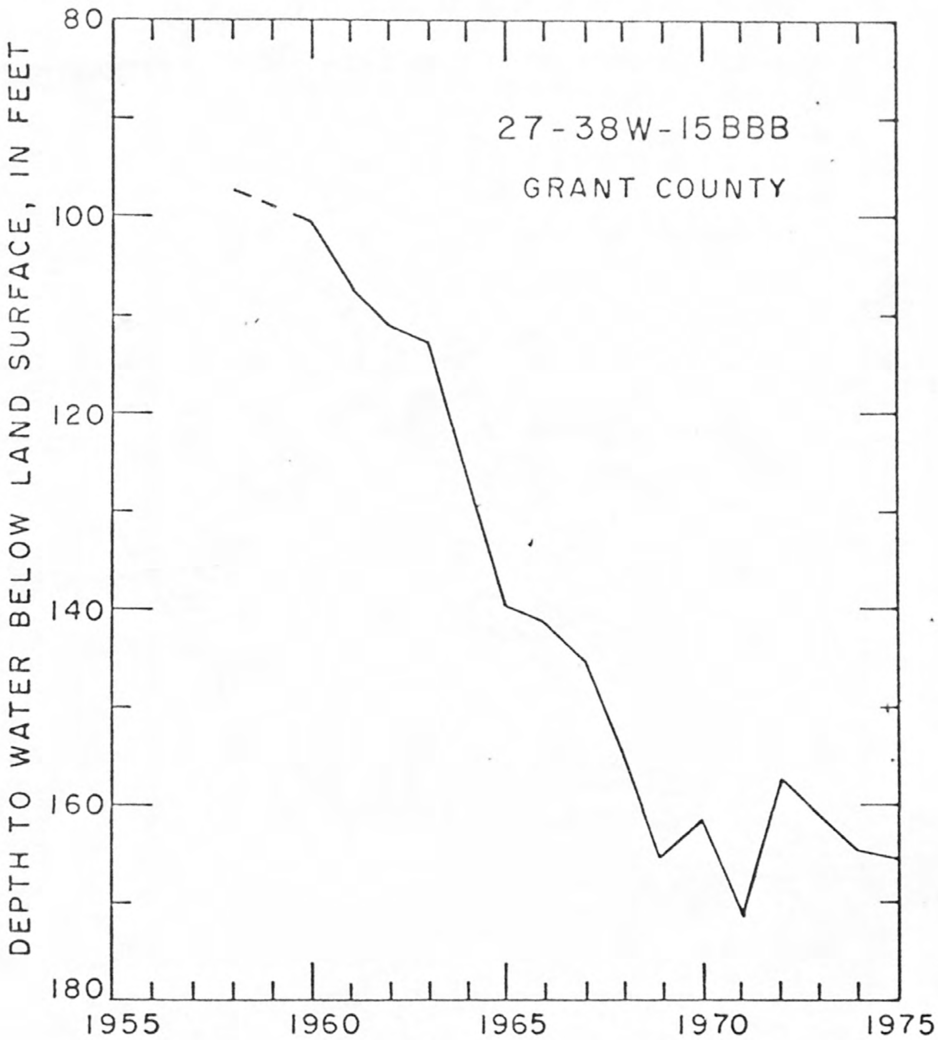

Figure 11.--Hydrograph of observation well 27-38W-15BBB.