Ground water in the Middle Arkansas River basin, Kansas and Oklahoma.

by

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U. S. Geological Survey.
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GROUND WATER IN THE MIDDLE ARKANSAS RIVER BASIN, KANSAS AND OKLAHOMA

Stuart W. Fader and Robert B. Morton

ABSTRACT

Ground water in the Middle Arkansas River basin occurs in consolidated rocks and unconsolidated deposits. Wells for domestic and stock supply generally can be drilled successfully in consolidated rocks. Wells for large-scale municipal, industrial, and irrigation supplies generally are successful in areas underlain by saturated unconsolidated deposits of sand and gravel.

Unconsolidated deposits in the basin receive about 2 million acre-feet of recharge annually, and about 84 million acre-feet of water is in temporary storage in the deposits. In 1968 and 1969 about 270,000 acre-feet of ground water was withdrawn annually for all purposes. Of the total withdrawn, about 167,000 acre-feet was applied for irrigation of about 122,000 acres of cropland. Total annual ground-water withdrawals for irrigation may be 1 million acre-feet by the year 2000.

INTRODUCTION

This report, which describes ground water in the Middle Arkansas River basin (fig. 1), was prepared by the U.S. Geological Survey at the request of the U.S. Corps of Engineers, Tulsa District, for inclusion in the Corps' overall planning report on the water resources of the basin. The report is a compilation of available data from previous reports (see Selected References) and from the files of the U.S. Geological Survey and cooperating State agencies. The data generally were collected during water-resources investigations made by the U.S. Geological Survey in cooperation with various State and local agencies and with other Federal agencies. Few additional data were collected for this investigation.

The information contained herein consists primarily of maps showing areal geology, configuration of the potentiometric surface, saturated thickness of unconsolidated deposits, potential yield of wells, and location of selected wells within the basin. Also included is information about the current and projected use of ground water, the amount of ground water in storage, the chemical quality of the ground water, the geologic and hydrologic properties of rocks, and the cost of developing ground-water supplies in the individual counties.

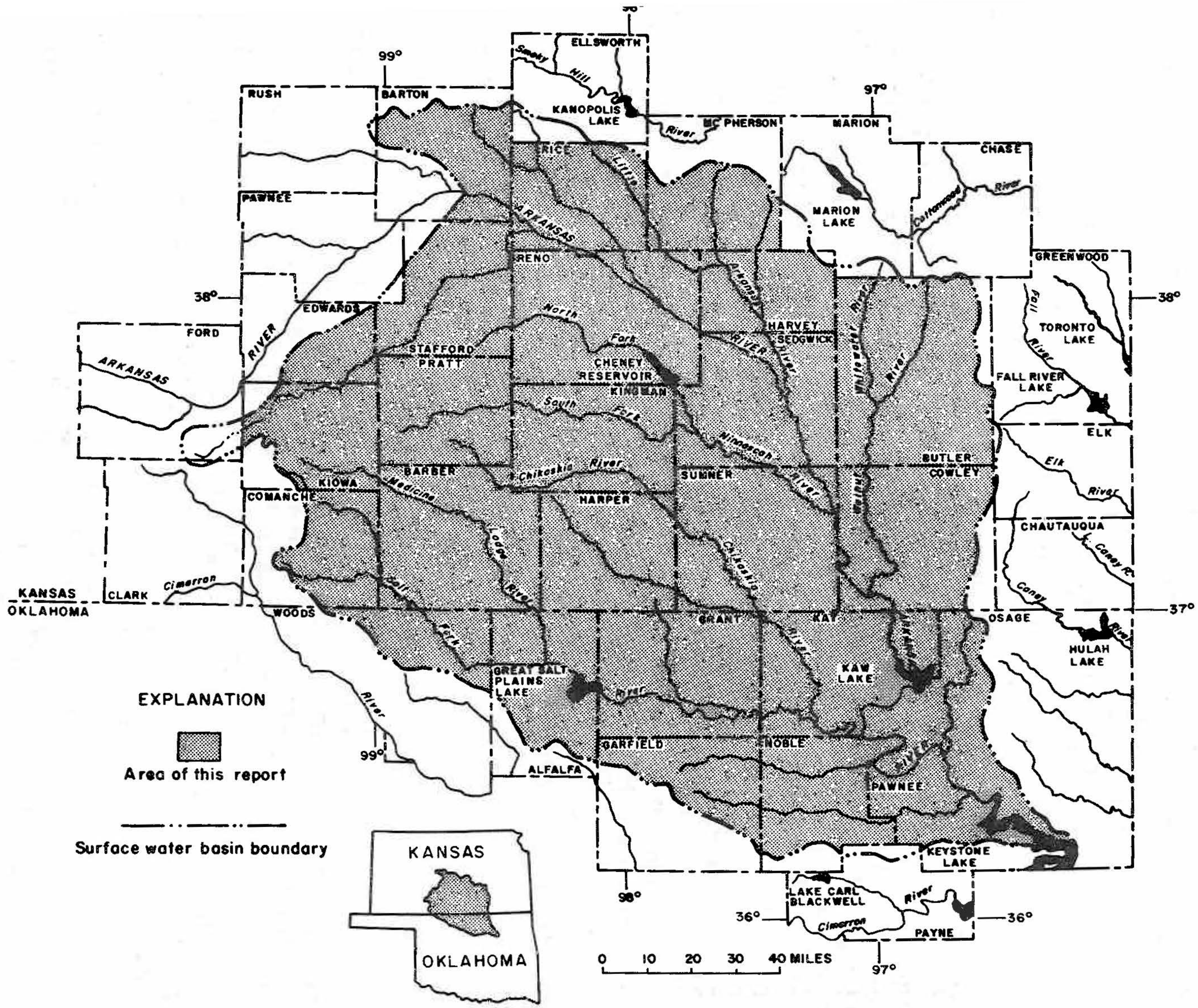

Figure 1.--Location of study area.

The availability of ground water is an important consideration in planning the development of water resources in the Middle Arkansas River basin. In much of the basin large-capacity wells can furnish a dependable and economical supply for municipal, industrial, and agricultural uses. In some places ground water may be the only local source of water for continued growth of the economy. Ground water, although limited in parts of the basin, might be used for temporary municipal or industrial supply until another source could be developed.

WELL-NUMBERING SYSTEM

In this report all wells are numbered according to the U.S. Bureau of Land Management system of land subdivision. In this numbering system, the first set of digits of a well number indicates the township; the second set, the range; and the third set, the section in which the well is located. Sections are subdivided into quarter section, quarter-quarter section, and quarter-quarter-quarter section. The quadrants are lettered a, b, c, and d in a counterclockwise direction beginning in the northeast quadrant. The first letter denotes the 160-acre tract; the second, the 40-acre tract; and the third, the 10-acre tract. In Reno County, Kans., for example, the number 23S-5W-19baa indicates that the well is in the NE¼NE¼NW¼ sec.19, T.23 S., R.5 W. (fig. 2). In Kansas the townships are numbered south from the north State boundary and the ranges are numbered east or west of the sixth principal meridian. In Oklahoma the townships are numbered north from the Oklahoma base line and the ranges are numbered east or west of the Indian meridian for the area discussed in this report.

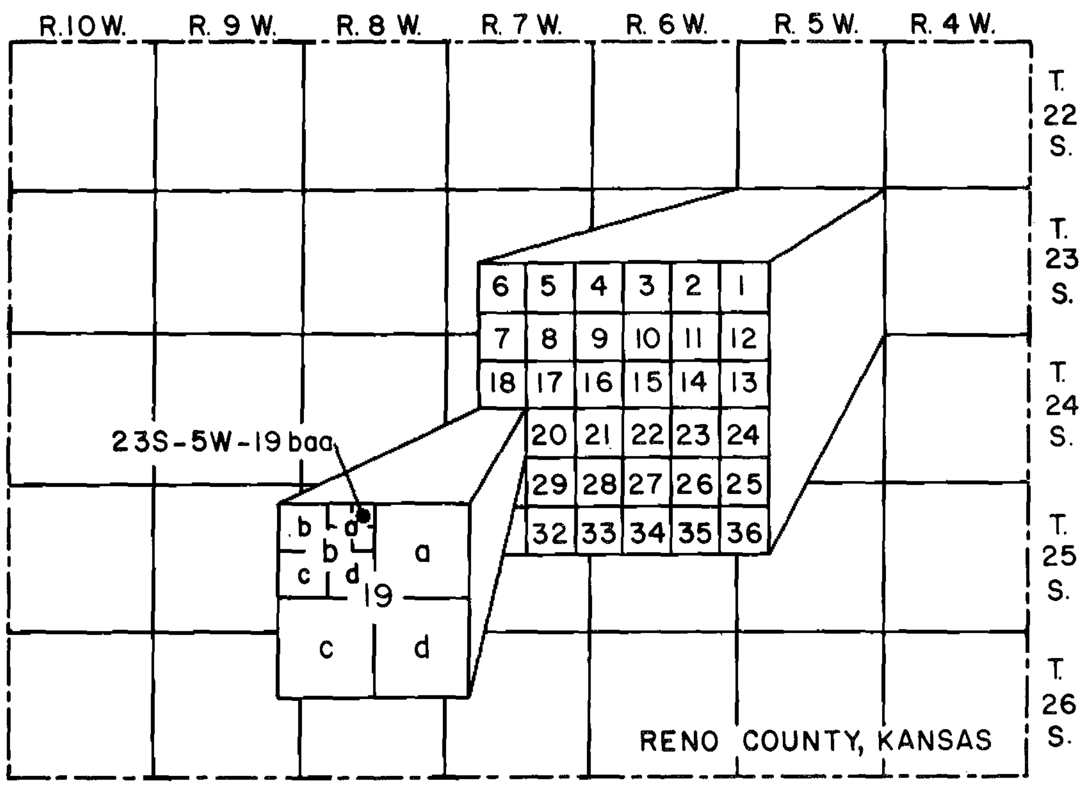

Figure 2.--Well-numbering system.

GEOLOGIC SETTING

The rocks that crop out or that are aquifers in the Middle Arkansas River basin are grouped, for this report, in two general categories--consolidated and unconsolidated deposits. The consolidated deposits (bedrock), which include the formations of Pennsylvanian to Cretaceous age, consist mainly of shale, limestone, sandstone, siltstone, and some dolomite and gypsum. The Pennsylvanian rocks crop out in the eastern tier of counties and are overlain westward by rocks of Permian age or by unconsolidated deposits. Rocks of Cretaceous age partly overlie the Permian rocks and crop out in the northern and western counties of the basin.

The unconsolidated deposits, which include younger surficial sediments, consist mainly of gravel, sand, silt, and clay ranging in age from Tertiary to Quaternary. The thickness of the unconsolidated deposits ranges from less than 10 feet in the upland valleys to 350 feet southeast of Hutchinson (Reno County), Kans.

The principal geologic units in the Middle Arkansas River basin are listed in table 1, and the areas of outcrop are shown on the geologic maps (pls. 1, 2). Additional information about the geologic units is given in the generalized sections for the individual counties.

GROUND WATER

Aquifer Characteristics

The availability of ground water in an area depends primarily on the ability of the aquifers (rocks that will yield significant quantities of water to wells) underlying the area to store and transmit water.

The storage coefficient (S) of an aquifer is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. The storage coefficient is a dimensionless number. The storage coefficient for the consolidated aquifers might be as large as 0.2 in areas of outcrop where the water is unconfined. Where the consolidated aquifers contain water that is semi-confined or artesian, storage coefficients are assumed to range from 0.0001 to 0.005. The coefficient for the unconsolidated aquifers ranges from 0.01 to 0.2 and averages about 0.15. The lower storage coefficients of the unconsolidated deposits are related to the semiconfined water that occurs locally.

Transmissivity (T) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. The units for transmissivity are square feet (sq ft) per day. The term "transmissivity" replaces the term "coefficient of transmissibility," which was formerly used by the U.S. Geological Survey and which was reported in the inconsistent units of gallons per day per foot. To convert a value for coefficient of transmissibility to the equivalent value of transmissivity, multiply by 0.134; to convert from transmissivity to coefficient of transmissibility, multiply by 7.48. The

Table 1.--Generalized columnar section of geologic units for the Middle Arkansas River basin, Kansas and Oklahoma. The stratigraphic nomenclature and correlations used are from several sources and may not necessarily follow usage of the U.S. Geological Survey.

System	Kansas			Oklahoma		
	Series	Group	Geologic unit	Series	Group	Geologic unit
Quaternary	Holocene and Pleistocene		Alluvium	Holocene and Pleistocene		Alluvium
			Dune sand			Terrace deposits
			Silt			
			Undifferentiated Pleistocene deposits			
			Loveland Formation			
			Crete Formation			
			Sappa Formation			
			Grand Island Formation			
			Fullerton Formation			
			Holdrege Formation			
Tertiary	Pliocene		Ogallala Formation	Pliocene		Ogallala Formation
Cretaceous	Upper Cretaceous	Colorado	Carlile Shale			
			Greenhorn Limestone			
			Graneros Shale			
	Lower Cretaceous		Dakota Sandstone			
			Kiowa Shale			
			Cheyenne Sandstone			
Permian	Upper Permian	Whitehorse	Whitehorse Sandstone	Guadalupe	Whitehorse	
	Lower Permian	Nippewalla	Dog Creek Shale	Leonard	El Reno	
			Blaine Gypsum			Blaine Gypsum
			Flowerpot Shale			
			Salt Plain Formation			
			Harper Siltstone		Clear Fork	Hennessey Shale Cedar Hills Sandstone Member
		Sumner	Stone Corral Formation			
			Ninnescah Shale			Garber Sandstone
			Wellington Formation		Wichita	Wellington Formation
		Chase		Wolfcamp	Chase	
		Council Grove			Council Grove	
		Admire			Admire	
Pennsylvanian	Upper Pennsylvanian	Wabaunsee		Virgil	Wabaunsee	Vanoss Formation
						Ada Formation
					Shawnee	Lecompton Limestone
					Douglas	Vamoosa Formation
				Missouri	Ochelata	
					Skiatook	

transmissivity is equal to the product of aquifer saturated thickness and hydraulic conductivity. The transmissivity of the consolidated aquifers is not known, but is believed to be less than 2,700 sq ft per day. Aquifer tests have shown that the transmissivity of the unconsolidated aquifers ranges from 1,300 to 53,000 sq ft per day.

The hydraulic conductivity (K) of a water-bearing material is the volume of water at the prevailing kinematic viscosity that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for hydraulic conductivity are feet per day. The term "hydraulic conductivity" replaces the term "field coefficient of permeability," which was formerly used by the U.S. Geological Survey and which was reported in the inconsistent units of gallons per day per square foot. To convert a value for field coefficient of permeability to the equivalent value of hydraulic conductivity, multiply by 0.134; to convert from hydraulic conductivity to coefficient of permeability, multiply by 7.48.

The values for hydraulic conductivity and saturated thickness presented later in this report and storage coefficient (assumed) can be used to estimate the drawdown at various distances from a well discharging at a constant rate. In southwestern Stafford County, Kans., for example, the saturated thickness (b) is 200 feet (pl. 3). The hydraulic conductivity of the Grand Island Formation (see table, page 62) ranges from 130 to 500 ft per day. Because the average hydraulic conductivity for a formation generally is nearer the lower limit of the range, 200 ft per day was assumed to be a proper value to compute transmissivity as follows:

$$T = bK = (200)(200) = 40{,}000 \text{ sq ft per day.}$$

This transmissivity value was then used to construct the lines on figure 3. The theory, mathematical equations, and assumptions for constructing such graphs are described by Theis (1935), Wenzel (1942), and Jacob (1950). Graphs as shown on figure 3 also can be used to compute the mutual interference of wells as defined in most text books on ground-water hydrology. Examples of the use of these curves are given by Fader (1957, 1967).

Availability

The yield of a well depends on the thickness and hydraulic conductivity of the water-bearing materials, the amount of penetration of these materials by the well, the diameter of the well, the efficiency of the well screen, the efficiency of the pump, and other factors. Because of the wide range in these factors, well yields cannot be predicted accurately. However, an estimate of yield is possible if the following assumptions are made: (1) sites for the wells are selected after proper test drilling, (2) wells are constructed to specifications used by successful drillers in the area, (3) properly designed pumping equipment is used, (4) the wells penetrate the entire thickness of the aquifer, and (5) hydraulic conductivity of the water-bearing materials is uniform. In practice, the hydraulic conductivity of the materials differs considerably owing to the heterogeneous distribution of the materials in the aquifer. Thus, a well screened in coarse gravel in an area where the saturated thickness is less than 40 feet may yield more water than a well screened in fine-grained material having a much greater saturated thickness.

Plates 3 and 4 show estimated well yields, which reflect the general availability of water to properly constructed wells.

In general, yields of less than 10 gpm (gallons per minute), or 0.02 cfs (cubic feet per second), of good quality water are obtained from

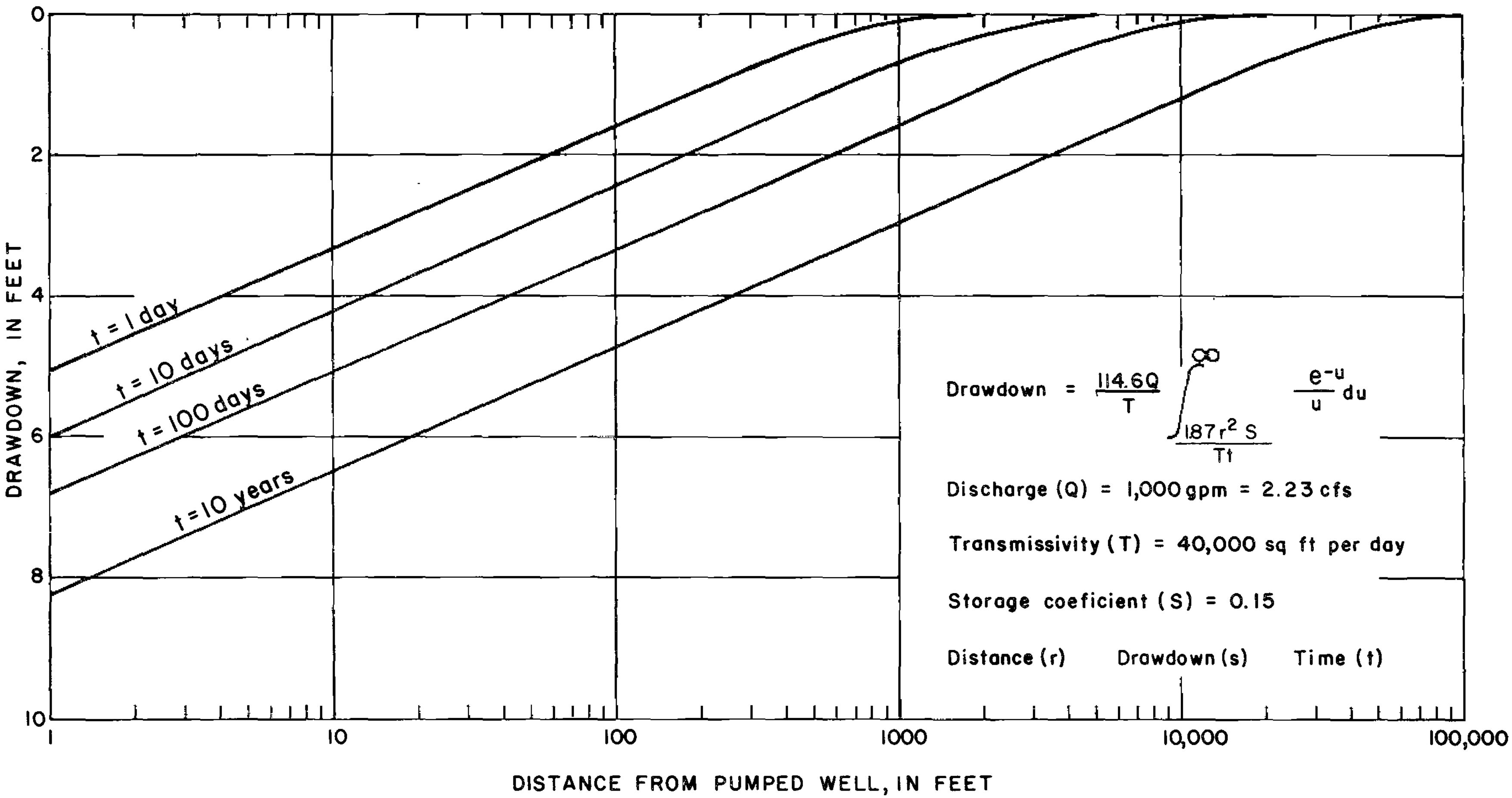

Figure 3.--Theoretical drawdown of water level at various distances from a well discharging at a constant rate.

shallow wells in outcrop areas of the consolidated rock formations. If the wells were drilled deeper to penetrate a larger thickness of aquifer, the well yield probably would be greater, but the water might be so highly mineralized that it would be unusable. There are exceptions, as yields of 350 gpm (0.78 cfs) have been reported from wells penetrating solution channels in the Sumner Group in the eastern part of the basin.

Yields to wells screened in the unconsolidated deposits, which are the principal aquifer in the basin, have been reported to be as large as 4,000 gpm (8.9 cfs). Although wells in this aquifer in many places will yield more than 1,200 gpm (2.67 cfs), most pumping plants are designed to pump at a smaller rate.

Chemical Quality

Chemical analyses of water from selected wells are given in tables for each individual county. In general, the water from the consolidated aquifers is of undesirable chemical quality for most uses. Exceptions occur in areas of outcrop, where the aquifers are recharged by fresh water from precipitation. Even in these areas, however, water from deeper wells generally is more mineralized than water from the unconsolidated deposits.

Water from the unconsolidated deposits in Kansas is generally of good chemical quality for irrigation and is commonly used by municipalities without treatment (other than chlorination). However, many residents use home water softeners to reduce hardness. Locally, the lower parts of the unconsolidated aquifers may contain water that is highly mineralized from natural sources, and the upper parts of the aquifers may contain highly mineralized water that has seeped from surface streams or water that has become highly mineralized due to man's activities. In areas where the lower parts of the unconsolidated aquifers contain highly mineralized water, thin clay or silt lenses may be deterring the upward movement of highly mineralized water to wells; therefore, test holes that penetrate these separating layers or lenses must be carefully plugged and production wells must be screened above the clay lenses. Even then, the highly mineralized water may move into the wells after long periods of heavy pumping.

The quality of the water from the unconsolidated aquifers in Oklahoma differs widely from area to area, and the water commonly may contain high concentrations of sulfate and chloride ions.

Extent of Development

Annual Withdrawals

In 1968 about 240,000 acre-feet of ground water was withdrawn for all uses in the Kansas part of the Middle Arkansas River basin. About 150,000 acre-feet of water was used to irrigate about 110,000 acres of cropland. More than 95 percent of all water withdrawn was from the unconsolidated aquifers. In 1969 about 30,000 acre-feet of ground water was withdrawn for all uses in the Oklahoma part of the basin. About 17,000 acre-feet of water was used to irrigate about 12,000 acres of cropland.

Water-Level Changes

Representative changes in water level in the Middle Arkansas Basin are shown by hydrographs (fig. 4) and maps (figs. 5, 6). Hydrographs for wells 25S-1W-26db in Sedgwick County and 20S-13W-12ada in Barton County (fig. 4) reflect water-level fluctuations due to changes in climate. The rest of the wells shown on figure 4 are in the Wichita well field where water-level fluctuations are related to both changes in climate and pumping of ground water. The maximum fluctuation since 1937 due to change in climate only is about 10 feet. Water levels declined more than 28 feet in part of the Wichita well field from 1940 to 1956, but have subsequently recovered owing to increased precipitation (and, consequently, a reduced pumping load) and a shifting of part of the pumping load to surface-water sources. The areal extent of the decline of water level in the Wichita well field is depicted on figure 7.

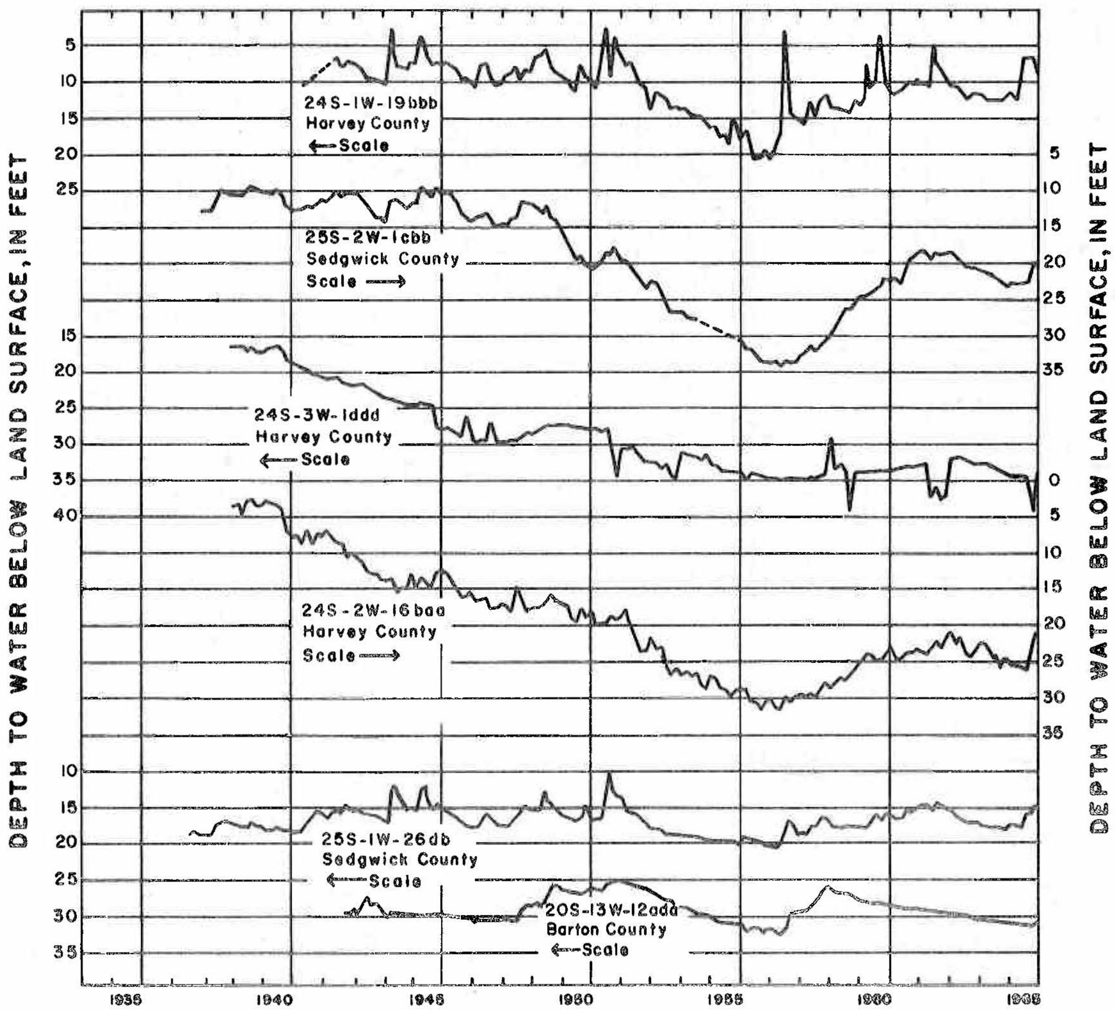

Figure 4.--Hydrographs for selected wells in Barton, Harvey, and Sedgwick Counties, Kans. (modified from Broeker and Winslow, 1966, fig. 2).

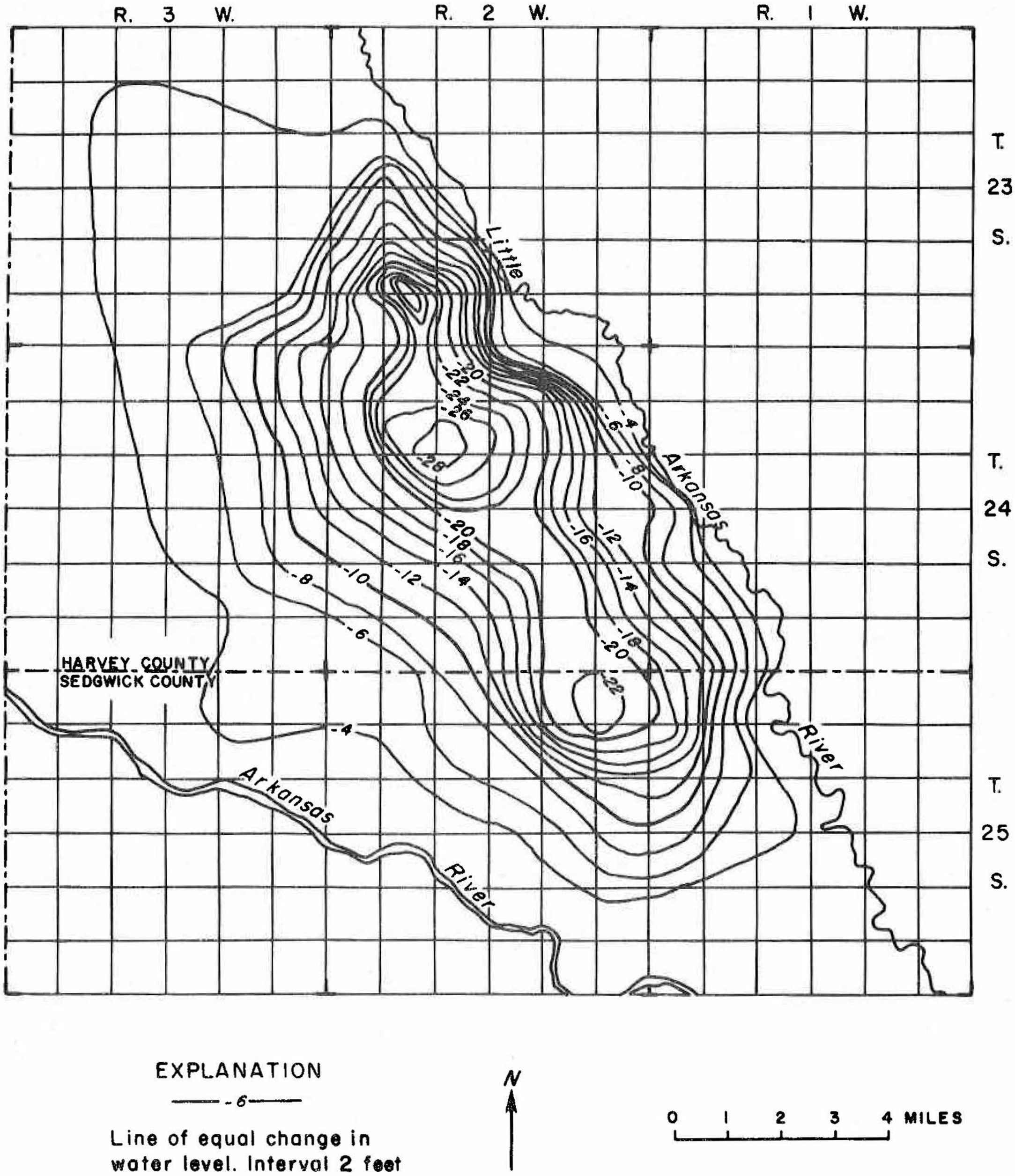

Figure 5.--Change in water level from August 30, 1940, to December 31, 1956, Wichita well-field area, Kans. (from Stramel, 1967, fig. 6).

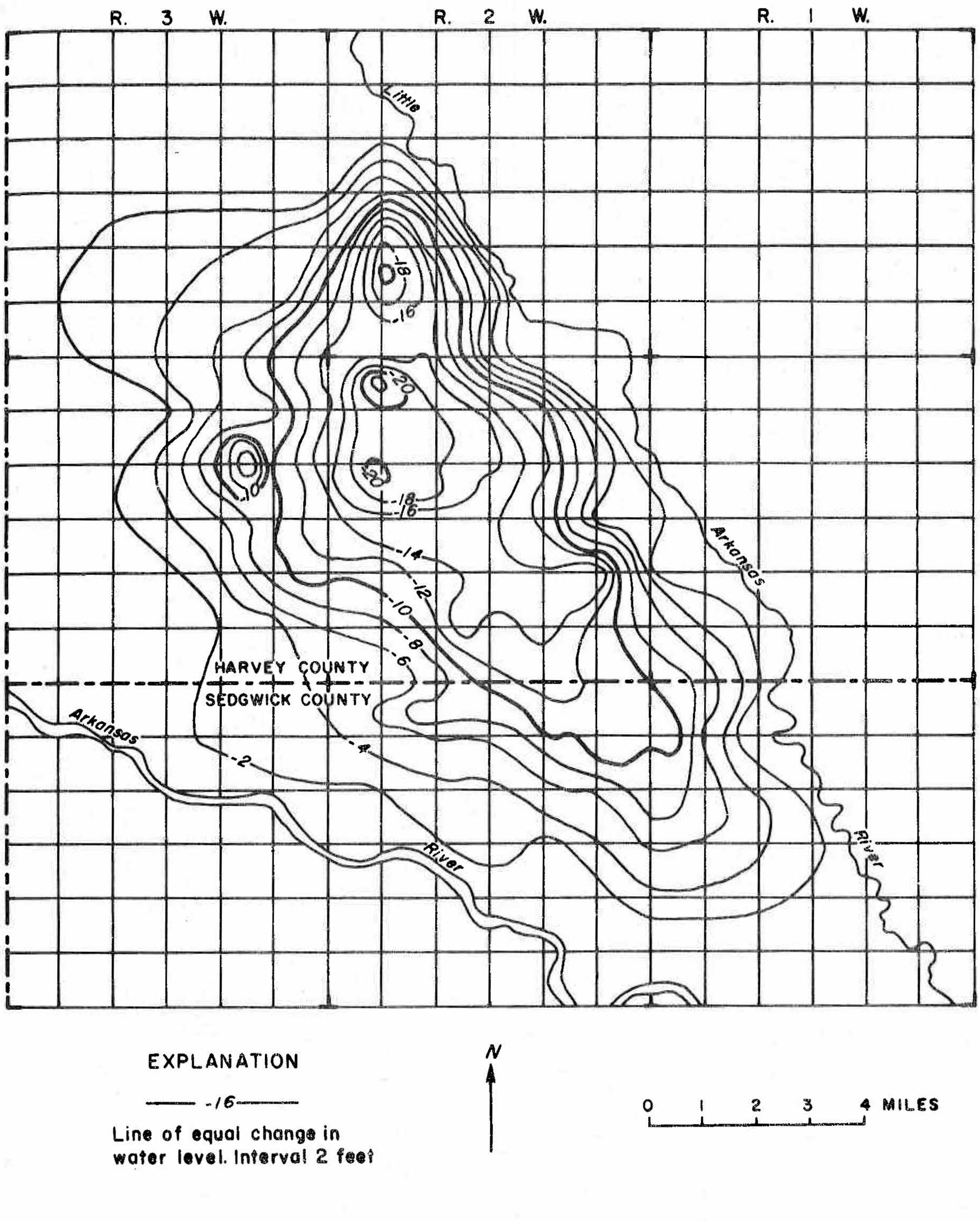

Figure 6.--Change in water level from August 30, 1940, to January 1, 1971, Wichita well-field area, Kans.

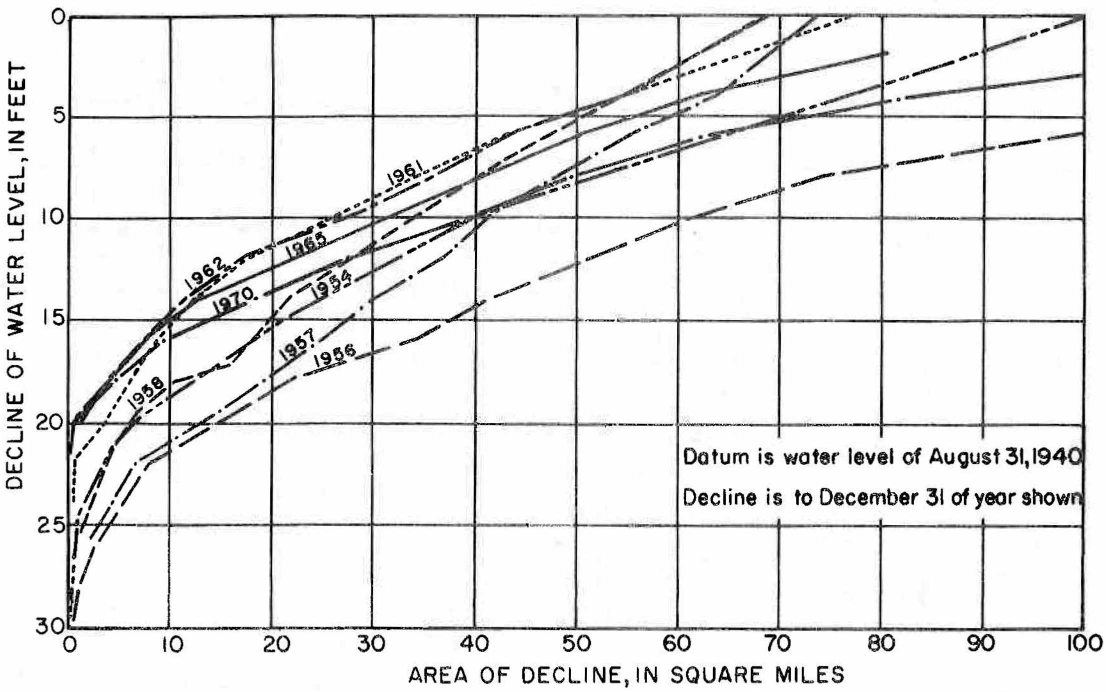

Figure 7.--Areal decline of water level in the Wichita well-field area, Kans. (modified from Stramel, 1967, fig. 16).

Potential For Development

Ground-Water Storage

The total amount of ground water in storage in the consolidated-rock aquifers in the Middle Arkansas River basin, though not determined, is probably as large or larger than that given for the unconsolidated aquifers.

The total amount of ground water stored in unconsolidated aquifers in the basin is about 84 million acre-feet, which was estimated by multiplying the volume of saturated unconsolidated deposits in the basin by a storage coefficient of 0.15 (or 0.20 in some areas of Oklahoma). However, this volume of water does not represent the amount that can be pumped; drilling enough wells to drain all the water from the aquifer is not economically feasible. As water levels are lowered by pumping, the saturated thickness decreases, well yields decrease, and pumping lifts increase; thus, pumping becomes impractical or uneconomical for most users before the aquifer is completely dewatered. Probably only 50 percent of the water in storage is economically recoverable.

Annual Recharge

The unconsolidated aquifers are recharged at a rate of about 2 million acre-feet annually. This figure is the sum of estimates given on the second part of the individual county discussions. Recharge to the consolidated aquifers was not estimated.

Projected Development

Small well fields might be developed almost anywhere in areas of outcrop of consolidated aquifers; the wells would obtain water from sandstone, sandy shale, or solution channels in limestone and dolomite. However, because of the low hydraulic conductivity of most of these rocks and the generally poor chemical quality of the water, large-scale development of water supplies from these sources is not expected.

The unconsolidated aquifers have been extensively developed north of Wichita in northern Sedgwick and southern Harvey Counties and near some of the other large communities in the basin. Away from these areas, large supplies of ground water are still undeveloped but available. The extent of future development will depend on many factors, including intended use of water, economics, soil type, pumping lift, location and extent of highly mineralized water in the aquifer, and management decisions as to how the aquifer systems should be operated. If the amount of water that is recharged annually is the principal criterion, the maximum rate of withdrawal will be about 2 million acre-feet per year. This rate would easily satisfy the 1 million acre-feet of water estimated for irrigation needs in the year 2000 with an excess for other uses. If mining of ground water is allowed, perhaps half of the water in storage, or about 42 million acre-feet of water, can be withdrawn over a period of years in addition to the annual recharge.

Large withdrawals of ground water would cause significant lowering of water levels and could eventually reduce or deplete the flow in the streams of the area. The extent and rate of withdrawals of ground water eventually will become a management decision. A digital-computer or electrical analog model to estimate the effects of withdrawals on ground-water levels and on streamflow would aid in making these decisions and could be planned for future projects. Although models are available, a model study was beyond the scope of this project.

GROUND WATER BY COUNTIES

Sources of Data and Methods of Estimation

The first part of each county discussion contains a generalized columnar section of the geologic formations that are in the subsurface or are shown on plates 1 and 2, and estimates of the water-bearing properties of the formations. The information given is from existing ground-water reports for the county described or is estimated from information in reports for adjacent counties and from information in the files. Estimates of yields to wells are based on information given in existing county reports, on maps by Schoff (1955) and Bayne and Ward (1967), and on data in the files of the Oklahoma Water Resources Board. The ranges of yield shown are generalized from very limited data and the reader is cautioned that the upper limit shown may not be available at any given site. The values for hydraulic conductivity are based on aquifer tests or are estimates by the authors.

The comments about chemical quality of water shown in the remarks column of the generalized section were compiled from previous reports or from information in the files. In general the chemical quality of water for municipal and domestic use was described as good if the water contained concentrations of less than 500 mg/l (milligrams per liter) dissolved solids or less than 250 mg/l chloride and sulfate, fair if it contained between 500 and 1,000 mg/l dissolved solids or between 250 and 500 mg/l chloride and sulfate, and poor if it contained more than 1,000 mg/l dissolved solids or more than 500 mg/l chloride and sulfate. However, because the suitability of the water was not defined by previous authors, the evaluations shown for each county should be used only as guidelines.

The second part of each county discussion contains related hydrologic information. The estimated irrigated area for Kansas is from R. L. Herpich (written commun., 1970) and for Oklahoma is from data provided by the Oklahoma Water Resources Board. The volume of water applied was determined from the 1966 rate of application computed from the report by the Kansas Water Resources Board (1967) or was estimated by the authors. The estimated volume of ground water pumped by municipal and industrial users is from data in the files compiled for the report by Murray (1968) and from data reported to the Oklahoma Water Resources Board. The projected irrigated area in the year 2000 for Kansas is from the Kansas Water Resources Board (1967) (modified by the authors' estimate of water available in a few instances), and for Oklahoma was estimated by the authors.

The estimated annual recharge to the unconsolidated aquifers in Kansas was modified from a report by the Kansas Water Resources Board (1967). The annual recharge in Oklahoma was estimated by the authors from data published in previous ground-water reports and from base flow in the streams in the area, as shown by the U.S. Geological Survey (1968, 1969).

The amount of ground water in storage in the unconsolidated deposits was estimated from data published by the Kansas Water Resources Board (1967), a map by Bayne and Ward (1969), and from data compiled by the authors.

The estimated cost per 1,000 gallons of water from a well field capable of producing a minimum of 1 million gallons per day includes the following: cost of construction of one or more wells allocated on the basis that large-capacity wells are used one-fourth of the year, cost of pumping equipment connected to the power and water lines at the well site, interest cost at 6½ percent for a period of 25 years, and cost of power for pumping. The estimated cost does not include the cost of water lines from the well field to the consumer or the cost of electrical power lines to the pumps. The cost data in this report are principally for municipal systems. The cost per 1,000 gallons for an irrigation system may be one-third to two-thirds that shown in this report. Estimated costs are based on 1970 values.

The third part of each county discussion contains a table of chemical analyses of water from selected wells. The concentrations for the chemical constituents and hardness are from previous reports or from the files of the U.S. Geological Survey. In Kansas most of the water samples were analyzed by the Division of Environmental Health of the Kansas State Department of Health. In Oklahoma the samples were analyzed by the U.S. Geological Survey.

Plates 1 and 2 are geologic maps showing potentiometric contours; the maps were modified from existing State Geological Survey of Kansas reports and State geologic maps. Where no previous report showed potentiometric contours, the contours were inferred from reported water levels and from points where land-surface contours crossed perennial streams. Few additional data were collected for this report; therefore, most of the potentiometric contours represent data collected during a period of about 20 years. In general, the potentiometric contours were mapped as water-table contours in previous reports. However, the authors of this report are of the opinion that water in parts of the area is semiconfined, and the term "potentiometric contour" is more appropriate.

Plates 3 and 4 are maps showing generalized potential well yield, saturated thickness of unconsolidated deposits, and location of selected wells. The data for the maps showing potential well yield and saturated thickness were modified from the same sources as those used to estimate the water in storage. In some areas shown as unconsolidated deposits on the geologic maps, the saturated thickness is not known or is less than the interval shown in the explanation. These areas are outlined by zero-saturated-thickness lines on the saturated thickness maps. In areas where the saturated thickness of unconsolidated deposits is small for the well yields shown, the yields are from one or more consolidated aquifers or from both consolidated and unconsolidated aquifers. The locations of the wells shown were obtained from previous ground-water reports, from applications for water rights as shown by the Kansas Water Resources Board (1967), from the files of the Oklahoma Water Resources Board, and from the files of the U.S. Geological Survey. None of the locations were field checked; therefore, some duplication can be expected from the several sources of information. Also, a number of the applications are never completed (the wells are never drilled); consequently, more wells may be shown than actually existed in 1966.

BARBER COUNTY, KANSAS

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	70	Silt, sand, and gravel in major stream valleys.	0-500	70-260	
			Dune sand	40	Fine to medium sand.	0-10	--	Generally is unsaturated.
			Loveland and Crete Formations	90	Eolian silt and clay. Thin sand and gravel lenses in base of Crete Formation.	0-500	70-400	
			Sappa and Grand Island Formations	50	Sand, gravel, and silt with local clay and volcanic ash lenses.	0-1,000	70-700	Locally covered by dune sand in the northern part of the county.
Cretaceous	Lower Cretaceous		Kiowa Shale and Cheyenne Sandstone	100	Dark-gray shale and fine- to medium-grained sandstone.	--	--	Generally is unsaturated.
Permian	Upper Permian	Whitehorse	Whitehorse Sandstone	195	Reddish-brown shale and sandstone beds with some gypsum, dolomite, and anhydrite.	0-10	--	Water probably of poor chemical quality.
	Lower Permian	Nippewalla						

The irrigated area in 1968 was 840 acres and a total of 1,300 acre-feet of water was applied. Of this total, about 870 acre-feet was ground water. An additional 1,500 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 5,500 acres. The unconsolidated deposits receive 40,000 acre-feet of recharge annually, and 700,000 acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 10 to 100 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.100 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
30S-13W-18aa	--	8-18-41	Loveland and Crete Formations	329	7.4	14	280
31S-11W-30cc	21	9- 6-45	Alluvium	627	120	150	190
31S-12W-24aaa	25	9- 7-45	Alluvium	286	35	15	200
31S-12W-24acc	28	9- 8-45	Alluvium	472	77	84	270
32S-12W-12abb	94	8-25-45	Nippewalla Group	8,440	2,300	3,100	2,100
34S-10W-16bda	50	8-15-67	Alluvium	930	260	78	550
35S-13W- 6aa	--	8-27-41	Sappa or Grand Island Formation	480	99	31	340

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	146	Very coarse gravel, sand, silt, and clay. Material probably finer in small valleys.	1,000+	130-700	In Arkansas and Walnut Valleys.
						0-500	70-130	In Cheyenne Bottoms and smaller valleys. Water in Cheyenne Bottoms probably of poor chemical quality.
			Dune sand	50	Fine to medium sand; contains minor amounts of silt and clay.	0-10	--	Generally is unsaturated.
			Silt		Silt and sandy silt.	--	--	Generally is unsaturated.
			Undifferentiated Pleistocene deposits	40	Silt, sandy silt, fine sand, and clay with caliche and local lenses of sand and gravel.	0-10	--	
			Loveland and Crete Formations	140	Silt, sandy silt, and fine sand with local lenses of coarse sand and gravel.	0-100	30-130	Covered by silt deposits. Water may be of poor chemical quality.
			Grand Island Formation	187	Sand, gravel, silt, and clay	500-1,000+	130-400	Covered by dune sand. Water may be of poor chemical quality.
Cretaceous	Upper Cretaceous	Colorado	Carlile Shale	85	Chalky shale and thin beds of chalky limestone. Contains thin flat concretions in lower part.	0-10	--	Water generally hard or very hard.
			Greenhorn Limestone	90	Light-gray to bluish-gray shale with hard chalk beds. Contains thin crystalline limestone beds in lower part.	0-10	--	
			Graneros Shale	30-40	Dark-gray shale. Contains selenite, pyrite, and thin beds of sandstone.	0-10		
	Lower Cretaceous		Dakota Sandstone	300	Alternating beds or lenses of varicolored clay, shale, siltstone, and sandstone. Contains lignite, pyrite, and thin ironstone beds.	0-100	1-70	Chief source of water in upland areas. Water may be of poor chemical quality.
			Kiowa Shale	168	Light-gray to black shale and sandy shale. Contains lenses of sandstone.	0-10	--	
			Cheyenne Sandstone	134	Very fine to medium-grained sandstone and siltstone. Contains some clay and shale lenses or beds.	0-10	--	Water probably of poor chemical quality.

The irrigated area in 1968 was 8,200 acres and a total of 12,300 acre-feet of water was applied. Most of this total was ground water. An additional 4,600 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 50,000 acres. The unconsolidated deposits receive 60,000 acre-feet of recharge annually, and 5 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and less than 200 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.039 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
16S-14W- 2cb	43	10-16-44	Greenhorn Limestone	356	9.0	23	310
16S-14W-26bb	20	9- 7-44	Carlile Shale	2,280	100	440	1,600
17S-11W-36cc	60	10-12-44	Undifferentiated Pleistocene deposits	320	6.2	16	270
17S-12W-27cc	154	10-15-44	Dakota Sandstone	818	310	25	540
18S-15W- 1bc	220	10-16-44	Dakota Sandstone	858	76	260	45
19S-12W-28cc	25	10-16-44	Alluvium	898	140	260	450
19S-13W-34cd	70	10-27-42	Undifferentiated Pleistocene deposits	379	69	33	240
19S-15W-34aa	30	9- 6-44	Alluvium	768	53	170	450
20S-11W-18ba	31	10-24-42	Alluvium	508	36	150	240
20S-15W-33db	35	9- 7-44	Alluvium	611	78	150	350

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	35	Silt, sand, and chert and limestone gravel.	0-500	70-400	Water may be of poor chemical quality.
			Silt	10	Silt, fine sand, and clay.	0-10	--	Generally is unsatu-rated.
Permian	Lower Permian	Sumner	Wellington Formation	350	Light-grayish-green and some red silty shale beds. Contains a few discontinuous limestone beds. Locally thin seams of gypsum in the lower part.	0-500	--	Water generally of poor chemical quality. Larger yields are from solution zones in the gypsum beds.
		Chase		300	Multicolored shale, limestone, and few dolomite beds.	0-100	--	Water generally of poor chemical quality.
		Council Grove		400	Limestone and shale beds.	0-10	--	Water generally of poor chemical quality.

The irrigated area in 1968 was 1,200 acres and a total of 1,500 acre-feet of water was applied. Of this total, about 150 acre-feet was ground water. An additional 2,100 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 2,000 acres. The unconsolidated deposits in the valleys receive about 10,000 acre-feet of recharge annually, and aquifers in upland areas receive about 30,000 acre-feet of recharge. The amount of water stored in the unconsolidated deposits is 15,000 acre-feet. The amount of water stored in consolidated rock aquifers is unknown. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 10 to 85 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.060 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
23S- 3E-17bad	72	8-21-68	Alluvium	920	330	57	680
23S- 7E-36dcc	42	8- 6-63	Chase Group	--	94	99	440
24S- 3E-17cad	46	1-30-67	Sumner Group	777	290	15	560
24S- 4E-29dba	74	9-15-67	Chase Group	2,160	1,100	220	1,300
24S- 4E-30cad	24	8- 8-63	Alluvium	--	498	660	1,000
24S- 5E-34cdd	106	8-14-63	Chase Group	--	227	58	450
26S- 3E-16acd	70	2-13-68	Sumner Group	2,170	1,300	74	1,500
27S- 6E-22bba	38	5-31-66	Alluvium	356	32	12	300

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	135	Sand, gravel, and silt.	0-500	130-400	Higher yields generally from stream valleys.
			Dune sand	40	Fine to medium sand.	Not known to yield water to wells.	--	Generally is unsaturated.
			Loveland and Crete Formations	60	Silt and sandy silt with some clay stringers; sand and gravel in lower parts in some areas.	0-100	70-400	
			Grand Island Formation	170	Silt, sand, gravel, and caliche; contains some clay lenses.	0-100	70-260	Locally covered by dune sand in northern part of county.
Tertiary	Pliocene		Ogallala Formation	50	Silt, fine sand, gravel, clay, and caliche.	0-100	--	Generally is unsaturated.
Cretaceous	Lower Cretaceous		Kiowa Shale	300	Dark-gray and black shale; contains lenses of fine sand and sandstone.	0-10	--	Water probably of poor chemical quality.
			Cheyenne Sandstone	50	Gray, tan, and white fine- to medium-grained sandstone.	0-10	1-70	Water probably of poor chemical quality.
Permian	Upper Permian	Whitehorse	Whitehorse Sandstone		Fine-grained friable sandstone, siltstone, and shale.	0-10	--	Water probably of poor chemical quality.
	Lower Permian	Nippewalla						

The irrigated area in 1968 was 1,700 acres and a total of 2,500 acre-feet of water was applied. Most of this total was ground water. An additional 650 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 2,500 acres. The unconsolidated deposits receive about 20,000 acre-feet of recharge annually, and 700,000 acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 30 to 100 feet in the uplands. Water of questionable quality for stock and domestic use is probably available from the consolidated rock formations throughout the county. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.090 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
32S-20W-34cdc	67	8-21-67	Alluvium	320	38	17	250

COWLEY COUNTY, KANSAS

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick- ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc- tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	55	Silt, clay, and arkosic sand and gravel in Arkansas Valley.	100-1,000	260-700	Water may be of poor chemical quality.
					Silt, clay and chert gravel in other stream valleys.	0-100	40-130	Water probably of poor chemical quality.
			Silt	30	Silt.	0-10	--	Generally is unsatu- rated.
			Loveland and Crete Formations	55	Upper part is silt and sandy silt. Lower part is silt, clay, sand, and arkosic gravel in Arkansas Valley, and locally chert gravel in Walnut Valley.	0-500	40-400	Generally is unsatu- rated.
			Sappa and Grand Island Formations	40	Upper part is silt and sandy silt. Lower part is silt, clay, sand, and gravel. Arkosic sand and gravel in Arkansas Valley; chert gravel elsewhere.	0-500	30-260	Unsaturated in some areas.
Permian	Lower Permian	Sumner	Wellington Formation	80	Light-gray, green, and some red silty calcareous shale. Contains some discontinuous limestone beds. Locally thin seams of gypsum in lower part.	0-10	--	Water generally of poor chemical quality. Some hard water may be obtained from wells near outcrop.
		Chase		385	Multicolored shale, limestone, and some dolomite beds.	0-100	--	Water generally of poor chemical quality.
		Council Grove		270	Limestone and shale beds.	0-10	--	Water generally of poor chemical quality.
		Admire		110	Grayish-blue shale and limestone beds.	0-10	--	Water generally of poor chemical quality.
Pennsyl- vanian	Upper Penn- sylvanian	Wabaunsee		210	Shale, sandy shale, and limestone beds with some sandstone and coal.	0-10	--	Water generally of poor chemical quality.

The irrigated area in 1968 was 5,400 acres and a total of 6,500 acre-feet of water was applied. Of this total, about 4,870 acre-feet was ground water. An additional 4,500 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 10,000 acres. The unconsolidated deposits receive about 70,000 acre-feet of recharge annually, and 500,000 acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 40 to 120 feet in the uplands. Water in the lower parts of the unconsolidated deposits may be of poor chemical quality. Small quantities of usable water may be obtained from the consolidated rock formations in localized areas. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.030 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
31S- 4E-18cbb	34	9-25-58	Alluvium	621	96	100	370
31S- 6E- 3bcc	20	1-24-67	Alluvium	325	15	10	280
31S- 8E-17cdd	75	10- 2-58	Council Grove Group	392	44	25	92
32S- 3E-18bba	35	8-12-56	Alluvium	--	120	8,300	--
32S- 3E-18cab	40	1-14-59	Silt deposits	436	78	25	330
32S- 3E-25bdc	113	9- 4-63	Chase Group	1,330	620	83	850
33S- 3E-25bbb	34	3-20-44	Loveland and Crete Formations	525	60	51	250
33S- 3E-34dcc	45	9-22-58	Sumner Group	498	18	92	280
33S- 6E-13bcd	38	3-15-67	Alluvium	1,340	430	110	610
33S- 7E-14adc	100	10- 2-58	Council Grove Group	423	20	17	310
34S- 8E-30abc	365	10- 2-58	Wabaunsee Group	838	33	180	24
35S- 4E- 6bdc	30	3-13-67	Alluvium	1,270	280	420	460

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	100	Coarse sand and gravel. Contains silt and clay.	10-1,000+	400-700	
			Dune sand	50	Fine to medium sand.	0	--	Generally is unsaturated.
			Undifferentiated Pleistocene deposits	150	Silt and clay. May contain sand and gravel in the lower parts.	10-500	160-260	
			Grand Island Formation	300	Sand, gravel, silt, and clay.	1,000+	130-540	Covered by dune sand.
Tertiary	Pliocene		Ogallala Formation	70	Silt, sand, gravel, and caliche.	0	--	Generally is unsaturated.
Cretaceous	Upper Cretaceous	Colorado	Greenhorn Limestone	120	Chalky shale. Contains thin crystaline limestone beds at base and granular to chalky limestone in upper part.	0-10	--	
			Graneros Shale	35	Dark-gray shale. Contains sandy shale and sandstone lenses.	0-10	--	
	Lower Cretaceous		Dakota Sandstone	225	Varicolored sandy shale and clay. Contains lenticular beds of fine-grained sandstone.	10-100	1-70	Subsurface unit. Fluoride content of water may exceed standards.[1]
			Kiowa Shale	200	Dark-gray shale. Contains lenses of sandstone.	0-10	--	Subsurface unit.
			Cheyenne Sandstone	50	Gray, tan, and white fine- to medium-grained sandstone.	May be a supplemental source west of the Arkansas River.	1-70	Subsurface unit. Water may be of poor chemical quality.

[1]U.S. Federal Water Pollution Control Administration (1968)

The irrigated area in 1968 was 14,200 acres and a total of 20,000 acre-feet of water was applied. Most of this total was ground water. An additional 1,000 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 110,000 acres. The unconsolidated deposits receive about 50,000 acre-feet of recharge annually, and 7 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and less than 50 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.040 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
23S-19W- 9cc	67	8-15-45	Dakota Sandstone	666	290	21	340
23S-20W-16dd	124	8-18-45	Dakota Sandstone	415	88	22	200
24S-16W- 2bb	51	8-28-45	Grand Island Formation	277	18	16	190
24S-19W- 9ab	36	8-18-45	Alluvium	493	33	35	300
24S-20W-11dc	33	8-28-45	Undifferentiated Pleistocene deposits	347	7	7	280
25S-19W- 1ab	89	4-26-66	Grand Island Formation	176	15	6	130
25S-19W- 8add	60	5-25-66	Alluvium	1,140	520	43	540
25S-20W-16dc	74	8-18-45	Undifferentiated Pleistocene deposits	428	19	19	330
26S-16W- 6db	86	7-27-65	Grand Island Formation	263	15	10	170
26S-20W-18dcc	47	9-16-65	Alluvium	663	220	38	400

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	30	Silt, sand, and gravel.	0-100	--	
			Dune sand	20	Fine to medium sand and some silt.	0-500	--	Generally is unsaturated.
			Silt	10	Silt and locally clay.	0-10	--	Generally is unsaturated.
			Undifferentiated Pleistocene deposits	100	Sand and gravel chiefly in deeper channels; silt and some colluvium in upper part of unit.	0-500	130-200	Water may be of poor chemical quality in localized areas.
			Sappa Formation	25	Silt, fine sand, and some volcanic ash.	0-100	70-130	
			Grand Island Formation	45	Sand, gravel, silt, and some volcanic ash.	0-500	130-340	
			Fullerton Formation	20	Silt, clay, and some sand.	0-10	--	Covered by Sappa and Grand Island deposits.
			Holdrege Formation	45	Sand, gravel, silt, and clay.	10-500	70-400	
Permian	Upper Permian	Whitehorse	Whitehorse Sandstone					
	Lower Permian	Nippewalla	Salt Plain Formation	265	Red silty shale, siltstone, and sandstone beds.	0-10	--	Water may be of poor chemical quality.
			Harper Siltstone					
		Sumner	Ninnescah Shale	450	Varicolored shale, siltstone, and very fine grained silty sandstone.	0-10	--	Water may be of poor chemical quality.

The irrigated area in 1968 was 980 acres and a total of 1,300 acre-feet of water was applied. Most of this total was ground water. An additional 1,400 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 1,600 acres. The unconsolidated deposits receive about 60,000 acre-feet of recharge annually, and 900,000 acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and from 20 to 50 feet in the uplands. Water in the lower parts of the unconsolidated deposits may be of poor chemical quality in some areas. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.030 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
31S- 5W-10aaa	32	8-22-56	Undifferentiated Pleistocene deposits	386	33	32	190
31S- 6W- 1cdd	50	8-22-56	Ninnescah Shale	597	180	25	340
31S- 9W-16ddd	80	4-25-56	Grand Island Formation	285	10	14	180
32S- 7W-21ccc	70	4-24-56	Nippewalla Group	3,600	2,100	360	1,700
33S- 7W-12ccd	77	2- 1-66	Undifferentiated Pleistocene deposits	510	88	41	270
33S- 7W-34cdd	40	8-21-41	Undifferentiated Pleistocene deposits	731	110	41	260
34S- 7W- 8aaa	35	8-25-56	Undifferentiated Pleistocene deposits	1,190	120	190	370

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	50	Sand, gravel, silt, and clay in upper parts in Arkansas and Little Arkansas valleys.	1,000-2,000	130-1,300	Water may be of poor chemical quality adjacent to the Arkansas River.
					Silt, clay, and fine sand with some gravel locally in other valleys.	10-500	40-130	
			Dune sand	75	Fine to medium eolian sand.	--	--	Generally is unsatu-rated.
			Silt	30	Tan to pink calcareous eolian silt. Contains sandy zones and caliche nodules.	0-10	--	Generally is unsatu-rated.
Tertiary and Quaternary	Pliocene and Pleistocene		Undifferen-tiated terrace deposits and Ogallala(?) Formation	230	Tannish-gray silt and clay, coarse sand, and arkosic gravel. Locally contains lenticular beds of volcanic ash.	1,000-2,000	90-700	Covered by dune sand, alluvium, and silt deposits.
Permian	Lower Permian	Sumner	Ninnescah Shale	200	Alternating beds of brownish-red silty shale and siltstone; a few thin beds of gray-green silty shale in lower part; some gypsum.	0-10	--	Subsurface unit.
			Wellington Formation	600	Calcareous gray and blue shale; contains several thin beds of impure limestone and thin beds of gypsum and anhydrite.	0-350	--	Water generally of poor chemical quality. Usable water may be obtained from solution zones in gypsum beds in eastern part of county.

The irrigated area in 1968 was 6,600 acres and a total of 7,000 acre-feet of water was applied. Most of this total was ground water. An additional 30,000 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 15,000 acres. The unconsolidated deposits receive about 90,000 acre-feet of recharge annually, and 6 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 20 to 50 feet in the uplands. The depth to water may exceed 50 feet in the eastern part of the county. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.020 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
22S- 1W-16ac	89	10-25-37	Wellington Formation	1,110	520	79	640
22S- 3W-14aab	33	11-23-38	Undifferentiated Pleistocene deposits	482	41	63	430
23S- 2W-29cbb	231	12-16-49	Undifferentiated Pleistocene deposits	192	10	12	110
24S- 1W-34bca	46	3-21-41	Alluvium	424	64	17	330
24S- 2W-16bcc	244	12-22-49	Undifferentiated Pleistocene deposits	246	19	16	140

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	30	Silt, sand, and gravel in channels of major streams.	0-100	70-200	
			Dune sand	30	Fine to medium sand, some silt.	--	--	Generally is unsatu-rated.
			Silt	20	Silt and silty sand.	0-10	--	Generally is unsatu-rated.
			Undifferen-tiated Pleistocene deposits	50	Silt, sand, and some gravel deposited on slopes by sheet wash. Forms terraces in eastern part of county.	0-20	--	Yields water to wells in small areas in eastern part of county.
			Sappa and Grand Island Formations	150	Silt, clay, sand, and gravel; locally contains volcanic ash.	0-1,000	130-340	
			Fullerton and Holdrege Formations	162	Silt, clay, sand, and gravel underlie Sappa and Grand Island Formations in western half of county.	0-500	70-400	
Ter-tiary	Plio-cene		Ogallala Formation	26	Silt, sand, and gravel of local origin.	0-20	30-130	
Permian	Lower Permian	Nippewalla	Salt Plain Formation	265	Reddish-brown siltstone, thin sandy siltstone, and fine-grained sandstone beds.	--	--	
			Harper Siltstone	130	Brownish-red siltstone and silty shale and a few thin beds of silty sandstone.	0-10	--	Yields water to wells from weathered zone in central part of county. Water may be of poor chemical quality.
		Sumner			Brownish-red calcareous and dolo-mitic silty clay shale; contains some grayish-green beds; contains some thin beds of silty dolomite, limestone, and siltstone.		--	Water may be of poor chemical quality in southeastern part of county.

The irrigated area in 1968 was 1,200 acres and a total of 1,600 acre-feet of water was applied. Of this total, about 480 acre-feet was ground water. An additional 2,300 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 3,000 acres. The unconsolidated deposits receive about 150,000 acre-feet of recharge annually, and 3 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 20 to 70 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.030 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
27S- 7W- 3adc	55	10-11-56	Undifferentiated Pleistocene deposits	343	19	15	220
27S- 7W-30ccb	55	9-15-64	Holdrege Formation	247	15	12	140
28S-10W- 5dbb	96	10-11-56	Grand Island Formation	231	7	15	170
30S- 5W-35cbb	60	10- 9-56	Sumner Group	1,920	1,000	190	1,000
30S- 6W-21cda	35	10-20-55	Harper Siltstone	481	120	24	340

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	40	Very coarse gravel, sand, and silt.	0-500	10-400	Water generally of poor chemical quality.
			Dune sand	60	Fine to medium sand.	Does not yield water to wells in county.	--	Generally is unsaturated.
			Loveland and Crete Formations	100	Light-tan to brown silt and sandy silt with some clay stringers. Contains sand and gravel in lower parts.	--	--	Generally is unsaturated.
			Grand Island Formation	300	Interbedded lenses of clay, silt, sand, and gravel; consolidated and unconsolidated. Contains nodules, stringers, and irregular beds of caliche.	0-1,000+	90-260	Locally covered by dune sand and Loveland and Crete Formations.
Tertiary	Pliocene		Ogallala Formation	65	Silt, sand, and gravel with caliche cemented lenses and layers.	500-1,000	70-200	Covered by dune sand and Loveland and Crete Formations.
Cretaceous	Lower Cretaceous		Dakota Sandstone	90	Varicolored shale, sandy shale, clay, fine- to coarse-grained sandstone, and thin beds of ironstone.	Not known to yield water to wells in county.	1-70	
			Kiowa Shale	300	Dark-gray shale; contains lenses of sandstone.	0-10	--	
			Cheyenne Sandstone		Gray, tan, and white fine- to medium-grained sandstone.	0-10	1-70	Water probably of poor chemical quality.
Permian	Upper Permian	White-horse	Whitehorse Sandstone	60	Red poorly bedded fine-grained friable sandstone and siltstone containing some shale.	0-10	--	Supplies hard water to wells in southeastern part of county.

The irrigated area in 1968 was 10,600 acres and a total of 18,000 acre-feet of water was applied. Most of this total was ground water. An additional 1,400 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 100,000 acres. The unconsolidated deposits receive about 50,000 acre-feet of recharge annually, and 6 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 30 to 200 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.040 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
28S-16W- 8cc	160	2- -41	Grand Island Formation	224	3.7	10	150
29S-18W- 7bb	181	10- 2-41	Ogallala Formation	256	12	8.2	220
29S-18W-35db	275	9-20-41	Cheyenne Sandstone	3,140	280	1,600	330
30S-16W- 3cb	18	9-20-41	Alluvium	545	130	50	330
30S-16W- 9bc	30	10- 1-41	Alluvium	2,400	1,500	31	1,800
30S-16W-23ca	55	9-20-41	Whitehorse Sandstone	1,690	1,000	47	1,100
30S-20W- 2aa	95	9-19-41	Grand Island Formation	253	11	10	220

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	92	Gravel, sand, and silt in principal valleys. Mostly silt in tributary valleys.	10-1,000	130-1,300	
Quaternary	Pleistocene and Holocene		Dune sand	50	Fine to medium eolian sand.	--	--	Generally is unsaturated.
Quaternary	Pleistocene and Holocene		Silt	20	Silt and silty sand.	--	--	Generally is unsaturated.
Tertiary and Quaternary	Pliocene and Pleistocene		Undifferentiated terrace deposits and Ogallala Formation	180	Sand, gravel, silt, and clay. Generally more sand and gravel in the lower parts.	10-3,000	90-400	Covered by silt deposits. Water in lower parts may be of poor chemical quality.
Cretaceous	Lower Cretaceous		Kiowa Shale	120	Dark-gray to black and gray to buff sandy shale; some soft cross-bedded and hard limonitic sandstone lenses.	10-50	1-50	Water may be of poor chemical quality.
Permian	Lower Permian	Sumner	Ninnescah Shale	250	Alternating beds of brownish-red silty shale and siltstone; a few thin beds of grayish-green silty shale in lower part. Contains some gypsum.	0-10	--	Water may be of poor chemical quality.
Permian	Lower Permian	Sumner	Wellington Formation	600	Calcareous gray and blue shale containing some thin beds of limestone, gypsum, and anhydrite.	0-350	--	Water of poor chemical quality. Usable water may be obtained from solution zones in gypsum beds in eastern part of county.

The irrigated area in 1968 was 700 acres and a total of 1,000 acre-feet of water was applied. Of this total, about 500 acre-feet was ground water. An additional 6,000 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 50,000 acres. The unconsolidated deposits receive about 140,000 acre-feet of recharge annually, and 4 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 20 to 90 feet in other areas. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.023 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
17S- 3W-17acc	90	4-18-68	Alluvium	721	180	68	510
17S- 4W-22dbb	20	11-25-38	Ninnescah Shale	2,620	1,400	110	1,900
18S- 3W- 5ddd	41	11-25-38	Wellington Formation	2,040	37	680	1,000
18S- 5W-26aad	33	1- -44	Ninnescah Shale	420	19	74	310
19S- 2W-35dcc	140	12- 2-37	Undifferentiated Pliocene and Pleistocene deposits	22,900	32	14,000	8,500
19S- 3W-31aaa	153	4-18-57	Undifferentiated Pleistocene deposits	366	24	22	280
20S- 2W- 2abb	35	12- 2-37	Undifferentiated Pleistocene deposits	7,830	39	4,800	5,000
20S- 3W-31dad	75	11-23-38	Undifferentiated Pleistocene deposits	396	18	61	320
21S- 2W-29bba	139	8- 2-67	Undifferentiated Pleistocene deposits	283	12	23	200

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	30	Silt, sand, and gravel in channels of major streams.	10-500	70-260	
			Dune sand	40	Well-sorted very fine to medium sand in upland areas.	0-10	--	Generally is unsaturated except in northwestern part of county.
			Undifferentiated Pleistocene deposits	150	Silt, sand, and gravel.	100-500	70-700	
			Loveland and Crete Formations	56	Eolian silt and clay. Thin basal sand and gravel in Crete Formation.	0-10	--	Generally is unsaturated.
			Sappa and Grand Island Formations	196	Sand, gravel, and silt with local clay and volcanic ash lenses. Gravel more abundant in lower part.	0-1,000	70-700	Locally covered by dune sand.
			Fullerton and Holdrege Formations	82	Sand, gravel, and silt with local clay and calcareous zones.	500-1,000	70-400	Subsurface unit. Water generally of poor chemical quality.
Cretaceous	Lower Cretaceous		Kiowa Shale		Gray to black silty shale with thin lenses of sandstone.	0-10	--	Subsurface unit. Water probably of poor chemical quality.
Permian	Upper Permian	Whitehorse	Whitehorse Sandstone	270	Interbedded red claystone, siltstone, sandstone, and shale.	0-10	--	Subsurface unit. Water probably of poor chemical quality.
	Lower Permian	Nippewalla	Dog Creek Shale, Blaine Gypsum, and Flowerpot Shale, undifferentiated	1,000	Siltstone, sandstone, shale, dolomite, anhydrite, and salt.	0-10	--	Subsurface unit. Water probably of poor chemical quality.

The irrigated area in 1968 was 13,100 acres and a total of 21,000 acre-feet of water was applied. Most of this total was ground water. An additional 2,500 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 100,000 acres. The unconsolidated deposits receive about 150,000 acre-feet of recharge annually, and 11 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 50 to 100 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.020 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
26S-11W-30add	66	8-21-67	Grand Island Formation	336	18	21	240
27S-11W-30ccc	95	9-18-56	Holdrege Formation	2,480	150	1,200	330
27S-11W-31add	35	8- 7-64	Grand Island Formation	244	12	14	170
27S-11W-33bbb	23	6- 7-66	Alluvium	182	12	5	140
29S-14W-19ddc	207	9- 2-64	Holdrege Formation	148	5.8	10	88
29S-15W-34aaa	38	5-25-64	Grand Island Formation	230	21	8	160

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	130	Sand, gravel, and silt.	0-1,000	70-700	
			Dune sand	120	Fine to medium sand.	10-100	--	
			Silt	15	Eolian and water-laid silt.	Not known to yield water to wells in county.	--	Generally is unsatu-rated.
			Undifferen-tiated Pleistocene deposits	40	Sand, gravel, and silt.	0-500	70-400	In part of county is unsaturated.
			Sappa Formation	40	Silt and very fine sand.	10-100	--	In part of county is unsaturated.
			Grand Island Formation	100	Sand, gravel, and some silt.	500-1,000+	70-700	Locally covered by dune sand. Water in lower part may be of poor chemical quality in some areas.
			Fullerton Formation	30	Silt, clay, and some sand.	Not known to yield water to wells in county.	--	Locally exposed but generally covered by the Grand Island Formation.
			Holdrege Formation	110	Sand, gravel, and some silt and clay.	0-500	70-400	Locally exposed but generally covered by the Fullerton Formation. Water in channels prob-ably of poor chemical quality.
Permian	Lower Permian	Nippe-walla	Harper Siltstone	200	Red siltstone and very fine grained silty sandstone.	0-10	--	Water of poor chemical quality.
		Sumner	Stone Corral Formation	20	White and light-gray anhydrite and dolomite.	0	--	Water of poor chemical quality.
			Ninnescah Shale	300	Red and grayish-green shale, siltstone, and very fine grained silty sandstone.	0-10	--	Yields water of poor chemical quality to wells in outcrop areas.
			Wellington Formation	700	Gray to bluish-gray shale and thin interbedded calcareous zones. Con-tains the thick Hutchinson Salt Member.	0-10	--	

The irrigated area in 1968 was 3,600 acres and a total of 5,000 acre-feet of water was applied. Most of this total was ground water. An additional 2,800 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 12,000 acres. The unconsolidated deposits receive about 270,000 acre-feet of recharge annually, and 13 million acre-feet of water is in storage. The depth to water generally is about 20 feet, but may be as much as 50 feet locally. Water in the lower parts of the unconsolidated deposits may be of poor chemical quality in some areas. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.025 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
22S- 4W-28cb	20	4-25-50	Grand Island Formation	403	7.8	20	280
22S- 6W-21dd	69	12- 1-45	Alluvium	779	120	210	350
22S- 9W-20dd	212	11-18-49	Holdrege Formation	18,200	1,200	9,900	1,700
22S- 9W-30aad	30	4-25-50	Grand Island Formation	252	14	44	110
23S- 4W-11dab	35	4-26-50	Grand Island Formation	788	21	390	490
23S- 5W-29aa	38	10-30-45	Alluvium	1,240	140	490	290
23S- 6W-12cd	73	6- 6-38	Alluvium	662	120	130	330
23S- 8W-18cc	38	12- 3-49	Grand Island Formation	405	8.6	50	220
23S-10W-23dc	108	11-22-49	Undifferentiated Pleistocene deposits	315	9.5	29	170
24S- 6W-12bb	148	11- 2-45	Holdrege Formation	268	19	16	140
25S-10W-16dd	30	12- 3-49	Undifferentiated Pleistocene deposits	227	18	13	100
26S- 5W-20ab	22	4-25-50	Ninnescah Shale	361	44	16	260

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	30	Gravel, sand, and silt in principal valleys. Mostly silt in tributary valleys.	0-1,000	70-700	
			Dune sand	40	Fine to medium sand containing minor amounts of silt, clay, and coarse sand.	Yields small quantities of water to wells.	--	Generally is unsaturated.
			Silt	70	Silt and sandy silt.	0-10	--	
			Undifferentiated Pleistocene deposits	120	Silt, sandy silt, and fine sand with local lenses of coarse sand and gravel.	10-100	50-130	Covered by silt, dune sand, and alluvium.
			Grand Island Formation	40	Silt, clay, and caliche in upper part. Sand and gravel in lower part.	500-1,000+	70-600	Covered by dune sand in southwestern part of county. Water from basal gravel may be of poor chemical quality.
			Holdrege Formation	70	Silt and caliche in upper part. Sand and gravel in lower part.	100-1,000		Locally lies in deep channels below the Grand Island Formation. Water generally of poor chemical quality.
Cretaceous	Lower Cretaceous		Dakota Sandstone	150	Alternating beds or lenses of varicolored clay, shale, siltstone, and fine- to coarse-grained sandstone.	0-100	1-70	Water probably of poor chemical quality in southern part of county.
			Kiowa Shale	130	Light-gray and yellowish-brown fine- to medium-grained sandstone in upper part. Dark-gray to black shale in lower part.	0-50	1-50	Upper part yields moderate supplies of water to wells. Water probably of poor chemical quality in southern part of county.
			Cheyenne Sandstone	40	White, light-gray and greenish-gray siltstone and fine-grained sandstone.	Not known to yield water to wells in county.	--	Water probably of poor chemical quality.
Permian	Lower Permian	Nippewalla	Harper Siltstone	200	Red siltstone and silty sandstone.	0-10	--	Water probably of poor chemical quality.
		Sumner	Ninnescah Shale	300	Red and greenish-gray shale, siltstone, and very fine grained sandstone.	0-10	--	Subsurface unit. Underlies the Nippewalla Group in eastern part of county. Water probably of poor chemical quality.

The irrigated area in 1968 was 9,800 acres and a total of 14,000 acre-feet of water was applied. Most of this total was ground water. An additional 6,200 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 60,000 acres. The unconsolidated deposits receive about 75,000 acre-feet of recharge annually, and 4 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 20 to 55 feet in other areas. Water in the lower parts of the unconsolidated deposits may be of poor chemical quality. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.030 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
18S- 9W- 7da	85	12-17-45	Dakota Sandstone	396	21	26	270
19S- 7W- 6aa	65	12-17-45	Dakota Sandstone	413	12	29	360
19S- 9W-15dc	80	12-17-45	Dakota Sandstone	569	28	160	340
20S- 6W- 6cd	24	12-20-45	Kiowa Shale	1,260	140	210	590
20S- 9W-10cd	118	10-12-46	Grand Island Formation	472	24	90	230
21S- 7W-15dd	61	9-26-46	Alluvium	366	49	48	190
21S- 8W-16bb	39	10- 1-46	Alluvium	390	61	47	210
21S- 8W-21bac	92	8-22-46	Alluvium	721	110	150	330
21S- 8W-22bbb	86	9-30-46	Alluvium	1,870	850	290	800
21S- 9W-27bc	50	6-24-66	Alluvium	341	23	53	160

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	45	Fine to coarse sand and arkosic gravel; grades upward into clay and silt.	500-1,000+	90-700	Water probably highly mineralized in areas adjacent to the Arkansas River.
			Dune sand	20	Fine to medium sand.	--	--	Generally is unsaturated.
			Silt	74	Tan to pink calcareous silt. Contains sandy zones and caliche nodules.	0-100	--	Generally is unsaturated.
			Undifferentiated Pleistocene deposits	75	Fine to coarse sand and arkosic gravel; grades upward into sandy silt. Locally contains silt and clay lenses.	0-1,000	70-400	Covered by silt deposits west of the Arkansas River valley.
				157	Tannish-gray silt and clay, sand, and arkosic gravel. Locally contains lenticular beds of volcanic ash.	1,000-2,000	90-700	Underlies the Arkansas River valley and is exposed on the upland area in the western part of the county. Water probably of poor chemical quality adjacent to the Arkansas River.
Tertiary	Pliocene		Ogallala(?) Formation	150?	Lenticular beds of calcareous gray to pinkish-tan silt, clay, sand, and gravel.	500-1,000	70-260	Subsurface unit.
Permian	Lower Permian	Sumner	Ninnescah Shale	175	Alternating beds of brownish-red silty shale and siltstone. Contains a few thin beds of grayish-green shale in lower part and some gypsum.	0-10	--	Water probably of poor chemical quality.
			Wellington Formation	550	Calcareous gray and blue shale containing several thin beds of impure limestone and thin beds of gypsum and anhydrite. The thick Hutchinson Salt Member is present near the middle of the formation in the western part of the county.	0-350	--	Water generally of poor chemical quality. However, usable water may be obtained from solution zones in gypsum beds near eastern county line.

The irrigated area in 1968 was 4,100 acres and a total of 4,500 acre-feet of water was applied. Most of this total was ground water. An additional 21,000 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 25,000 acres. The unconsolidated deposits receive about 200,000 acre-feet of recharge annually, and 6 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 20 to 50 feet in the uplands. Water levels may exceed 50 feet in the eastern part of the county. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.016 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
25S- 2E- 6ddd	28	11-20-58	Wellington Formation	1,370	74	200	1,000
25S- 1W-36ac	46	10-19-66	Undifferentiated Pleistocene deposits	484	100	19	360
25S- 2W-16cc	17	9-10-38	Alluvium	1,460	170	590	470
25S- 3W-21bbc	100	6-20-66	Undifferentiated Pliocene and Pleistocene deposits	483	30	69	220
26S- 2E-25ccd	62	11-25-58	Wellington Formation	4,080	800	1,700	2,200
26S- 2W- 2cbb	126	3- 5-68	Undifferentiated Pleistocene deposits	1,150	4	660	82
26S- 3W-22baa	100	4-27-60	Wellington Formation	1,240	14	210	810
28S- 1E-32aaa	50	2-26-68	Undifferentiated Pleistocene deposits	696	100	140	300
28S- 2E-31ddd	90	11-29-58	Wellington Formation	764	280	15	550
28S- 4W- 8bcd	64	2-12-63	Ninnescah Shale	388	46	33	280

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	20	Sand and silt. Contains some gravel, fine sand, and clay.	0-500	130-260	
			Dune sand	35	Fine to medium sand. Contains minor amounts of silt, clay, and coarse sand.	Not known to yield water to wells in area.	--	Generally is unsaturated.
			Grand Island Formation	210	Sand, gravel, silt, and clay. Contains caliche.	500-1,000+	130-500	Generally covered by dune sand. May contain water of poor chemical quality in lower part in some areas.
Cretaceous	Lower Cretaceous		Dakota Sandstone	50	Alternating beds or lenses of varicolored clay, shale, siltstone, and fine- to coarse-grained sandstone. Contains ironstone in thin beds, lignite, and pyrite.	10-100	1-70	Subsurface unit, northern part of county.
			Kiowa Shale	150	Light-gray to black shale and sandy shale. Contains lenses of sandstone.	10-100	--	Subsurface unit.
			Cheyenne Sandstone	60	Very fine to medium-grained sandstone and siltstone. Contains some clay and shale.	0-10	--	Subsurface unit. Water probably highly mineralized.

The irrigated area in 1968 was 24,400 acres and a total of 39,000 acre-feet of water was applied. Most of this total was ground water. An additional 920 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 150,000 acres. The unconsolidated deposits receive about 190,000 acre-feet of recharge annually, and 12 million acre-feet of water is in storage. The depth to water generally is about 20 feet, but may be as much as 50 feet in some areas. Ground water in the lower parts of the unconsolidated deposits may be of poor chemical quality. In the northeast part of the county nearly all ground water is of poor chemical quality. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.030 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
21S-12W-25bb	212	5-17-45	Grand Island Formation	44,700	3,100	24,000	3,400
21S-12W-28bb	85	6-15-44	Grand Island Formation	214	2.7	14	160
22S-12W- 9bc	116	10-25-42	Grand Island Formation	236	8.8	13	190
22S-12W-23cc	159	5-17-45	Grand Island Formation	27,000	1,900	15,000	2,200
24S-15W-15cc	73	5-15-48	Grand Island Formation	431	42	54	250
25S-11W-15dd	41	10-25-42	Grand Island Formation	288	17	20	190
25S-12W-11cb	39	10-25-42	Grand Island Formation	367	16	72	240
25S-14W-30cac	72	6-21-66	Grand Island Formation	283	14	16	200

SUMNER COUNTY, KANSAS

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	75	Chiefly arkosic sand and gravel. Contains discontinuous lenses of silt and clay.	0-1,000+	130-1,300	
			Silt	20	Silt and clay. Contains minor amounts of fine sand.	0-100	--	Generally is unsaturated.
			Undifferentiated Pleistocene deposits	75	Silt, clay, and fine sand in upper part. May contain arkosic sand and gravel with lenses of silt and clay in the lower part.	0-100	70-400	
			Loveland and Crete Formations	65	Silt and clay in upper part. Poorly sorted sand and gravel in lower part with silt and clay locally.	0-500	70-400	Water may be of poor chemical quality.
			Fullerton and Holdrege Formations	90	Medium to coarse sand and gravel. Contains silt and clay locally.	0-500	130-400	Water may be of poor chemical quality.
Permian	Lower Permian	Sumner	Ninnescah Shale	250	Brownish-red silty shale with green lenses. Contains dolomite, calcareous siltstone, and fine-grained sandstone beds.	0-10	--	Water probably of poor chemical quality.
			Wellington Formation	650	Gray, green, and red shale and silty shale. Contains lenticular beds of gypsum, silty limestone, and dolomite. Contains silt beds near the base.	0-10	--	Water probably of poor chemical quality.

The irrigated area in 1968 was 100 acres and a total of 120 acre-feet of water was applied. Most of this total was ground water. An additional 1,500 acre-feet of water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 4,000 acres. The unconsolidated deposits receive about 80,000 acre-feet of recharge annually, and 1 million acre-feet of water is in storage. The depth to water generally is less than 20 feet in the major stream valleys and ranges from 20 to 50 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.020 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
30S- 1E-36caa	40	2-19-68	Alluvium	261	26	27	120
30S- 2E-16ccc	18	5- 2-56	Alluvium	946	420	23	720
30S- 2W-22ada	45	9-14-56	Wellington Formation	3,360	1,400	580	1,700
30S- 4W-16ccb	20	9-14-56	Holdrege Formation	192	18	12	96
31S- 3W-23baa	54	9-15-56	Ninnescah Shale	311	13	17	240

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	40	Sand and gravel interbedded with lesser amounts of silt and clay.	10-1,000	130-260	Water generally of poor to good chemical quality, but hard. Chloride and sulfate concentrations may be significant.
			Terrace deposits	40	Sand and gravel, slightly indurated, interbedded with lesser amounts of silt and clay.	10-700	65-200	Water generally of good chemical quality.
Permian	Leonard	El Reno		400	Shale, siltstone, gypsum, and dolomite.	0-10[1]	--	Sulfate concentration and hardness values usually high.
		Clear Fork	Cedar Hills Sandstone Member of Hennessey Shale	200	Alternating series of orange-brown fine-grained, sandstones and reddish-brown shale.	10-500	1-80	Chemical quality of water acceptable for most uses.
			Hennessey Shale	400	Reddish-brown shale interbedded with greenish-gray siltstone and orange-brown sandstone and siltstone.	0-10	--	Water generally of poor chemical quality.

[1]Locally the Blaine Gypsum may yield several hundred gallons per minute.

The irrigated area in 1969 was 3,000 acres and a total of 2,700 acre-feet of water was applied. Most of this total was ground water. An additional 1,000 acre-feet of ground water was pumped for municipal, recreation, and wildlife supplies. The irrigated area in year 2000 may be about 8,000 acres. The unconsolidated deposits receive about 40,000 acre-feet of recharge annually, and 900,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 125 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.021 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
25N-11W- 3b	38	5-18-66	Alluvium	2,860	1,200	370	1,400
26N-10W-28b	52	8-29-60	Terrace deposits	423	54	75	220
26N-11W- 2cb	40	7-27-50	Alluvium	515	63	86	310
27N- 9W-25d	--	5-28-55	Terrace deposits	76	10	7	28
27N-10W-17a	10	9-19-60	Alluvium	3,770	1,000	1,000	1,700
27N-11W-20b	25	1- 7-64	Alluvium	1,560	710	150	900
27N-12W-18a	27	7-26-66	Alluvium	1,360	610	90	860
28N-10W-24ab	20	1- 4-66	Alluvium	765	50	230	330
28N-11W- 9bb	36	3-23-63	Terrace deposits	1,090	340	140	610
29N- 9W-19d	41	1-31-64	Alluvium	380	41	44	220

GARFIELD COUNTY, OKLAHOMA

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	60	Sand and gravel interbedded with lesser amounts of silt and clay.	10-200	90-200	Water generally of fair chemical quality, but hard. Chloride and sulfate concentrations may be high.
			Terrace deposits	70	Slightly indurated sand and gravel interbedded with lesser amounts of silt and clay.	10-500	65-160	Water generally of good chemical quality.
Permian	Leonard	Clear Fork	Cedar Hills Sandstone Member of Hennessey Shale	200	Alternating series of orange-brown fine-grained sandstones and reddish-brown shale.	10-500	1-80	Water generally of fair to poor chemical quality.
			Hennessey Shale	500	Reddish-brown shale interbedded with greenish-gray siltstone and orange-brown sandstone and siltstone.	0-10	--	Water generally of fair to poor chemical quality.
			Garber Sandstone	400	Red shale with minor amounts of gray shale, thin limestone beds, and calcareous sandstone and sand.	0-10	--	Water generally of fair to good chemical quality.
		Wichita	Wellington Formation	600	Mostly gray, green, and maroon shale and silty shale. Also includes salt, anhydrite, and silty limestone and dolomite.	0-10	--	Water generally of poor chemical quality.

The irrigated area in the drainage of the Arkansas River in 1969 was 30 acres and a total of 20 acre-feet of water was applied. Most of this total was ground water. An additional 250 acre-feet of ground water was pumped for municipal and industrial supplies. The irrigated area in year 2000 may be about 60 acres. The unconsolidated deposits receive about 2,000 acre-feet of recharge annually, and 10,000 acre-feet of water is in storage. The values given above are about 5 percent of those values for the entire county. The depth to water ranges from less than 20 feet in the major stream valleys to slightly more than 100 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.027 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
20N- 8W-23cc	104	12-13-50	Terrace deposits	242	16	6	190
21N- 4W-11d	--	8-24-51	Hennessey Shale	596	51	150	220
21N- 7W-23bbb	52	12-13-50	Cedar Hills Sandstone Member	1,960	1,000	110	1,000
22N- 8W-18a	40	12-13-50	Cedar Hills Sandstone Member	1,040	80	270	460
23N- 4W-25c	--	8- 8-51	Garber Sandstone	598	66	120	220
23N- 7W- 7b	--	5-28-52	Cedar Hills Sandstone Member	458	27	34	180
23N- 7W-28a	66	6- 2-50	Terrace deposits	207	8	23	120

GRANT COUNTY, OKLAHOMA

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	45	Sand and gravel interbedded with lesser amounts of silt and clay.	10-800	130-260	Water generally of poor to good quality, but hard. Chloride and sulfate concentrations may be high.
			Terrace deposits	45	Slightly indurated sand and gravel interbedded with lesser amounts of silt and clay.	10-600	65-130	Water generally of good chemical quality.
Permian	Leonard	Clear Fork	Cedar Hills Sandstone Member of Hennessey Shale	20	Alternating series of orange-brown fine-grained sandstones and reddish-brown shale.	0-10	--	Water generally of poor to fair chemical quality.
			Hennessey Shale	400	Reddish-brown shale interbedded with greenish-gray siltstone and orange-brown sandstone and siltstone.	0-10	--	Water generally of poor chemical quality.
			Garber Sandstone	400	Red shale with minor amounts of gray shale, thin limestone beds, and calcareous sandstone and sand.	0-10	--	Water generally of poor chemical quality.
		Wichita	Wellington Formation	500	Chiefly gray, green, and maroon and silty shale. Also includes salt, anhydrite, silty limestone, and dolomite.	0-10	--	Water generally of poor chemical quality.

The irrigated area in 1969 was 4,860 acres and a total of 10,000 acre-feet of water was applied. Most of this total was ground water. An additional 1,000 acre-feet of ground water was pumped for municipal supplies. The irrigated area in year 2000 may be 10,000 acres. The unconsolidated deposits receive about 35,000 acre-feet of recharge annually, and 870,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 90 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.021 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
25N- 5W- 6cc	30	10- 4-37	Alluvium	2,000	170	910	350
26N- 3W-31bd	32	8-24-51	Terrace deposits	754	140	70	350
26N- 6W-24d	54	--	Terrace deposits	684	95	85	310
28N- 7W-36c	25	10-30-34	Garber Sandstone	2,300	600	560	630
29N- 8W-16da	25	10-30-34	Alluvium	924	250	89	510

KAY COUNTY, OKLAHOMA

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	20	Sand and gravel interbedded with lesser amounts of silt and clay.	10-1,500	130-465	Water generally of poor chemical quality, but hard. Chloride and sulfate concentrations may be high.
			Terrace deposits	25	Slightly indurated sand and gravel interbedded with lesser amounts of silt and clay.	10-500	65-200	Water generally of good chemical quality.
Permian	Leonard	Clear Fork	Garber Sandstone	20	Red shale with minor amounts of gray shale, thin limestone beds, and calcareous sandstone and sand.	0-10	--	Water generally of poor chemical quality.
		Wichita	Wellington Formation	160	Chiefly gray, green, and maroon shale and silty shale. Includes salt, anhydrite, silty limestone, and dolomite.	0-10	--	Water generally of poor chemical quality.
	Wolfcamp	Chase		340	Red and green shale, and chert-bearing limestone.	0-10	--	Water generally of poor chemical quality.
		Council Grove		380	Limestone and shale interbedded.	0-10	--	Water generally of poor chemical quality.

The irrigated acreage in 1969 was 800 acres, and a total of 1,300 acre-feet of water was applied. Most of this total was ground water. An additional 6,600 acre-feet of ground water was pumped for municipal, industrial, and other supplies. The irrigated area in year 2000 may be 1,500 acres. The unconsolidated deposits receive about 40,000 acre-feet of recharge annually, and 500,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 125 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.021 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
25N- 1W- 4a	26	6-29-58	Terrace deposits	812	200	85	480
25N- 1W-25a	--	Pre-1952	Alluvium	524	29	48	370
25N- 1W-26d	--	Pre-1952	Alluvium	4,970	74	2,400	2,900
25N- 2E- 3cd	--	2- 9-32	Terrace deposits	303	14	66	130
26N- 1E-22aa	--	1936	Wellington Formation	667	80	120	380
26N- 2E- 3cc	--	1936	Wellington Formation	2,630	350	950	980
26N- 2E-26b	--	2-20-48	Terrace deposits	324	48	64	250
27N- 4E-35d	49	4- 8-32	Alluvium	1,070	130	380	360
28N- 1W-17cc	--	9-21-51	Alluvium	1,080	390	150	650
28N- 2E-14bd	--	1936	Wellington Formation	1,640	130	370	920
28N- 3E-23d	35	10-25-34	Alluvium	782	150	120	370
29N- 1E-20b	30	3- 1-49	Wellington Formation	1,260	250	270	550

NOBLE COUNTY, OKLAHOMA

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Holocene		Alluvium	20	Sand and gravel interbedded with lesser amounts of silt and clay.	10-500+	130-400	Water generally of poor to good chemical quality, but hard. Chloride and sulfate concentrations may be high.
Permian	Leonard	Clear Fork	Garber Sandstone	200	Red shale with minor amounts of gray shale, thin limestone beds, and calcareous sandstone and sand.	0-10	--	Water generally of fair to good chemical quality.
Permian	Leonard	Wichita	Wellington Formation	200	Mostly gray, green, and maroon shale and silty shale. Also salt, anhydrite, and silty limestone and dolomite.	0-10	--	Water generally of poor chemical quality.
Permian	Wolf-camp	Chase		350	Red and green shale, and chert-bearing limestone.	0-10	--	Water generally of poor chemical quality.

The irrigated area in 1969 was 500 acres and a total of 140 acre-feet of water was applied. Of this total, about 56 acre-feet was ground water. An additional 100 acre-feet of ground water was pumped for municipal and industrial supplies. The irrigated acreage in year 2000 may be about 700 acres. The unconsolidated deposits receive about 17,000 acre-feet of recharge annually, and 140,000 acre-feet of water is in storage. Depth to water ranges from less than 20 feet in the major stream valleys to 125 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.021 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
20N- 2W-20	--	12- 9-36	Garber Sandstone	260	21	43	110
21N- 1W-22b	70	3-25-38	Wellington Formation	7,860	3,400	1,800	3,000
22N- 2W-27b	--	3-24-37	Wellington Formation	510	Trace	220	240
24N- 1W-12bb	23	3- 6-36	Wellington Formation	4,070	60	2,400	1,200
24N- 2W-29d	--	Pre-1903	Wellington Formation	1,180	150	320	300
24N- 2E-35aa	--	1936	Wellington Formation	17,500	2,000	4,400	2,300

OSAGE COUNTY, OKLAHOMA

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	40	Sand and gravel interbedded with lesser amounts of silt and clay.	10-1,500	130-465	Water generally of poor to good chemical quality, but hard. Chloride concentrations may be high.
			Terrace deposits	50	Slightly indurated sand and gravel interbedded with lesser amounts of silt and clay.	10-500	65-200	Water generally of good chemical quality.
Permian	Leonard	Wichita	Wellington Formation	30	Mostly gray, green, and maroon shale and silty shale. Also salt, anhydrite, and silty limestone and dolomite.	0-10	--	Water generally of poor chemical quality.
	Wolfcamp	Chase		340	Red and green shales, chert-bearing limestone, and sandstone.	0-10	--	Water generally of poor chemical quality.
		Council Grove		380	Limestone and shale interbedded.	0-10	--	Water generally of poor chemical quality.
		Admire		50	Predominantly shale with some thin limestone and lenticular sandstone.	0-10	--	Water generally of poor chemical quality.
Pennsylvanian	Virgil	Wabaunsee	Vanoss and Ada Formations	400	Gray to red shale and sandy shale interbedded with crossbedded sandstone and thin limestone.	0-10	--	Water generally of poor chemical quality.
		Shawnee	Lecompton Limestone	10	Thinly bedded fossiliferous limestone and interbedded shale.	--	--	--
		Douglas	Vamoosa Formation	300	Varicolored shale, sandstone, siltstone, and thin limestone.	0-50	0-4	Water generally of good chemical quality.
	Missouri	Ochelata		600	Predominantly shale and limestone interbedded with lesser amounts of sandstone.	0-10	--	Water generally of fair chemical quality.
		Skiatook		650	Interbedded sandstone, shale, limestone, and siltstone.	0-10	--	Water generally of poor to fair chemical quality.

The irrigated area in 1969 was 2,000 acres and a total of 1,800 acre-feet of water was applied. Most of this total was ground water. An additional 4,500 acre-feet of ground water was pumped for municipal, industrial, and other supplies. The irrigated area in year 2000 may be 4,500 acres. The unconsolidated deposits in the drainage of the Arkansas River receive 25,000 acre-feet of recharge annually, and 350,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 250 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.018 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
20N-10E-15ad	136	7- 8-48	Ochelata Group	1,250	400	100	710
21N-12E- 9dd	61	7-13-48	Skiatook Group	1,740	280	620	500
22N-10E-35	240	7- 9-63	Ochelata Group	1,050	45	420	410
24N- 3E-24c	--	8-25-49	Alluvium	808	89	210	380
24N- 5E-14dd	30	1-16-35	Alluvium	930	90	300	480
24N- 9E-22d	--	9-18-51	Vamoosa Formation	221	31	11	160
25N- 3E-31aa	--	1936	Alluvium	443	47	45	370
26N- 4E-32da	--	1936	Alluvium	355	13	9	350
26N- 5E-25cc	--	9-19-51	Alluvium	794	36	160	510
26N- 7E-11	386	8- 5-36	Vanoss and Ada Formations	6,360	750	2,800	240
28N- 7E-29cd	860	12-17-34	Admire Group	3,360	89	1,700	160

PAWNEE COUNTY, OKLAHOMA

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thick-ness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conduc-tivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	30	Gravel, sand, silt, and clay.	10-1,000	105-465	Water generally of poor to good chemical quality, but hard. Chloride and sulfate concentrations may be high.
			Terrace deposits	25	Mostly red silty clay with small amount of very fine sand, slightly indurated.	10-100	30-70	Water generally of fair to good chemical quality.
Permian	Wolfcamp	Chase		280	Mostly red and green shale inter-bedded with thin limestone and sand-stone.	0-10	--	Water generally of poor chemical quality.
		Council Grove		480	Predominantly shale with some thin limestone and lenticular sandstone.	0-10	--	Water generally of poor chemical quality.
		Admire		140	Predominantly shale with some thin limestone and lenticular sandstone.	0-10	--	Water generally of poor chemical quality.
Pennsylvanian	Virgil	Wa-baun-see	Vanoss and Ada Formations	475	Gray to red shale and sandy shale interbedded with crossbedded sandstone and thin limestone.	0-10	--	Water generally of poor chemical quality. May be good quality locally.
		Shawnee	Lecompton Limestone	10	Thinly bedded fossiliferous lime-stone interbedded with shale.	--	--	
		Dou-glas	Vamoosa Formation	400	Predominantly sandstone interbedded with lesser amounts of shale.	10-50	--	Water generally of good chemical quality.
	Missouri	Ochelata		450	Sandstone interbedded with red and gray shale.	0-10	--	Water generally of good chemical quality.

The irrigated area in 1969 was 630 acres and a total of 600 acre-feet of water was applied. Of this total, about 150 acre-feet was ground water. The irrigated area in year 2000 may be 400 acres. The unconsolidated deposits in the drainage of the Arkansas River receive about 24,000 acre-feet of recharge annually, and 160,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 140 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.020 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collec-tion	Geologic source	Dis-solved solids	Sul-fate (SO_4)	Chlo-ride (Cl)	Total hard-ness as $CaCO_3$
20N- 7E-28bc	300	11-10-34	Vanoss and Ada Formations	594	49	81	58
21N- 5E-10c	36	3-19-01	Admire Group	2,740	170	1,200	72
21N- 6E-18b	--	12- 3-00	Vanoss and Ada Formations	2,920	110	1,300	260
21N- 6E-14a	47	1898	Vanoss and Ada Formations	2,320	170	1,000	380
21N- 8E- 5	40	11-10-34	Alluvium	2,520	44	1,200	930
22N- 4E-36d	32	1897	Alluvium	2,920	1,305	160	1,300
23N- 5E- 2	25	5-23-32	Alluvium	451	9	15	360

WOODS COUNTY, OKLAHOMA

Generalized section of geologic units and their water-bearing properties.

System	Series	Group	Geologic unit	Maximum thickness (feet)	Physical character	Estimated yield to wells (gpm)	Estimated hydraulic conductivity (ft per day)	Remarks
Quaternary	Pleistocene and Holocene		Alluvium	35	Sand and gravel interbedded with lesser amounts of silt and clay.	10-500	130-200	Water generally of fair to good chemical quality, but hard. Sulfate concentrations may be high.
Quaternary	Pleistocene and Holocene		Terrace deposits	35	Slightly indurated sand and gravel interbedded with silt and clay.	10-100	65-130	Water generally of good chemical quality.
Tertiary	Pliocene		Ogallala Formation	100	Gravel, sand, silt, clay, and caliche.	10-50	25-65	Water generally of good chemical quality.
Permian	Guadalupe	Whitehorse		200	Fine-grained orange-brown sandstone and siltstone interbedded with lesser amounts of reddish-brown shale.	0-10	--	Water acceptable for most uses but may be hard and chloride and sulfate concentration may be high.
Permian	Leonard	El Reno		400	Shale, siltstone, gypsum, and dolomite.	0-10[1]	--	Sulfate concentration and hardness values generally high.
Permian	Leonard	Clear Fork	Cedar Hills Sandstone Member of Hennessey Shale	200	Alternating series of fine-grained, orange-brown sandstones and reddish-brown shales.	0-100	1-65	Water acceptable for most uses. May be hard.

[1]Locally the Blaine Gypsum may yield several hundred gallons per minute.

The irrigated area in 1969 was 100 acres, and a total of 140 acre-feet of water was applied. Most of this total was ground water. An additional 200 acre-feet of ground water was pumped for municipal supplies. The values given above are about 10 percent of those values for the entire county. The irrigated area in year 2000 may be 500 acres. The unconsolidated deposits receive about 3,000 acre-feet of recharge annually, and 200,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 185 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day is $0.025 per 1,000 gallons.

Chemical analyses of water from selected wells. Dissolved constituents and hardness in milligrams per liter.

Well number	Depth (feet)	Date of collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
27N-14W-24	--	8-17-51	Alluvium	194	11	8	130
28N-14W-27c	40	10-20-66	Alluvium	3,040	1,700	210	1,800
28N-14W-34cbc	38	6-13-67	Alluvium	1,600	770	150	920
28N-19W-20acc[1]	80	3-28-67	El Reno Group	2,700	1,600	80	1,800

[1]This well is outside the report area but the water analysis shown probably is representative of water analyses from the same geologic source within the report area.

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