GROUND WATER IN THE VERDIGRIS RIVER BASIN, KANSAS AND OKLAHOMA

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ABSTRACT

Ground water in the Verdigris River basin occurs in consolidated rocks and unconsolidated deposits ranging in age from Mississippian to Quaternary. Water for municipal, industrial, and irrigation supplies generally can be obtained in limited quantities from the alluvial deposits in the stream valleys. Except for water in the alluvial deposits in the stream valleys and in the outcrop areas of the bedrock aquifers, the ground water is generally of poor chemical quality. Owing to the generally poor chemical quality of water and low yields to wells, an increase in the use of ground water from the consolidated rocks is improbable.

The unconsolidated rocks in the Verdigris River basin receive about 166,000 acre-feet of recharge annually, and about 1 million acre-feet of water is in temporary storage in the deposits. In 1968 about 4,200 acre-feet of ground water was withdrawn for all uses. About 800 acre-feet of ground water and 5,000 acre-feet of surface water were pumped for irrigation of 5,300 acres of cropland. The total annual withdrawal of ground water for irrigation may be 2,000 acre-feet by the year 2000.

INTRODUCTION

This report, which describes ground water in the Verdigris River basin (fig. 1), was prepared by the U.S. Geological Survey at the request of the U.S. Army 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

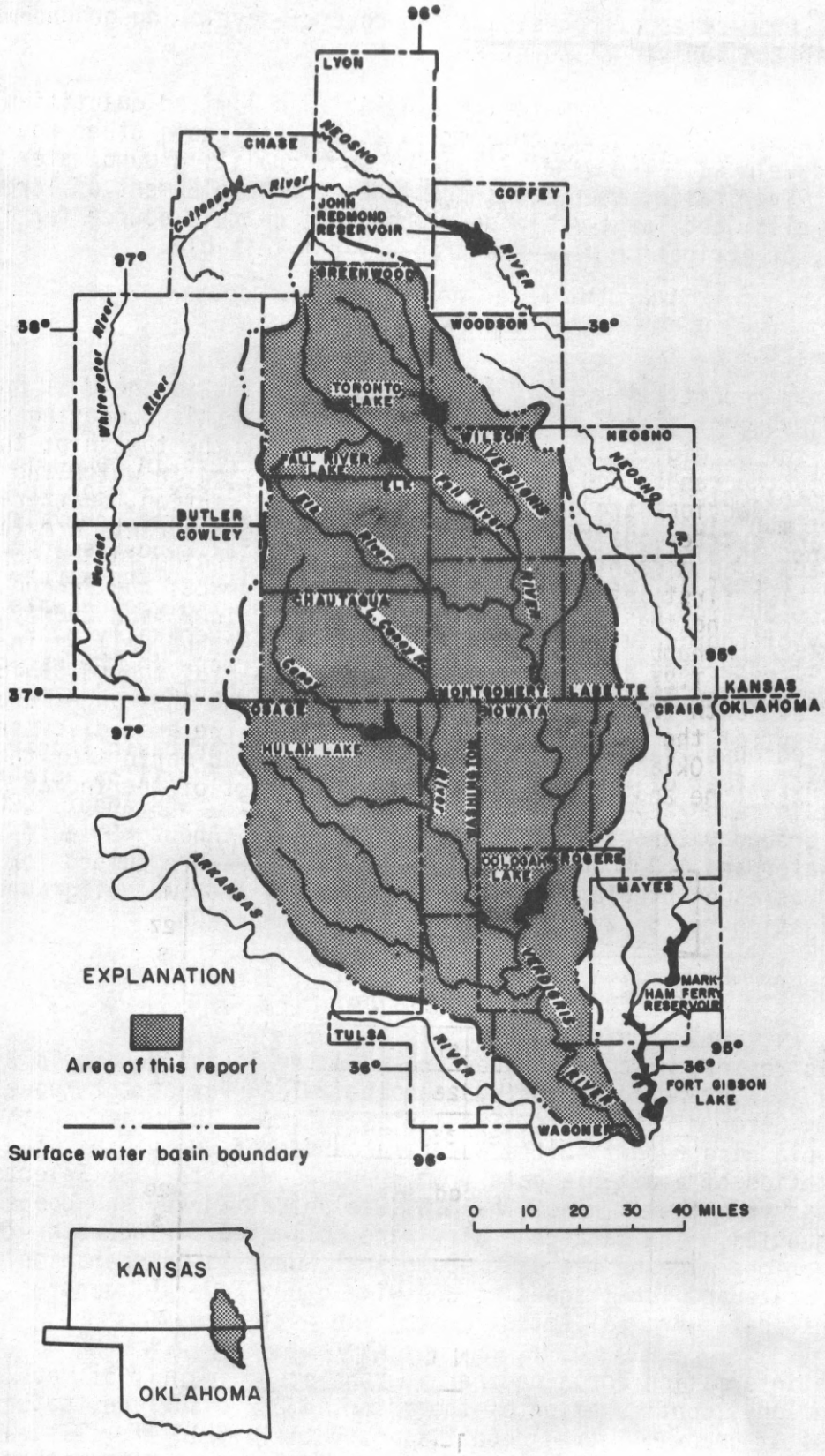

Figure 1.--Location of study area.

hydrologic properties of rocks, and the cost of developing ground-water supplies in the individual counties.

In most places ground water is available in limited quantities, but it might be used temporarily on a small scale until some other source could be developed. The general lack of good quality ground water in the Verdigris River basin, therefore, precludes the development of large-capacity wells, and large-scale developments from this source for industrial, municipal, or irrigation uses are probably not feasible.

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 Wilson County, Kans., for example, the number 27S-16E-7cad indicates that the well is in the SE¼NE¼SW¼ sec.7, T.27 S., R.16 E. (fig. 2). In Kansas the townships are numbered south from the north State boundary and the ranges are numbered east of the sixth principal meridian for the area discussed in this report. In Oklahoma the townships are numbered north from the Oklahoma base line and the ranges are numbered east of the Indian meridian.

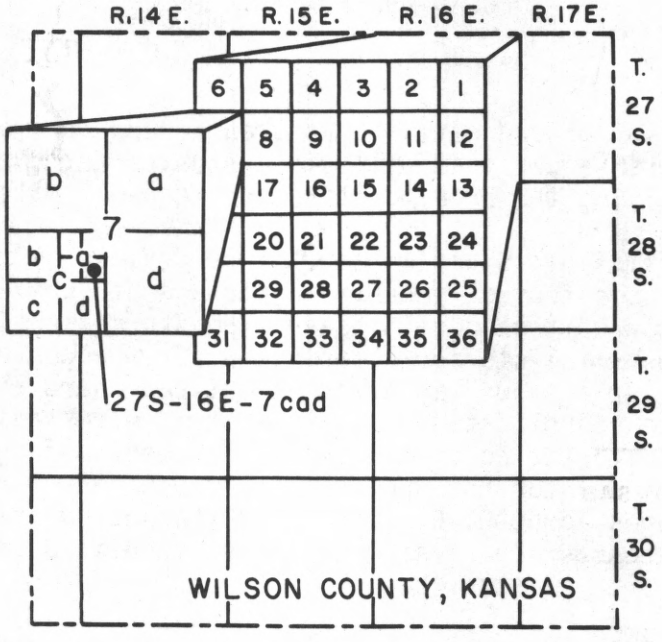

Figure 2.--Well-numbering system.

GEOLOGIC SETTING

The rocks that crop out or that are aquifers in the Verdigris River basin are grouped, for this report, in two general categories--consolidated and unconsolidated deposits. The consolidated deposits include the bedrock formations and consist mainly of shale, limestone, sandstone, siltstone, dolomite, and some gypsum. Small areas of igneous rocks (probably not older than Cretaceous) crop out in southern Woodson County, Kans., but are not water-bearing and are not discussed further in this report. The bedrock formations that crop out range in age from Mississippian to Permian. Pennsylvanian rocks crop out in the southern part of the basin and are overlain to the north and west by rocks of Permian age. The bedrock units generally dip gently westward. A series of northeast-trending normal faults occurs in the southeastern part of the basin.

The unconsolidated deposits, which include the younger surficial sediments, consist mainly of sand, gravel, silt, and clay of Quaternary age. The thickness of the unconsolidated deposits ranges from less than 10 feet in the heads of the tributary valleys to as much as 60 feet in the major stream valleys. Unconsolidated deposits overlie the bedrock formations in stream valleys and occur as terrace deposits adjacent to the stream valleys.

The principal geologic units in the Verdigris 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 deposits 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

Table 1.--Generalized columnar section of geologic units for the Verdigris River basin, Kansas and Oklahoma. The stratigraphic nomenclature and correlations used were determined 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
			Undifferentiated Pleistocene deposits			Terrace deposits
Cretaceous(?)			Igneous rocks			
Permian	Lower Permian			Leonard	Wichita	Wellington Formation
		Chase		Wolfcamp	Chase	
		Council Grove			Council Grove	
		Admire			Admire	
Pennsylvanian	Upper Pennsylvanian	Wabaunsee		Virgil	Wabaunsee	Vanoss Formation
						Ada Formation
		Shawnee			Shawnee	Lecompton Limestone
		Douglas			Douglas	Vamoosa Formation
		Lansing		Missouri	Ochelata	
		Kansas City			Skiatook	
		Pleasanton				
	Middle Pennsylvanian	Marmaton		Des Moines	Marmaton	
		Cherokee			Cabaniss	
					Krebs	
				Atoka		Atoka Formation
				Morrow		
Mississippian				Chester		Boone Formation
				Meramec		
				Osage		
				Kinderhook		
Devonian						Chattanooga Shale
Ordovician	Lower Ordovician	Arbuckle	Cotter and Jefferson City Dolomites undifferentiated	Canadian	Arbuckle	Cotter Dolomite
						Jefferson City Dolomite
			Roubidoux Formation			Roubidoux Formation
			Gasconade Dolomite			Gasconade Dolomite

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 transmissivity of the consolidated aquifers is not known, but is believed less than 2,700 sq ft per day. The estimates of transmissivity of the unconsolidated aquifers are based on aquifer tests in other basins and range from 500 to 3,300 sq ft per day.

The hydraulic conductivity (K) of a water-bearing material is the volume of water of 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 hydraulic conductivity is equal to the transmissivity divided by the aquifer saturated thickness.

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 10 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 indicate the general availability of water to properly constructed wells.

Sufficient saturated thickness of unconsolidated deposits to yield water to wells occurs only in the stream valleys or the adjacent terraces in the Verdigris River basin. Although yields to wells screened in these deposits have been reported to be 500 gpm (gallons per minute), or 1.11 cfs (cubic feet per second), the average yield is about 20 gpm (0.04 cfs).

In general, yields of less than 10 gpm (0.02 cfs) of good quality water are obtained from shallow wells in areas of outcrop of the consolidated rocks. 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. Locally yields of 50 gpm (0.1 cfs) have been reported from wells penetrating the rocks of the Douglas Group in Kansas and the Boone Formation in Oklahoma. Although the yield shown on the maps for the outcrop areas of these rocks ranges from 10 to 100 gpm, the maximum yield is probably closer to 50 gpm.

Chemical Quality

Chemical analyses of water from selected wells are given in tables for each individual county. Except in the areas of outcrop, water from the consolidated aquifers is generally of poor chemical quality. In the areas of outcrop, the aquifers receive small amounts of fresh water from precipitation and the water from shallow wells is probably of good chemical

quality, but the water from deeper wells may be of poor chemical quality. Little or no precipitation for several years may cause deterioration in chemical quality of the water from the shallow wells.

Water from the unconsolidated deposits is generally of good chemical quality for irrigation and of fair chemical quality for most other uses. Some municipalities may use the water without treatment (other than chlorination), but the water from the alluvium generally is very hard.

Extent of Development

Annual Withdrawals

In 1968 about 4,200 acre-feet of ground water was withdrawn for all uses in the Verdigris River basin, most of which was from the unconsolidated aquifers. About 800 acre-feet of ground water and 5,000 acre-feet of surface water were pumped for irrigation of 5,300 acres of cropland.

Water-Level Changes

The changes in water level in the Verdigris River basin are not shown by hydrographs, as no data are available for construction of the hydrographs. However, the changes in water level in the outcrop areas of the consolidated aquifers and in the alluvial aquifers should be similar to those presented for the Grand (Neosho) River basin (a companion report).

Potential for Development

Ground-Water Storage

The total amount of ground water in storage in the consolidated-rock aquifers in the Verdigris River basin is probably as large or larger than that shown for the unconsolidated aquifers, but the amount was not estimated for this report.

The amount of ground water stored in unconsolidated aquifers in the basin is about 1 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 less than 50 percent of the water in storage is economically recoverable.

Annual Recharge

The unconsolidated aquifers are recharged at a rate of about 166,000 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. Because of the low hydraulic conductivity of most of these rocks and the generally poor chemical quality of the water, the consolidated aquifers have not been and probably will not be extensively developed throughout most of the area. However, water considered to be of poor chemical quality today might be desirable for supplies to the demineralizing plants of the future.

The unconsolidated aquifers have not been extensively developed in the area, mainly because surface water is generally available and commonly of better chemical quality. Small well fields, capable of producing as much as 200,000 gallons per day, generally can be developed in the alluvial valleys, but, owing to the thin aquifers and low storage capabilities, yields may be less during a year of drought. As much as 2,000 acre-feet of ground water and 12,000 acre-feet of surface water may be pumped to irrigate 12,000 acres of cropland by the year 2000.

The withdrawals of ground water from the alluvial valleys could be increased considerably at a cost of installing large numbers of low yielding wells and connecting pipe lines. If this were done, the unconsolidated aquifers would be seriously depleted in the areas of the wells and flows would be reduced in the nearby streams. However, recharge is quite rapid in the stream valleys and the aquifers probably would be refilled during the first period of adequate rainfall.

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 should be planned for future projects. Although models are available on a limited basis, 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 from 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 Bayne and Ward (1967) and Schoff (1955), 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 of the ranges shown may not be available at any given site. The values for hydraulic conductivities 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. The statements about chemical quality given in this report are the opinions of the authors based on information in the files and in previous reports; as these opinions may have been formed on information other than actual measurements, the degree of conformance to the above limits is unknown.

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, or the Oklahoma State University Irrigation Specialist. The volume of water applied in Kansas 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 the 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), from 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.

In some counties the only source of ground water is the thin alluvial aquifers in the valleys or the upper parts of the consolidated aquifers. One or more low-yielding wells may produce sufficient water from these aquifers for small communities, but a well field capable of producing 1 million gallons per day may not be economically feasible, owing to the number of wells required and the necessarily large distance between wells to reduce interference. In these counties, the cost estimate for producing 1 million gallons per day is omitted or restated for 100,000 gallons per day.

The third part of each county discussion contains a table of chemical analyses of water from selected wells. The values for the chemical constituents and hardness are from previous reports or from the files of the Geological Survey. In Kansas most of the water samples were analyzed in the Division of Environmental Health of the Kansas State Department of Health. In Oklahoma the samples were analyzed by the 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 the 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 map showing 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 ranges of yield shown are generalized from very limited data and the reader is cautioned that the maximum yields of the ranges shown may not be available at any given site. The locations and number of wells on the Kansas county maps were obtained from reports of previous ground-water studies, 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.

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	Chert gravel, sand, silt, and clay.	0-50	70-700	Water probably of good chemical quality. Yields may decrease considerably during drought years.
Permian	Lower Permian	Council Grove		150	Limestone and shale.	0-10	--	Water may be of poor chemical quality.
		Admire		110	Shale, sandy shale, and limestone with some sandstone.	0-10	--	Water may be of poor chemical quality.
Pennsylvanian	Upper Pennsylvanian	Wabaunsee		400	Limestone, shale, and sandy shale beds with some sandstone.	0-10	--	Water generally of poor chemical quality.
		Shawnee		400	Limestone, shale, sandy shale, and sandstone.	0-10	--	Water generally of good chemical quality near surface.
		Douglas		220	Shale, sandy shale, sandstone, and limestone.	0-50	--	Water generally of good chemical quality near surface.

The irrigated area in 1968 was 750 acres and 750 acre-feet of surface water was applied. One hundred acre-feet of ground water was pumped for municipal use. The irrigated area in year 2000 may be 1,100 acres. The unconsolidated deposits receive about 10,000 acre-feet of recharge annually, and 20,000 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 0 to 100 feet in the uplands. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.15 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 $CaCO_3$
32S-11E-22cbd	285	5-16-68	Shawnee Group	541	66	13	88
32S-13E-28dbd	120	5-14-68	Douglas Group	330	65	11	250
33S- 9E- 9bbc	95	5-20-70	Wabaunsee Group	578	63	33	400
33S-12E-33dbc	21	5-15-68	Alluvium	1,560	380	310	540
34S-12E-21ddd	250?	9-14-66	Douglas Group	921	170	180	390
35S-10E-14dba	40	3-13-67	Alluvium	650	71	95	460
35S-10E-15bbd	235	8-20-57	Shawnee Group	--	--	15,000	--

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	Chert gravel, sand, silt, and clay.	0-50	70-700	Water may be of poor chemical quality. Yields may decrease considerably during drought years.
Permian	Lower Permian	Chase		110	Limestone and shale.	0-10	--	Water may be highly mineralized at depth.
		Council Grove		290	Limestone and shale.	0-10	--	Water may be highly mineralized at depth.
		Admire		110	Shale, sandy shale, and limestone with some sandstone.	0-10	--	Water is probably of poor chemical quality.
Pennsylvanian	Upper Pennsylvanian	Wabaunsee		400	Limestone, shale, and sandy shale with some sandstone.	0-10	--	Water is probably of poor chemical quality.
		Shawnee		400	Limestone, shale, sandy shale, and sandstone.	0-10	--	Water generally of good chemical quality.
		Douglas		220	Shale, sandy shale, sandstone, and limestone.	0-50	--	Water generally of good chemical quality.

None of the area was irrigated in 1968 and no ground water was pumped for municipal or industrial supply. The irrigated area in year 2000 may be 600 acres. The unconsolidated deposits receive about 10,000 acre-feet of recharge annually, and 15,000 acre-feet of water is in storage. The depth to water is generally less than 20 feet in the major stream valleys and ranges from flowing or above land surface to 120 feet in the uplands. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.20 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-11E-24cd	26	1-16-51	Shawnee Group	5,130	2,100	560	2,300
28S-13E-27ba	50	1-16-51	Alluvium	225	37	15	120
29S-10E- 1dd	18	1-16-51	Wabaunsee Group	409	28	24	270
30S-12E- 1bd	48	1-15-51	Douglas Group	635	40	130	35
31S- 8E-35aa	36	1-16-51	Wabaunsee Group	877	140	89	560
31S-12E-36bd	97	1-15-51	Douglas Group	493	110	32	300
31S-13E-21dd	21	1-15-51	Alluvium	1,990	45	350	1,300

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	50	Silt, clay, and chert sand and gravel.	0-100	70-700	Water may be of poor chemical quality. Yields may decrease considerably during drought years.
Permian	Lower Permian	Chase		120	Limestone and shale.	0-10	--	Water may be of poor chemical quality at depth.
		Council Grove		300	Shale, limestone, and some cavernous limestone.	0-10	--	Water may be of poor chemical quality at depth.
		Admire		120	Shale, sandy shale, and limestone with some sandstone.	0-10	--	Water probably of poor chemical quality.
Pennsylvanian	Upper Pennsylvanian	Wabaunsee		400	Limestone, shale, and sandy shale with some sandstone.	0-10	--	Water probably of poor chemical quality.
		Shawnee		400	Limestone, shale, sandy shale, and sandstone.	0-10	--	Water generally of poor chemical quality.
		Douglas		220	Shale, sandy shale, sandstone, and limestone.	0-50	--	Water generally of poor chemical quality.

The irrigated area in 1968 was 600 acres and 350 acre-feet of surface water was applied. One hundred and ten acre-feet of ground water was pumped for municipal supply. The irrigated area in year 2000 may be 1,200 acres. The unconsolidated deposits receive about 10,000 acre-feet of recharge annually, and 50,000 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 100,000 gallons per day from the alluvium is $0.20 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 $CaCO_3$
24S- 9E-23bbb	23	5-16-68	Alluvium	424	37	15	370
24S-11E-11ddd	25	3-29-65	Alluvium	330	43	6	280
24S-13E- 6cc	34	11- 2-66	Alluvium	634	120	62	480
28S-12E- 9bd	100	5-16-68	Shawnee Group	721	140	120	470

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	Clay, silt, sand, and chert gravel. Chert gravel generally in the basal 10 feet beneath flood plains and terraces adjacent to the present stream channels.	0-100	20-70	Yields may decrease considerably during drought years.
			Undifferentiated Pleistocene deposits	20		0-20	10-40	Yields may decrease considerably during drought years.
Pennsylvanian	Upper Pennsylvanian	Kansas City		300	Shale, sandy shale, sandstone, and limestone.	0-10	--	Water may be of poor chemical quality.
		Pleasanton		250	Limestone and shale.	0-5	--	Water probably of poor chemical quality.
	Middle Pennsylvanian	Marmaton		250	Shale, sandy shale, sandstone, limestone, and siltstone.	0-40	--	Water may be of poor chemical quality.
		Cherokee		140	Shale, sandy shale, sandstone, limestone, and some thin coal beds.	0-10	--	Water of poor chemical quality from upper part; may be highly mineralized in eastern part of county.
Mississippian				360	Gray and blue shale with limestone and sandy shale beds.	0-10	--	Subsurface unit. Water may be of poor chemical quality. Generally high in sulfate concentration.
Ordovician	Lower Ordovician	Arbuckle	Cotter and Jefferson City Dolomites undifferentiated	245	White and gray limestone and dolomite with chert and sandstone.	10-100	1-10	Subsurface unit. Water of good chemical quality may be available in southeastern part of county.
			Roubidoux Formation	350	White and gray loose sandstone and cherty limestone.			
			Gasconade Dolomite	150	Cherty limestone and sandstone.			

No ground water was pumped in the Verdigris River basin for municipal, irrigation, or industrial supply. The irrigated area in year 2000 may be 100 acres. The unconsolidated deposits in the drainage of the Verdigris River receive about 100 acre-feet of recharge annually, and 1,000 acre-feet of water is in storage. The depth to water generally is less than 15 feet in the major stream valleys and ranges from 5 to 60 feet in the uplands. Depth to water in the deeper Ordovician aquifers ranges from 90 to 240 feet in the southeast corner of the county and the water generally is confined. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.20 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-17E-11da	190	2-18-65	Kansas City Group	617	120	67	220
31S-19E-28bb	74	6-18-64	Pleasanton Group	1,300	210	83	270
31S-21E- 7bb	88	6-19-64	Marmaton Group	2,870	250	1,200	590
31S-21E- 9cc	28	6-22-64	Undifferentiated Pleistocene deposits	439	20	7.0	400
31S-21E-22aa	33	2-18-65	Undifferentiated Pleistocene deposits	1,710	920	44	970
33S-18E-33cb	23	2-18-65	Marmaton Group	1,120	89	76	650
34S-21E-29cd	102	7- 9-65	Cherokee Group	1,670	660	100	180

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	60	Clay, sandy clay, silt, sand, and chert gravel. Sand and gravel generally in basal 3 to 10 feet.	0-100	70-700	Water may be of poor chemical quality. Yields may decrease considerably during drought years.
Pennsylvanian	Upper Pennsylvanian	Douglas		120	Shale, sandy shale, sandstone, and limestone.	0-10	--	Water generally of good chemical quality.
		Lansing		80	Shale and sandy shale with limestone.	0-10	--	Water may be of poor chemical quality.
		Kansas City		350	Shale, sandy shale, sandstone, and limestone.	0-10	--	Water may be of poor chemical quality.
		Pleasanton		250	Limestone and shale.	0-5	--	Water probably of poor chemical quality.
	Middle Pennsylvanian	Marmaton		250	Shale, sandy shale, sandstone, limestone, and siltstone.	0-10	--	Water may be of poor chemical quality.

The irrigated area in 1968 was 340 acres and 340 acre-feet of surface water was applied. No ground water was pumped for irrigation, municipal, or industrial supply. The irrigated area in year 2000 may be about 800 acres. The unconsolidated deposits receive about 20,000 acre-feet of recharge annually, and 120,000 acre-feet of water is in storage. The depth to water is generally less than 20 feet in the major stream valleys and ranges from 2 to 100 feet in the uplands. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.20 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-15E-26ba	64	6- 2-59	Kansas City Group	908	140	150	240
31S-16E- 5bbb	22	5- 2-60	Alluvium	1,250	450	65	740
31S-16E-20dad	25	5- 2-60	Alluvium	530	170	10	350
32S-13E-26bb	56	5-14-68	Douglas Group	267	81	9	200
33S-15E-27cc	74	4-25-63	Kansas City Group	2,170	1,300	16	1,400
33S-16E-32bd	59	5- 3-60	Kansas City Group	175	12	9	110
34S-17E-34aa	23	4-25-63	Marmaton Group	1,100	310	140	750
35S-14E- 9dd	265	5- 4-60	Lansing Group	1,500	35	600	88

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	50	Silt, clay, sand, and chert gravel.	0-50	70-700	Water probably of good chemical quality. Yields may decrease considerably during drought years.
Pennsylvanian	Upper Pennsylvanian	Shawnee		50	Shale, sandy shale, and limestone.	0-10	--	Water may be of poor chemical quality.
		Douglas		300	Shale, sandy shale, sandstone, and limestone.	0-50	--	Water may be of poor chemical quality.
		Lansing		80	Shale and sandy shale with limestone.	0-10	--	Water may be of poor chemical quality.
		Kansas City		350	Shale, sandy shale, sandstone, and limestone.	0-10	--	Water may be of poor chemical quality.

The irrigated area in 1968 was 520 acres and 500 acre-feet of surface water was applied. No ground water was pumped for irrigation, municipal, or industrial supply. The irrigated area in year 2000 may be about 1,500 acres. The unconsolidated deposits receive about 20,000 acre-feet of recharge annually, and 125,000 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 2 to 50 feet in the uplands. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.30 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 $CaCO_3$
27S-13E-14dcc	135	11-13-51	Shawnee Group	260	48	40	170
27S-14E- 7ddd	56	11-13-51	Alluvium	436	1.2	19	340
27S-16E- 7cad	70	11-14-51	Lansing Group	664	88	88	300
27S-17E-21cdd	25	11-14-51	Lansing Group	314	40	80	270
28S-17E-21add	89	11-13-51	Kansas City Group	514	11	58	98
29S-14E-33ccc	36	11-14-51	Douglas Group	212	75	13	110
30S-13E-14cbb	41	11-14-51	Douglas Group	1,400	600	51	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	35	Silt, clay, fine sand, and gravel. Gravel generally in lower 4 feet.	0-100	70-700	Water probably highly mineralized. Yields may decrease considerably during drought years.
Cretaceous(?)					Igneous rocks.	0	--	
Pennsylvanian	Upper Pennsylvanian	Wabaunsee		80	Shale and sandy shale.	0-10	--	Water probably of poor chemical quality.
		Shawnee		350	Predominately limestone and shale with thin sandstone and sandy shale zones.	0-10	--	Water probably of poor chemical quality.
		Douglas		300	Sandstone, shale, and sandy shale with few thin limestone beds.	0-50	--	Water probably of poor chemical quality.
		Lansing		80	Predominately limestone with shale and sandy shale.	0-10	--	Water probably of poor chemical quality.

No ground water was pumped in the Verdigris River basin for irrigation, municipal, or industrial supply. The irrigated area in year 2000 may be 100 acres. The unconsolidated deposits receive about 3,000 acre-feet of recharge annually, and 10,000 acre-feet of water is in storage, most of which is in the Grand River basin. The depth to water is generally less than 20 feet in the major stream valleys and ranges from 5 to 85 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day from the alluvium is $0.30 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 $CaCO_3$
24S-14E- 3aaa	15	7-10-68	Shawnee Group	5,170	1,600	1,700	3,500
24S-16E- 6ddd	23	7-10-68	Douglas Group	896	390	83	500
24S-16E-34abb	19	7-10-68	Alluvium	354	66	23	140
25S-14E-16ccb	30	7-10-68	Douglas Group	402	36	12	330
26S-14E- 5ddd	82	7-10-68	Douglas Group	1,350	180	350	900
26S-16E-25bbc	20	7-10-68	Alluvium	1,430	800	8.0	870

CRAIG 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	30	Clay and silt in upper part grading downward to sand and gravel near base.	0-50	3-8	Water generally of good chemical quality, but may be hard.
Pennsylvanian	Des Moines	Marmaton		350	Mostly shale with thick fossiliferous limestone. Lesser amounts of sandstone and coal.	0-10	--	Water of poor to good chemical quality, but hard. Chloride and sulfate ion concentration may be high.
		Cabaniss		300	Generally thick cross-bedded sandstone in bottom half, overlain by alternating series of shale, sandstone, limestone, and thin coal beds.	0-10	--	Water of poor to good chemical quality, but may be hard. Sulfate concentration may be high.
		Krebs		400	Mostly shale interbedded with thinner units of sandstone and limestone. Thin coal beds common.	0-10	--	Water of poor to fair chemical quality, but may be hard. Sulfate concentration may be high.
	Morrow-Atoka		Atoka Formation	40	Brown fine to medium grained cross-bedded bituminous sandstone occurring as channel fill.	--	--	
	Morrow							
Mississippian	Chester			100	Fossiliferous limestone and shale, interbedded. Some fine-grained sandstone.	0-10	--	Water probably of good chemical quality.
	Meramec		Boone Formation	200	Commonly massive bedded limestone, chert, and cherty limestone; fossiliferous, fractured, locally dolomitic and oolitic. Small amount of shale.	10-50	1-9	Water of good chemical quality, but hard. Yield may be much higher locally.
	Osage							
	Kinderhook		Chattanooga Shale	70	Black, fissile, carbonaceous shale.	--	--	
Devonian								
Ordovician	Canadian	Arbuckle	Cotter Dolomite	185	Mostly dolomite and magnesium limestone. Cherty with lesser amounts of shale and oolites.	10-50	1-5	Water probably of fair chemical quality and probably hard.
			Jefferson City Dolomite	350	Cherty dolomite.	10-50	1-5	Water probably of acceptable chemical quality for most uses.
			Roubidoux Formation	200	Sandy cherty oolitic dolomite.	10-1,000	13-40	Water generally of fair chemical quality, but may be hard. Chloride concentration may be high.

None of the area was irrigated in 1969 and no ground water was pumped for municipal or industrial supply. The irrigated area in year 2000 probably will be negligible. The unconsolidated deposits, outside the inundated areas, receive about 2,000 acre-feet of recharge annually and a negligible amount of water is in storage. However, 2.2 million acre-feet of water is stored in the Mississippian aquifers and 1.8 million acre-feet is stored in the Ordovician aquifers. The depth to water ranges from less than 20 feet in the major stream valleys to 300 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day from the Boone Formation is $0.10 per 1,000 gallons, and from the Roubidoux Formation is $0.12 per 1,000 gallons.

Typical depth intervals for the consolidated rocks in T.28 N., R.20 E., are as follows: Pennsylvanian from land surface to 400 feet, Mississippian and Devonian from 400 to 750 feet, and Ordovician from 750 to more than 800 feet. Water in the deeper aquifers generally is confined. Most of the above information is for the Grand (Neosho) River basin.

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 $CaCO_3$
24N-19E-14abb	51	10-30-68	Krebs Group	1,320	820	72	150
24N-20E-20ccd	73	10-31-68	Krebs Group	1,420	530	7.2	780
25N-18E- 1cbb	82	10-29-58	Cabaniss Group	2,040	1,300	19	860
25N-18E-28aab	32	10-30-68	Cabaniss Group	372	170	5.2	212
25N-20E-12	1,139	3-10-50	Roubidoux Formation	1,210	28	620	190
25N-21E-25ddd	48	10-30-68	Boone Formation	209	8.1	2	180
26N-18E-18add	26	10-31-68	Marmaton Group	1,890	11	720	54
26N-19E-13cbc	30	10-31-68	Krebs Group	940	350	25	500
27N-19E-15ccc	29	10-29-68	Marmaton Group	275	39	1.8	250
27N-20E-12bdd	688	1-14-69	Roubidoux Formation	872	3.2	400	120
27N-21E-28dcc	155	10-30-68	Krebs Group	3,210	2,100	11	1,300
28N-18E- 5aaa	35	11- 8-68	Marmaton Group	394	27	6.4	330
28N-19E-17abb	54	11-13-68	Marmaton Group	1,070	390	70	630
28N-20E- 7ddd	52	11- 8-68	Cabaniss Group	450	130	12	60
28N-20E-25bbc	90	11- 8-68	Krebs Group	552	120	50	350
29N-20E-23cdd	43	11-12-68	Cabaniss Group	2,120	1,700	5.4	1,100

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	Mostly fine sand, silt, and clay.	10-100	--	Water of fair to good chemical quality, but generally hard.
Pennsylvanian	Missouri	Ochelata		150?	Sandstone, shale, limestone, and small amount of conglomerate.	0-10	--	Water generally of fair to good chemical quality, but may be hard.
		Skiatook		500	Mostly shale, silty shale, sandstone, and limestone.	0-10	--	Water of poor to good chemical quality, but may be hard.
	Des Moines	Marmaton		500	Mostly shale with lesser amounts of limestone and some sandstone.	0-10	--	Water generally of good chemical quality, but hard. Quality may be fair locally.
		Cabaniss		300	Predominately dark-gray to black shale, interbedded with lesser amounts of sandstone, limestone, and slight amount of coal.	0-10	--	Water of good to fair chemical quality.

The irrigated area in 1969 was 20 acres and 40 acre-feet of surface water was applied. No ground water was pumped for irrigation, municipal, or industrial supply. The irrigated area in year 2000 may be 40 acres. The unconsolidated deposits, outside inundated areas, receive about 7,000 acre-feet of recharge annually, and 30,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 150 feet in the upland areas. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.15 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-14E-11dda	60	11-14-68	Skiatook Group	1,410	2.3	670	180
25N-16E-29daa	27	11-14-68	Marmaton Group	1,290	200	140	310
26N-14E- 1cdd	38	11-14-68	Skiatook Group	549	66	28	440
26N-17E-29cdc	98	11-13-68	Marmaton Group	510	72	5	420
27N-15E-24bba	39	11- 5-68	Skiatook Group	185	9	24	72
27N-16E-29ddd	21	11-13-68	Marmaton Group	517	21	25	380
28N-16E-23cbb	58	11-13-68	Marmaton Group	580	71	40	400
28N-17E-23ddd	52	11-13-68	Marmaton Group	479	54	14	340
29N-14E-23ccd	75	8-12-44	Ochelata Group	560	120	61	360

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	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	Predominately 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	Predominately 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 300 acres and a total of 200 acre-feet of water was applied. Most of this total was ground water. An additional 400 acre-feet of ground water was pumped for municipal, industrial, and other supplies. The irrigated area in year 2000 may be 400 acres. The unconsolidated deposits in the drainage of the Verdigris River receive about 25,000 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 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 collection	Geologic source	Dissolved solids	Sulfate (SO_4)	Chloride (Cl)	Total hardness 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

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	Mostly fine sand, silt, and clay with some gravel and coarser sand near base.	0-10	--	Water generally of good chemical quality, but generally hard.
			Terrace deposits	10	Clay, silt, and sand, slightly indurated.	10-100	--	Probably above potentiometric surface in most places.
Pennsylvanian	Missouri	Skiatook		400	Mostly shale, silty shale, sandstone, and limestone.	0-10	--	Water of poor to good chemical quality, but generally very hard.
	Des Moines	Marmaton		500	Mostly shale with lesser amounts of limestone and some sandstone.	0-10	--	Water of fair to good chemical quality, but generally very hard.
		Cabaniss		300	Predominately dark-gray to black shale, interbedded with lesser amounts of sandstone, limestone, and slight amount of coal.	0-10	--	Water generally of good chemical quality, but hard.
		Krebs		400	Mostly shale interbedded with thinner units of sandstone and limestone. Thin coal beds common.	0-10	--	Water of poor to good chemical quality, but generally very hard.

The irrigated area in 1969 was 1,000 acres and 1,300 acre-feet of surface water was applied. About 4 acre-feet of ground water was pumped for industrial supply. The irrigated area in year 2000 may be 1,000 acres. The unconsolidated deposits, outside inundated areas, receive about 15,000 acre-feet of recharge annually, and 25,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 100 feet in the uplands. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.20 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 $CaCO_3$
19N-16E-14add	41	12- 9-68	Krebs Group	231	55	14	120
20N-14E-12daa	37	12- 9-68	Alluvium	296	.5	30	160
20N-16E- 1dcd	65	11-15-68	Krebs Group	634	20	55	28
20N-16E-31bca	53	12- 9-68	Cabaniss Group	169	44	19	96
20N-17E-11adb	80	12-11-68	Krebs Group	2,800	83	1,500	160
21N-14E-22cc	41	7-13-48	Marmaton Group	1,680	280	500	630
21N-15E- 9cac	--	10-15-68	Marmaton Group	428	26	12	370
22N-16E- 2bbb	47	12- 9-68	Cabaniss Group	545	78	5	340
22N-17E-33bbb	66	12-11-68	Krebs Group	223	44	5.7	150
23N-14E-25cbb	40	11-15-68	Skiatook Group	2,200	950	250	860
23N-15E-23dab	60	10-29-68	Marmaton Group	450	9.7	52	280
23N-15E-23dbb	70	10-30-68	Marmaton Group	1,100	1.8	360	120
24N-15E-20cbb	83	11-13-68	Marmaton Group	1,160	430	120	580
24N-16E-12aad	40	11-14-68	Cabaniss Group	583	200	120	350
24N-17E-34	59	12- 9-68	Cabaniss Group	208	47	25	110
24N-18E-35abb	47	11-15-68	Krebs Group	284	10	7.6	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, silt, and clay.	0-500	130-265	Water generally of fair to good quality, but hard.
			Terrace deposits	50	Slightly indurated gravel, sand, silt, and clay.	10-100	30-70	Water generally of good chemical quality, but may be hard locally.
Pennsylvanian	Missouri	Ochelata		650	Shale, sandstone, and lesser amounts of limestone, dolomite, and coal.	0-10	--	Water generally of fair chemical quality.
		Skiatook		900	Mostly shale, some sandstone, and small amount of limestone and conglomerate.	0-10	--	Water generally of poor to good chemical quality, but may be hard.
	Des Moines	Marmaton		700	Mostly shale with lesser amounts of of limestone and some sandstone.	0-10	--	Water generally of fair chemical quality, but may be hard.
		Cabaniss		250	Predominately dark-gray to black shale, interbedded with lesser amounts of sandstone, limestone, and slight amount of coal.	0-10	--	Water generally of fair to good chemical quality.

The irrigated area in 1969 was 600 acres and a total of 850 acre-feet of water was applied. Of this total, 600 acre-feet was ground water. An additional 2,800 acre-feet of ground water was pumped for municipal, industrial, and other supplies. The irrigated area in year 2000 may be 3,000 acres. The unconsolidated deposits in the drainage of the Verdigris River receive about 9,000 acre-feet of recharge annually and 75,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to about 150 feet in the uplands. The estimated cost of water from a well field capable of producing 100,000 gallons per day is $0.10 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 $CaCO_3$
16N-12E- 2bb	40	11- 8-48	Skiatook Group	9,580	4,800	850	2,800
17N-12E-14cb	59	6-24-48	Skiatook Group	974	35	190	130
17N-13E-25cc	18	6-24-48	Alluvium	366	32	9	260
18N-13E-19ba	18	7-14-48	Alluvium	326	5	70	310
18N-13E-28aa	60	6-25-48	Terrace deposits	105	8	3	34
19N-10E-14a	96	6-27-48	Skiatook Group	586	84	36	120
19N-11E-11db	29	7- 7-48	Terrace deposits	270	33	24	170
19N-12E- 3cd	20	7-14-48	Alluvium	1,340	130	530	630
19N-12E-25aa	34	7-13-48	Alluvium	642	220	24	450
19N-13E- 7d	130	7-14-48	Skiatook Group	308	67	11	230
19N-14E-33ad	65	6-25-48	Marmaton Group	823	24	220	73
20N-13E-12aa	28	7-10-48	Marmaton Group	980	23	310	460
21N-13E-16da	83	7-13-48	Skiatook Group	1,960	270	680	320
22N-12E- 2aa	28	7-14-48	Alluvium	741	5	260	350
22N-13E-13da	81	7-14-48	Skiatook Group	1,440	5	640	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	35	Generally silt and fine sand in upper part grading downward to coarse sand and fine gravel.	10-500	130-260	Water generally of good chemical quality, but very hard.
			Terrace deposits	30	Clayey silt in upper part grading downward to fine sand and then to coarse sand and fine gravel.	10-100	1-4	Water generally of good chemical quality.
Pennsylvanian	Des Moines	Marmaton		100	Mostly shale with lesser amounts of limestone and some sandstone.	0-10	--	Water of fair to good chemical quality, but generally very hard.
		Cabaniss		300	Predominately dark-gray to black shale interbedded with lesser amounts of sandstone and limestone, and a slight amount of coal.	0-10	--	Water generally of good chemical quality, but generally hard.
		Krebs		400	Mostly shale interbedded with thinner units of sandstone and limestone. Thin coal beds common.	0-10	--	Water of fair to good chemical quality.
	Atoka		Atoka Formation	300	Thin conglomerate at base, sandy limestone, crystalline oolitic fossiliferous limestone, sandstone, siltstone, and shale.	0-10	--	Water generally of good chemical quality.
	Morrow							
Mississippian	Chesterian			180	Fossiliferous limestone and shale interbedded. Some fine-grained sandstone and siltstone.	0-10	--	Water of fair to good chemical quality, but may be hard.
	Meramec							
	Osage		Boone Formation	250	Commonly massive-bedded limestone, chert, and cherty limestone; fossiliferous, fractured, locally dolomitic and oolitic. Small amount of shale.	0-50	1-6	Water of good chemical quality, but hard.
	Kinderhook							

The irrigated area in 1969 in the Verdigris basin was 100 acres and a total of 70 acre-feet of water was applied. Of this total, 10 acre-feet was ground water. No ground water was pumped for municipal or industrial supply. The irrigated area in year 2000 may be about 1,000 acres. The unconsolidated deposits in the drainage of the Verdigris River receive about 30,000 acre-feet of recharge annually and 240,000 acre-feet of water is in storage in the basin. The depth to water ranges from less than 20 feet in the major stream valleys to 100 feet in the uplands. The estimated cost of water from a well field capable of producing 1 million gallons per day from the unconsolidated deposits is $0.010 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 $CaCO_3$
16N-15E-11add	55	11-15-66	Krebs Group	[1] 822	42	60	28
16N-16E-19aaa	20	12-14-66	Alluvium	658	20	95	440
16N-16E-20	22	--	Alluvium	518	19	48	480
16N-17E-11bbc	29	11-15-66	Krebs Group	297	11	6	160
16N-18E-27cdd	67	10-18-66	Terrace deposits	231	6	6.3	66
16N-19E-32dc	38	6- 5-46	Alluvium	400	7.7	21	--
16N-19E-34c	31	6- 5-46	Alluvium	264	25	28	--
17N-16E- 9daa	47	10-18-66	Krebs Group	728	36	100	100
17N-18E- 3bad	31	10-18-66	Krebs Group	[1] 382	5	39	38
17N-19E-33dcc	225	8- 4-65	Atoka Formation and Morrow(?) Series, undifferentiated	3,380	110	[2]1,700	320
18N-15E-14ada	32	12- 9-68	Cabaniss Group	222	25	41	140
18N-15E-18abb	375	10-19-65	Cabaniss Group(?)	840	42	200	20
18N-16E-26daa	46	12- 9-68	Krebs Group	296	96	43	82
18N-18E-13aac	54	12- 4-68	Atoka Formation and Morrow Series, undifferentiated	324	50	4.9	250
18N-18E-19ada	72	12- 4-68	Krebs Group	978	250	190	110
19N-15E-14dcd	73	12- 9-68	Cabaniss Group	614	99	39	360

[1]Estimated.
[2]Well apparently producing below the fresh-salt water interface or contamination has occurred.

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	Fine sand, clay, and locally coarse sand and (or) gravel near the base.	10-100	3-8	Water generally of good chemical quality, but very hard.
Pennsylvanian	Virgil	Douglas, Shawnee	Vamoosa Formation	20	Vari-colored shale, sandstone, siltstone, and thin limestone.	0-10	--	Water generally of good chemical quality.
	Missouri	Ochelata		480	Sandstone, shale, limestone, conglomerate, and a small amount of coal.	0-10	--	Water generally of fair to good chemical quality, but may be hard locally.
		Skiatook		500	Mostly shale, silty shale, sandstone, and limestone.	0-10	--	Water generally of poor to fair chemical quality.

The irrigated area in 1969 was 1,100 acres, and 1,400 acre-feet of surface water was applied. No ground water was pumped for irrigation or industrial supply. The irrigated area in year 2000 may be 1,100 acres. The unconsolidated deposits receive about 5,400 acre-feet of recharge annually and 140,000 acre-feet of water is in storage. The depth to water ranges from less than 20 feet in the major stream valleys to 270 feet in the uplands. The estimated cost of water from a well field capable of producing 100,000 gallons per day from the alluvium is $0.15 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 $CaCO_3$
24N-12E-13aaa	16	11- 5-68	Ochelata Group	370	210	12	300
24N-13E- 3aba	76	11- 5-68	Skiatook Group	992	6.4	340	340
24N-13E-27d	[1] 20	5-17-32	Alluvium	330	49	52	220
25N-13E-12ddd	36	11- 7-68	Skiatook Group	912	140	170	490
26N-13E- 5add	100	2- 4-30	Skiatook Group	4,370	2	2,500	170
27N-13E-24bab	50	11- 7-68	Skiatook Group	388	150	21	300
27N-13E-30a	[1] 25	2-17-32	Alluvium	1,170	100	360	440
28N-13E-16abb	26	11- 5-68	Ochelata Group	121	7.8	4.2	80
28N-14E-18aab	73	11- 7-68	Ochelata Group	1,800	450	340	1,000
29N-14E-21ca	270	8-12-44	Ochelata Group	572	42	28	280

[1]Approximate value.

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