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GEOHYDROLOGY OF THE VAMOOSA–ADA AQUIFER EAST–CENTRAL OKLAHOMA

JOSEPH J. D'LUGOSZ AND ROGER G. MCCLAFLIN

With a section on

CHEMICAL QUALITY OF WATER

MELVIN V. MARCHER

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SUMMARY OF INFORMATION REQUIRED TO MEET OKLAHOMA GROUND-WATER LAW

This section of the report is included as agreed upon by the U.S. Geological Survey, the Oklahoma Geological Survey, and the Oklahoma Water Resources Board. The information is provided in order for the Oklahoma Water Resources Board to meet the requirements of Oklahoma State Law (82 Oklahoma Statutes Supp. 1973, paragraph 1020.1 et seq.) which became effective July 1, 1973. This law requires that the Oklahoma Water Resources Board make a determination of the maximum annual yield of each ground-water basin in the State for a minimum 20-year-life based on the following:

1. The total land area overlying the basin or subbasin.
2. The amount of water in storage in the basin or subbasin.
3. The rate of natural recharge to the basin or subbasin and total discharge from the basin or subbasin.
4. Transmissivity of the basin or subbasin.
5. The possibility of pollution of the basin or subbasin from natural sources.

According to determinations made by the Oklahoma Water Resources Board, the total amount of ground water established under prior rights[1] is 11,946 acre-ft per year and the total amount of land covered by prior rights is 8,503 acres.

Based on this study, the following information is provided to assist the Oklahoma Water Resources Board to meet the requirements of Oklahoma ground-water law:

1. The total land area overlying the basin is 1,484,000 acres. "Ground-water basin" by Oklahoma law means a distinct underground body of water overlain by contiguous land and having substantially the same geologic and hydrologic characteristics and yield capacities. As used in this report, "basin" refers to that part of the Vamoosa–Ada aquifer lying between the outcrop of the base of the aquifer in the east and the approximate location in the subsurface, projected to the surface, where the aquifer contains water having a dissolved solids concentration of 1,500 mg/L on the west.
2. The amount of water in storage in the "basin" and available for use is estimated at 36 million acre-ft as of July 1, 1973.
3. The rate of natural recharge to the "basin" is estimated at 93,000 acre-ft per year. Total discharge from the basin is estimated to be about equal to recharge. If the hydrologic system remained completely static except for recharge and if all the water available from storage could be removed over the 20-year life of the "basin," the amount that could be pumped is estimated at 1.2 acre-ft per acre per year.
4. The transmissivity of the "basin" ranged from 70 to 490 ft^2/day in July 1, 1973.
5. The major source of natural pollution to the "basin" is brines lying below the zone of fresh water being discharged to the aquifer or on the land surface as a result of petroleum development activities. In addition, excessive local pumping may lower the head in the aquifer sufficiently to induce upward migration of the underlying brine.

[1] Prior rights, as defined by the Oklahoma Water Resources Board, is the right to use ground water established by compliance with the laws in effect prior to July 1, 1973, the effective date of the Ground Water Act.

GEOHYDROLOGY OF THE VAMOOSA–ADA AQUIFER EAST–CENTRAL OKLAHOMA

Joseph J. D'Lugosz[1] and Roger G. McClaflin[2]

Abstract—The Vamoosa–Ada aquifer, which underlies an area of about 2,320 mi^2, consists principally of the Vamoosa Formation and the overlying Ada Group of Pennsylvanian age. Rocks comprising the aquifer were deposited in a nearshore environment ranging from marine on the west to nonmarine on the east. Because of changes in depositional environments with time and from place to place, the aquifer is a complex sequence of fine- to very fine-grained sandstone, siltstone, shale, and conglomerate, with interbedded very thin limestone. The aggregate thickness of water-bearing sandstones is greatest south of the Cimarron River, where it reaches a maximum of 550 ft in the vicinity of Seminole. North of the Cimarron River, the average aggregate thickness of the sandstones is about 100 ft, but locally it may be as much as 200 ft.

Transmissivity values derived from seven aquifer tests made for this study range from 70 to 490 ft^2 per day; values decrease from south to north with decreasing sandstone thickness. Hydraulic-conductivity values range from 2 to 4 ft per day. Storage coefficients for the confined part of the aquifer, as determined from four aquifer tests made during 1944, have an average value of 0.0002. The average storage coefficient for the unconfined part of the aquifer is estimated at 0.12, based on an analysis of geophysical logs and grain-size data. The specific capacity of wells tested is generally less than 1 gallon per minute per foot of drawdown.

An approximate hydrologic budget for the aquifer for 1975 gives values, in acre-feet per year, of 93,000 for recharge, 233,000 for runoff, and 2,003,000 for evapotranspiration. The total of these values is almost equal to the average annual precipitation of 2,330,000 acre-ft per year. The estimated amount of water containing a maximum of 1,500 milligrams per liter of dissolved solids stored in the aquifer is estimated at 60 million acre-ft. Of this amount, an estimated 36 million acre-ft is available for use.

The quality of water in the Vamoosa–Ada aquifer generally is suitable for municipal, domestic, and stock use. Of 55 water samples analyzed in the laboratory, about 75 percent were of the sodium bicarbonate or sodium calcium bicarbonate type; the remainder were of the sodium sulfate, calcium sulfate, sodium chloride, or indeterminate types. Laboratory and on-site chemical-quality data indicate that mineralization of both ground and surface waters is greater than normal in some areas. Water samples from 7 wells and 12 stream sites had concentrations of bromide exceeding 1 milligram per liter; the only known source of bromide in the area is brine associated with petroleum production.

INTRODUCTION

Purpose and Scope

Urbanization, economic growth, and improved standards of living in rural areas of east-central Oklahoma require ever-increasing amounts of water; a potential source of this water is the Vamoosa–Ada aquifer. Information on the availability and usability of water from the aquifer is needed to provide planners and individual water users with adequate data for orderly development and wise use of this vital resource. Recognizing the need for such information, the Oklahoma Geological Survey requested the U.S. Geological Survey to make an appraisal of the Vamoosa–Ada aquifer; this report presents the results of that appraisal.

The purpose of this report is to describe the geologic framework and hydrologic characteristics of the Vamoosa–Ada aquifer and to provide a general evaluation of the chemical quality of water in the aquifer. Information used to prepare the report was obtained from on-site and laboratory studies and from published and unpublished records of Federal, State, and local agencies.

[1] Hydrologist, U.S. Geological Survey, Water Resources Division, Oklahoma City.
[2] Hydrologic Technician, U.S. Geological Survey, Water Resources Division, Oklahoma City.

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The authors express their gratitude to the organizations, city officials, and individuals who contributed data or assistance during the project.

City officials of Seminole, Bowlegs, Prague, Stroud, Cushing, and Drumright permitted aquifer tests of city wells. Schlumberger, Ltd., provided assistance in interpretation of geophysical logs.

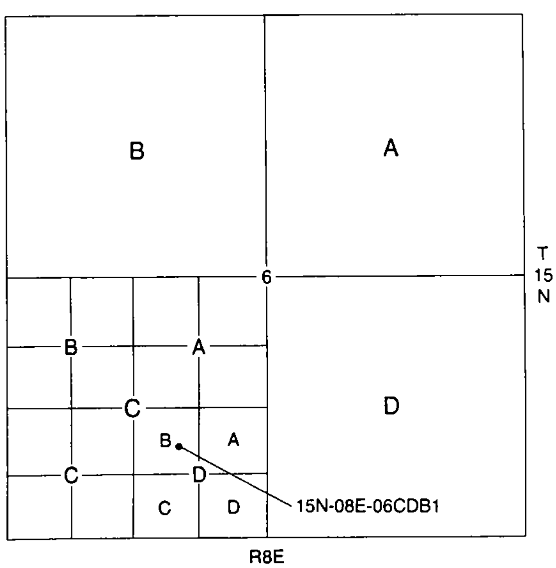
Conversion Factors

U.S. customary units used in this report may be converted to SI (International System of Units) metric units by the following conversion factors:

Inch–pound unit	Multiply by	Metric unit obtained
in. (inch)	25.40	mm (millimeter)
ft (foot)	0.3048	m (meter)
mi (mile)	1.609	km (kilometer)
ft/mi (foot per mile)	0.1894	m/km (meter per kilometer)
acre-ft (acre-foot)	1.233×10^{-3}	hm^3 (cubic hectometer)
ft^3/s (cubic foot per second)	0.02832	m^3/s (cubic meter per second)
gal/min (gallon per minute)	0.06309	L/s (liter per second)
(gal/min)/ft (gallon per minute per foot)	0.207	(L/s)/m (liter per second per meter)
acre	4047.	m^2 (square meter)
ft^2/d (foot squared per day)	0.0929	m^2/d (square meter per day)
ft/d (foot per day)	0.3048	m/d (meter per day)
acre-ft/mi^2 (acre-foot per square mile)	4.76×10^{-4}	hm^3/km^2 (cubic hectometer per square kilometer)
gal/d (gallon per day)	3.785×10^{-3}	m^3/d (cubic meter per day)

Explanation of Site-Location Method

The standard method of giving location by fractional section, section, township, and range is replaced by the method illustrated in the diagram below. The location of the site indicated by the dot normally would be described as the NW¼SE¼SW¼ sec. 6, T. 15 N., R. 8 E. The method used in this report reverses this order by giving township, range, section, and indicated quarter subdivisions of the section by letters. By this method the location of the site is given as 15N-08E-06CDB 1. The final digit (1) is the sequential number of a site within the smallest fractional subdivision.



Previous Studies

Limited geohydrologic data pertaining to the Vamoosa–Ada aquifer are given in reports by Hart (1974), Bingham and Moore (1975), and Bingham and Bergman (1980). The geology of stratigraphic units that compose the Vamoosa–Ada aquifer is described in reports by Greig (1950), Oakes (1959), Ries (1954), and Tanner (1956a and 1956b). Descriptions of the lithology and sedimentary structures of certain sandstone units within the Vamoosa Formation are presented in reports by Terrell (1972) and Shelton and Rowland (1974).

Location and Geographic Setting

The Vamoosa–Ada aquifer extends from the Canadian River to the Kansas State line and underlies an area of about 2,320 mi^2 in east-central Oklahoma (fig. 1). The eastern boundary of the aquifer is the contact of the Vamoosa Formation with the underlying formations. The western boundary is approximately the location in the subsurface, projected to the surface, where the aquifer contains water having a dissolved-solids concentration of about 1,500 mg/L (milligrams per liter), the approximate limit of water potability (Kelly, 1962).

The area is a southeasterly sloping, gently rolling plain interrupted at intervals of several miles by eastward-facing escarpments. Altitudes of the land surface range from about 725 ft in Seminole County to slightly more than 1,100 ft in northern Osage County.

Climate

The climate of the area is continental, subhumid. The difference between the average summer and the average winter temperatures is about 40°F. The prevailing winds generally are from the north from December to February and from the south the rest of the year. Average annual precipitation ranges from 36 to 40 in. in the southern part of the area to 34 to 36 in. in the northern part. Average runoff ranges from 4 to 6 in. per year. The growing season lasts about 200 days

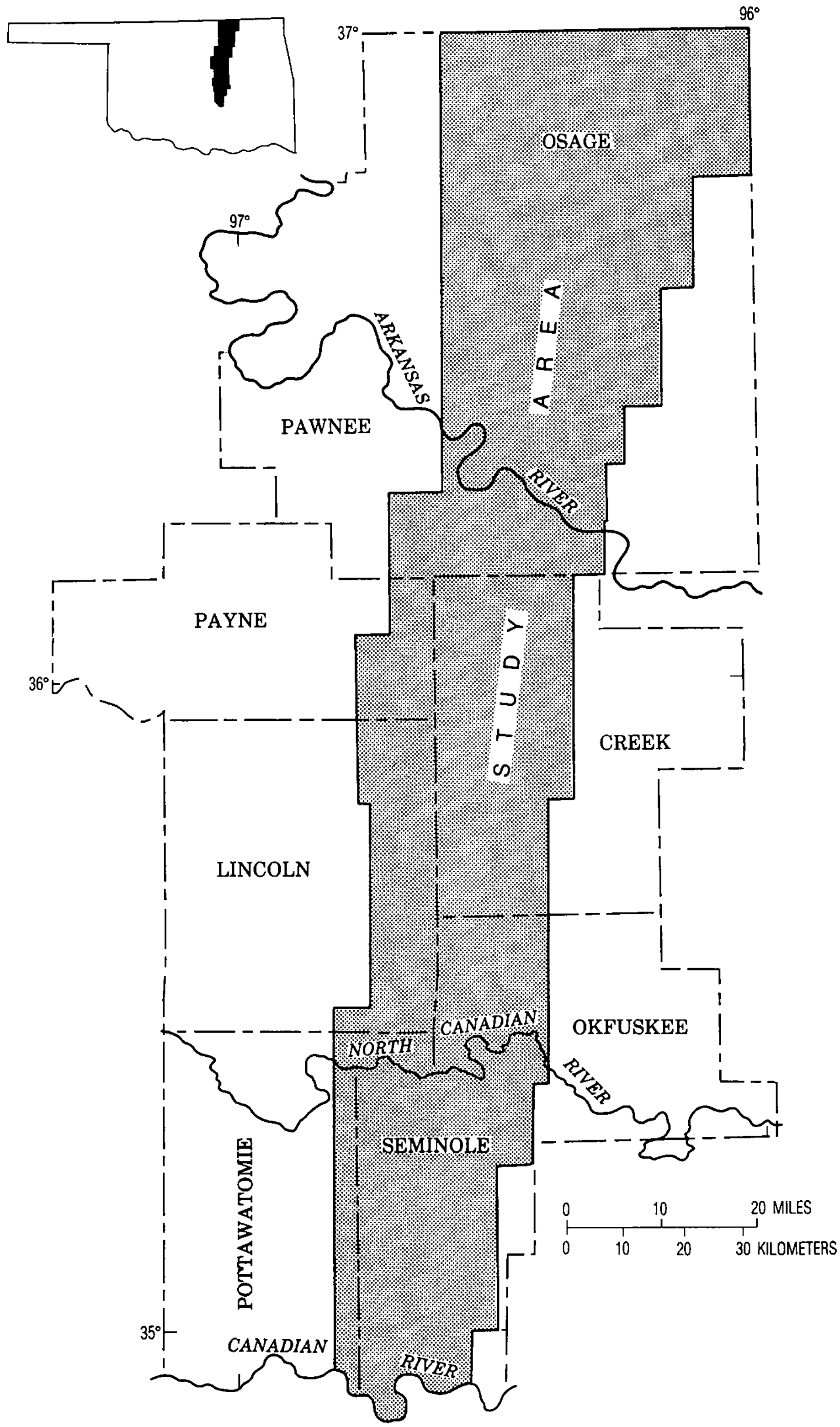


Figure 1. Location of study area.

from early April to late October, and the annual precipitation generally is adequate for the types of crops grown. Only about 200 acres of land was irrigated during 1976.

Definition of Vamoosa–Ada Aquifer

The Vamoosa–Ada aquifer, as defined herein, consists principally of the Vamoosa Formation and the overlying Ada Group[1] (see geologic map, pl. 1). In extreme southern Seminole County, some sandstone beds of the Vanoss Group,[1] which overlies the Ada Group, are included in the aquifer; these beds make up less than 10 percent of the total sandstone thickness in this part of the area. Near the eastern edge of the Vamoosa outcrop, some sandstone beds of the underlying Hilltop, Barnsdall, or Tallant Formation, whichever is present, may be in hydrologic connection with overlying units of the Vamoosa Formation and may be the source of water to a few wells. However, these sandstones are insignificant in comparison with the total body of the aquifer. All the units are Pennsylvanian in age.

GEOLOGIC FRAMEWORK OF VAMOOSA–ADA AQUIFER

The occurrence and movement of water in the Vamoosa–Ada aquifer is controlled by regional and local geologic structure, lateral and vertical distribution of sandstone and shale units, and physical characteristics of the rocks. The physical characteristics of the rocks, which also control the hydraulic properties of the aquifer, are directly related to source areas and environments of deposition.

Regional and Local Structure

Structurally, the Vamoosa–Ada aquifer lies on a westward-sloping homocline that dips 30 to 90 ft/mi. Superimposed on the homocline are en echelon faults in belts that extend from southern Seminole County across Okfuskee, Creek, and eastern Pawnee Counties, and into northern Osage County (geologic map, pl. 1). The faults are mainly normal and occur in parallel bands that trend northwest or northeast. Few faults exceed 3 mi in length, and most average about 2 mi. Vertical displacement across the faults is rarely more than 100 ft and is usually about 50 ft. Subsurface evidence shows that the amount of displacement diminishes with depth and that the faults probably do not extend below rocks of Pennsylvanian age (Levorsen, 1929, p. 338).

Environments of Deposition

The Vamoosa–Ada aquifer consists of a complex sequence of fine- to very fine-grained sandstone, siltstone, shale, and conglomerate. These are interbedded with very thin limestones. The water-yielding capabilities of the aquifer are generally controlled by lateral and vertical distribution of the sandstone beds and their physical characteristics. These in turn are related to the environments of deposition. Most of the rocks were deposited in a nearshore environment ranging from marine on the west to nonmarine on the east. Several subenvironments can be differentiated on the basis of geometry, distribution, and lithology of the sandstone units (Terrell, 1972). The more significant subenvironments, hydrologically, include: (1) stream channel and near channel, (2) distributary channel, (3) deltaic, and (4) delta fringe and shallow marine.

The lateral distribution and aggregate thickness of the sandstone units are shown on plate 2. These maps show that major sequences of sandstone are principally confined to the southern half of the area. Areas where sandstone is greater than 25 ft thick probably represent sand-rich deltaic sequences. Areas where sandstone is less than 25 ft thick probably represent delta-fringe and shallow-marine deposits. The location of the deltaic deposits, primarily in the southern part of the area, as well as the trend of major sequences of sandstone, which is from north to south and from southeast to northwest, indicates that the principal sources of sediment were the Arbuckle and Ouachita Uplifts, although minor amounts of sediment may have been contributed by the Ozark Uplift.

The vertical distribution of the sandstone units is illustrated by the geohydrologic sections (pl. 1); the locations of the sections are shown on the geologic map on plate 1. Only those sandstone units that can be correlated with some degree of confidence from one well to another are included. These sections show that individual sandstone units thicken and thin or even pinch out over short distances, thus reflecting the variable and shifting nature of the depositional environments.

Individual sandstone units are either thin bedded or lenticular. Although both types are fine grained and well sorted, thin-bedded units generally are finer grained and less well sorted.

Thin-bedded sandstones are 1 to 5 ft thick and are laterally extensive. Maximum grain di-

[1] The stratigraphic nomenclature and age determinations used in this report are those accepted by the Oklahoma Geological Survey and do not necessarily agree with those of the U.S. Geological Survey.

ameters are 0.167 to 0.30 mm, median diameters are 0.084 to 0.170 mm, and mean diameters are 0.095 to 0.171 mm (Terrell, 1972). These sands probably were deposited in the delta-fringe--shallow-marine environment.

Lenticular sandstones are 5 to 30 ft thick and are 10 to 600 ft wide. These units are characterized by an overall upward decrease in grain size. Maximum grain diameters are 0.170 to 0.405 mm, median diameters are 0.091 to 0.240 mm, and mean diameters are 0.101 to 0.225 mm (Terrell, 1972). The lenticular sandstones have well-defined upper, lower, and lateral contacts. These sandstones probably represent distributary, channel, or near-channel deposits.

Geologic Control of Ground Water

Of the several geologic conditions that control the occurrence and movement of ground water in the Vamoosa–Ada aquifer, variations in sandstone thickness are the most significant. For example, where the sandstone sequence is thick, the zone of potable water is thick, and vice versa, as shown by comparing the maps on plate 2 with map B on plate 3. Comparison of the maps on plate 2 with map C on plate 3 shows that where the sandstone grades into less-permeable shale and siltstone toward the west, the base of potable water rises in altitude.

Studies by Terrell (1972) show that lenticular sandstones have a preferred direction of grain orientation. Measurements of these sandstones show that maximum horizontal permeability is parallel to the preferred direction of grain orientation and that horizontal permeability is 18 percent greater than vertical permeability. Thin-bedded sandstones do not display this preferred direction of permeability.

The en echelon faults mentioned earlier in this report may be hydrologically significant in that either they retard ground-water flow or provide open conduits for rapid recharge to the aquifer. This depends on the amount of fracturing of near-surface rocks and the amount of brecciation and shearing along the fault zones.

Regional movement of ground water is presumed to be toward the west in accordance with the regional dip of the aquifer. However, water-level data to substantiate this assumption are not available.

Hydrologic Properties of the Aquifer

The hydraulic properties of the Vamoosa–Ada aquifer are largely controlled by the lateral and vertical distribution of sandstone and shale units and the physical characteristics of these rocks.

In order to determine some of the hydraulic properties, recovery tests were made on seven wells completed in the confined part of the aquifer; only those wells having adequate construction data were used. The results of the tests were analyzed using the Theis recovery equation. They are summarized in table 1. Transmissivity values derived from these tests range from 70 to 490 ft^2/d. An overall decrease in transmissivity occurs from south to north corresponding with decreasing saturated thickness and sand thickness. Hydraulic-conductivity values range from 2 to 4 ft/d and are consistent for all the tests. A value of 3 ft/d for hydraulic conductivity was used to compute values of theoretical transmissivity for both the unconfined and confined parts of the aquifer (pl. 2, maps A and B).

Unpublished storage coefficients determined from four aquifer tests made during 1944 by the U.S. Geological Survey ranged from 0.0001 to 0.0003. A value of 0.0002 probably is close to the average that can be applied to the confined part of the aquifer. Specific yield, which is virtually the same as the storage coefficient for the unconfined part of the aquifer, was estimated by determining porosity from neutron logs and comparing the percentage difference between porosity and specific yield for various materials as given by Johnson (1967). For the Vamoosa–Ada aquifer, specific yield is estimated to be 60 percent of porosity (20 percent), or 0.12.

Specific-capacity measurements in the Vamoosa–Ada aquifer are usually less than 1 (gal/min)/ft, because gun-perforated casings rather than screens are used in most wells. The use of screens undoubtedly would increase well efficiency. For example, in a similar aquifer in central Oklahoma, screened wells had an average specific capacity of 2.5 (gal/min)/ft, whereas gun-perforated wells had an average specific capacity of 1.2 (gal/min)/ft (Marsh, 1966).

The range of specific capacities shown in the maps on plate 2 were determined by methods given in Bentall (1963) and are entirely theoretical. Theis' equation (Bentall, 1963, p. 332) was applied to the unconfined zone, and Brown's equation (Bentall, 1963, p. 336) was applied to the confined zone.

GROUND WATER

In order to evaluate the hydrology of the Vamoosa–Ada aquifer, records of about 380 wells (table 2), including water-level measurements, were collected on site or taken from the files of the U.S. Geological Survey. In addition, periodic

TABLE 1.—RESULTS OF AQUIFER TESTS

Well location	Length of test (days)	Well depth (feet)	Perforated interval (feet)	Static water level below land surface (feet)	Drawdown (feet)	Average discharge (gallons per minute)	Transmissivity (feet squared per day)	Hydraulic conductivity (feet per day)
09N-06E-20ABD-1	2.2	816	275	259	160	290	490	2
12N-06E-27BCB-1	3	420	45	172	186	90	130	3
15N-06E-28DBD-1	2.5	408	59	125	57	40	190	3
17N-05E-03ACB-1	2	697	200	168	155	208	280	2
17N-07E-08CBD-1	2	425	40	219	161	110	170	4
18N-06E-36DAD-1	1	538	--	206	138	60	70	-
18N-06E-36DAA-1	1	275	--	214	172	85	70	-

TABLE 2.—RECORDS OF WELLS IN THE VAMOOSA–ADA AQUIFER

[Water use: C, commercial; H, domestic; I, irrigation; N, industrial; P, public supply; S, stock supply; U, unused. Units of measurement: ft (feet); in. (inches); gal/min (gallons per minute); μmho/cm (micromhos per centimeter at 25°C)]

Location	Well depth (ft)	Casing diameter (in.)	Use of water	Depth to water (ft)	Date measured	Well yield (gal/min)	Altitude (ft)	Specific conductance (μmho/cm)	Chemical analyses in table 4
CREEK COUNTY									
14N-07E-05 CDC	130	6	U	57	10-74	---	895	---	
14N-07E-09 ABA	168	8	H	146	10-74	---	945	360	
14N-07E-09 CCB	104	6	U	89	9-70	---	910	---	
14N-07E-10 CBB	153	--	H	113	4-71	---	890	896	X
14N-07E-11 ABC	46	6	U	41	10-70	---	810	---	
14N-07E-12 CCC	61	--	H	37	10-74	---	800	---	
14N-07E-16 CAA	45	--	H	43	10-74	---	860	---	
14N-07E-23 DDD	35	--	H	26	4-70	---	820	---	
14N-08E-04 AAC	55	--	H	20	6-70	---	775	251	X
14N-08E-06 CCB	13	6	U	12	10-74	---	760	---	
14N-08E-07 BCD	24	--	H	13	10-74	---	760	221	
15N-07E-10 CBD	68	6	U	24	10-70	---	840	---	
15N-07E-12 DAA	42	10	U	32	10-74	---	902	---	
15N-07E-13 BAA	108	6	H	77	10-74	---	910	---	
15N-07E-14 BAB	142	6	H	90	10-74	---	890	920	
15N-07E-15 ADD	35	6	U	33	10-74	---	845	---	
15N-07E-24 AAD	122	8	U	87	10-74	---	865	---	
15N-07E-25 AAD	74	6	U	29	10-74	---	880	---	
15N-07E-25 CCC	149	6	H	65	10-74	---	820	365	X
15N-07E-27 BBB	95	--	H	35	11-70	---	810	---	
15N-07E-27 BBC	58	6	U	20	11-70	---	817	---	
15N-07E-30 DAB	95	6	U	36	10-74	---	780	---	
15N-07E-32 BBC	216	6	S	108	10-74	---	950	6828	
15N-08E-04 BBC	162	8	I	3	---	370	800	---	
15N-08E-06 CDB	185	--	P	---	---	35	820	426	X
15N-08E-20 CDD	71	6	H	25	10-74	---	840	---	
15N-08E-30 CBB	107	10	H	72	10-74	---	845	445	
16N-07E-09 BA-	650	10	N	206	---	---	965	---	

TABLE 2.—*Continued*

Location	Well depth (ft)	Casing diameter (in.)	Use of water	Depth to water (ft)	Date measured	Well yield (gal/min)	Altitude (ft)	Specific conductance (µmho/cm)	Chemical analyses in table 4
				CREEK COUNTY--Continued					
16N-07E-11 DCC	45	6	H	28	2-75	---	900	830	
16N-07E-14 CAC	30	6	H	21	11-70	---	890	---	
16N-07E-14 DBC	40	6	H	26	11-70	---	860	1390	
16N-07E-18 ABB	29	6	H	22	2-75	---	915	---	
16N-07E-21 ADA	117	--	H	---	---	---	925	110	X
16N-07E-33 DDA	99	--	-	---	---	---	885	536	X
16N-07E-35 AB-	650	12	I	77	9-70	90	880	---	
16N-08E-09 DDA	48	8	U	26	11-70	---	88-	---	
16N-08E-22 CCD	92	8	U	65	10-70	---	850	---	
17N-07E-06 ACB	260	--	P	85	---	35	930	---	
17N-07E-08 CBD	425	13	P	219	11-75	110	---	908	
17N-07E-08 CCA	487	--	P	135	---	---	920	644	X
17N-07E-25 ADD	130	--	H	40	4-71	---	1010	244	X
17N-07E-30 DAD	142	6	U	60	1-75	---	1030	211	
17N-08E-02 CDD	42	8	U	21	12-74	---	885	---	
17N-08E-08 ACC	136	--	H	---	---	---	920	382	X
17N-08E-09 AAA	41	6	U	25	12-74	---	950	---	
17N-08E-09 BBA	97	--	H	34	10-74	---	910	470	
17N-08E-11 DCD	53	6	U	27	10-70	---	820	---	
17N-08E-16 ADA	97	--	H	22	10-74	---	850	535	
17N-08E-18 AAA	164	6	H	44	10-74	---	930	555	
17N-08E-19 BBC	60	--	H	30	10-74	---	1010	175	
17N-08E-20 AAC	157	--	H	119	10-74	---	945	550	
17N-08E-23 BBB	59	--	H	20	10-74	---	900	530	
17N-08E-29 DAD	130	--	H	33	10-74	---	925	930	
17N-08E-30 CBB	58	6	U	41	11-69	---	970	---	
17N-08E-33 BAB	60	6	U	12	1-75	---	910	---	
17N-08E-35 BDA	121	6	H	24	1-75	30	960	51	X
18N-06E-36 DAD	538	8	P	206	8-75	---	940	654	X
18N-06E-36 DAA	362	--	P	206	10-75	---	960	---	
18N-06E-36 DDD	490	7	P	100	---	75	950	546	X
18N-07E-13 AAD	77	--	-	64	8-71	---	850	218	X

18N-07E-16 BAD	600	--	P	276	4-75	---	940	1300	X
18N-07E-20 A--	124	--	C	--	---	---	870	733	X
18N-07E-28 CBC	443	10	N	265	---	---	830	---	
18N-07E-35 DDA	230	--	H	---	---	---	1000	648	X
18N-08E-09 DDD	70	6	H	45	4-75	---	935	190	
18N-08E-14 DAD	99	6	H	42	2-75	---	990	520	
18N-08E-18 BCC	120	--	H	50	11-72	---	800	376	X
18N-08E-23 BBD	94	6	U	73	12-74	---	905	---	
18N-08E-26 CDC	98	--	H	14	1-75	---	890	---	
18N-08E-32 CCC	50	8	H	35	1-75	---	880	900	
18N-08E-32 ABD	44	5	U	8	1-75	---	890	---	
18N-08E-33 DDD	194	6	U	22	1-75	---	925	126	X
19N-07E-03 CDD	180	6	H	60	2-73	---	810	1530	X
19N-07E-20 AAA	120	6	H	105	4-75	---	860	750	
19N-07E-25 CDC	180	6	H	---	---	---	823	350	
19N-08E-04 DCC	67	6	H	35	2-73	---	800	208	X
19N-08E-24 ACB	125	6	H	30	4-75	---	805	---	
19N-08E-33 AAA	198	4	U	29	4-75	---	900	---	

LINCOLN COUNTY

12N-05E-35 DDC	97	8	U	64	1-75	---	1005	---	
12N-06E-01 AAA	173	6	H	72	10-74	---	890	521	
12N-06E-06 BAB	71	--	U	17	1-75	---	850	---	
12N-06E-10 BCC	67	5	U	21	1-75	---	780	760	
12N-06E-20 DDB	356	--	P	---	---	---	---	600	
12N-06E-20 DAC	367	--	P	---	---	---	---	690	
12N-06E-24 CCC	124	6	H	56	1-75	---	970	---	
12N-06E-27 BCB	420	8	P	172	5-75	90	1010	---	
12N-06E-28 DAD	412	8	P	---	---	---	1005	1040	X
12N-06E-29 CCA	374	--	P	---	---	---	---	650	
13N-06E-08 AAA	46	6	P	7	1-75	---	---	---	
13N-06E-14 DDD	74	6	U	17	1-75	---	860	---	
13N-06E-18 DCD	42	--	U	24	1-75	---	950	---	
13N-06E-25 BCC	137	--	-	63	10-74	15	860	---	
13N-06E-28 DDC	183	6	H	40	1-75	---	825	865	
13N-06E-29 AAA	26	--	-	12	1-75	---	910	490	
13N-06E-31 ADD	100	6	H	27	1-75	---	910	605	
14N-06E-02 AAD	180	--	H	128	10-74	---	885	1535	

TABLE 2.—*Continued*

Location	Well depth (ft)	Casing diameter (in.)	Use of water	Depth to water (ft)	Date measured	Well yield (gal/min)	Altitude (ft)	Specific conductance (μmho/cm)	Chemical analyses in table 4
				LINCOLN COUNTY--Continued					
14N-06E-11 ABB	69	6	H	64	2-75	---	845	880	
14N-06E-35 BCC	62	--	U	32	2-75	---	810	---	
15N-06E-02 CCB	77	--	U	37	10-74	---	920	---	
15N-06E-07 BAB	190	--	H	41	10-74	---	960	817	
15N-06E-10 BBA	124	8	H	44	10-74	---	905	767	
15N-06E-12 BCB	130	6	H	67	10-74	---	910	789	
15N-06E-12 CBB	126	6	U	81	10-74	---	890	---	
15N-06E-15 BDD	260	5	U	30	10-74	---	925	655	
15N-06E-17 DDB	120	8	H	53	10-74	---	885	1180	
15N-06E-25 CBD	41	8	U	22	10-74	---	825	---	
15N-06E-28 DBA	275	7	P	---	---	18	---	---	
15N-06E-28 DBD	408	7	P	130	7-75	40	900	720	X
15N-06E-28 DAD	265	7	P	60	6-75	35	880	---	
15N-06E-29 AAA	339	7	P	182	6-75	---	890	---	
15N-06E-36 BAA	248	8	H	83	10-74	---	850	748	
16N-05E-23 DDD	196	8	S	25	2-75	---	960	1160	X
16N-05E-36 BBC	115	6	U	29	2-75	---	935	825	
16N-06E-03 DCD	43	6	U	7	2-75	---	1005	---	
16N-06E-05 CCC	111	6	H	32	2-75	---	910	---	
16N-06E-22 ABB	107	8	H	76	3-75	---	1025	490	
16N-06E-23 BBB	97	6	-	21	3-75	---	990	3600	X
16N-06E-33 ACD	160	6	H	91	10-74	---	945	575	
17N-05E-23 B--	357	6	N	85	8-52	---	980	3680	X
				OKFUSKEE COUNTY					
11N-06E-12 DDC	188	6	H	104	1-75	---	975	370	
11N-07E-12 AAA	60	--	-	34	2-70	---	895	---	

11N-07E-16-DCC	85	6	U	63	2-70	---	1015	---	
11N-08E-11 CBB	66	5	H	24	1-75	---	925	990	
12N-07E-02 BBC	104	--	H	70	10-74	---	860	164	
12N-07E-04 ABA	110	8	H	50	10-74	---	940	432	
12N-07E-06 ADD	72	8	H	46	10-74	---	940	---	
12N-07E-07 AAD	181	7	-	43	10-74	---	890	---	
12N-07E-08 DAD	106	8	-	23	10-74	---	895	---	
12N-07E-10 ABD	126	--	U	42	10-74	---	880	546	
12N-07E-11 ABB	121	8	H	54	10-74	---	870	390	
12N-07E-13 CDD	41	5	U	16	2-70	---	870	---	
12N-07E-17 DCC	157	8	H	97	10-74	---	990	---	
12N-07E-18 ADA	142	8	H	129	10-74	---	990	---	
12N-07E-20 BBA	104	6	H	55	10-74	---	940	620	
12N-07E-21 AAA	300	--	P	---	---	60	1010	---	
12N-07E-27 BBB	105	6	H	---	---	---	965	708	X
12N-08E-08 BAA	87	6	U	58	10-74	---	910	---	
13N-07E-09 CCC	67	5	H	20	10-74	---	800	633	
13N-07E-12 DCD	45	6	U	23	10-74	---	845	---	
13N-07E-13 DDD	101	6	U	4	10-74	---	818	---	
13N-07E-16 ADA	130	--	H	52	10-74	---	850	485	
13N-07E-19 CCD	112	4	U	76	---	---	---	2750	
13N-07E-20 BBC	52	6	U	43	12-69	---	800	---	
13N-07E-21 DDC	131	--	H	--	---	---	900	413	X
13N-07E-25 AAB	92	6	U	37	10-74	---	835	---	
13N-07E-25 ABB	48	5	H	23	1-71	---	880	---	
13N-07E-26 ABA	140	6	H	41	10-74	---	830	610	
13N-07E-26 CCB	56	6	U	44	10-74	---	---	---	
13N-07E-28 ABB	52	8	H	32	10-74	---	930	---	
13N-07E-31 ADD	254	8	H	49	10-74	---	890	---	
13N-08E-08 DAA	32	6	H	14	2-70	---	850	172	X
13N-08E-20 DDA	44	5	U	23	2-70	---	850	---	
13N-08E-31 ADA	46	6	H	26	10-74	---	925	830	
13N-08E-32 CDD	50	6	H	32	10-74	---	885	580	
13N-08E-32 DDC	54	6	U	47	10-74	---	910	---	
OSAGE COUNTY									
21N-07E-03 ABB	389	--	H	150	---	30	1000	---	
21N-07E-11 CAA	42	--	S	24	7-73	---	800	256	X

TABLE 2.—*Continued*

Location	Well depth (ft)	Casing diameter (in.)	Use of water	Depth to water (ft)	Date measured	Well yield (gal/min)	Altitude (ft)	Specific conductance (μmho/cm)	Chemical analyses in table 4
OSAGE COUNTY--Continued									
21N-08E-12 CBD	300	8	U	215	4-75	---	915	---	
21N-08E-24 BDB	130	--	H	60	---	6	749	---	
21N-08E-24 BDC	130	--	H	60	---	7	754	---	
21N-09E-23 DCC	220	--	H	161	4-75	---	940	600	
22N-07E-08 CDD	150	--	H	60	---	15	870	---	
22N-07E-16 BBD	21	2	H	14	---	---	765	999	X
22N-08E-04 BCC	120	--	H	60	---	20	1025	---	
22N-08E-11 DDC	152	6	H	71	4-75	---	810	1550	
22N-08E-15 CDD	250	6	H	60	11-73	---	910	360	
22N-08E-31 ACC	125	6	H	115	4-75	---	810	1020	
22N-08E-33 BAA	100	--	H	---	---	---	860	708	X
22N-08E-35 BDA	465	--	H	150	---	30	1020	---	
22N-09E-08 ABC	110	--	H	60	---	20	780	---	
22N-09E-16 BDA	187	6	U	75	4-74	---	---	---	
22N-09E-17 CCC	200	--	H	50	---	10	805	770	X
23N-07E-09 BDA	87	--	S	42	---	---	910	740	X
23N-08E-07 DCC	350	--	H	85	4-75	---	1040	2995	X
23N-08E-11 DDA	65	6	H	---	---	---	790	1360	
23N-09E-02 BAC	141	--	U	21	4-74	---	890	---	
23N-09E-06 CCB	169	10	H	32	10-74	---	795	---	
23N-09E-07 DCC	201	5	H	---	---	3	---	820	
23N-09E-10 DAA	55	--	H	9	---	---	820	598	
23N-09E-25 BCC	187	6	S	96	4-75	---	850	1010	X
23N-09E-27 DDD	99	--	H	27	4-75	---	770	---	
23N-10E-06 ACC	70	8	H	13	3-75	---	890	150	
23N-10E-08 DDD	185	6	H	131	4-75	---	900	260	
24N-07E-35 DCC	55	10	S	22	1-73	---	980	---	
24N-08E-11 BAC	75	5	H	75	10-74	---	900	965	

24N-08E-14 DDD	27	24	H	2	10-74	---	850	525	
24N-08E-33 CCA	25	--	H	---	---	---	850	862	X
24N-08E-35 ADB	26	30	U	10	10-74	---	850	1320	
24N-08E-36 CAD	86	5	H	80	10-74	---	820	---	
24N-09E-01 AAD	227	--	H	151	10-74	---	875	---	
24N-09E-03 DAA	260	6	H	152	4-75	---	885	1060	X
24N-09E-03 CBC	280	6	H	104	4-75	---	930	---	
24N-09E-08 BAC	130	5	H	55	10-74	---	920	470	
24N-09E-10 BAA	200	6	H	100	4-75	---	875	---	
24N-09E-20 ABB	325	--	H	---	---	---	1005	406	X
24N-09E-27 ABA	107	--	H	27	4-75	---	895	---	
24N-10E-06 BBA	260	--	H	150	---	20	880	---	
25N-07E-10 AAA	300	--	H	211	3-75	---	1090	710	
25N-07E-31 ADA	40	--	S	15	4-73	---	980	---	
25N-08E-02 DDD	235	6	P	114	3-75	---	975	670	
25N-08E-03 DDD	235	--	H	150	11-72	6	960	---	
25N-08E-11 ABB	300	--	H	150	---	10	950	---	
25N-08E-28 DAD	115	--	H	63	10-74	---	1060	---	
25N-08E-29 ACD	235	10	U	86	10-74	---	1065	---	
25N-09E-01 BCC	84	6	U	37	3-75	---	800	---	
25N-09E-01 DBD	106	6	H	---	---	---	780	580	
25N-09E-08 DAA	188	6	H	133	4-75	---	855	1100	
25N-09E-20 CAA	172	6	H	84	---	---	1025	1420	
25N-09E-24 BAD	240	--	H	85	---	---	845	978	X
25N-09E-33 ADA	97	6	U	70	4-75	---	895	---	
25N-09E-35 BAA	45	6	H	4	4-75	---	885	1080	
25N-09E-35 BAD	255	--	H	150	---	20	900	1090	X
25N-10E-17 CCB	83	6	H	21	---	---	760	950	
25N-10E-35 DCB	200	--	-	100	---	15	800	---	
26N-08E-01 ADD	210	12	U	170	3-73	---	990	---	
26N-08E-09 BDC	28	--	H	6	---	---	1025	210	
26N-08E-32 BBC	100	6	H	9	4-75	---	1010	1080	
26N-09E-08 BDC	60	6	U	6	4-75	---	1005	---	
26N-09E-14 ACB	109	6	H	20	---	---	870	291	X
26N-09E-23 CCC	222	5	H	---	---	7	980	---	
26N-09E-31 CBC	127	6	H	44	4-75	---	980	1200	

TABLE 2.—*Continued*

Location	Well depth (ft)	Casing diameter (in.)	Use of water	Depth to water (ft)	Date measured	Well yield (gal/min)	Altitude (ft)	Specific conductance (μmho/cm)	Chemical analyses in table 4
OSAGE COUNTY--Continued									
26N-09E-32 DDD	40	--	H	18	4-75	---	775	1750	
26N-10E-03 ACA	256	--	H	140	---	---	900	---	
26N-10E-03 ABB	255	6	H	50	---	---	925	---	
26N-10E-09 ADA	130	--	H	15	---	---	775	2695	X
26N-10E-28 AAA	44	--	U	27	3-75	---	900	---	
27N-08E-03 ACC	227	--	S	9	3-75	---	1050	---	
27N-08E-20 ADD	100	--	S	21	3-75	---	1000	---	
27N-09E-27 ACC	125	6	H	30	---	---	850	1120	X
28N-07E-29 DDA	900	--	H	---	---	---	---	4000	X
28N-08E-03 AAA	300	--	H	180	---	---	940	1010	X
28N-08E-08 DDA	500	--	H	460	---	---	1030	2070	X
28N-09E-15 DAC	160	--	H	6	---	---	875	893	X
28N-10E-11 DBB	141	--	U	31	3-75	---	900	---	
28N-10E-17 BBB	125	--	S	80	3-73	---	820	---	
28N-10E-33 ADA	153	6	H	92	---	---	900	394	X
28N-11E-04 DBB	78	6	H	30	11-72	---	735	---	
28N-11E-10 ABD	90	6	H	29	11-72	---	775	---	
28N-11E-28 DAB	125	--	U	11	3-75	---	800	---	
29N-09E-23 CDA	90	--	H	30	---	---	790	1210	X
29N-10E-13 BCD	100	8	H	37	3-75	---	900	580	
29N-10E-23 CCC	73	--	H	21	3-75	---	760	890	
29N-10E-29 BCA	125	6	H	36	---	5	---	3520	
29N-10E-29 BDC	65	8	U	42	12-71	---	875	922	X
29N-11E-19 DDD	59	8	U	18	3-75	---	800	---	
29N-11E-33 DDC	80	6	H	9	11-72	---	---	---	

				PAYNE COUNTY					
17N-05E-03 ACB	697	4	P	167	10-75	200	920	575	X
17N-06E-16 CDD	97	6	S	36	2-75	---	830	---	
18N-06E-16 DDD	30	6	S	18	---	---	---	864	X
18N-06E-17 CCC	136	4	H	48	---	---	820	1300	
18N-06E-28 BCC	183	8	H	7	4-75	---	810	1010	
18N-06E-31 BCB	160	8	H	86	4-75	---	890	1950	X
				POTTAWATOMIE COUNTY					
08N-05E-33 AAB	668	--	-	---	---	---	945	2090	X
08N-05E-33 ABB	650	6	P	238	11-74	25	950	---	
08N-05E-33 ACC	650	6	P	208	11-74	55	930	---	
09N-05E-04 DCC	248	--	H	140	1-75	---	1065	5720	X
09N-05E-08 BAA	165	6	U	63	1-75	---	1015	---	
09N-05E-08 CAA	700	6	U	215	1-75	---	1015	---	
09N-05E-29 AAA	47	--	H	3	1-75	---	970	830	
11N-06E-06 CCC	220	--	H	40	---	---	985	872	X
11N-06E-15 ADD	72	8	U	53	6-70	---	995	---	
				PAWNEE COUNTY					
20N-07E-01 CDD	137	6	H	60	---	3	890	2900	
20N-07E-01 DAD	90	6	H	---	---	---	900	2880	X
20N-07E-05 ACA	142	6	U	70	5-72	---	850	---	
20N-07E-27 BBD	200	6	U	192	5-72	---	---	---	
20N-08E-05 DDA	28	--	-	---	---	---	1005	369	X
20N-08E-06 CCC	---	6	H	---	---	---	915	1650	X
20N-08E-09 DCD	20	--	-	--	---	---	---	1030	X
20N-08E-12 CCC	114	6	H	50	---	---	790	960	
20N-08E-17 AAD	80	--	H	---	---	---	860	1170	X
20N-08E-19 DCA	128	--	H	60	---	---	825	---	
21N-07E-21 ADB	266	--	H	---	---	---	860	760	
21N-07E-24 CCD	156	6	H	---	---	---	920	1360	
21N-07E-24 CDD	90	6	H	44	4-75	---	840	1020	
21N-07E-34 CCD	35	6	U	15	5-72	---	890	---	
21N-08E-20 DCA	85	--	H	---	---	---	905	591	X
21N-08E-29 AAD	65	--	H	---	---	---	930	1360	X
22N-07E-20 DBC	92	6	U	34	5-72	---	920	---	

TABLE 2.—*Continued*

Location	Well depth (ft)	Casing diameter (in.)	Use of water	Depth to water (ft)	Date measured	Well yield (gal/min)	Altitude (ft)	Specific conductance (μmho/cm)	Chemical analyses in table 4
				SEMINOLE COUNTY					
05N-05E-10 BBB	700	8	H	60	11-74	---	1040	---	
05N-05E-12 ABB	202	6	H	37	11-74	---	920	465	
05N-05E-25 DAD	236	--	H	170	11-74	---	950	1220	X
05N-06E-04 BDC	150	6	H	84	11-74	---	855	790	
06N-05E-10 CCD	123	6	U	24	5-70	---	915	---	
06N-05E-11 BAB	160	--	H	71	11-74	---	920	1100	
06N-05E-11 CDD	70	--	-	39	11-74	---	900	1120	
06N-06E-07 DAD	196	8	-	24	11-74	---	930	580	
06N-06E-12 ACC	214	--	H	39	11-74	---	870	555	
06N-06E-25 CCC	81	6	H	36	11-74	---	950	1400	
07N-05E-02 AAA	52	6	U	28	5-70	---	---	---	
07N-05E-13 ACC	65	6	H	49	11-74	---	865	535	
07N-05E-26 BBB	180	--	H	15	11-74	---	915	650	
07N-05E-27 AAA	40	6	U	7	11-74	---	925	---	
07N-06E-05 CDD	82	4	U	36	11-74	---	920	545	
07N-06E-16 AAA	84	5	H	20	5-70	---	---	1890	
07N-06E-16 CCD	82	6	U	54	11-74	---	---	---	
07N-06E-23 BCB	321	6	H	121	11-74	---	855	1340	X
07N-06E-33 BDD	126+	6	N	60	11-74	---	945	1110	X
07N-06E-34 DCD	217	6	H	87	11-74	---	870	940	
07N-07E-05 ABB	180	6	H	46	11-74	---	980	676	X
07N-07E-10 CCC	75	6	U	13	5-70	---	---	---	
08N-05E-10 DDD	143	--	U	37	11-74	---	943	385	
08N-05E-11 AAD	125+	6	U	59	12-74	---	975	---	
08N-05E-12 DDD	75	--	U	8	11-74	---	930	---	
08N-05E-24 BDA	92	6	U	32	11-74	---	925	445	
08N-05E-36 DAA	131	6	H	23	11-74	---	925	815	
08N-06E-03 DDC	550	--	P	284	11-74	---	970	460	
08N-06E-07 DDC	215+	--	H	194	11-74	---	1020	650	
08N-06E-09 DDD	410	6	U	184	11-74	---	875	---	
08N-06E-10 BBC	178	--	-	---	---	---	920	2086	

08N-06E-14 DCC	500	6	U	162	11-74	---	955	6750	X
08N-06E-14 DDD	500	6	H	195	11-74	---	975	674	X
08N-06E-21 DAA	550	6	P	174	11-74	---	930	770	X
08N-06E-25 CCD	165	6	H	---	---	---	880	445	X
08N-06E-26 CDC	125	6	H	91	11-74	---	935	845	
08N-07E-06 BC-	160	--	N	37	---	40	---	---	
08N-07E-07 ADD	600	--	P	105	11-74	80	805	430	X
08N-07E-29 ABA	50	8	H	20	11-74	---	895	2500	
08N-07E-31 BAB	50	6	H	10	4-71	---	945	352	X
08N-07E-32 CCD	100	--	H	78	11-74	---	975	---	
08N-07E-36 CCC	55	5	H	10	5-70	---	---	103	
08N-08E-28 ABB	40	6	U	16	5-70	---	---	---	
09N-05E-03 BBA	135	6	H	26	11-74	---	995	---	
09N-05E-11 AAA	180+	6	H	158	12-74	---	980	965	
09N-05E-15 DDD	112	6	U	29	12-74	---	962	2600	X
09N-05E-34 AAD	110	6	H	49	12-74	---	915	640	
09N-06E-17 AC-	718	11	P	173	---	75	900	---	
09N-06E-17 BBC	496	8	U	114	9-47	---	950	---	
09N-06E-20 AA-	753	12	P	---	---	150	930	1360	X
09N-06E-20 ABD	816	8	P	258	---	290	935	490	X
09N-06E-21 DBC	757	11	P	217	---	90	915	---	
09N-06E-22 ---	650	--	P	---	---	---	---	374	
09N-06E-22 AC-	704	--	P	150	---	170	895	---	
09N-06E-22 BB-	734	11	P	150	---	200	880	---	
09N-06E-22 BBC	698	--	P	198	---	135	875	---	
09N-06E-23 AB-	200	--	H	---	---	---	---	2500	
09N-06E-26 CA-	450	--	N	---	---	---	900	2260	X
09N-06E-27 ACB	734	--	P	---	---	140	850	---	
09N-06E-27 BB-	641	9	P	200	---	80	870	---	
09N-06E-27 CC-	625	10	P	200	---	30	855	---	
09N-06E-28 C--	553	--	P	126	---	50	860	---	
09N-06E-28 DD-	620	--	P	200	---	150	858	---	
09N-07E-03 CDB	150	--	H	42	2-74	---	990	117	X
09N-07E-09 BBA	120	6	S	86	1-70	---	1040	275	X
09N-07E-20 DDB	165	6	H	129	12-74	---	945	515	
09N-07E-32 DCD	250	6	H	74	12-74	---	965	365	
09N-08E-15 BBA	55	8	H	14	5-70	---	---	460	
09N-08E-34 CDD	215	6	U	20	5-70	---	---	---	
10N-05E-01 CBB	189	6	H	29	1-75	---	965	1380	X
10N-05E-13 CDD	38	8	U	15	1-70	---	970	---	

TABLE 2.—*Continued*

Location	Well depth (ft)	Casing diameter (in.)	Use of water	Depth to water (ft)	Date measured	Well yield (gal/min)	Altitude (ft)	Specific conductance (µmho/cm)	Chemical analyses in table 4
SEMINOLE COUNTY--Continued									
10N-05E-35 DDD	34	5	U	29	1-70	---	1000	---	
10N-06E-01 CCD	85	6	H	21	1-75	---	955	420	
10N-06E-13 CCD	150	6	H	41	1-75	---	975	890	
10N-06E-17 ADD	25	6	U	9	1-70	---	915	269	X
10N-06E-32 DDD	60	6	U	27	1-70	---	1025	---	
10N-06E-34 AAD	---	6	H	120	1-75	---	1065	725	
10N-07E-11 BAA	78	6	H	19	1-75	---	905	340	
10N-07E-18 BCC	42	8	H	19	5-70	---	995	166	X
10N-07E-27 CDD	113	6	U	25	12-71	---	1000	---	
10N-08E-05 BBB	85	6	H	22	5-70	---	---	---	
10N-08E-16 CCC	58	6	U	26	5-70	---	---	---	
10N-08E-18 BBB	46	6	-	21	5-70	---	---	---	
10N-08E-27 AAB	66	5	H	48	4-70	---	---	---	
11N-05E-24 DCC	150	6	H	17	1-75	---	945	---	
11N-05E-35 DCC	175	6	H	75	1-75	---	980	840	
11N-05E-36 BBB	88	6	U	37	1-70	---	---	---	
11N-05E-36 DDD	280	6	H	81	1-75	---	985	960	
11N-06E-34 BCC	198	6	C	---	---	---	928	751	X
11N-06E-33 CCD	100	6	H	41	1-75	---	965	575	
11N-06E-35 BBC	116	6	H	61	1-75	---	928	815	
11N-07E-13 CBB	112	--	H	95	1-75	---	935	310	
11N-07E-31 CBB	81	6	U	47	5-70	---	985	---	
11N-07E-32 BAA	179	6	H	72	1-75	---	950	880	
11N-07E-35 AAC	152	5	H	15	---	---	905	626	X
11N-08E-09 AAA	32	7	H	20	1-70	---	---	93	
11N-08E-16 DDC	60	6	-	31	5-70	---	---	---	
11N-08E-22 BBB	82	6	H	18	1-75	---	890	480	

or continuous water-level measurements in selected wells and base-flow measurements of selected streams were made during the course of the study. Precipitation records were obtained from the National Weather Service. Analysis of these various data, in conjunction with necessary geologic information, provides a basis for describing the occurrence and movement of water within the aquifer and for estimating amounts of recharge, storage, and discharge.

Occurrence and Movement

Vertical and lateral variations in hydraulic characteristics of the Vamoosa–Ada aquifer, caused by variations in lithology, result in water occurring under unconfined, semiconfined, and confined conditions. Separation of the confined and unconfined parts of the aquifer, as shown on plate 2, is based on interpretation of about 600 geophysical logs. The interface between the unconfined and the confined zones is not sharply defined, as may be indicated by the maps, but probably is gradational through a zone where the water is semiconfined.

Unconfined conditions generally exist in the outcrop area of the aquifer and probably for a short distance westward from the point where it is overlain by less permeable rocks. Excluding some municipal and industrial wells, most wells completed in the Vamoosa–Ada aquifer penetrate only enough of the unconfined sandstone beds to obtain an adequate water supply. Measurements made in these wells were used to construct the water-table map (pl. 3, map A). Water-table contours, as shown on the map, were adjusted to fit the topography. A similar map for the confined part of the aquifer could not be prepared, because of lack of data.

In general, the regional slope of the water table is toward the east, similar to the eastward slope of the land surface. The principal component of ground-water movement is virtually lateral from areas of recharge to areas of discharge. As shown by the map, water levels are highest in the uplands between the streams. From these areas, the water moves toward the stream valleys, where it is discharged as springs or streamflow. This discharge maintains the flow of many streams during dry periods. Because water levels are close to the land surface in the stream valleys, most of the discharge by evapotranspiration takes place in these areas.

A secondary local component of ground-water movement is vertical—either downward or upward, depending on differences in hydraulic head. Measurements made in wells completed in the confined part of the aquifer at Seminole, Prague, Stroud, Cushing, and Drumright show that the confined hydraulic head ranges from about 70 to 150 ft below the unconfined hydraulic head as determined from the water-table map. Because of these hydraulic-head differences, water moves from the upper, unconfined part of the aquifer into the lower, confined part. Conversely, upward flow probably occurs where major streams, such as the Arkansas, North Canadian, and Canadian Rivers, are entrenched into the aquifer. This upward-moving water flows into the alluvium along the streams and eventually into the streams themselves during periods of low flow.

Movement of water in the deeper parts of the aquifer cannot be determined, because of lack of water-level data. Presumably, the regional direction of movement is toward the west, in the same direction as the regional dip of the aquifer.

Recharge

Most recharge to the Vamoosa–Ada aquifer is derived from precipitation falling directly on the outcrop area. Some recharge may occur where the aquifer is connected to the surface by sandstone beds in overlying rocks.

The base-flow of streams, that is, streamflow derived from ground water during dry periods, represents recharge that has entered the aquifer where it was temporarily stored until it was gradually discharged through springs and seeps. Thus, base-flow records and precipitation data can be used to obtain minimum estimates of recharge. To make such an estimate for the Vamoosa–Ada aquifer, base-flow measurements of Hilliby Creek in Okfuskee County and Polecat Creek in Creek County were used. The amounts of precipitation falling on the creek basins were obtained from the nearest climatological stations and were weighted to give average values. During 1975, precipitation on the two basins, which have a total area of 90 mi^2, amounted to approximately 190,000 acre-ft. During the same period, base flow from the two basins totaled about 7,300 acre-ft, or nearly 4 percent of the total precipitation. This value for recharge probably is small, because recharge to similar sandstone aquifers in western and central Oklahoma was estimated to be about 10 percent of the annual precipitation (Tanaka and Davis, 1963, p. 34; Carr and Marcher, 1977, p. 15). Nevertheless, the value of 4 percent amounts to about 93,000 acre-ft for the principal recharge area of the Vamoosa–Ada aquifer (about 1,090 mi^2).

Potable Water in Storage

The map showing the thickness of the zone of potable water (pl. 3, map B) was prepared by contouring differences in altitude between the base of potable water (pl. 3, map C) and the water-table surface of the unconfined part of the aquifer (pl. 3, map A). The map shows that the approximate maximum thickness of the potable-water zone decreases from 900 ft in the southern part of the area to 700 ft in the central part and to only 400 ft in the northern part. These changes in thickness largely reflect variations in the thickness of saturated sandstones, as shown by comparing the maps on plate 2 with map B on plate 3.

The volume of potable water stored in the Vamoosa–Ada aquifer can be estimated by multiplying the volume of the sandstone by its porosity. The volume of only the sandstone is considered, because even though the interbedded shale and siltstone contain large amounts of water, it is available only by very slow drainage during a long period of time. The total area of the aquifer, as considered in this report, is about 2,320 mi^2. Based on an average sandstone thickness of 200 ft and an average porosity of 0.20, as determined from neutron logs, the total amount of potable water stored in the aquifer is estimated at about 60 million acre-ft.

Porosity limits the amount of water that can be stored in an aquifer. Even with 100-percent water saturation, however, the aquifer will yield less than this limit, because some of the water is retained in the pores of the rock. Therefore, an estimate of the amount of water available from storage can be made by using specific yield, which is the ratio of the volume of water that a rock, after being saturated, will yield by gravity to the volume of the rock. Although no direct determinations of the specific yield for the Vamoosa–Ada aquifer have been made, a value of 0.12 was estimated by comparing the lithology and porosity of the aquifer with similar sandstones for which specific yields have been determined (Johnson, 1967). Using this value, the amount of potable water theoretically available from storage is estimated at 36 million acre-ft.

Changes in storage reflect a net difference in water movement, either natural or man-made, into or out of the aquifer. A regional loss or gain in storage would be indicated by a lowering or rising of the water level over a broad area. Water-level hydrographs (fig. 2) of three widely spaced wells in the Vamoosa–Ada aquifer show that the general trend of water levels for the periods of record is upward, indicating a regional increase in storage. Based on a specific yield of 0.12 and an average rise in water level of 4 ft throughout the outcrop area of 1,090 mi^2, an estimated gain of 335,000 acre-ft of available water was added to the aquifer between 1971 and 1975.

Discharge

Water is discharged from the Vamoosa–Ada aquifer by evapotranspiration, streamflow, and pumping; of these losses, evapotranspiration is by far the largest. An estimate of evapotranspiration was obtained by use of the formula $ET = KF$, where ET = evapotranspiration, K = empirical coefficient depending on crop type and modified by vegetation factors, and F = the sum of the monthly consumptive use factors for the period. The consumptive use factor for each month is computed as the product of the mean monthly temperature and monthly percentage of daytime hours of the year (Blaney and Criddle, 1962, p. 43).

A value of 0.7 was used for K throughout the study area. Vegetation-density factors ranged from 0.7 to 0.9. In order to compute ET, data were obtained from five climatological stations. The results of the computations for 1975, as given below, show that evapotranspiration accounted for about 85 percent of the total precipitation during the year.

Station	*Precipitation (inches)*	*Evapotranspiration (inches)*	*Percent*
Seminole	42.1	37.9	90
Bristow	39.6	37.0	93
Cushing	40.9	34.0	83
Cleveland	38.4	32.4	84
Pawhuska	39.0	30.7	79

Because evapotranspiration accounts for such a large percentage of the water discharged, monthly values were determined for each of the five stations. The average of these values, in inches, for all five stations is given below:

Jan.	1.6	May	3.8	Sept.	3.2
Feb.	1.4	June	4.2	Oct.	2.8
Mar.	2.2	July	4.4	Nov.	1.9
Apr.	3.0	Aug.	4.2	Dec.	1.6

Discharge from the aquifer by streamflow was estimated from base-flow measurements of Hilliby and Polecat Creeks. During 1975, the yearly base-flow discharge for Hilliby Creek was 3,160 acre-ft and for Polecat Creek 4,115 acre-ft, for a total of 7,275 acre-ft. The total area of the two basins is approximately 90 mi^2; hence, base-flow discharge from both was about 80 acre-ft/mi^2. Applying this value to the outcrop area of 1,090 mi^2 for the Vamoosa–Ada aquifer, the total amount of ground water discharged by streamflow amounted to about 87,000 acre-ft during 1975.

Total yearly discharge from the aquifer by pumping is based on city pumping records, records obtained from rural water districts, and estimates of rural population based on 1972 census figures. Water withdrawal from the Vamoosa–Ada

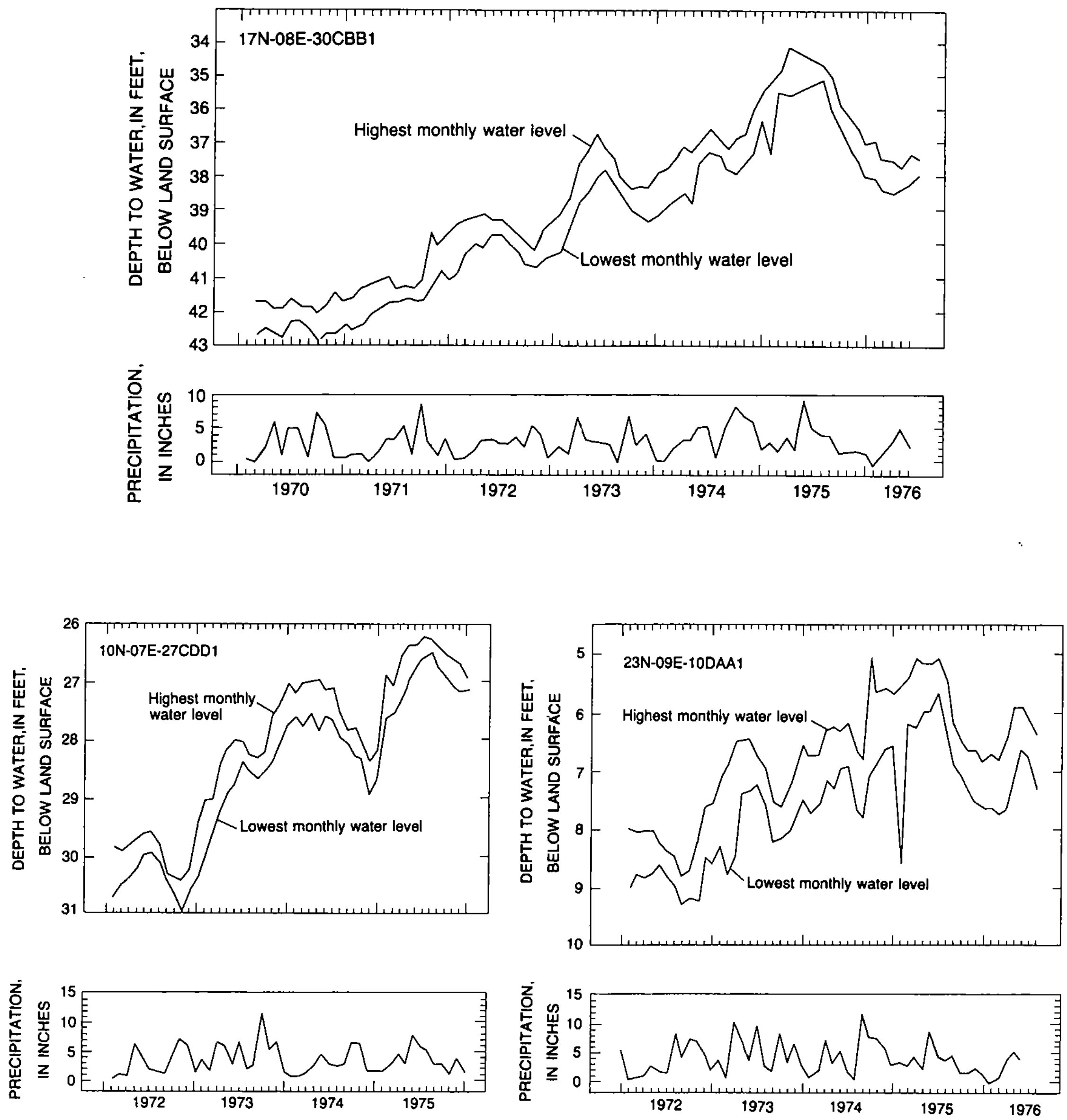


Figure 2. Water-level hydrographs for wells in the Vamoosa–Ada aquifer and monthly precipitation at nearby stations.

TABLE 3.—MUNICIPAL WATER USE DURING 1975

City and source of water	Monthly water use (acre-ft)												Total water use (acre-ft)	Per capita use (gallons per day)	Number of wells used
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.			
Cushing: Surface water	100.5	92.0	104.7	93.7	133.4	156.6	158.9	150.6	145.8	129.2	128.9	125.0	1519.3	180	--
Well	--	--	--	--	30.9	61.5	35.9	34.6	34.5	9.1	23.5	8.6	238.6	28	3
Drumright: Well water	45.0	37.4	36.0	35.5	38.3	47.5	48.4	52.5	46.4	41.7	38.0	35.6	503.2	164	8
Prague: Well water	13.5	14.6	16.8	16.8	17.8	21.2	30.0	23.3	22.1	19.1	14.7	15.4	255.3	106	9
Seminole: Well water	92.4	85.1	93.0	96.0	101.9	105.8	128.3	134.7	116.4	114.2	105.1	108.1	1281.0	114	14
Stroud: Surface water	18.7	15.2	17.5	19.4	18.6	20.4	26.4	22.9	18.7	20.4	18.5	18.4	235.1	84	--
Well	5.2	5.3	5.8	5.6	5.8	5.0	5.6	5.8	5.6	5.7	5.5	5.7	66.6	24	1

aquifer for 1975, in acre-feet, is summarized below:

County	*Rural use*	*Municipal use*	*Total*
Creek	250	660	910
Lincoln	90	290	380
Okfuskee	70	120	190
Osage	280	315	595
Pawnee	60	65	125
Payne	50	240	290
Pottawatomie	40	120	160
Seminole	350	1,540	1,890
Totals:	1,190	3,350	4,540

Fewer than 200 acres of crops are irrigated; thus, ground-water withdrawals for irrigation are insignificant.

Major towns in the study area that rely, entirely or in part, on ground water for municipal supply include Cushing, Drumright, Prague, Seminole, and Stroud. Water-use data for these towns are shown in table 3.

GENERAL HYDROLOGIC BUDGET

A hydrologic budget is a semiquantitative accounting of the balance between total water gains and losses for a given area for a given period of time, as calculated by:

$$Pc = Rc + Rn + ET \quad (1)$$

where

Pc = precipitation, in inches;
Rc = recharge, in inches;
Rn = runoff, in inches; and
ET = evapotranspiration, in inches.

Runoff was estimated using the following relationship:

$$Rn = Pc - (Rc + ET). \quad (2)$$

Estimates of recharge (Rc) and evapotranspiration (ET) were given in the preceding section of this report. Based on these data, the estimated annual water budget for 1975 at five climatological stations is as follows, with all values in inches:

Station	Pc	Rc	Rn	ET
Bristow	39.6	1.6	1.0	37.0
Cleveland	38.4	1.5	4.5	32.4
Cushing	40.9	1.6	5.3	34.0
Pawhuska	39.0	1.6	6.7	30.7
Seminole	42.1	1.7	2.5	37.9

CHEMICAL QUALITY OF WATER

MELVIN V. MARCHER[1]

As stated earlier, one purpose of this report is to provide a general evaluation of the chemical quality of water from the Vamoosa–Ada aquifer. This evaluation is based on laboratory and on-site data. Laboratory data include (1) analyses of water from 88 wells (table 4) to determine concentrations of common constituents (calcium, magnesium, sodium plus potassium, bicarbonate, sulfate, chloride, and dissolved solids); and (2) analyses of water from 37 wells (table 4) and 12 stream sites (table 5) to determine concentrations of bromide as an indicator of mineralization by brines. On-site data include determinations of specific conductance of water from 212 wells (table 2) and 199 stream sites (table 5).

All natural waters contain mineral constituents dissolved from the rocks and soils with which they have been in contact. The concentration of dissolved constituents depends primarily on the type of soil or rock, to some extent the length of contact time, and pressure and temperature conditions. In addition to these natural conditions, man's activities, such as disposal of sewage and industrial wastes, diversion and use of the water, and activities associated with oil production, locally can have a significant effect on the chemical quality of the water.

Base of Potable Water

Delineation of the base of potable water, as shown by plate 3, map C, was determined from geophysical logs of approximately 500 oil and gas tests (1950 to 1972). For purposes of this report, the base of potable water is the base of the deepest zone containing water with a concentration of about 1,500 mg/L of dissolved solids. This concentration is used because it is the approximate maximum limit of dissolved solids the water can contain and still be considered potable or suitable for drinking (Kelly, 1962). The position of the base of potable water is significant, because wells that are completed below the base will yield water that is unsuitable for drinking and for some other uses. In addition, local overpumping of wells that are completed to near the base may induce upward movement of more-mineralized water into the potable-water zone.

Within the study area, the contact between the base of potable water and the underlying nonpotable water generally is rather abrupt; locally, however, the change occurs within a vertical distance of several tens of feet. Altitudes of the base range from near sea level in the southern part of the study area to about 900 ft above sea level in the northern part. These variations in altitude primarily reflect differences in rock permeability, although local geologic or hydrologic conditions are significant. The depth to the base of potable water at a particular locality can be estimated by comparing the altitude of the land surface determined from topographic maps with the altitude of the base of potable water.

Water Types

Examination of the data in table 4 shows that the type of water in the Vamoosa–Ada aquifer is variable. Of the 55 analyses that are complete enough to classify the water, about 75 percent are sodium bicarbonate or sodium calcium bicarbonate types. The remaining 25 percent are sodium sulfate, calcium sulfate, sodium chloride, or indeterminate types.

Water type is affected by depth, because concentrations of chemical constituents generally change with depth. The relationship between well depths and concentrations of selected chemical constituents is given in table 6. Comparison of mean values of each constituent at different depths shows that calcium and magnesium decrease with depth; sodium, bicarbonate, sulfate, and dissolved solids increase with depth; and chloride remains nearly constant. Dissolved solids, which is an index of the amount of total mineralization, exceeded 1,000 mg/L in 15 of 78 samples, or about 20 percent; of these, 8 samples were from wells 300 or more feet deep. Concentrations of chloride, which may indicate invasion of part of the aquifer by brines, exceeded 250 mg/L in 8 of 83 samples, or about 10 percent.

[1] Chief, Hydrologic Studies Section, U.S. Geological Survey, Water Resources Division, Oklahoma City, Oklahoma.

TABLE 4.—CHEMICAL ANALYSES OF WATER FROM WELLS IN THE VAMOOSA–ADA AQUIFER

[Concentrations of chemical constituents are given in milligrams per liter; specific conductance is given in micromhos per centimeter at 25° Celsius]

Location	Date sample collected	Well Depth (feet)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Bicar-bonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids	Bromide (Br)	Specific conduc-tance
05N-05E-25 DAD	11-1974	236	76	22	180	426	180	64	788	0.2	1220
07N-06E-23 BCB	11-1974	321	8.1	3.6	280	281	110	210	785	.7	1340
07N-06E-33 BDD	11-1974	126+	99	59	67	502	52	98	652	.6	1110
07N-07E-05 ABB	12-1974	180	65	44	14	386	44	15	387	.1	676
08N-05E-33 AAB	11-1974	668	2.0	0.8	520	895	190	100	--	.5	2090
08N-06E-10 BBC	3-1964	178	12	35	390	452	215	320	1300	--	2086
08N-06E-14 DCC	11-1974	500	280	150	950	324	21	2300	4500	8.2	6750
08N-06E-14 DDD	11-1974	500	2.9	1.7	160	349	29	14	408	.1	674
08N-06E-14 DDD	12-1975	500	3.6	2.0	160	346	32	16	406	.1	650
08N-06E-21 DAA	11-1974	550	1.7	.2	190	454	18	9.2	474	.0	770
08N-06E-25 CCD	11-1974	165	45	25	5.7	251	11	7.5	226	.1	445
08N-07E-07 ADD	11-1974	600	48	21	8.3	232	14	8.4	221	.0	430
08N-07E-31 BAB	4-1971	50	--	--	20	186	21	8	194	--	352
09N-05E-04 DCC	6-1975	248	--	--	--	202	210	71	--	.3	5720
09N-05E-15 DDD	12-1974	112	--	--	--	--	--	62	2020	.2	2600
09N-06E-20 AA-	12-1974	753	186	33	79	132	601	25	1080	--	1360
09N-06E-20 ABD	12-1975	816	25	5.7	86	208	48	6.5	343	.0	490
09N-06E-26 CA-	9-1947	450	146	12	356	135	796	175	1540	--	2260
09N-07E-03 CDB	12-1974	150	11	4.6	5.4	51	6.2	5.7	76	.0	117
09N-07E-09 BBA	5-1970	120	--	--	8.0	142	11	9.1	165	--	275
10N-05E-01 CBB	1-1975	189	--	--	--	370	85	210	--	1.0	1380
10N-06E-17 ADD	1-1970	25	--	--	11	154	4.8	8	197	--	269
10N-07E-18 BCC	5-1970	42	--	--	11	20	24	13	113	--	166
11N-06E-06 CCC	3-1971	220	--	--	80	450	28	34	502	--	872
11N-06E-34 BCC	8-1970	198	--	--	134	248	163	11	478	--	751
11N-07E-35 AAC	5-1970	152	--	--	45	324	57	14	374	--	626
12N-06E-28 DAD	5-1975	412	160	54	160	253	470	200	1260	.5	1810
12N-07E-27 BBB	1-1971	105	--	--	10	432	16	19	386	--	708
13N-07E-21 DDC	4-1971	131	--	--	12	242	9	10	222	--	413
13N-08E-08 DAA	2-1970	32	--	--	6.7	68	16	9	102	--	172

14N-07E-10 CBB	4-1971	153	--	--	25	374	7	100	486	--	896
14N-08E-04 AAC	11-1970	55	--	--	30	76	15	30	146	--	251
15N-06E-28 DBD	7-1975	408	23	5	140	335	93	12	455	.1	720
15N-07E-25 CCC	10-1974	149	12	15	13	217	2.8	6.9	201	.1	365
15N-08E-06 CDB	6-1971	185	--	--	12	254	11	7	243	--	426
16N-05E-23 DDD	2-1975	196	57	28	100	332	22	110	478	.5	790
16N-06E-23 BBB	3-1975	97	330	100	350	122	20	1300	2510	7.7	3600
16N-07E-21 ADA	6-1971	117	--	--	4.9	46	11	9	77	--	110
16N-07E-33 DDA	6-1971	99	--	--	26	306	24	16	324	--	536
17N-05E-03 ACB	10-1975	697	37	3.8	90	222	98	6.5	370	.1	575
17N-05E-23 B--	7-1952	357	80	20	757	--	1660	23	2740	--	3680
17N-07E-08 CCA	7-1971	487	--	--	110	302	28	45	388	--	644
17N-07E-25 ADD	4-1971	130	--	--	17	108	14	13	134	--	244
17N-08E-08 ACC	6-1971	136	--	--	25	240	4.4	7.0	235	--	382
17N-08E-35 BDA	1-1975	121	19	8.5	8.8	76	16	11	--	.2	51
18N-06E-16 DDD	8-1973	30	89	33	35	259	50	27	608	--	864
18N-06E-31 BCB	4-1975	160	170	82	180	200	110	670	1570	.4	1950
18N-06E-36 DAD	10-1975	538	11	1.2	140	273	79	16	405	.1	654
18N-06E-36 DDD	7-1971	490	--	--	66	256	63	12	340	--	546
18N-07E-13 AAD	12-1971	77	--	--	5.2	92	22	8.6	142	--	218
18N-07E-16 BAD	4-1975	600	19	1.9	190	266	180	49	595	.2	1300
18N-07E-20 A--	6-1971	124	--	--	29	266	110	52	480	--	733
18N-07E-35 DDA	6-1971	230	--	--	25	390	30	13	358	--	648
18N-08E-18 BCC	11-1972	120	40	16	17	323	11	5	207	--	376
18N-08E-33 DDD	1-1975	194	7	3.1	11	12	17	8.6	88	.2	126
19N-07E-03 CDD	2-1973	180	110	72	130	486	180	140	960	--	1530
19N-08E-04 DCC	2-1973	67	14	4.6	23	76	13	5.4	132	--	208
20N-07E-01 DAD	4-1975	90	390	130	110	413	970	270	2220	.7	2880
20N-08E-05 DDA	8-1971	28	--	--	34	24	12	110	239	--	369
20N-08E-06 CCC	4-1975	--	140	110	74	487	450	80	1200	.3	1650
20N-08E-09 DCD	8-1971	20	--	--	81	44	66	220	676	--	1030
20N-08E-17 AAD	8-1971	80	--	--	150	140	250	150	744	--	1170
21N-07E-11 CAA	7-1973	42	30	5.6	13	108	13	7.8	192	--	256
21N-08E-20 DCA	8-1971	85	--	--	32	72	91	90	382	--	591
21N-08E-29 AAD	8-1971	65	--	--	102	50	58	360	998	--	1360
22N-07E-16 BBD	7-1973	21	110	28	64	372	60	68	712	--	999
22N-08E-33 BAA	8-1971	100	--	--	72	376	28	31	408	--	708
22N-09E-17 CCC	1-1973	200	6	8	180	416	38	25	466	--	770
23N-07E-09 BDA	1-1973	87	22	13	140	386	59	16	454	--	740

TABLE 4.—*Continued*

Location	Date sample collected	Well Depth (feet)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Bicar-bonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids	Bromide (Br)	Specific conduc-tance
23N-08E-07 DCC	4-1975	350	220	57	140	176	120	570	1410	3.3	2995
23N-09E-25 BCC	4-1975	187	87	60	77	205	110	190	708	.6	1010
24N-08E-33 CCA	8-1971	25	--	--	40	388	120	28	560	--	862
24N-09E-03 DAA	4-1975	260	5.1	3.1	240	420	54	53	627	.3	1060
24N-09E-20 ABB	8-1971	325	--	--	53	192	37	11	250	--	406
25N-09E-24 BAD	11-1972	240	33	28	160	480	86	43	582	--	978
25N-09E-35 BAD	2-1973	255	120	34	67	262	150	110	658	--	1090
26N-09E-14 ACB	4-1973	109	19	7.8	19	37	7.6	39	199	--	291
26N-10E-09 ADA	3-1975	130	11	2.8	600	447	640	17	1490	3.8	2695
27N-09E-27 ACC	2-1973	125	4	1.2	270	590	94	18	674	--	1120
28N-07E-29 DDA	3-1975	900	8.1	3.4	860	560	860	200	2290	4.5	4000
28N-08E-03 AAA	4-1973	300	8.7	1.8	19	378	40	110	637	--	1010
28N-08E-08 DDA	3-1975	500	4.7	2	440	411	200	440	1140	.7	2070
28N-09E-15 DAC	3-1975	160	1.8	.1	210	386	63	56	542	.4	893
28N-10E-33 ADA	1-1973	153	42	14	17	158	40	20	235	--	394
29N-09E-23 CDA	3-1975	90	99	31	150	336	280	45	1030	1.8	1210
29N-10E-29 BDC	11-1973	65	140	14	25	317	36	120	568	.8	922
29N-10E-29 BDC	1-1974	65	140	14	24	304	34	120	533	.5	890

TABLE 5.—SPECIFIC-CONDUCTANCE, DISCHARGE, AND BROMIDE DATA FOR STREAMS DRAINING THE VAMOOSA–ADA AQUIFER

[Br = bromide. Units of measurement: Specific conductance, µmho/cm (micromhos per centimeter at 25° Celsius; estimated flow, ft^3/s (cubic foot per second); and bromide, mg/L (milligram per liter)]

Site location	Name	Specific conductance (µmho/cm)	Date measured	Estimated flow (ft^3/s)	Remarks
CREEK COUNTY					
14N-07E-01 DDD	Salt Creek	920	2-12-75	25	
14N-07E-01 DDD	Salt Creek	2800	10-13-76	0.1	Oil on water
14N-08E-31 BBC	Deep Fork Creek	520	8-22-75		
14N-08E-06 DCD	Tributary of Salt Creek	470	2-12-75	4	
14N-08E-24 ABC	Deep Fork of Canadian River	1320	10-13-76	75	Oil on water
14N-09E-08 AA	West Fork of Sandy Creek	1300	10-13-76	0.1	Oil on water
15N-07E-15 BCC	Tributary of Camp Creek	1360	8-20-75		
15N-07E-21 CDD	Camp Creek	705	8-22-75	4	
15N-07E-26 CCD	Tributary of Salt Creek	215	8-22-75	1	
15N-07E-27 ABB	Tributary of Salt Creek	535	2-12-75	1	
15N-07E-28 CB	Tributary of Salt Creek	3200	10-13-76	0.1	Oil on water
15N-07E-31 BBA	Tributary of Salt Creek	515	2-12-75	1	
15N-07E-33 AAA	Salt Creek	2750	10-13-76	0.1	Oil on water
15N-07E-33 AAD	Tributary of Salt Creek	650	2-12-75	1	
15N-07E-35 BAB	Tributary of Salt Creek	195	2-12-75	1	
15N-07E-36 BAB	Tributary of Salt Creek	260	2-12-75	1	
16N-07E-04 AAB	West Spring Creek	7900	2-13-75	5	
16N-07E-04 AAB	West Spring Creek	2600	8-19-75	4	
16N-07E 14 AAB	East Spring Creek	925	2-12-75	8	
16N-07E-14 AAB	East Spring Creek	770	8-19-75	4	
16N-07E-27 DDA	Little Deep Fork Creek	225	8-20-75	6	
16N-07E-28 ADA	Little Deep Fork Creek	260	8-20-75	3	
16N-08E-04 BCB	Tributary of Catfish Creek	1490	8-18-75		
16N-08E-11 CCC	Little Catfish Creek	250	8-18-75	4	
16N-08E-22 BBC	Catfish Creek	3250	10-13-76	0.2	Oil on water
17N-07E-02 CAD	Tributary of Tiger Creek	15000	10-13-76	0.1	Oil on water
17N-07E-03 BDA	Tributary of Tiger Creek	20000	10-13-76	0.1	Oil on water
16N-09E-08 CCC	Tributary of Sand Creek	4000	8-18-75	1	
17N-07E-04 ABA	Tributary of Tiger Creek	17500	10-13-76	0.2	Oil on water
17N-07E-04 AAD	Tributary of Tiger Creek	8500	10-13-76	0.1	Oil on water
17N-07E-03 BDB	Tributary of Tiger Creek	4600	8-19-75	6	
17N-07E-16 CC	Tributary of Tiger Creek	1120	8-19-75	0.3	
17N-07E-23	Spring Creek	5100	8-19-75	0.2	Creek flows through oil field
17N-07E-26 AAB	Spring Creek	16000	8-21-75		
17N-07E-31 DAA	Tributary of Little Deep Fork Creek	705	2-13-75		
17N-07E-31 DAA	Tributary of Little Deep Fork Creek	220	8-19-75	0.2	
17N-07E-33 AAC	Tributary of West Spring Creek	3800	8-20-75	1	Creek flows through oil field
17N-08E-10 D	Dog Creek	790	8-18-75	1	
17N-08E-17 DCC	Tributary of Dog Creek	500	2-13-75	2	
17N-08E-17 DCC	Tributary of Dog Creek	550	8-20-75	0.2	

TABLE 5.—*Continued*

Site location	Name	Specific conductance (μmho/cm)	Date measured	Estimated flow (ft^3/s)	Remarks
CREEK COUNTY--Continued					
17N-09E-07 BCC	Polecat Creek	490	10-13-76	0.5	
17N-09E-16 BCB	Mosquito Creek	730	8-18-75	1.5	
17N-09E-30 BDC	Mosquito Creek	1300	10-13-76	0.5	Oil on water
18N-07E-03 CDD	Dry Creek	3100	8-20-75	1	Br = 3.8 mg/L
18N-07E-29 BCD	Tiger Creek	4180	10-13-76	1.5	Oil on water
18N-07E-33 BCC	Tributary of Tiger Creek	11400	10-13-76	0.3	Oil on water
18N-07E-33 DCC	Tributary of Tiger Creek	14000	10-13-76	0.2	Oil on water
18N-08E-06 CDC	Buckeye Creek	260	8-19-75	4	
18N-08E-06 CDC	Buckeye Creek	420	10-13-76	1	
18N-08E-18 CDD	Buckeye Creek	270	8-10-75		Not base flow
18N-08E-18 CDD	Buckeye Creek	275	10-13-76	1	
18N-08E-26 DDD	Deep Creek	220	8-18-75	2	
18N-08E-33 AAD	Polecat Creek	310	8-19-75	5	
18N-08E-33 AAA	Tributary of Polecat Creek	220	10-13-76	1	
18N-08E-36 DDD	Figure Eight Creek	250	8-18-75	0.8	
18N-09E-19 DDC	Figure Eight Creek	160	10-13-76	0.2	
19N-07E-35 BAA	Dry Creek	1450	8-20-75	2	
19N-07E-36 AAA	Buckeye Creek	500	10-13-76	2	
19N-08E-32 AAB	Sand Creek	330	8-20-75	0.8	
19N-08E-34 BAA	Rock Canyon Creek	230	8-20-75	2	
19N-08E-36 BAB	Cottonwood Creek	470	8-19-75	1.5	
LINCOLN COUNTY					
12N-06E-03 BAB	Deer Creek	900	2-14-75		
12N-06E-03 BAB	Deer Creek	340	8-18-75	1.5	
12N-06E-10 CDD	Deer Creek	610	8-18-75	0.4	
13N-06E-04 CDD	Deer Creek	940	2-14-75		
13N-06E-09 CCC	Deer Creek	730	8-18-75	6	
13N-06E-11 ABB	Barby Creek	1090	2-17-75		
13N-06E-21 ABA	Deer Creek	995	1-30-75		
14N-06E-03 DDC	Tributary of Deep Fork of Canadian River	4600	2-12-75		
14-N-06E-03 DCD	Tributary of Deep Fork of Canadian River	1120	1-30-75		
14N-06E-15 CBB	Deep Fork of Canadian River	435	8-19-75		
14N-06E-34 AAB	Tributary of Deep Fork of Canadian River	1300	8-19-75		Br = 2.2 mg/L Oil lining creek bank
14N-06E-36 CDD	Barby Creek	535	2-12-75		
14N-06E-36 CDD	Barby Creek	415	8-19-75		
15N-06E-22 BBB	Salt Creek	2200	8-19-75	4	
16N-05E-01 AAD	Tributary of Euchee Creek	330	8-19-75	5	
16N-05E-36 AAA	Fourmile Creek	1180	2-13-75		
16N-06E-06 CDD	Euchee Creek	1150	2-12-75		
16N-06E-06 CDD	Euchee Creek	210	8-19-75		
17N-06E-18 DCD	Euchee Creek	2600	2-13-75		
17N-06E-18 DCD	Euchee Creek	245	8-20-75	0.5	
17N-06E-19 CDC	Euchee Creek	220	8-20-75	0.5	

TABLE 5.—*Continued*

Site location	Name	Specific conductance (μmho/cm)	Date measured	Estimated flow (ft^3/s)	Remarks
OKFUSKEE COUNTY					
11N-08E-13 ADD	North Canadian River	1850	10-12-76	80	
11N-08E-14 AAA	Tributary of North Canadian River	220	10-12-76	1	
12N-07E-06 BBA	Pettiquah Creek	270	8-18-75	3	
13N-07E-31	Pettiquah Creek	1190	1-30-75		
13N-07E-02 DDC	Hilliby Creek	625	8-22-75	1	
13N-08E-01 CCD	Wolf Creek	370	10-13-76	0.1	
13N-09E-06 AAD	Deep Fork of Canadian River	1220	10-13-76	70	
OSAGE COUNTY					
21N-10E-04 CDA	Tributary of Wildhorse Creek	100	10-14-76	0.1	
22N-09E-13 CDC	Boar Creek	480	10-14-76	2	
22N-10E-20 BDB	Wildhorse Creek	325	10-14-76	0.5	
22N-10E-21 AAC	Eagle Creek	2250	10-14-76	0.3	
22N-10E-29 CCD	Buck Creek	175	10-14-76	0.5	
22N-10E-32 DDD	Wildhorse Creek	270	10-14-76	0.3	
23N-08E-05 CBC	Rainbow Creek	8650	10-14-76	0.1	
23N-08E-35 CDA	Penn Creek	490	10-14-76	0.5	
23N-09E-27 ADD	Sunset Creek	280	10-14-76	1	
23N-09E-30 ADA	Tributary of Hominy Creek	2000	8-18-75		Not base flow
23N-09E-33 D	Tributary of Hominy Creek	320	10-14-76	1	
23N-09E-34 ADD	Mahala Creek	280	10-14-76	1	
23N-09E-36 DAB	Sand Creek	850	10-14-76	1	
23N-10E-34 CDC	Bull Creek	3750	10-14-76	0.2	
24N-07E-10 D	Hominy Creek	1380	8-18-75	4	
24N-07E-10 D	Hominy Creek	16000	10-14-76	0.2	
24N-07E-33 A	Tributary of Sycamore Creek	1900	8-18-75	1	Not base flow
24N-07E-33 C	Tributary of Sycamore Creek	890	8-18-75	5	
24N-08E-09 ADA	Little Hominy Creek	1340	10-14-76	0.1	
24N-08E-14 CAB	Little Hominy Creek	2400	8-18-75		
24N-08E-14 CAB	Little Hominy Creek	3500	10-14-76	2	
24N-08E-25 BA	Little Hominy Creek	18500	8-14-75	4	Br = 31.0 mg/L
24N-09E-32 DDA	Tributary of Twomile Creek	1600	10-14-76	0.1	
24N-08E-36 BAA	Little Hominy Creek	2850	8-18-75	10	
24N-10E-01 DDA	Red Eagle Branch	430	10-14-76	0.2	
24N-10E-17 DAD	Birch Creek	1040	8-18-75		
24N-10E-17 DAD	Birch Creek	920	10-14-76	0.1	
24N-10E-30 CAA	Fourmile Creek	920	8-20-75		Not base flow
25N-08E-18 A	Tributary of Clear Creek	780	10-14-76	2	
25N-08E-19 CBB	Tributary of Little Hominy Creek	13000	8-18-75		Br = 18.0 mg/L
25N-08E-19 CDD	Tributary of Little Hominy Creek	42000	8-19-75		Brine flowing into creek from brine pit
25N-08E-23 BDD	Clear Creek	7200	8-19-75		
25N-10E-16 CDD	Nelagoney Creek	250	8-20-75		Not base flow
25N-10E-18 BCC	Quapaw Creek	2650	8-20-75		Not base flow
25N-10E-20 DBB	Saucy Calf Creek	810	10-14-76	1	
25N-10E-21 BCB	Buffalo Creek	480	3-26-75		
25N-10E-21 BCB	Buffalo Creek	1860	3-26-75	20	

TABLE 5.—*Continued*

Site location	Name	Specific conductance (µmho/cm)	Date measured	Estimated flow (ft^3/s)	Remarks
OSAGE COUNTY--Continued					
25N-10E-32 DDC	Tributary of Cochahee Creek	420	10-14-76	0.5	
26N-09E-12 AAD	Cedar Creek	640	8-20-75		
26N-10E-04 CAD	Rock Creek	600	8-20-75		
26N-10E-15 AAA	Sand Creek	700	8-20-75	11	
26N-10E-19 BDB	Sand Creek	420	8-20-75		
27N-10E-07 CB	Tributary of Rock Creek	340	8-21-75	0.4	
27N-10E-08 BDD	Tributary of Rock Creek	590	8-21-75	0.2	Oil on water
27N-10E-08 CDD	Rock Creek	260	8-21-75	0.2	
27N-10E-30 CBD	Elm Creek	340	8-21-75	0.4	
28N-08E-03 ABA	Buck Creek	220	3-06-75		
29N-08E-23 CBC	Smith Creek	420	8-21-75	0.2	
29N-08E-22 DAA	Smith Creek	350	3-06-75		
29N-09E-13 DAB	Caney River	395	8-21-75		Not base flow
29N-09E-23 DAC	Buck Creek	450	3-06-75		
29N-09E-23 DAC	Buck Creek	660	8-21-75		Not base flow
29N-10E-16 ABB	Coon Creek	400	3-06-75		
29N-10E-17 AAB	Cedar Creek	460	3-06-75		
29N-10E-17 DA	Caney River	120	3-26-75		
29N-11E-18 DDD	Tributary of Turkey Creek	2900	8-21-75	0.2	
29N-11E-18 DDD	Tributary of Turkey Creek	3500	10-14-76	0.5	Oil on water
29N-11E-30 AAB	Turkey Creek	1200	3-06-75		
29N-11E-30 AAB	Turkey Creek	4800	8-21-75	2	Br = 12.0 mg/L Oil on water
29N-11E-30 ABC	Turkey Creek	3500	10-14-76	0.1	
PAWNEE COUNTY					
20N-08E-02 DAD	Bear Creek	2300	8-21-75	1	
20N-08E-02 DAD	Bear Creek	1160	10-14-76	0.1	
20N-08E-06 DDD	Tributary of House Creek	4050	8-21-75	1	Br = 06.7 mg/L
20N-08E-13 BBA	Cowskin Creek	3100	8-21-75	0.1	
20N-08E-32 ABA	Tributary of House Creek	350	8-21-75	2	
21N-07E-21 BC	Turkey Creek	310	8-21-75		
21N-07E-21 BC	Turkey Creek	360	10-13-76	0.1	
21N-08E-17 BCB	Cedar Creek	4150	8-21-75	3	Br = 05.8 mg/L
21N-08E-17 BCB	Cedar Creek	4650	10-13-76	0.5	Oil on water
PAYNE COUNTY					
17N-05E-15 CCC	Tributary of Cottonwood Creek	500	8-19-75	4	Creek flows through oil field
17N-05E-13 DAA	Cottonwood Creek	250	8-19-75	15	Creek flows through oil field, not base flow
POTTAWATOMIE COUNTY					
11N-05E-11 DCC	Tributary of North Canadian River	620	8-19-75	0.1	
11N-06E-16 ABB	Shan Creek	590	8-19-75	0.2	

TABLE 5.—*Continued*

Site location	Name	Specific conductance (μmho/cm)	Date measured	Estimated flow (ft^3/s)	Remarks
SEMINOLE COUNTY					
05N-05E-11 A	Negro Creek	1160	10-11-76	0.2	
05N-06E-03 ABC	Jumper Creek	915	8-21-75	15	
05N-06E-03 ABC	Jumper Creek	1320	10-12-76	0.2	
05N-06E-19 ABD	Tributary of Canadian River	590	10-11-76	1.5	
05N-07E-23 AAA	Tributary of Canadian River	44000	10-12-76	> 0.05	Spring, dead foliage and trees around spring
05N-07E-26 AD	Tributary of Canadian River	10100	10-12-76	0.2	Flows through salt water injection area
06N-06E-33 B	Jumper Creek	1750	10-12-76	0.5	Oil residue on creek bed
06N-07E-08	Little River	1700	10-12-76	0.5	
06N-07E-19 AAD	Rock Creek	415	8-21-75	0.1	
06N-08E-30 BC	Little River	4200	10-12-76	4	
07N-06E-03 CBC	Little River	1800	10-12-76	0.1	
07N-06E-14 BCC	Tributary of Salt Creek	20000	2-13-75	0.1	
07N-06E-15 ADD	Tributary of Salt Creek	9200	2-13-75		
07N-06E-19 CDC	Mud Creek	1480	8-20-75	0.8	
07N-06E-27 CBC	Salt Creek	2920	8-20-75	8	
07N-06E-34 CCC	Sandy Creek	2950	8-20-75	0.2	
07N-07E-05 DBC	Tributary of Little River	7300	8-21-75		Salt water disposal pit in outcrop one-half mile south
07N-07E-08 DCD	Tributary of Little River	1500	8-21-75	0.2	
07N-07E-20 BBA	Little River	1320	8-20-75	25	
08N-06E-06	Tributary of Wewoka Creek	660	8-19-75	0.1	
08N-07E-07 CDD	Wewoka Creek	5800	8-19-75	9	Br = 8.0 mg/L
08N-07E-07 CDD	Wewoka Creek	1100	10-12-76	2	
08N-07E-32 ADD	Tributary of Wewoka Creek	255	8-19-75		
09N-05E-13 DCD	Tributary of Wewoka Creek	15500	10-11-76	> 0.1	
09N-05E-15 BCD	Wewoka Creek	44000	8-21-75	0.1	Br = 83.0 mg/L Leaking injection well one-fourth mile south
09N-05E-23 BBB	Wewoka Creek	41000	8-19-75	0.2	Br = 83.0 mg/L Water clear, foams easily, oil sediment on streambed

TABLE 5.—*Continued*

Site location	Name	Specific conductance (μmho/cm)	Date measured	Estimated flow (ft^3/s)	Remarks
SEMINOLE COUNTY--Continued					
09N-05E-23 BBB	Wewoka Creek	18000	10-12-76	0.1	
09N-06E-14 CDD	Carter Creek	9800	8-18-75	0.3	Br = 18.0 mg/L
09N-06E-29 BAB	Tributary of Wewoka Creek	870	8-19-75	0.1	
09N-06E-30 AAB	Wewoka Creek	19000	8-19-75	0.1	Br = 33.0 mg/L
10N-06E-03 CCC	Turkey Creek	9250	2-13-75		
10N-06E-03 CCC	Turkey Creek	9250	8-18-75	0.3	Br = 14.0 mg/L
10N-06E-03 CCC	Turkey Creek	6600	10-12-76	1	
10N-06E-17 DCC	Turkey Creek	1100	10-12-76	> 0.1	
10N-07E-09 DAA	Snake Creek	800	2-13-75		
10N-07E-09 DAA	Snake Creek	510	8-18-75	0.8	
10N-07E-17 CDD	Snake Creek	875	8-18-75		

Variations in Chemical Quality

To determine variations in mineralization of water in the Vamoosa–Ada aquifer, specific-conductance measurements made at well or stream sites were used to compare and contrast ground and surface waters within and between basins. Specific conductance is used because it provides a rapid and simple means of estimating the total concentration of dissolved minerals in the water. The ratio of dissolved solids to specific conductance, as determined from data provided by analysis of 81 samples (table 4) from wells of various depths, ranged from 0.46 to 0.85 and averaged 0.63. Thus, by measuring the value of specific conductance of the water and multiplying by the average value of 0.63, an approximation of the dissolved-solids concentration is obtained. Specific-conductance measurements, however, cannot be used to identify individual anions or cations in the water.

During periods of base flow, when water in the streams is derived from ground water, the specific conductance of stream and ground waters in a given basin should be about the same, provided that minerals are not being added to the stream from an outside source. Specific conductance of water from wells in the Vamoosa–Ada aquifer, based on 212 measurements, ranged from 51 to 6,828 μmho (micromhos at 25° C); the median value was 729 μmho. Water from 23 wells, or about 11 percent of the total, exceeded 1,600 μmho, which is approximately equivalent to 1,000 mg/L dissolved solids. In comparison, specific conductance of stream water, based on measurements at 191 sites during periods of base flow, ranged from 100 to 44,000 μmho: the median value was 920 μmho. Water at 65 sites, or about 34 percent, had a specific conductance greater than 1,600 μmho.

Comparison of specific-conductance measurements of water from two basins in the outcrop area of the Vamoosa–Ada aquifer—Polecat and Wewoka Creeks—shows marked differences in the mineralization of the water. For example, the specific conductance of water from two tributaries of Polecat Creek (Dog Creek and a tributary of Dog Creek), Creek County, during base flow was 500 and 790 μmho, while specific conductance of ground water in the basin ranged from 380 to 555 μmho. In contrast, specific conductance of water from Wewoka Creek, Seminole County, and its tributaries ranged from 255 to 44,000 μmho and that of ground water in Wewoka Creek basin ranged from 430 to 6,750 μmho.

Because of the variations in specific conductance of water in Wewoka Creek, a series of measurements was made during a base-flow period in August 1975 to determine the entrance points of mineralized water into the creek; the data are presented in figure 3. The measurements show that specific conductance increased from 5,800 μmho near the mouth of the creek to 19,000 μmho about 8 mi upstream. From that point, specific

TABLE 6.—CONCENTRATIONS OF SELECTED CHEMICAL CONSTITUENTS IN RELATION TO WELL DEPTH

[Number in parentheses is number of analyses used to determine the mean values]

Well Depth (feet)		Calcium	Mangnesim	Sodium plus potassium	Bicarbonate	Sulfate	Chloride	Dissolved solids
	Minimum	14	4.6	5.2	20	4.8	5.4	102
0-99	Mean	99(9)	28(9)	33(22)	131(22)	30(22)	29(22)	418(22)
	Maximum	390	130	350	413	970	1,300	2,510
	Minimum	1.8	0.1	4.9	12	2.8	5	76
100-299	Mean	26(22)	16(22)	27(36)	281(39)	34(38)	20(39)	437(36)
	Maximum	170	82	600	590	640	670	2,020
	Minimum	1.7	0.2	8.3	132	14	6.5	221
300-900	Mean	23(19)	3.8(19)	150(22)	270(20)	96(22)	35(22)	616(20)
	Maximum	280	150	950	895	1,660	2,300	4,500
	Minimum	1.7	0.1	4.9	12	2.8	5	76
0-900	Mean	32(50)	14(50)	70(80)	259(81)	46(82)	27(83)	470(78)
	Maximum	390	150	950	895	1,660	2,300	4,500

conductance increased to 44,000 μmho near the headwaters of the creek; the discharge of the creek did not change significantly in the upstream reaches. These measurements show that mineralized water was entering the upstream reach of Wewoka Creek during August 1975. The specific conductance of 9,800 μmho for a south-flowing tributary, which enters about 3 mi upstream from the mouth of the creek, indicates that mineralized water also was being added upstream from this site.

Because much of the area of the Vamoosa–Ada aquifer has been the scene of oil production since the early 1900's, brines associated with petroleum are a potential source of mineralization of the ground and surface waters. Brines associated with petroleum contain as much as 6,000 mg/L bromide (Collins, 1975, p. 163) and, as far as is known, are the only possible source of readily detectable (1 mg/L or more) bromide in the area. Accordingly, bromide concentrations were determined for water samples from 39 wells (table 4) and 13 stream sites (table 5) during the course of this study. Water samples from 32 of the wells had less than 1.0 mg/L bromide, and, of the remaining wells, the bromide content was 1 mg/L or more in seven. Water samples from the 13 stream sites had bromide concentrations ranging

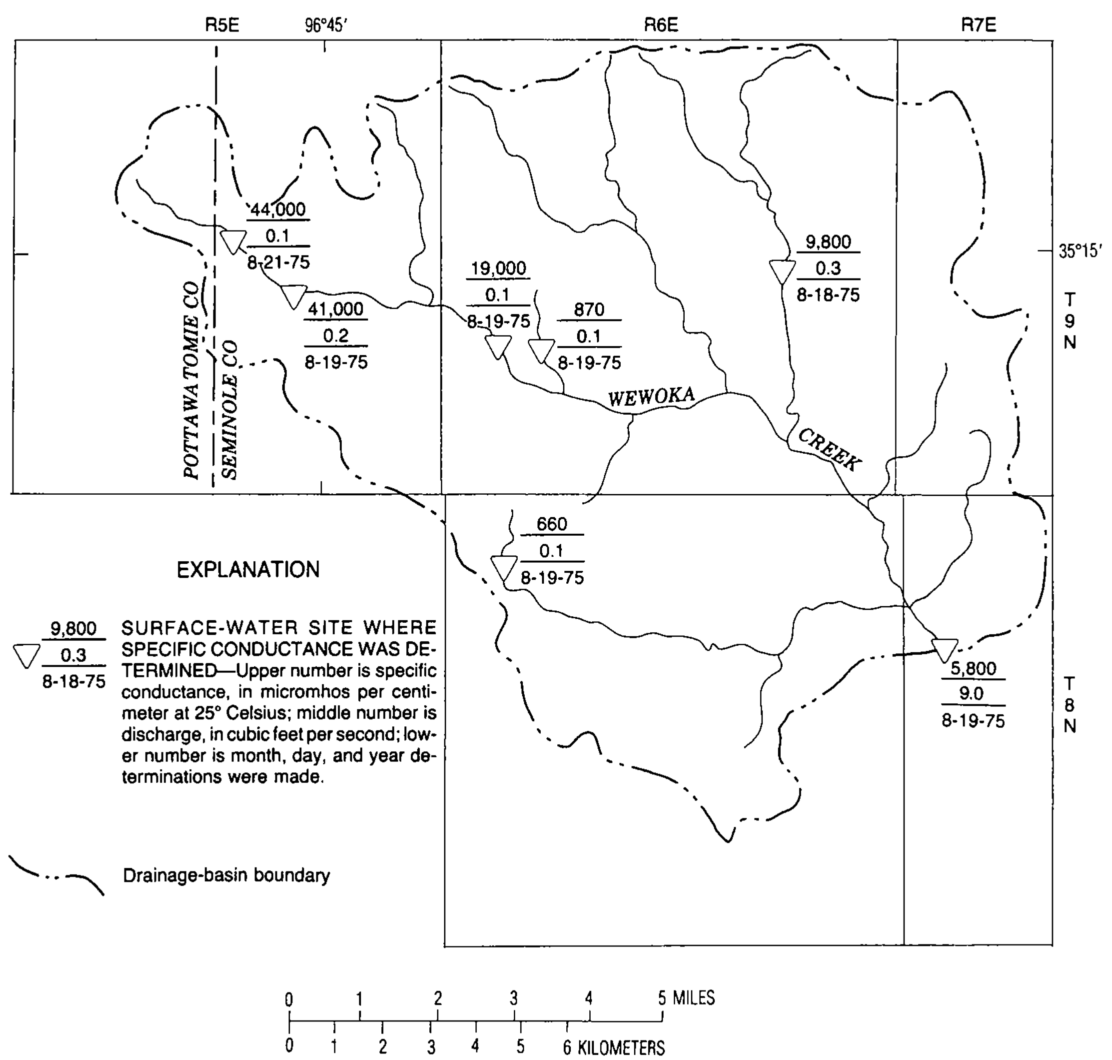


Figure 3. Specific conductance of water measured in Wewoka Creek basin, August 1975.

from 2.2 to 83 mg/L. Information on bromide concentration in brines underlying the Vamoosa–Ada aquifer is not available, so the relation between relative concentrations of bromide in the brines and in the fresh water cannot be determined.

Although the available data indicate that mineralization of ground water by petroleum-associated brines has occurred in parts of the area, the data do not provide a basis for determining how such mineralization has taken place. Mineralization of surface water is more extensive than that of ground water. A source of this mineralization is readily available from the many areas, observable in the field, where petroleum-associated brines have been discharged onto the surface to penetrate the soil and then be washed into the streams by rainfall.

Trace Elements

Concentrations of some trace elements, as determined by the Oklahoma Department of Public Health, which are present in water from the Vamoosa–Ada aquifer used for municipal supply, are listed in table 7. None of the elements listed occurred in concentrations greater than the mandatory limits established by the U.S. Environmental Protection Agency (1976).

OUTLOOK FOR THE FUTURE

This study shows that the Vamoosa–Ada aquifer is a potential source of large amounts of potable water. Compared with the estimated amounts of potable water available from storage (36 million acre-ft) and the annual recharge (93,000 acre-ft), the amount withdrawn annually (less than 5,000 acre-ft in 1975) is insignificant. If properly developed and managed, the aquifer should meet the area's water requirements into the foreseeable future. One problem in fully using the aquifer is that the areas most favorable for development—that is, where the saturated sandstone sequences are thickest—are not near the cities and towns where the water is needed. However, this is principally a problem of water distribution and not one of water availability.

Water from the Vamoosa–Ada aquifer generally is suitable for municipal, domestic, and stock supply. However, in some areas, dissolved minerals derived from brines associated with petroleum production are being added to the freshwater system.

TABLE 7.—TRACE ELEMENTS, IN MILLIGRAMS PER LITER, PRESENT IN MUNICIPAL WATER SUPPLIES

Element	Mandatory limit [1]	Cushing	Drumright	Prague	Seminole	Stroud
Arsenic	0.05	.001	.001	.003	.003	.003
Cadmium	0.010	.003	---	.001	.001	.002
Chromium	0.050	.017	.040	.022	.025	.029
Lead	0.050	.014	.011	.015	.005	.004
Mercury	0.002	.0005	.0005	.0004	.0005	.0004
Silver	0.05	0.001	0.001	0.002	0.001	0.001

[1] U.S. Environmental Protection Agency (1976).

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