GEOHYDROLOGY OF THE VAMOOSA-ADA AQUIFER, EAST-CENTRAL OKLAHOMA

U.S. GEOLOGICAL SURVEY

Open-File Report 81-62

Prepared in cooperation with the

OKLAHOMA GEOLOGICAL SURVEY

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UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOHYDROLOGY OF THE VAMOOSA-ADA AQUIFER, EAST-CENTRAL OKLAHOMA

By Joseph J. D'Lugosz and Roger G. McClaflin

With a section on

CHEMICAL QUALITY OF WATER

By Melvin V. Marcher

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Oklahoma City, Oklahoma

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INCH-POUND METRIC EQUIVALENTS

Inch-pound units	Multiply by	Metric
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 (square meter)
ft^2/d (foot squared per day)	0.0929	m^2/d (square meter 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)

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ABSTRACT

The Vamoosa-Ada aquifer, which underlies an area of about 2,320 square miles, consists principally of the Vamoosa Formation and the overlying Ada Group of Pennsylvanian age. Rocks comprising the aquifer were deposited in a near-shore environment ranging from marine on the west to nonmarine to 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. Aggregate thicknesses of water-bearing sandstones are greatest south of the Cimarron River where they reach a maximum of 550 feet in the vicinity of Seminole. North of the Cimarron River, the average aggregate thickness of the sandstones is about 100 feet but locally it may be as much as 200 feet.

Transmissivity values derived from seven aquifer tests made for this study range from 70 to 490 feet squared per day; values decrease from south to north with decreasing sandstone thickness. Hydraulic conductivity values range from 2 to 4 feet 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-feet 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-feet. Of this amount, an estimated 36 million acre-feet 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 usage 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.

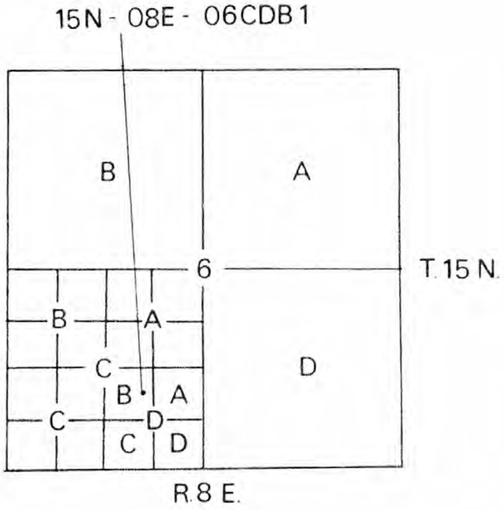
The purpose of this report is to describe the geologic framework and hydrologic characteristics of the Vamoosa-Ada aquifer and to provide a general evaluation of the chemical quality of water in the aquifer. Information used to prepare the report was obtained from on-site and laboratory studies and from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

Acknowledgments

The authors wish to 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 Limited provided assistance in interpretation of geophysical logs.

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 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 (Kelley, 1962).

FIGURE 1
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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.

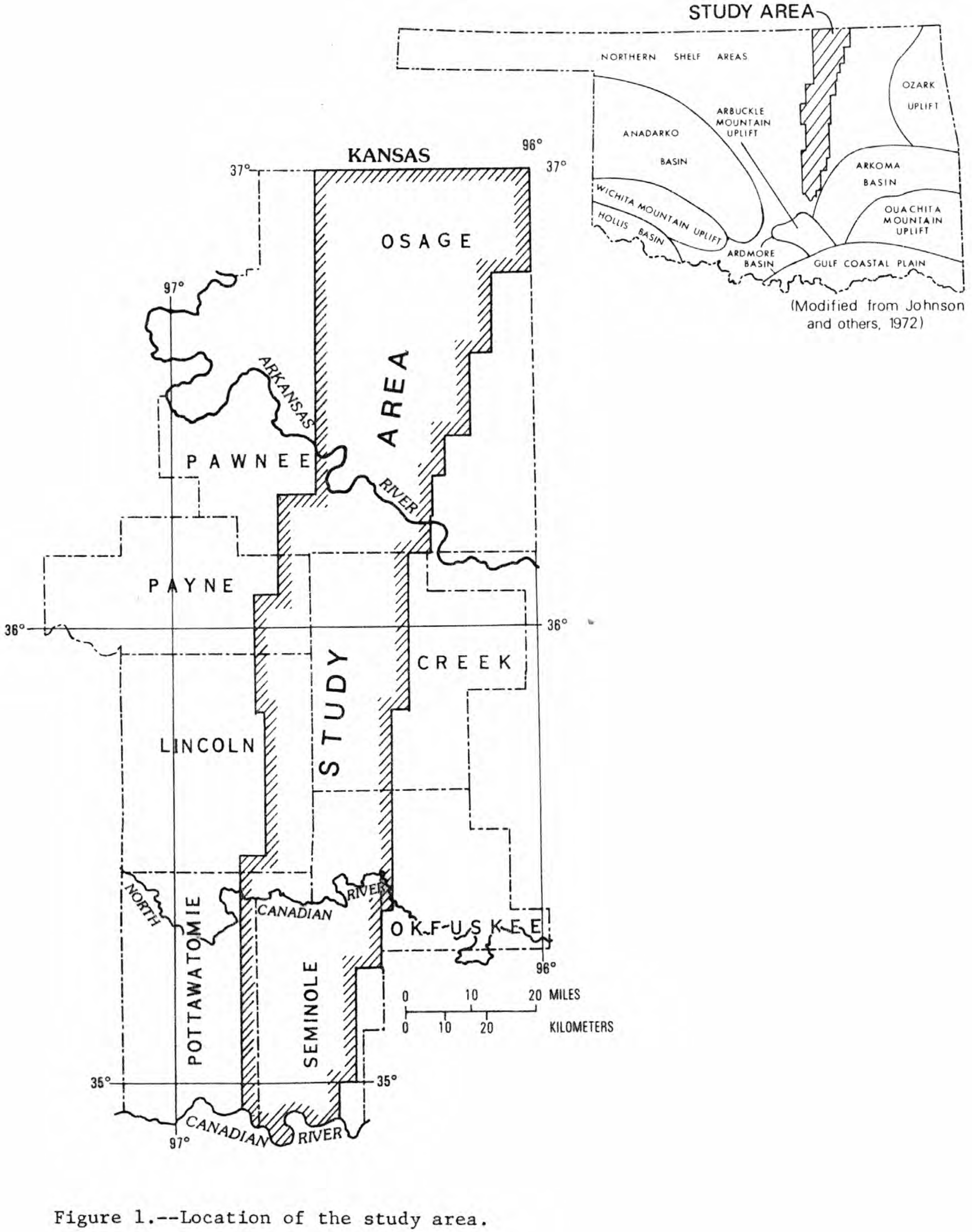

Figure 1.--Location of the study area.

Climate

The climate of the area is continental, subhumid. The difference between the average summer and the average winter temperatures is about 40° Fahrenheit. 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 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 were irrigated during 1976.

Definition of the Vamoosa-Ada Aquifer

The Vamoosa-Ada aquifer, as defined herein, consists principally of the Vamoosa Formation and the overlying Ada[1] Group (fig. 2). In extreme southern Seminole County, some sandstone beds of the Vanoss[1] Group, which overlies the Ada Group, are included in the aquifer; these beds comprise 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 Formations, 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 age.

FIGURE 2
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[1] Designated formation rank by the U.S. Geological Survey.

Figure 2.--Geologic map of the Vamoosa Formation and younger units, east-central Oklahoma.

GEOLOGIC FRAMEWORK OF THE 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 is located on a westward-sloping homocline which has a dip of 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 (fig. 2). 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. Displacement of 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, with interbedded very thin limestones. The water-yielding capabilities of the aquifer are generally controlled by the lateral and vertical distribution of the sandstone beds and their physical characteristics which, in turn, are related to the environments of deposition. Most of the rocks were deposited in a near-shore 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 is shown in figure 3 and 4. These maps show that major sequences of sandstone are principally confined to the southern one-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, indicate that the principal sources of sediment were the Arbuckle and Ouachita uplifts (fig. 1) although minor amounts of sediment may have been contributed by the Ozark uplift.

FIGURE
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Figure 3.--Map showing aggregate sandstone thickness, theoretical transmissivity, and theoretical specific capacities of wells for the confined part of the Vamoosa-Ada aquifer, east-central Oklahoma.

Figure 4.--Map showing aggregate sandstone thickness, theoretical transmissivity, and theoretical specific capacities of wells for the unconfined part of the Vamoosa-Ada aquifer, east-central Oklahoma.

FIGURE 5 NEAR HERE

The vertical distribution of the sandstone units is illustrated by the geohydrologic sections (fig. 5); the locations of the sections are shown on figure 2. 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 discontinue 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 diameters 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.

Figure 5.--Geohydrologic sections showing major sandstone units in the Vamoosa-Ada aquifer, east-central Oklahoma.

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 is the most significant. For example, where the sandstone sequence is thick, the zone of potable water is thick and vice versa as shown by comparison of figures 3 and 4 with figure 7. Comparison of figures 3 and 4 with figure 9 shows that where the sandstone 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 made on 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 (page 9), may be hydrologically significant in that they either retard groundwater flow or provide open conduits for rapid recharge to the aquifer depending upon 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 those 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 and 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 (figs. 3 and 4).

TABLE 1
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Table 1.--Results of aquifer tests.

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 on figures 3 and 4 were determined by methods given in Bentall (1963) and are entirely theoretical. Theis's 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

TABLE 2
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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 or continuous water-level measurements in selected wells and baseflow 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 conjuction with necessary geologic information, provide a basis to describe the occurrence and movement of water within the aquifer and to estimate 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 figures 3 and 4 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.

Table 2.--Records of wells in the Vamoosa-Ada aquifer.

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 (fig. 6). 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.

FIGURE 6 NEAR HERE

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.

Figure 6.--Map showing the water-table surface in the unconfined part of the Vamoosa-Ada aquifer, east-central Oklahoma.

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 geologic structure.

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 baseflow 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, baseflow records and precipitation data can be used to obtain minimum estimates of recharge. To make such an estimate for the Vamoosa-Ada aquifer, baseflow 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, baseflow 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 and Carr and Marcher, 1977, p. 15). Nevertheless, the value of 4 percent amounts to about 93,000 acre-ft for the principal recharge area, about 1,090 mi^2, of the Vamoosa-Ada aquifer.

Potable Water in Storage

FIGURE 7 →
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The thickness of the zone of potable water (fig. 7) was prepared by contouring differences in altitude between the base of potable water (fig. 9) and the water-table surface of the unconfined part of the aquifer (fig. 6). 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 figures 3 and 4 with figure 7.

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 contains 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.

Figure 7.--Map showing thickness of the zone of potable water (maximum of 1,500 milligrams per liter of dissolved solids) in the Vamoosa-Ada aquifer, east-central Oklahoma.

Although porosity determines the amount of water stored in the aquifer, the amount it will yield is less because some of the water is retained in the pores of the rock. However, 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 manmade, into or out of the aquifer. A regional loss or gain in storage would be indicated by lowering or rising of the water level over a broad area. Water-level hydrographs (fig. 8) 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 335,000 acre-ft of available water was added to the aquifer between 1971 and 1975.

FIGURE 8 →
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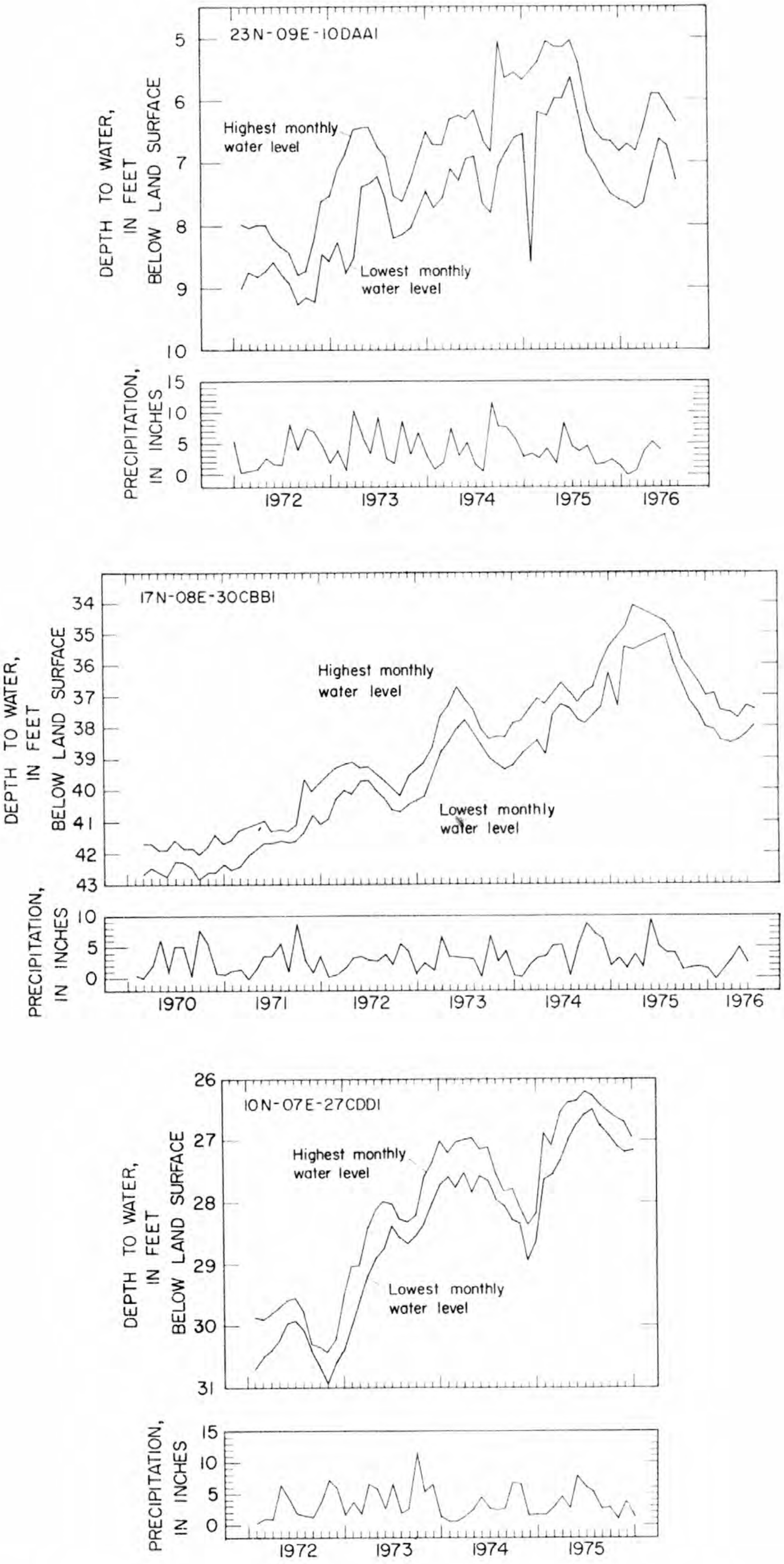

Figure 8.--Water-level hydrographs for wells in the Vamoosa-Ada aquifer and monthly precipitation at nearby stations.

Discharge

Water is discharged from the Vamoosa-Ada aquifer by evapotranspiration, streamflow, and pumping; of these, 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, which is the product of the mean monthly temperature and monthly percentage of day-time 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 it was 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 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

Less 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, Oilton, Prague, Seminole, and Stroud. Water use data for these towns are shown in table 3.

TABLE 3
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Table 3.--Municipal water use during 1975.

GENERAL HYDROLOGIC BUDGET

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

$$Pc = Rc + Rn + ET \qquad (2)$$

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:

$$Rn = Pc-(Rn+ET). \qquad (3)$$

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

By Melvin V. Marcher

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TABLE 5 NEAR HERE

As stated earlier (page 3), 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 constitutents (calcium, mangesium, 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.

Table 4.--Chemical analyses of water from wells in the Vamoosa-Ada aquifer.

Table 5.--Specific-conductance, discharge, and bromide data for streams draining the Vamoosa-Ada aquifer.

Base of Potable Water

FIGURE 9 NEAR HERE

Delineation of the base of potable water, as shown by figure 9, 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 (Kelley, 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.

Figure 9.--Map showing the altitude of the base of potable water (maximum of 1,500 milligrams per liter of dissolved solids) in the Vamoosa-Ada aquifer, east-central Oklahoma.

Within the study area, the contact between the base of potable water and the underlying non-potable 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 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, sodim 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 1000 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.

TABLE ____ NEAR HERE

Table 6.--Concentrations of selected chemical constituents in relation to well depth.

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 basins 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 baseflow 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 umhos (micromhos at 25° Celsius); the median value was 729 umhos. Water from 23 wells, or about 11 percent of the total, exceeded 1,600 umhos, 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 baseflow, ranged from 100 to 44,000 umhos: the median value was 920 umhos. Water at 65 sites, or about 34 percent, had a specific conductance greater than 1,600 umhos.

Comparison of specific-conductance measurements of water from two basins in the outcrop area of the Vamoosa-Ada aquifer - Polecat and Wewoka Creek - show 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 baseflow was 500 and 790 umhos while specific conductance of ground water in the basin ranged from 380 to 555 umhos. In contrast, specific conductance of water from Wewoka Creek, Seminole County, and its tributaries ranged from 255 to 44,000 umhos and that of ground water in Wewoka Creek basin ranged from 430 to 6,750 umhos.

FIGURE 10 NEAR HERE

Because of the variations in specific conductance of water in Wewoka Creek, a series of measurements were made during a baseflow period during August 1975, to determine the entrance points of mineralized water into the Creek; the data are presented in figure 10. The measurements show that specific conductance increased from 5,800 umhos near the mouth of the creek to 19,000 umhos about 8 mi upstream. From that point, specific conductance increased to 44,000 umhos 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 umhos 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.

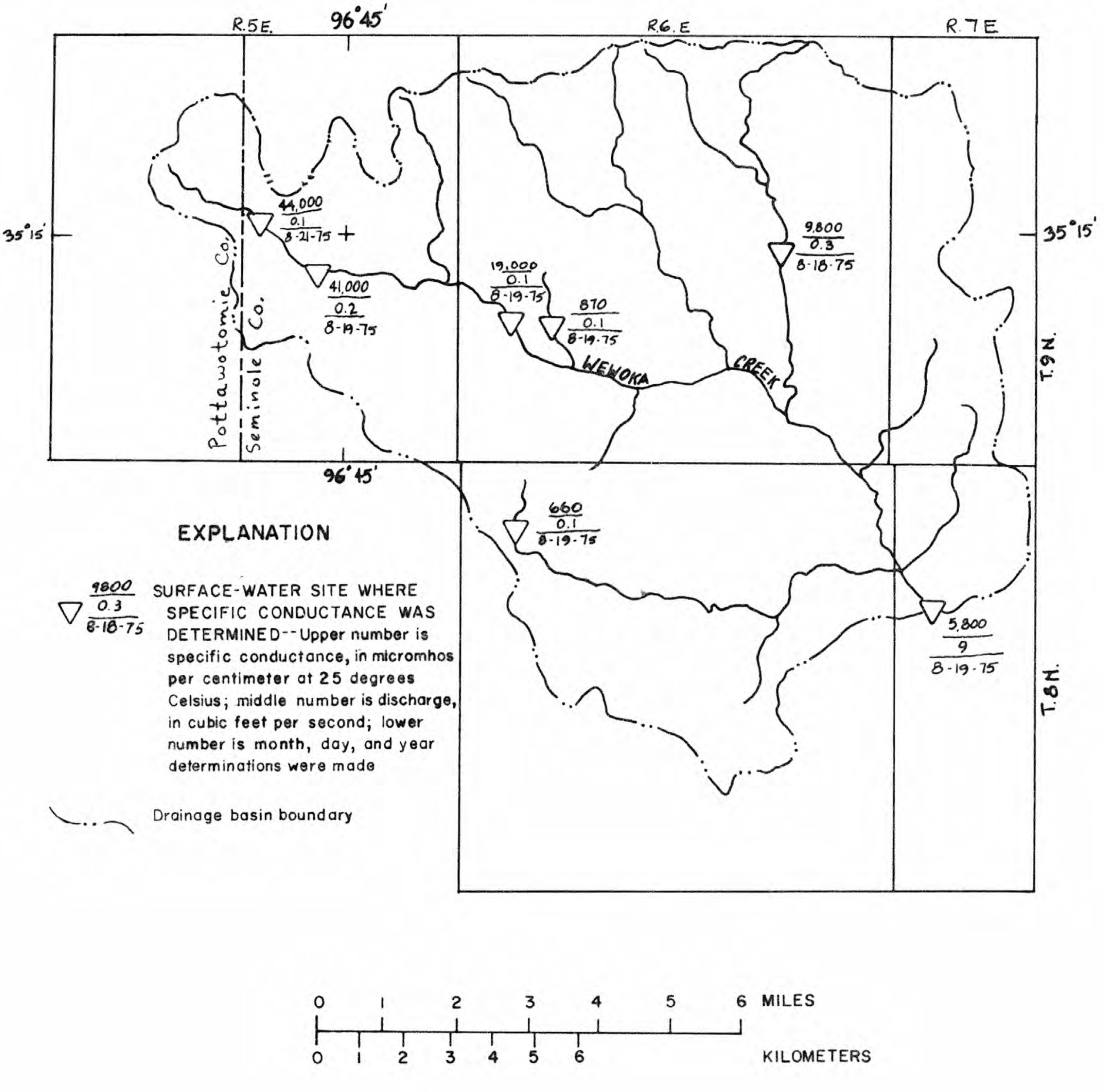

Figure 10.--Specific conductance of water measured in Wewoka Creek basin, August 1975.

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 12 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, bromide was 1 mg/L or more in seven. Water samples from the 12 stream sites had bromide concentrations ranging from 2.2 to 83 mg/L. Information on bromide concentration in brines underlying the Vamoosa-Ada aquifer is not available so that 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

TABLE 7 NEAR HERE

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).

Table 7.--Trace elements, in milligrams per liter, present in municipal water supplies.

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 town where the water is needed. However, this is principally a problem of water distribution and not one of water availability.

Water from the Vamoosa 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.

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 ________ acre-ft per year and the total amount of land covered by prior rights is _______ acres.

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[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.

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. Groundwater basin by Oklahoma law means a distinct underground body of water overlain by contiguous land and having substantially the same geological and hydrological 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.

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