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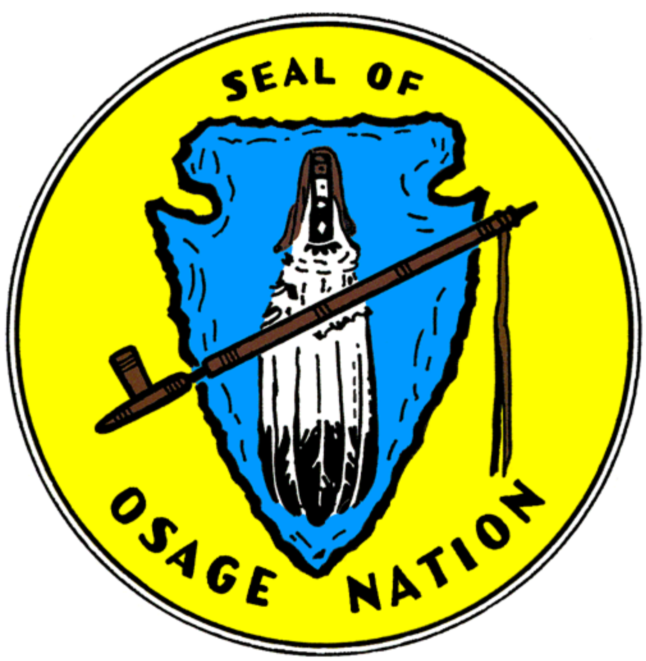
Water Quality of the Quaternary and Ada-Vamoosa Aquifers on the Osage Reservation, Osage County, Oklahoma, 1997

Water-Resources Investigations Report 99–4231



U.S. Department of the Interior
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U.S. Geological Survey

U.S. Department of the Interior
Bruce Babbitt, Secretary

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
barrel (bbl), (petroleum, 1 barrel = 42 gal)	0.1590	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32) / 1.8

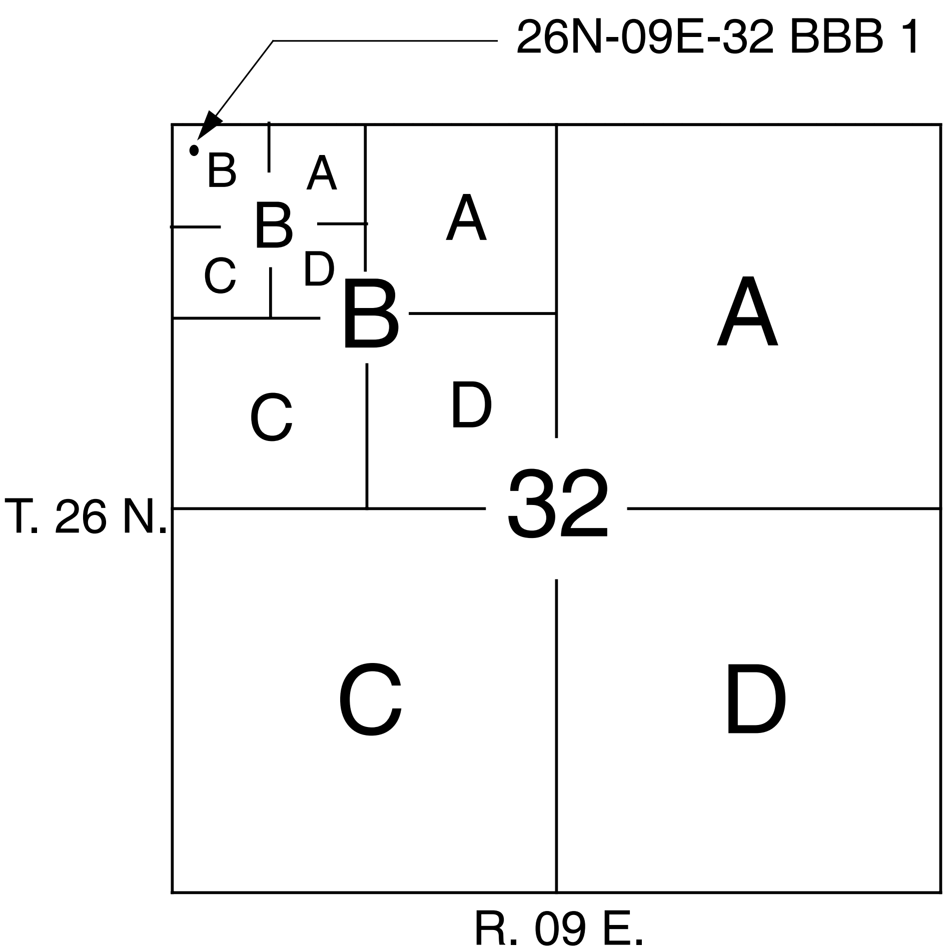
Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)— a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Explanation of the Site-numbering System

The locations of the sample-collection sites are identified by a site-id number and a local identifier number. The site-id number is composed of the latitude and longitude of the location to the nearest second plus a sequence number. The location of the dot in the figure is latitude 36°41'40" and longitude 96°21'59". A sequence number is added to make the local identifier unique in the U.S. Geological Survey data base. If the sequence number is 1, the complete site-id number is 364140096215901. The local identifier number includes the township and range followed by the section and a series of letters that designate the quarter-section subdivisions, from the largest to the smallest. The order of the quarter-section subdivisions differs from that used by the U.S. Bureau of Land Management and the public land survey. As illustrated in the figure, the public land survey description of the site indicated by the dot as NW1/4 NW1/4 NW1/4 sec. 32, T. 26 N., R. 09 E., is denoted by the local identifier number 26N–09E–32 BBB. If the sequence number is 1, the complete identifier number is 26N–09E–32 BBB 1.



Water Quality of the Quaternary and Ada-Vamoosa Aquifers on the Osage Reservation, Osage County, Oklahoma, 1997

By Marvin M. Abbott

Abstract

The project was to provide information on the quality of ground water from rural-domestic-water wells within the Osage Reservation and compare the water-quality to proximity to oil wells. About 38,500 oil wells have been drilled in the Reservation since drilling began in 1896. About 1,480 square miles or 64 percent of the Reservation is within a quarter mile of an oil well. The unconfined Quaternary sand aquifer covers about 315 square miles or about 14 percent of the Reservation and the confined Ada-Vamoosa sandstone aquifer covers about 800 square miles or about 35 percent of the Reservation. Fifty-eight percent of the Quaternary aquifer and 69 percent of the outcrop area of the Ada-Vamoosa aquifer are within a quarter mile of an oil well.

One hundred twenty domestic ground-water wells were sampled from the Quaternary and Ada-Vamoosa aquifers. Forty-nine percent of the Reservation is underlain by the aquifers. Ground-water quality is good on most of the Reservation, but the use of domestic-water-supply wells tend to minimize water-quality problems. Existing water-supply wells commonly are located in areas that produce usable volumes of potable water.

Several constituents in samples from the Ada-Vamoosa-aquifer within a quarter mile of an oil well were significantly greater than from the aquifer not near oil wells. The constituents include specific conductance, dissolved solids, sodium, sulfate, chloride, bromide, and silica. These ions are probably derived from brine water. In the Ada-Vamoosa aquifer subgroups, 57 percent of the samples near oil wells and 24 percent of the samples not near oil wells had dissolved-solids concentrations greater than 500 milligrams per liter.

The water quality in the Quaternary and Ada-Vamoosa aquifers is similar in areas where no oil wells have been drilled but is significantly different for several constituents. Median concentrations of major constituents from the Ada-Vamoosa aquifer not near oil wells were less than or equal to values from the Quaternary aquifer. Sixty-four percent of the water-quality samples from the Quaternary and 51 percent from the Ada-Vamoosa aquifers have dissolved-solids concentrations less than the secondary drinking water regulations of 500 milligrams per liter. Fifty-nine percent of the aquifer samples in the Quaternary aquifer subgroups not near oil wells and 70 percent of the samples near oil wells had dissolved solids less than 500 milligrams per liter.

Areas in the Ada-Vamoosa aquifer near Hominy, Pershing, and Hula Lake have dissolved-solids concentrations greater than the secondary drinking water regulations. Water-quality samples from the Quaternary aquifer in these areas also have dissolved-solids concentrations greater than 500 milligrams per liter.

Introduction

In response to concerns about the effects that oil production might have on water quality and to obtain information needed to plan and manage the increasing demands for water on the Osage Reservation, the U.S. Geological Survey, in cooperation with the Osage Tribe conducted a study of the water quality in the Quaternary and Ada-Vamoosa aquifers in the Osage Reservation, northeastern Oklahoma (fig. 1). The project included documenting information for rural-domestic-water wells, collecting 120 water-quality samples from those wells, and comparing the water-quality to proximity to oil wells. Locating and sampling the wells was conducted from September to December 1997.

About 38,500 oil wells have been drilled in the Reservation since drilling began in 1896 (fig. 2). Location of oil wells in the Reservation was from the Natural Resources Information System data base (Geo Information Systems, 1999). About 17,600 oil wells were drilled before 1940 (Bass and others, 1942) and 3,200 of these were dry and abandoned. In 1988 only about 12,680 oil wells were actively operated and 4,200 of these were classified as pressure maintenance, salt-water disposal, or water-flood injection wells. The remaining oil wells (about 26,000) are temporarily or permanently plugged and abandoned. About 1,480 square miles or 64 percent of the Reservation is within a quarter mile of an oil well. Peak annual production on the Reservation was more than 40,000,000 barrels in 1922 (Bass and others, 1942). The term “oil well” is an industry well drilled through the freshwater aquifers to oil and gas production depths; including oil and gas producers, nonproducing wells, injection wells, salt-water disposal wells, plugged wells, and abandoned wells.

Many subsurface formations listed in figure 3 have been oil-producing strata in the Reservation. Oil production is shallow by United States standards, with producing zones ranging from a few hundred to about 3,500 feet in depth.

Purpose and Scope

The report documents the water-quality data and presents the summary statistics of the water-quality data for the aquifers and aquifer subgroups, as determined by proximity to oil wells. The report describes nonparametric statistical comparison tests of the water-quality data for the aquifers and aquifer subgroups to determine if the groups are statistically different. The report compares the water-quality summary statistics for the aquifers and aquifer subgroups. Areal distribution of aquifer boundaries, water-quality sample locations, oil-well locations within a quarter-mile buffer zone, box plots of the summary statistics for selected constituents, and water-quality diagrams of the aquifer samples are presented.

Acknowledgments

The author thanks the organizations and individuals who contributed and assisted in the project. Many people throughout the study area helped locate wells and provided historical information concerning ground water during the field work. They included members of the Osage Tribe, Osage Agency of the Bureau of Indian Affairs, ranchers, farmers, oil company employees, and long-time area residents. Special thanks to the Osage Tribal Council, the Osage Environmental Council, and the U.S. Department of Energy for wanting a regional-ground-water evaluation in a densely drilled oil province. Diane Daniels, Norma Penny, and others at the U.S. Environmental Protection Agency-Underground Injection Control office in Pawhuska were of great help locating contacts and providing information. Thanks to U.S. Geological Survey colleagues Lan Pham, Lee Ann Alf, Lyn Osburn, John Kerestes, and Charles Bullock for assisting in the collection of water-quality data.

Description of the study area

The Osage Reservation, otherwise known as Osage County (fig. 1), consists of about 2,260 square miles. The Reservation is characterized by gently-rolling uplands with locally sharp cuestas formed by resistant sandstone and limestone ledges. The Arkansas River borders the Reservation on the south and southwest. The eastern and southeastern part of the Reservation is known informally as the Cross Timbers, an area characterized by open oak and hickory woodlands with scattered, grassy savannah areas. The western part of the Reservation, known informally as the Bluestem Hills, is mostly open savanna. The highest altitude is about 1,350 feet above sea level along the cuesta northeast of Foraker in the northwestern part of the Reservation; the lowest altitude is about 600 feet above sea level along Hominy and Delaware Creeks south of Skiatook in the southeastern part of the Reservation. Mean annual precipitation across the Reservation ranges from 34 inches near Ponca City, on the western edge to greater than 38 inches near Tulsa, in the southeast part (Oklahoma Climatological Survey, 1999).

The Reservation is underlain by sedimentary rocks of Quaternary, Permian, and Pennsylvanian[1] age that dip gently west-northwest (figs. 1 and 2). Rocks under the western part of the Reservation in the open savanna consist predominately of limestone, dolomite, and shale; whereas rocks under the eastern part in the woodlands consist primarily of sandstone, shale, and some limestone and dolomite.

Description of hydrogeologic units

Fresh ground-water aquifers on the Reservation consist of alluvial and terrace deposits of Quaternary age and sandstones of Pennsylvanian age (fig 4). Water in the aquifers is comprised of recharge from rainwater and surface water, connate water deposited with the sediments, and brines from greater depths (Drever, 1988, Richter and Kreitler, 1991). Most of the fresh water in the aquifers is from the infiltration of rainwater into the aquifer through the outcrops. Regionally fresh ground water is underlain by briny water (Richter and Kreitler, 1991).

Quaternary Aquifers

The Quaternary aquifer covers about 315 square miles or about 14 percent of the Reservation (fig. 1) and consists of alluvial and terrace deposits of sand, silt, clay, and gravels (fig. 4). The alluvium is deposited by water in the stream and river valleys. Thickness of these deposits ranges from 30 to 80 feet along major streams and from 0 to 60 feet along minor streams (Bingham and Bergman, 1980, plates 1 and 2). The terrace deposits are wind-deposited, and the maximum thickness of those deposits is 75 feet along major streams (Bingham and Bergman, 1980). The Quaternary is an unconfined aquifer and is uncemented in most areas.

Recharge to the Quaternary alluvial and terrace deposits in the Reservation was estimated to be similar to the Enid isolated terrace aquifer that receives 2.3 inches of recharge from 31 inches of precipitation or 7.4 percent of mean annual precipitation (Kent and others, 1982). The Enid isolated terrace aquifer, 50 miles west of the Reservation, is of similar age, deposition, and cementation and has hydraulic-conductivity values ranging from 93 to 134 feet per day (Beausoleil, 1981). Using the Enid aquifer as a model, recharge to the Quaternary aquifer in the Reservation would range from about 2.5 inches near Ponca City to about 2.8 inches near Tulsa.

[1]The stratigraphic nomenclature and age determination 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.

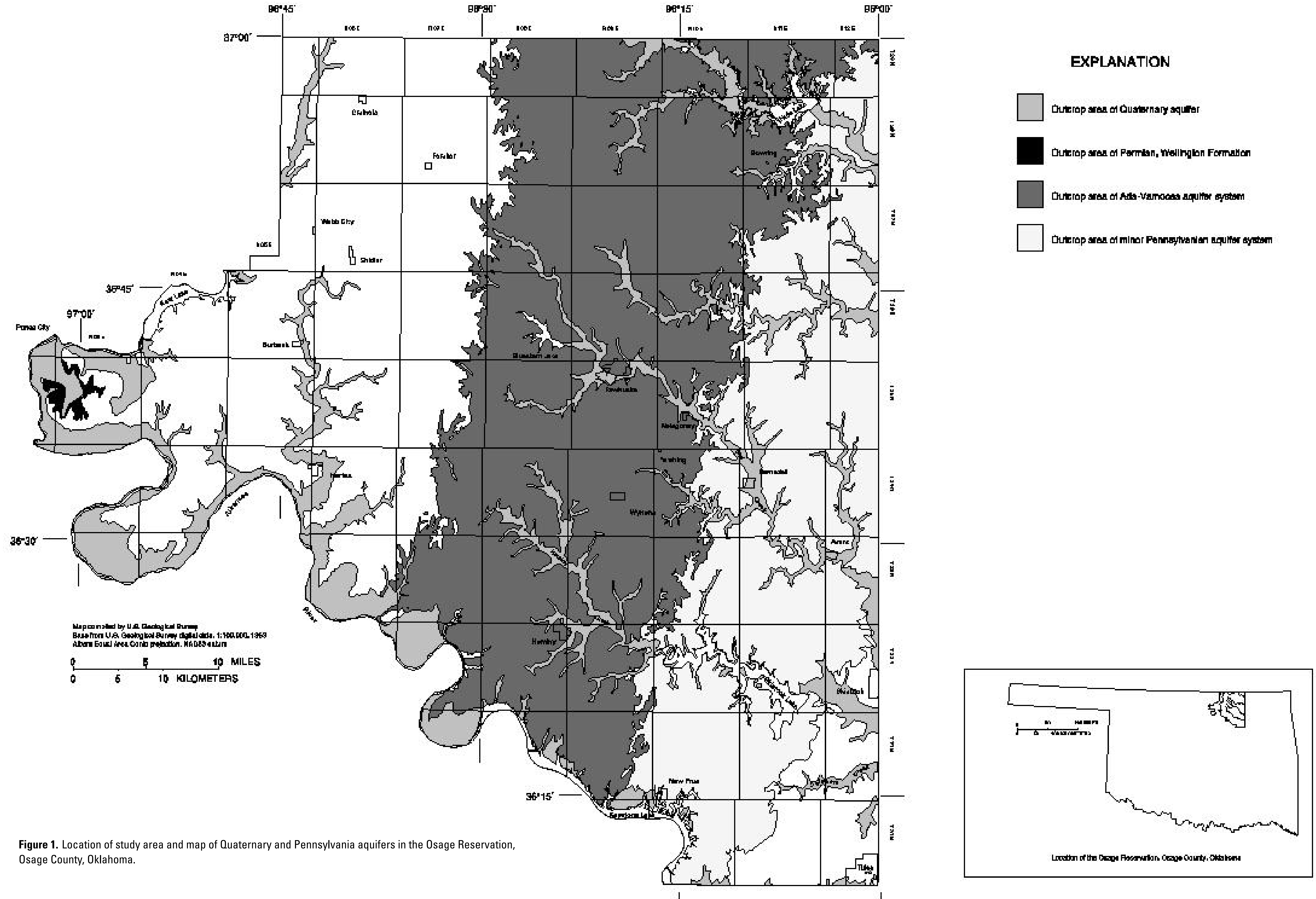


Figure 1. Location of study area and map of Quaternary and Pennsylvania aquifers in the Osage Reservation, Osage County, Oklahoma.

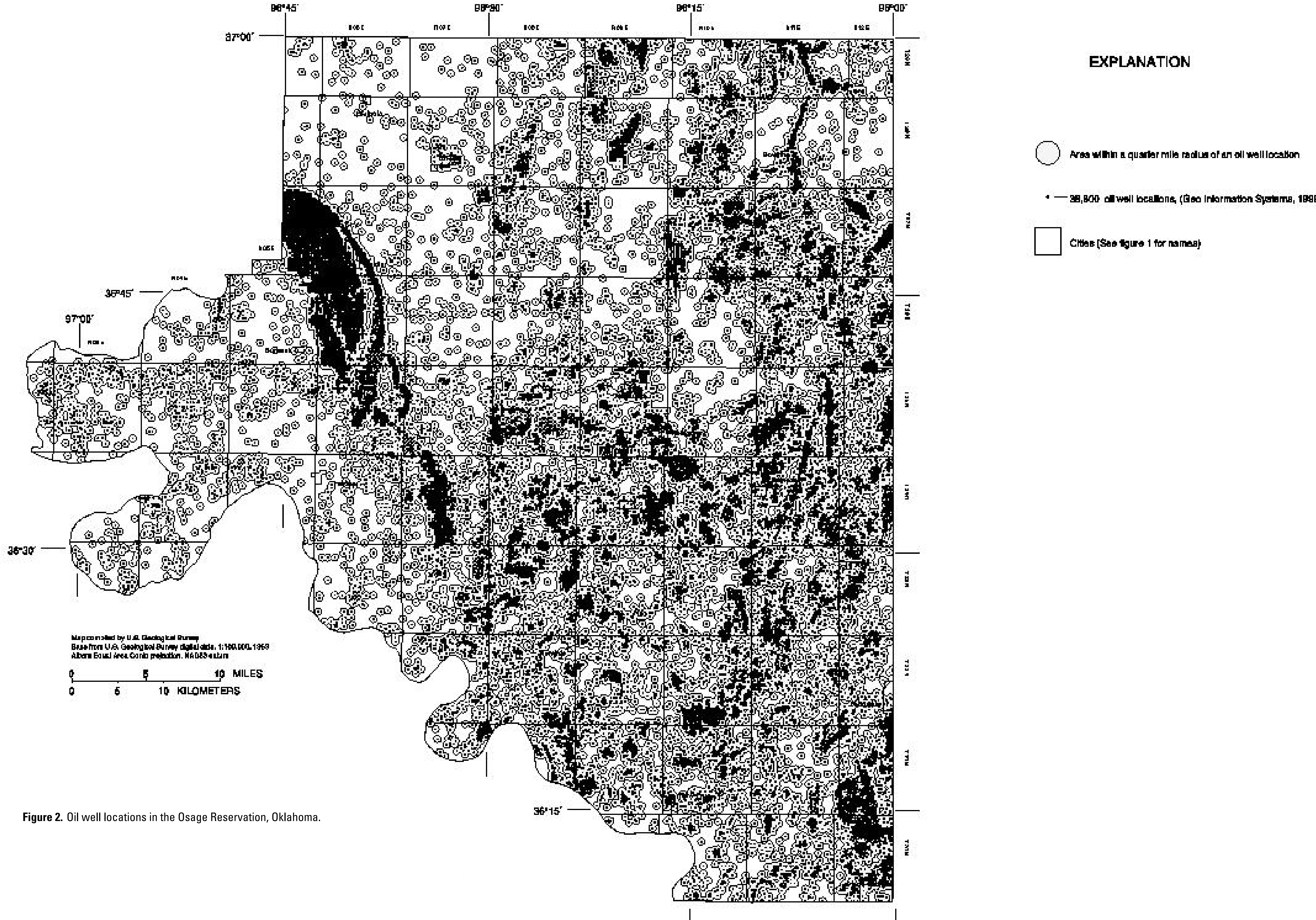


Figure 2. Oil well locations in the Osage Reservation, Oklahoma.

System	Series	Group	Formation	Informal subsurface unit
Pennsylvanian	Desmoinesian	Marmaton	Oologah Limestone Fort Scott Limestone	Big lime Peru sand Oswego lime
		Cabaniss		Prue sand Verdigris lime Skinner sand Pink lime
		Krebs		Red Fork sand Burbank sand Bartlesville sand Burgess sand
Mississippian			Pitkin Limestone Fayetteville Shale Batesville Hindsville Limestone Moorefield Keokuk Limestone Reeds Spring	Mississippi chat Mississippi lime
		St. Joe Group		
Mississippian/Devonian			Chattanooga Shale	
Ordovician			Simpson	
Cambrian/Ordovician			Arbuckle Limestone	Siliceous lime

Figure 3. Subsurface-geologic and major time-stratigraphic units in the Osage Reservation, Oklahoma (from Bass and others, 1942; Marcher and Bingham, 1971, and Miser, 1954).

Pennsylvanian Age Sandstone Aquifers

The outcrop for the Ada-Vamoosa aquifer system includes about 800 square miles or about 35 percent of the Reservation in a broad north-south band (figs. 1 and 2) (Bingham and Bergman, 1980, plates 1 and 2). The Ada Formation in the Reservation is about 400 feet thick and consists of interbedded limestone and shale units near the Kansas border grading into fine-grained sandstones interbedded with limestone and shale near the southern border of the Reservation. The Vamoosa Formation is about 630 feet thick and consists of alternating layers of shale and fine to coarse-grained sandstone with some limestone (Bingham and Bergman, 1980, plate 1). The aquifer is mostly semiconfined or confined by the alternating lithologic units, except where the individual sandstones crop out. The sandstones are well cemented to semicemented with clay and calcite (Oakes, 1959; Shelton and others, 1985; Greig, 1959). D'Lugosz and others (1986) reported hydraulic conductivity values ranging from 2 to 4 feet per day. Recharge to the aquifer was estimated to be 4 percent of mean annual precipitation (D'Lugosz and others, 1986) or an average of 1.4 inches across the Reservation. Recharge to the Ada-Vamoosa aquifer is about half the rate of recharge in the Quaternary aquifer. Most of the fresh ground water withdrawn from sandstone aquifers in the Reservation is from the Ada-Vamoosa aquifer (figs. 1 and 2) (Bingham and Bergman, 1980, plates 1 and 2).

The Tallant, Barnsdall, Wann, and Chanute Formations comprise the minor Pennsylvanian aquifer; crop out in a north-south band along the eastern portion of the Reservation, and underlie the Ada-Vamoosa aquifer (figs. 1 and 2) (Bingham and Bergman, 1980, plates 1 and 2). The combined outcrop of these units covers about 480 square miles or about 21 percent of the Reservation. The formations consist of shale, fine to medium-grained sandstone, and thin limestone layers. Combined thickness of these units ranges from 127 to 600 feet. Fresh ground water from the Tallant, Barnsdall, Wann, and Chanute Formations also is reported but in lesser amounts (figs. 1 and 2) (Bingham and Bergman, 1980, plates 1 and 2). Few ground-water wells are completed in the minor Pennsylvanian aquifer, possibly because of the limited amount of water available. The water-quality samples from the minor Pennsylvanian aquifer are included with the Ada-Vamoosa aquifer samples for statistical and discussion purposes.

Methods

Sampling Network Design

The ground-water-quality-sampling network was designed to randomly select sites to obtain a statistical representation of the water quality from areal subsets across the Reservation. The subsets had common spatial characteristics that divided the Reservation into categories, by aquifer type and proximity to oil wells, using a geographic information system. Water-quality samples were categorized as being from wells completed in:

- Quaternary aquifer, not near an oil well,
- Quaternary aquifer, near an oil well,
- Ada-Vamoosa aquifer, not near an oil well,
- Ada-Vamoosa aquifer, near an oil well.

The region of each category was divided into 30 equal-area cells, based on the number of samples initially planned for each category (Scott, 1990). Primary and alternate sampling sites were randomly selected within each cell. Initial efforts to locate an existing well within a cell were directed near these sites. If wells were not located near the selected sites, any available existing well within the cell was alternatively selected for sampling. Some cells contained no water wells.

An arbitrary radial distance of a quarter mile was selected to define the buffer zone in which an oil well might affect the quality of water in the freshwater aquifers. About 1,480 square miles or 64 percent of the Reservation is within the quarter-mile buffer zones of the oil wells (fig. 3). Fifty-eight percent of the Quaternary aquifer, 69 percent of the outcrop area of the Ada-Vamoosa aquifer, and 78 percent of the outcrop area of the minor Pennsylvanian aquifer are near oil wells. Oil wells with proper mechanical integrity and operating procedures have limited likelihood of affecting water quality in the freshwater aquifers. Possibly these wells may affect the aquifers only near the oil well borehole. Oil wells with poor mechanical integrity or poor operating procedures are more likely to affect water quality and may have a large area of influence some distance from the borehole.

Wells were located through a compilation of historical records, local drillers' records, and door-to-door contacts. Owners were contacted in person or by phone to obtain well information and permission to sample. Well depths and depths to water were determined where possible, and well construction was documented, where available. The well locations sampled are shown in figure 5 and the location and data analyzed for each well is listed in Appendices 1-4.

Sampling biases

No known method of site selection can remove all biases from a water-quality data set and ensure that sampling is representative of the ground-water quality in an aquifer. Some biases that may have occurred with this well network include:

(1) Existing water-supply wells commonly are located in areas that produce usable volumes of potable water. Thus, the use of water-supply wells introduces a bias that tends to minimize water-quality problems (Scott, 1990). All water-quality samples collected for this study were from existing domestic wells. Most sampled wells were used as a drinking-water source. Some wells were used for nondrinking water and livestock purposes. Some sampled wells were not being used.

(2) Existing wells may not be equally distributed throughout the study area (Scott, 1990). Many wells were no longer functioning or supplied with power in areas where rural-water districts operate. The areas in the Reservation that are supplied by rural-water districts are shown in figure 6 (Oklahoma Water Resources Board, 1998).

(3) The owner of a selected well may not want their well inventoried or sampled, which affects the areal distribution and random selection of sampled wells.

(4) Well design and completion methods can bias the data. Domestic-supply wells are designed for maximum available water collection and receive the combined input of all the strata contributing to the well.

Sampling Procedure and Constituent Selection

Water-quality samples were obtained from existing pumps in the wells or by bailing. Four wells in the Quaternary alluvium were sampled with bailers constructed of polyvinyl chloride plastic. Samples were collected from the remaining wells at outside faucets near the wells, to avoid any in-line-water softeners, which change the ionic concentrations in the samples.

Sampling from pumping wells consisted of a three-step process: (1) purging the well, (2) sampling and sample treatment, and (3) field analysis. Silicon tubing was attached to the faucet with a brass connection containing a rubber gasket, and Teflon coupling. Water was pumped into a five-gallon plastic bucket that contained pH and temperature probes. Water samples were collected once consistent pH and temperature measurements were obtained. Where sustained flow could not be obtained or where a limited amount of water could be obtained from a well, samples were collected after the well had been purged of the initial water in the system.

Specific conductance was measured using a portable conductivity meter with automatic temperature compensation. The conductivity meter calibration was checked daily using standard conductivity solutions that bracketed the expected field values. Water temperature was measured to the nearest 0.1 degree Celsius using an electronic thermistor. pH values were measured using a portable pH meter, with automatic temperature compensation. The pH meters were calibrated daily before starting measurements using standard buffer solutions that bracketed the expected field pH values. The calibration was subsequently corroborated, using a third buffer solution. Samples collected for the analysis of dissolved-inorganic constituents were filtered through a 0.45-micron pore size disposable-cartridge filter and preserved with acid. Alkalinity was mea-

System	Series	Group	Hydrogeologic unit	Formation	Member	Informal subsurface unit
Quaternary			Quaternary aquifer	Alluvium		
				Terrace		
Permian		Sumner		Wellington		
Pennsylvanian	Gearyan			Oscar		
				Vanoss		
	Virgilian		Ada-Vamoosa sandstone aquifer	Ada	Auburn Shale Wakarusa Limestone Soldier Creek Shale Burlingame Limestone Silver Lake Shale Rulo Limestone Cedar Vale Shale Happy Hollow Limestone White Cloud Shale Bird Creek Limestone Severy Shale Turkey Run Limestone Pearsonia Limestone Little Hominy Limestone Deer Creek Limestone Plummer Limestone Lecompton Limestone	
				Vamoosa	Elgin Sandstone Kanwaka Shale Wynona Sandstone Cochahee Sandstone Kiheki Sandstone Cheshewalla Sandstone	
	Missourian	Ochelata	Minor Pennsylvanian sandstone aquifer	Tallant		Revard sand Bigheart sand
				Barnsdall		Okesa sand
				Wann		Torpedo sand Clem Creek sand
				Iola		
				Chanute		
		Skiatook		Dewey Limestone		
				Nellie Bly		Mussellem sand Peoples sand
				Hogshooter Limestone		
				Coffeyville		Layton sand Cleveland sands
				Checkerboard Limestone		

Figure 4. Surficial-geologic and major-time stratigraphic units in the Osage reservation, Oklahoma (Bass and others, 1942; Bellis and Rowland, 1976; Bingham and Bergman, 1980, and Marcher and Bingham, 1971).

sured by an incremental titration (Wells and others, 1990) of a filtered aliquot. Alkalinity was measured at the sample site or from a chilled sample at the end of each day.

Water-quality constituents selected for analysis were those associated with oil brines (Collins, 1975), nutrients associated with agriculture and domestic processes, and trace elements associated with staining. Constituents associated with brines include sodium, potassium, calcium, magnesium, strontium, carbonate, sulfate, chloride, bromide, iodide, arsenic, boron, lithium and dissolved-organic carbon. Nutrient constituents are nitrogen and phosphorus. The trace elements associated with red and brown staining, iron and manganese, were expected in the water-quality samples because of reports from local residents. Standard methods described in Fishman and Friedman (1989) and by U.S. Environmental Protection Agency protocols were used in the analyses (table 1).

Water Quality

Quality-Assurance Sampling

Five duplicate and two blank samples were collected with the water-quality samples at seven (6 percent) sites. The quality-assurance samples collected during the study are listed in Appendix 1.

Duplicate samples consist of two sets of samples collected from the same source during the same sampling event and analyzed in exactly the same manner. The purpose of duplicate samples is to determine the precision and reproducibility of the sampling procedures and laboratory analytical methods. Relative percent difference between a water-quality sample and duplicate sample is calculated, as follows:

$$RPD = \frac{|C_1 - C_2|}{\left(\frac{(C_1 + C_2)}{2}\right)} \times 100 \qquad (1)$$

where RPD is the relative percent difference, C_1 is the concentration of the water-quality sample, and C_2 is the concentration of the duplicate sample. The results of the calculations of relative percent difference are shown in Appendix 2. The relative percent difference between water-quality and duplicate samples is less than 5 percent for specific conductance, alkalinity, dissolved solids, calcium, magnesium, sodium, potassium, sulfate, silicate, and strontium. A small RPD, generally ±10 percent, indicate the sampling and analytical procedures produce consistent data. The RPD is less than 20 percent for pH, chloride, boron, lithium, and manganese. The remaining RPD values range from 22.2 to 120 percent. These larger values are associated with samples having low concentrations, many of which are near the minimum reporting level. RPD could not be calculated for samples where values were less than the laboratory minimum reporting level for the water-quality or quality-assurance sample.

Equipment blanks were prepared at two sites, at the time of sampling, by processing blank water in exactly the same manner as the environmental water-quality samples. Blank water is inorganic-free water with low concentrations, less than the minimum reporting level, of the constituents analyzed. Equipment blanks identify contamination during the sampling or analysis procedures. Filtered equipment-blank samples were prepared by pumping inorganic blank water directly from the inorganic blank water bottle through a short length of silicon tubing and a cartridge filter into a sample bottle. Unfiltered equipment-blank samples were prepared in a similar manner; through silicon tubing without a cartridge filer. The silicon tubing was cleaned in a laboratory and sealed in a plastic bag prior to field work. The equipment blanks contained concentrations greater than the minimum reporting level (table 1) for calcium, magnesium, nitrogen as ammonia, total phosphorus, phosphorus as orthophosphate, boron, iron, and organic carbon (Appendix 1). Water-quality sample values for magnesium and boron are considered to be valid because the minimum value for the environmental samples is greater than the detected values in the equipment blanks. Very low concentrations of some chemical constituents can occur in blank samples exposed to field conditions, derived from the sampling equipment or from wind-blown particles.

All analyses were performed by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida. The analytical methods used by the laboratory for the analyses of the water-quality samples are listed in table 1. The laboratory maintains a blind sample program to test the bias and variability of laboratory analytical procedures. Blind samples of known composition are analyzed as routine environmental samples and are subjected to identical laboratory handling, processing, and analytical procedures. Blind samples are submitted at a rate of 3-5 percent of the annual environmental sample load for each analytical procedure. Standard reference sample water (Farrar and Long, 1997) is used to make the blind samples. These have an expected most-probable concentration. The laboratory sets control limits at ±2 standard deviation of the most-probable concentration. Precision and control charts are prepared to monitor the data quality and analytical results. Well information is summarized in Appendix 3 and analytical results are reported in Appendix 4.

Hypothesis Testing and Descriptive Statistics

Hypothesis testing was used to determine if the water-quality samples from the Quaternary and Ada-Vamoosa aquifers and the subgroups within each aquifer, either near or not near an oil well, were statistically different and which constituents were diagnostic of the difference. The Mann-Whitney test (Mann, 1945) (also called the Wilcoxon rank sum test (Wilcoxon, 1945, P-STAT, Inc., 1990) was used because it is a non-parametric test that requires no assumptions about the population distributions and is resistant to data outliers. The Mann-Whitney tests the median of the ranks of data, instead of the

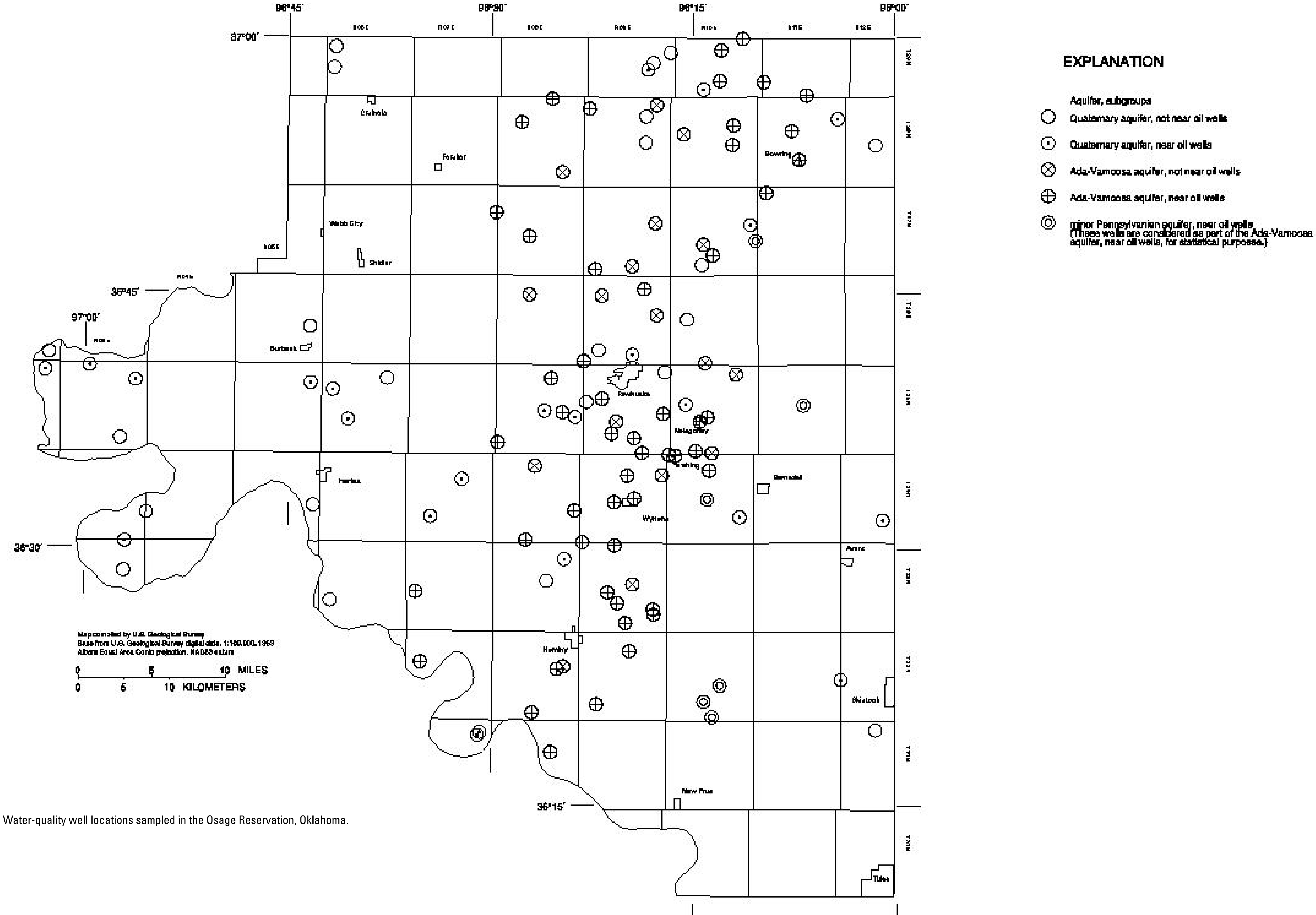


Figure 5. Water-quality well locations sampled in the Osage Reservation, Oklahoma.

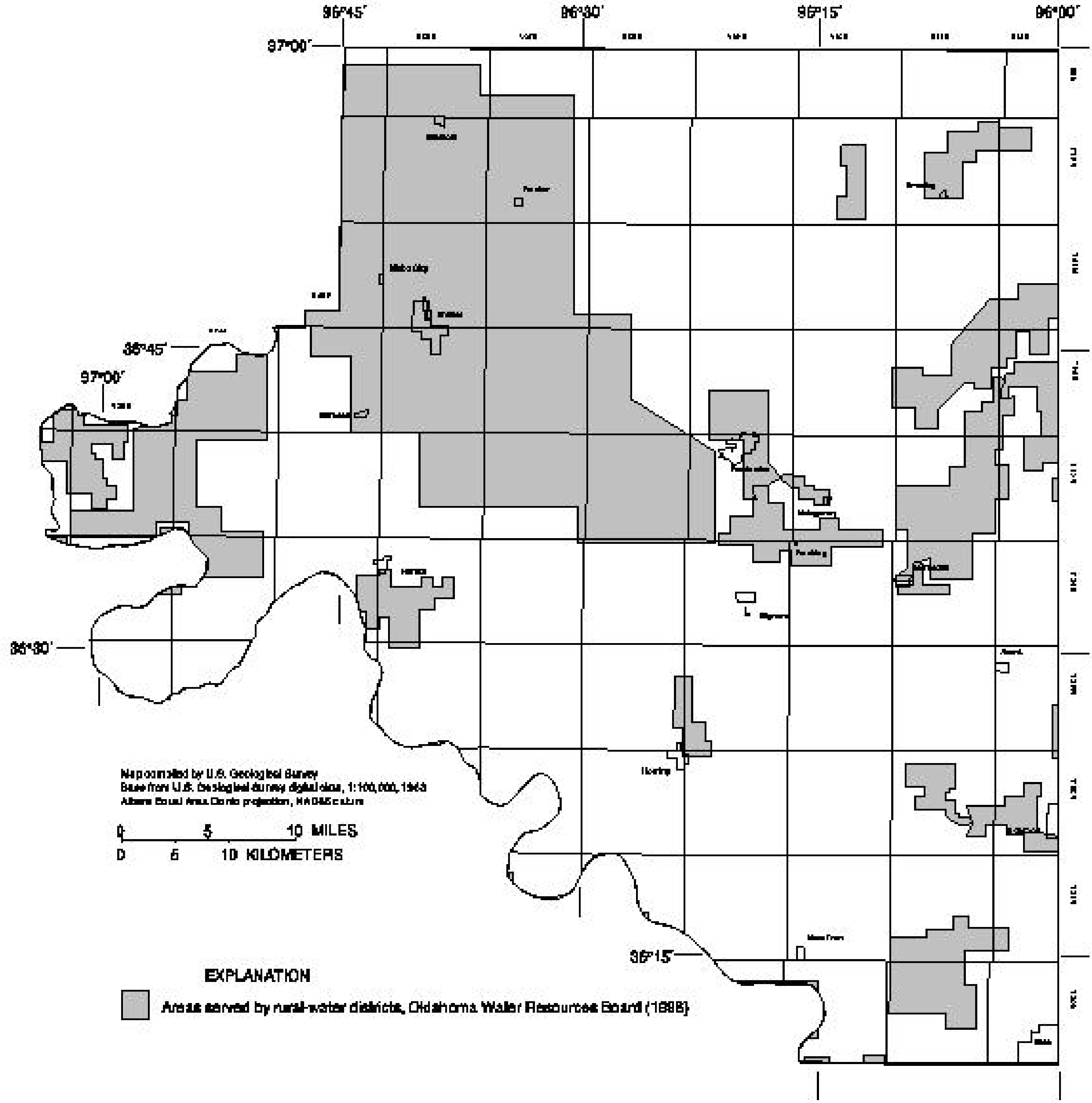


Figure 6. Rural-water districts in the Osage Reservation, Oklahoma.

Table 1. Listing of analytical methods used at the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; AE, atomic emission spectrophotometry; ICP, inductively coupled plasma spectrophotometry; AA, atomic absorption spectrophotometry; /T, trace; I- followed by numbers, a method code used by U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida; EPA- followed by numbers, a protocol described by the U.S. Environmental Protection Agency]

Constituents and reporting units	Method	Minimum reporting level
WATER PROPERTIES		
Specific conductance, field (µS/cm at 25^{o}C)		1
pH, field, standard units		0.1
Water temperature (^{o}C)		0.1
Dissolved solids, calculated sum (mg/L)		1
MAJOR CATIONS		
Calcium, dissolved (mg/L as Calcium)	EPA-200.7, ICP/T	0.02
Magnesium, dissolved (mg/L as Magnesium)	EPA-200.7, ICP/T	0.001
Sodium, dissolved (mg/L as Sodium)	I-1735-85, AA, direct	0.1
Potassium, dissolved (mg/L as Potassium)	I-1630-85, AA, direct	0.1
MAJOR ANIONS		
Alkalinity, total, field, (mg/L as Calcium Carbonate)	whole water, incremental titration	1
Sulfate, dissolved (mg/L as Sulfate)	SM 426-C, Turbidimetry, auto, background corrected	0.2
Chloride, dissolved (mg/L as Chloride)	I-2057-85, Colorimetry, thiocyanate, auto	0.1
Fluoride, dissolved (mg/L as Fluoride)	I-2327-85, Ion selective electrode, auto	0.1
Silica, dissolved (mg/L as Silica)	EPA-200.7, ICP/T	0.01
Bromide, dissolved (mg/L as Bromide)	EPA-300.0, Colorimetry, fluorescein, auto	0.05
Nutrients		
Nitrogen, nitrite plus nitrate, dissolved (mg/L as Nitrogen)	EPA-353.2	0.002
Nitrogen, ammonia, dissolved (mg/L as Nitrogen)	I-2522-85	0.002
Nitrogen, ammonia plus organic, dissolved (mg/L as Nitrogen)	EPA-351.2	0.2
Phosphorus, total dissolved (mg/L as Phosphorus)	I-4600-85	0.002
Phosphorus, orthophosphate dissolved (mg/L as Phosphorus)	I-4601-85	0.001
Carbon organic, total dissolved (mg/L as Carbon)	EPA-415.1	0.1
TRACE ELEMENTS		
Arsenic, dissolved (µg/L as Arsenic)	EPA-206.2,AA, hydride, auto	1
Boron, dissolved (µg/L as Boron)	EPA-200.7, ICP/T	3
Iron, dissolved (µg/L as Iron)	EPA-200.7, ICP/T	1
Lithium, dissolved (µg/L as Lithium)	I-1472-87, ICP	4
Manganese, dissolved (µg/L as Manganese)	I-3456-85, AE, ICP	0.2
Strontium, dissolved (µg/L as Strontium)	I-1472.87 AE, ICP	0.5

Table 2. Results of the Mann-Whitney tests, ρ-values, comparing the concentrations of constituents from water-quality samples collected in the Osage Reservation, Oklahoma

[ρ-values are decimal percentages; numbers in bold type and underlined indicate constituent concentrations are significantly different between the comparison groups at the 95 percent confidence level]

Constituents	Samples from Ada-Vamoosa aquifer and Quaternary aquifer	Samples from Ada-Vamoosa aquifer not near oil wells and near oil wells	Samples from Quaternary aquifer not near oil wells and near oil wells
Specific conductance, field	0.15	0.00	0.99
pH, field	0.03	0.51	0.28
Alkalinity, total, field	0.58	0.13	0.57
Dissolved solids, sum	0.38	**0.01**	0.96
Calcium	**0.00**	0.93	0.72
Magnesium	0.86	0.47	0.72
Sodium	**0.00**	**0.01**	0.64
Potassium	**0.01**	0.08	0.61
Sulfate	**0.01**	**0.02**	0.50
Chloride	**0.04**	**0.00**	0.77
Fluoride	0.34	0.16	0.70
Bromide	0.49	**0.00**	0.06
Silica	**0.00**	**0.05**	0.66
Nitrogen, nitrite plus nitrate	**0.05**	0.78	0.99
Nitrogen, ammonia	**0.03**	0.56	0.06
Phosphorus, total	**0.00**	0.87	0.60
Phosphorus, orthophosphate	**0.00**	0.31	0.40
Boron	**0.01**	0.11	0.58
Iron	0.15	0.42	0.16
Lithium	**0.01**	0.22	0.60
Manganese	0.47	0.55	0.38
Strontium	0.48	0.80	0.59
Carbon organic, total	0.45	0.22	0.80

actual constituent concentrations, to determine if the data sets are different. The Mann-Whitney test is appropriate for small and large data sets. The null hypothesis for the Mann-Whitney test is that the two data sets have the same median and distribution. The null hypothesis is rejected if the probability (r-value) of the 2-sided test is less than or equal to 0.05 (95 percent confidence of relation) The alternate hypothesis is that the data groups are significantly different for that constituent.

Censored data, concentrations reported as less than a largest-minimum-reporting level for a constituent, were assigned a value of half the minimum reporting level and given the same rank. The Mann-Whitney test utilized the data less than the largest-minimum-reporting level, and the r-value for censored data is essentially the same because of ranking the data (Helsel and Hirsch, 1992). The Mann-Whitney test cannot detect differences in the median for severely censored data (50 percent or greater) and conclusions should not be drawn (Helsel and Hirsch, 1992). Arsenic and nitrogen as ammonia plus organic nitrogen are not included in the results of the Mann-Whitney test (table 2) for this reason.

The comparison populations were the constituent concentrations in the water-quality samples from the:

- Quaternary aquifer and Ada-Vamoosa aquifer,
- Quaternary aquifer not near an oil well and Quaternary aquifer near an oil well,
- Ada-Vamoosa aquifer not near an oil well and Ada-Vamoosa aquifer near an oil well.

The results of the Mann-Whitney tests are discussed in comparison of water quality of the Quaternary and Ada-Vamoosa aquifers and comparison of water quality not near oil wells and near oil wells.

Summary statistics for the aquifers and subgroups, in the form of sample size, calculated percentiles, maximum and minimum concentrations, and largest-minimum-reporting level for the water-quality samples are presented in tables 3-8. Box plots of summary statistics for selected constituents are presented in figures 7-18. Box plots summarize the distribution, range, skewness, and median or center line data and are useful to visually compare several data sets (Helsel and Hirsch, 1992).

The chemical analyses for most constituents listed in Appendix 4 include censored data less than the largest-minimum-reporting levels, which are listed in tables 1 and 3-8. If no censored data were present for a constituent, percentiles were calculated by standard methods (tables 3-8). A procedure developed by Helsel and Cohn (1988) was used to calculate percentiles for the constituents with censored data. Percentiles less than the largest-minimum-reporting levels from censored data are noted in tables 3-8 with an asterisk. No percentiles were calculated for arsenic or nitrogen as ammonia plus organic nitrogen because values for each were greater than 50 percent censored data. No percentile values are reported less than detected equipment-blank values for nitrogen as ammonia, total phosphorus, phosphorus as orthophosphate, iron, and organic carbon

Comparison of Ground-Water Quality From Quaternary and Ada-Vamoosa Aquifers

The quality of water from the unconfined Quaternary aquifer is significantly different from the quality of water from the confined Ada-Vamoosa aquifer for many constituents at the 95-percent confidence level (table 2). The r-values calculated by the Mann-Whitney test for the physical properties and constituents that rejected the null hypothesis are indicated by values less than 0.05 and are shown in bold print and underlined. Constituents with r-values of 0.05 or less were pH, calcium, sodium, potassium, sulfate, chloride, silica, nitrogen as nitrite plus nitrate, nitrogen as ammonia, total phosphorus, phosphorus as orthophosphate, boron, and lithium. No significant difference was determined for dissolved-solids concentration of the two aquifers at the 95 percent confidence level.

Summary statistics of the water-quality data collected from the Quaternary aquifer is presented in table 3 and from the Ada-Vamoosa aquifer in table 4. Water in the Quaternary aquifer is predominately a calcium-bicarbonate-type water with median dissolved-solids concentration (fig. 7) of 439 milligrams per liter. Water in the Ada-Vamoosa aquifer is predominately a sodium-bicarbonate-type water with median dissolved solids concentration of 490 milligrams per liter. The National Primary Drinking Water Regulations and National Secondary Drinking Water Regulations are guidelines to evaluate health risks and drinking water quality (U.S. Environmental Protection Agency [USEPA], 1998). The primary regulations are enforceable for public water systems based on health risks; while the secondary regulations are guidelines for the aesthetic quality of drinking water. The standards recommend that the dissolved solids should not exceed a secondary regulation of 500 milligrams per liter. Over half of the water samples from the Quaternary and Ada-Vamoosa aquifers are better than the secondary regulations for dissolved-solids concentration without processing or purifying the water.

A pH of 7.0 indicates a neutral solution. Values greater than 7.0 indicate increasing alkalinity; values less than 7.0 indicate increasing acidity (Hem, 1992). Corrosiveness of water generally increases with decreasing pH, however, excessively alkaline water also may attack metals. The median pH in the Quaternary and Ada-Vamoosa aquifer samples (tables 3 and 4, fig. 8) is neutral. The median values for some acid soluble constituents such as alkalinity (fig. 9), calcium (fig. 10), and strontium are slightly greater in the Quaternary aquifer than the concentrations of those constituents in the Ada-Vamoosa aquifer samples. Calcium is the only acid soluble constituent that is significantly different between the two aquifers at the 95 percent confidence level. Other acid-soluble constituents such as iron and manganese are slightly less in the Quaternary aquifer than in the Ada-Vamoosa aquifer but are not significantly different.

Alkalinity is a measure of the capacity of a water to neutralize a strong acid, and is expressed in terms of an equivalent concentration of calcium carbonate. Alkalinity in natural water usually is caused by the presence of bicarbonate and carbonate ions. Bicarbonate and carbonate ions are common to most natural water because of the abundance of carbon dioxide and carbonate minerals in nature. Alkaline water may have a distinctively bitter taste. High alkalinity in irrigation water may increase the pH of the soil, leach organic material, decrease permeability of the soil, and impair plant growth. The alkalinity of natural water varies widely but rarely exceeds 400 to 500 milligrams per liter. Calcium and magnesium cause most of the hardness and scale-forming properties of water and reduce the effectiveness of soap.

Nitrogen (fig. 11) and phosphorus (tables 3 and 4), often associated with domestic sewage and animal waste contamination, have significantly greater median percentile values for samples from the unconfined, more vulnerable, Quaternary aquifer. The maximum contaminant level for nitrate is 10 milligrams per liter. High nitrate content has been reported to cause methemoglobinemia, blue-baby syndrome, (an often fatal disease in infants) and should not be used in infant feeding, pregnant women, or nursing mothers. About 14 percent of the water-quality samples from the Quaternary aquifer and 6 percent of the water-quality samples from the Ada-Vamoosa aquifer exceed 10 milligrams per liter. Nitrogen and phosphorus encourage the growth of algae and other organisms, which may cause odor problems in water supplies.

Water samples from the Ada-Vamoosa aquifer have greater median percentile values for specific conductance, dissolved solids (fig. 7), sodium (fig. 12), sulfate (fig. 13), chloride (fig. 14), and boron (tables 3 and 4) than samples from the Quaternary aquifer. These ions could be derived from either salt deposits or brine water from greater depths (Collins, 1975, Richter and Kreitler, 1991). Since there are no known salt deposits in the stratigraphic section in the Osage Reservation, deep-connate-brine water is probably the source of the ions.

Table 3. Summary statistics for field water-quality measurements and dissolved chemical constituents for samples from wells completed in the Quaternary aquifer in the Osage Reservation, Oklahoma

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; ^{o}C degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. Methods:1, no censored data, ordinary percentile calculation, 2, censored data present, percentiles calculated using method described by Helsel and Hirsch, 1992, 3, no calculation, more than 80 percent of the data were censored; MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods by Helsel and Hirsch, 1992, percentiles greater than this value are the same as ordinary percentile calculation); #, calculated value; -- MRL less than equipment-blank data, or MRL greater than minimum value; N/A, indicates no statistic available]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Specific conductance, field (µS/cm at 25 degrees C)	1	45	1.0	167	313	612	741	958	1,771	2,540
pH, field, standard units	1	44	0.1	6.0	6.4	6.9	7.0	7.4	9.0	9.1
Water temperature (^{o}C)	1	29	1.0	10	10	14.2	16	16.5	17.8	18.0
Alkalinity, total, field, (mg/L as $CaCO_3$)	1	45	1.0	39	44	182	295	332	425	588
Dissolved solids, calculated sum (mg/L)	1	45	#	127	208	354	439	595	1,150	1,290
Calcium, dissolved (mg/L as Ca)	1	45	0.02	1.1	1.3	53	80	115	214	270
Magnesium, dissolved (mg/L as Mg)	1	45	0.001	0.3	0.3	8.5	15	25.5	49.8	61
Sodium, dissolved (mg/L as Na)	1	45	0.1	9.8	14	24	38	83	227	240
Potassium, dissolved (mg/L as K)	1	45	0.1	0.1	0.2	0.7	1.1	2.0	5.3	6.9
Sulfate, dissolved (mg/L as SO_4)	1	45	0.2	8	10	17	28	56	250	330
Chloride, dissolved (mg/L as Cl)	1	45	0.1	2.7	6.7	11.5	28	44	326	750
Fluoride, dissolved (mg/L as F)	2	45	0.1	0.1	0.1	0.2	0.2	0.4	0.83	1
Bromide, dissolved (mg/L as Br)	2	45	0.05	--	[1]0.017	0.065	0.1	0.3	1.18	2.7
Silica, dissolved (mg/L as SiO_2)	1	45	0.01	8.8	9	14	20	23	34.7	35
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	2	44	0.002	0.002	0.002	0.184	1.3	5.3	41.5	49
Nitrogen, ammonia, dissolved (mg/L as N)	2	44	--	‡0.01	N/A	N/A	N/A	0.016	1.30	8.6
Nitrogen, ammonia plus organic, total dissolved (mg/L as N)	2	44	0.2	--	N/A	N/A	N/A	N/A	N/A	6.6
Phosphorus, total dissolved (mg/L as P)	2	44	--	‡0.005	N/A	0.006	0.02	0.08	0.32	2.6
Phosphorus, orthophosphate dissolved (mg/L as P)	2	44	--	‡0.004	N/A	N/A	0.03	0.078	0.27	2.3
Arsenic, dissolved (µg/L as As)	3	45	1.0	--	N/A	N/A	N/A	N/A	N/A	7.4
Boron, dissolved (µg/L as B)	1	45	3.0	23	25.3	44.5	85	225	711	1,100
Iron, dissolved (µg/L as Fe)	2	45	--	‡4.0	N/A	N/A	7	25	589	1,900
Lithium, dissolved (µg/L as Li)	2	45	4.0	--	*1.7	*3.4	6	10	20	20
Manganese, dissolved (µg/L as Mn)	2	45	0.2	--	*0.016	0.5	2.2	15.5	771	1,400
Strontium, dissolved (µg/L as Sr)	1	45	0.5	47	52.3	330	540	825	1,610	2,200
Carbon organic, total dissolved (mg/L as C)	2	44	--	0.5	N/A	N/A	0.5	0.8	4.1	6.2

[1]Value was estimated by using a log-probability regression to predict the values of data when the minimum value was less than the detection limit.

‡ Equipment-blank sample value greater than MRL, percentile values less than equipment-blank sample considered questionable and not available.

Table 4. Summary statistics for field water-quality measurements and dissolved chemical constituents for samples from wells completed in the Ada-Vamoosa aquifer in the Osage Reservation, Oklahoma

[mS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; mg/L, micrograms per liter. Methods:1, no censored data, ordinary percentile calculation, 2, censored data present, percentiles calculated using method described by Helsel and Hirsch, 1992, 3, no calculation, more than 80 percent of the data were censored; MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods by Helsel and Hirsch, 1992, percentiles greater than this value are the same as ordinary percentile calculation); #, calculated value; -- MRL less than equipment-blank data, or MRL greater than minimum value; N/A, indicates no statistic was calculated]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Specific conductance, field (µS/cm at 25°C)	1	75	1.0	180	240	571	829	1,180	3,508	4,540
pH, field, standard units	1	71	0.1	6.0	6.16	7.1	7.4	7.9	8.9	9.2
Water temperature (°C)	1	61	1.0	8	9.5	14	16	17	18	19
Alkalinity, total, field, (mg/L as $CaCO_3$)	1	75	1.0	7	70.40	176	264	350	484	525
Dissolved solids, calculated sum (mg/L)	1	75	#	103	139	329	490	692	2,106	3,120
Calcium, dissolved (mg/L as Ca)	1	75	0.02	1.3	1.94	21	45	64	146	660
Magnesium, dissolved (mg/L as Mg)	1	75	0.001	0.3	0.72	5.2	15	31	68	160
Sodium, dissolved (mg/L as Na)	1	75	0.1	7.4	11.8	38	85	190	610	1,000
Potassium, dissolved (mg/L as K)	1	75	0.1	0.5	0.6	1	1.6	2.9	5.2	14
Sulfate, dissolved (mg/L as SO_4)	1	75	0.2	3.2	9.72	22	56	100	616	1,300
Chloride, dissolved (mg/L as Cl)	1	75	0.1	2.5	6.04	15	35	110	656	1,300
Fluoride, dissolved (mg/L as F)	2	75	0.1	--	[1]0.1	0.2	0.3	0.4	1.4	2.2
Bromide, dissolved (mg/L as Br)	2	75	0.05	--	*0.012	0.07	0.1	0.4	2.2	9.2
Silica, dissolved (mg/L as SiO_2)	1	75	0.01	4.1	7.6	10	14	18	23.4	48
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	2	67	0.002	--	*0.001	0.052	0.36	3.6	12.6	18
Nitrogen, ammonia, dissolved (mg/L as N)	2	67	--	‡0.01	N/A	N/A	0.01	0.26	0.91	1.4
Nitrogen, ammonia plus organic, total dissolved (mg/L as N)	2	67	0.2	--	N/A	N/A	N/A	N/A	N/A	1.7
Phosphorus, total dissolved (mg/L as P)	2	67	--	‡0.005	N/A	N/A	N/A	0.008	0.046	0.14
Phosphorus, orthophosphate dissolved (mg/L as P)	2	67	--	‡0.004	N/A	N/A	N/A	0.007	0.04	0.14
Arsenic, dissolved (µg/L as As)	3	75	1.0	--	N/A	N/A	N/A	N/A	N/A	4.7
Boron, dissolved (µg/L as B)	1	75	3.0	21	28.4	53	190	650	2,660	3,400
Iron, dissolved (µg/L as Fe)	2	75	--	‡4.0	N/A	5	10	40	532	4,000
Lithium, dissolved (µg/L as Li)	2	75	4.0	--	*2.26	6	9	20	32	90
Manganese, dissolved (µg/L as Mn)	2	75	0.2	--	*0.08	0.6	5.6	22	160	220
Strontium, dissolved (µg/L as Sr)	1	75	0.5	57	67.8	190	430	860	2,800	13,200
Carbon organic, total dissolved (mg/L as C)	2	67	--	‡0.5	N/A	N/A	N/A	0.6	1.96	4.1

[1]Value was estimated by using a log-probability regression to predict the values of data when the minimum value was less than the detection limit.

‡ Equipment-blank sample value greater than MRL, percentile values less than equipment-blank sample considered questionable and not available.

Table 5. Summary statistics for field water-quality measurements and dissolved chemical constituents for samples from wells completed in the Quaternary aquifer not near oil wells in the Osage Reservation, Oklahoma

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. Methods:1, no censored data, ordinary percentile calculation, 2, censored data present, percentiles calculated using method described by Helsel and Hirsch, 1992, 3, no calculation, more than 80 percent of the data were censored; MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods by Helsel and Hirsch, 1992, percentiles greater than this value are the same as ordinary percentile calculation);#, calculated value; -- MRL less than equipment-blank data, or MRL greater than minimum value; N/A, indicates no statistic available]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Specific conductance, field (µS/cm at 25 degrees C)	1	22	1.0	309	328	615	692	1,024	2,426	2,540
pH, field, standard units	1	22	0.1	6.0	6.1	6.9	7.2	7.5	9.1	9.1
Alkalinity, total, field, (mg/L as $CaCO_3$)	1	22	1.0	50	55	209	305	345	565	588
Dissolved solids, calculated sum (mg/L)	1	22	--	208	217	354	405	630	1,300	1,300
Calcium, dissolved (mg/L as Ca)	1	22	0.02	1.3	1.3	52	82	112	262	270
Magnesium, dissolved (mg/L as Mg)	1	22	0.001	0.3	0.3	9	16	27	60	61
Sodium, dissolved (mg/L as Na)	1	22	0.1	9.8	11	25	46	97	237	240
Potassium, dissolved (mg/L as K)	1	22	0.1	0.1	0.12	0.78	1.2	2.2	4.4	4.5
Sulfate, dissolved (mg/L as SO_4)	1	22	0.2	8	8	16	26	52	318	330
Chloride, dissolved (mg/L as Cl)	1	22	0.1	2.7	3.6	9.9	29	50	678	750
Fluoride, dissolved (mg/L as F)	2	22	0.1	--	0.058	0.2	0.25	0.4	0.86	0.9
Bromide, dissolved (mg/L as Br)	2	22	0.05	--	0.025	0.08	0.2	0.4	2.4	2.6
Silica, dissolved (mg/L as SiO_2)	1	22	0.01	8.8	8.8	13	20	22	35	35
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	2	22	0.002	0.002	0.002	0.14	2.1	7.3	43	48
Nitrogen, ammonia, dissolved (mg/L as N)	2	22	--	‡0.01	N/A	N/A	N/A	0.042	7.6	8.6
Nitrogen, ammonia plus organic, total dissolved (mg/L as N)	2	22	0.2	--	N/A[1]0.1	N/A	N/A	N/A	N/A	6.6
Phosphorus, total dissolved (mg/L as P)	2	22	--	‡0.005	N/A	0.0068	0.01	0.09	2.3	2.6
Phosphorus, orthophosphate dissolved (mg/L as P)	2	22	--	‡0.004	N/A	N/A	0.025	0.1	2.0	2.3
Arsenic, dissolved (µg/L as As)	3	22	1.0	--	N/A	N/A	N/A	N/A	N/A	7.4
Boron, dissolved (µg/L as B)	1	22	3.0	23	24	45	98	218	1,043	1,100
Iron, dissolved (µg/L as Fe)	2	22	--	‡4.0	N/A	N/A	7	32	468	470
Lithium, dissolved (µg/L as Li)	2	22	4.0	--	*2	*2	6.5	10	20	20
Manganese, dissolved (µg/L as Mn)	2	22	0.2	--	*0.1	0.5	3.8	192	1,307	1,400
Strontium, dissolved (µg/L as) Sr	1	22	0.5	47	48	280	475	900	1,625	1,700
Carbon organic, total dissolved (mg/L as C)	2	22	--	‡0.5	N/A	N/A	0.55	0.82	4.3	4.5

[1]Value was estimated by using a log-probability regression to predict the values of data when the minimum value was less than the detection limit.

‡ Equipment-blank sample value greater than MRL, percentile values less than equipment-blank sample considered questionable and not available.

Table 6. Summary statistics for field water-quality measurements and dissolved chemical constituents for samples from wells completed in the Quaternary aquifer near oil wells in the Osage Reservation, Oklahoma

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. Methods:1, no censored data, ordinary percentile calculation, 2, censored data present, percentiles calculated using method described by Helsel and Hirsch, 1992, 3, no calculation, more than 80 percent of the data were censored; MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods by Helsel and Hirsch, 1992, percentiles greater than this value are the same as ordinary percentile calculation); #, calculated value; -- MRL less than equipment-blank data, or MRL greater than minimum value; N/A, indicates no statistic available]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Specific conductance, field (µS/cm at 25 degrees C)	1	23	1.0	167	198	590	748	935	1,366	1,420
pH, field, standard units	1	22	0.1	6.4	6.4	6.9	7.1	7.3	8.9	9.1
Alkalinity, total, field, (mg/L as $CaCO_3$)	1	23	1.0	39	40	122	285	320	401	402
Dissolved solids, calculated sum (mg/L)	1	23	--	127	143	351	454	603	711	724
Calcium, dissolved (mg/L as Ca)	1	23	0.02	1.1	3.9	51	77	120	138	140
Magnesium, dissolved (mg/L as Mg)	1	23	0.001	0.3	0.84	7	15	24	33	33
Sodium, dissolved (mg/L as Na)	1	23	0.1	14	14	24	31	75	212	230
Potassium, dissolved (mg/L as K)	1	23	0.1	0.3	0.32	0.6	1	1.9	6.6	6.9
Sulfate, dissolved (mg/L as SO_4)	1	23	0.2	9.6	10	21	30	58	192	210
Chloride, dissolved (mg/L as Cl)	1	23	0.1	6.6	6.7	13	23	36	306	350
Fluoride, dissolved (mg/L as F)	2	23	0.1	0.1	0.1	0.2	0.2	0.4	0.9	1.0
Bromide, dissolved (mg/L as Br)	2	23	0.05	--	[1]0.025	*0.025	0.1	0.2	0.82	0.9
Silica, dissolved (mg/L as SiO_2)	1	23	0.01	9.3	9.3	14	20	26	35	35
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	2	22	0.002	0.002	0.017	0.24	0.98	5.2	45	49
Nitrogen, ammonia, dissolved (mg/L as N)	2	22	--	‡0.01	N/A	N/A	N/A	0.014	0.14	0.15
Nitrogen, ammonia plus organic, total dissolved (mg/L as N)	2	22	0.2	--	N/A	N/A	N/A	N/A	N/A	0.94
Phosphorus, total dissolved (mg/L as P)	2	22	--	‡0.005	N/A	N/A	0.03	0.062	0.1	0.1
Phosphorus, orthophosphate dissolved (mg/L as P)	2	22	--	‡0.004	N/A	N/A	0.03	0.055	0.088	0.09
Arsenic, dissolved (µg/L as As)	3	23	1.0	--	N/A	N/A	N/A	N/A	N/A	1.3
Boron, dissolved (µg/L as B)	1	23	3.0	25	25	40	70	260	674	690
Iron, dissolved (µg/L as Fe)	2	23	--	‡4.0	N/A	4	7	10	1,648	1,900
Lithium, dissolved (µg/L as Li)	2	23	4.0	--	*2	*2	6	9	20	20
Manganese, dissolved (µg/L as Mn)	2	23	0.2	--	*0.1	0.4	1.5	11	210	240
Strontium, dissolved (µg/L as) Sr	1	23	0.5	52	62	380	630	810	2,000	2,200
Carbon organic, total dissolved (mg/L as C)	2	22	--	‡0.5	N/A	N/A	N/A	0.8	5.7	6.2

[1]Value was estimated by using a log-probability regression to predict the values of data when the minimum value was less than the detection limit.

‡ Equipment-blank sample value greater than MRL, percentile values less than equipment-blank sample considered questionable and not available.

Table 7. Summary statistics for field water-quality measurements and dissolved chemical constituents for samples from wells completed in the Ada-Vamoosa aquifer not near oil wells in the Osage Reservation, Oklahoma

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. Methods:1, no censored data, ordinary percentile calculation, 2, censored data present, percentiles calculated using method described by Helsel and Hirsch, 1992, 3, no calculation, more than 80 percent of the data were censored; MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods by Helsel and Hirsch, 1992, percentiles greater than this value are the same as ordinary percentile calculation);#, calculated value; -- MRL less than equipment-blank data, or MRL greater than minimum value; N/A, indicates no statistic available]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Specific conductance, field (µS/cm at 25 degrees C)	1	17	1.0	218	218	441	608	777	4,540	4,540
pH, field, standard units	1	13	0.1	6.5	6.5	7.1	7.5	8.0	8.9	8.9
Alkalinity, total, field, (mg/L as $CaCO_3$)	1	17	1.0	95	95	140	220	286	500	500
Dissolved solids, calculated sum (mg/L)	1	17	--	140	140	267	354	473	2,680	2,680
Calcium, dissolved (mg/L as Ca)	1	17	0.02	8.5	8.5	27.5	45	60	110	110
Magnesium, dissolved (mg/L as Mg)	1	17	0.001	2.9	2.9	7.0	13	24	35	35
Sodium, dissolved (mg/L as Na)	1	17	0.1	9.6	9.6	19.0	40	78	1,000	1,000
Potassium, dissolved (mg/L as K)	1	17	0.1	0.5	0.5	0.9	1.2	1.9	3.8	3.8
Sulfate, dissolved (mg/L as SO_4)	1	17	0.2	8	8	15	27	65	140	140
Chloride, dissolved (mg/L as Cl)	1	17	0.1	2.5	2.5	6.8	13	38	1,300	1,300
Fluoride, dissolved (mg/L as F)	2	17	0.1	--	0.1	0.2	0.2	0.3	2.0	2.0
Bromide, dissolved (mg/L as Br)	2	17	0.05	--	[1]0.025	*0.025	0.07	0.2	9.2	9.2
Silica, dissolved (mg/L as SiO_2)	1	17	0.01	7.8	7.8	12	17	21	23	23
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	2	16	0.002	--	*0.001	0.0078	0.84	3.1	6.9	6.9
Nitrogen, ammonia, dissolved (mg/L as N)	2	16	--	‡0.01	N/A	N/A	N/A	0.18	1.0	1.0
Nitrogen, ammonia plus organic, total dissolved (mg/L as N)	2	16	0.2	--	N/A	N/A	N/A	N/A	N/A	0.97
Phosphorus, total dissolved (mg/L as P)	2	16	--	‡0.005	N/A	N/A	N/A	0.0092	0.02	0.02
Phosphorus, orthophosphate dissolved (mg/L as P)	2	16	--	‡0.004	N/A	N/A	N/A	0.006	0.03	0.03
Arsenic, dissolved (µg/L as As)	3	17	1.0	--	N/A	N/A	N/A	N/A	N/A	N/A
Boron, dissolved (µg/L as B)	1	17	3.0	26	26	46	80	385	3,400	3,400
Iron, dissolved (µg/L as Fe)	2	17	--	‡4.0	N/A	N/A	20	80	4,000	4,000
Lithium, dissolved (µg/L as Li)	2	17	4.0	--	*2	5.5	6	10	30	30
Manganese, dissolved (µg/L as Mn)	2	17	0.2	--	*0.1	0.3	3	36	220	220
Strontium, dissolved (µg/L as) Sr	1	17	0.5	57	57	170	360	1,065	13,157	13,157
Carbon organic, total dissolved (mg/L as C)	2	16	--	‡0.5	N/A	N/A	N/A	N/A	0.9	0.9

[1]Value was estimated by using a log-probability regression to predict the values of data when the minimum value was less than the detection limit.

‡ Equipment-blank sample value greater than MRL, percentile values less than equipment-blank sample considered questionable and not available.

Table 8. Summary statistics for field water-quality measurements and dissolved chemical constituents for samples from wells completed in the Ada-Vamoosa aquifer near oil wells in the Osage Reservation, Oklahoma

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. Methods:1, no censored data, ordinary percentile calculation, 2, censored data present, percentiles calculated using method described by Helsel and Hirsch, 1992, 3, no calculation, more than 80 percent of the data were censored; MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods by Helsel and Hirsch, 1992, percentiles greater than this value are the same as ordinary percentile calculation); #, calculated value; -- MRL less than equipment-blank data, or MRL greater than minimum value; N/A, indicates no statistic available]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Specific conductance, field (µS/cm at 25°C)	1	58	1.0	180	244	730	886	1,292	3,457	4,100
pH, field, standard units	1	58	0.1	6.0	6.1	7.0	7.3	7.9	9.0	9.2
Alkalinity, total, field, (mg/L as $CaCO_3$)	1	58	1.0	6.9	62	190	280	352	482	525
Dissolved solids, calculated sum (mg/L)	1	58	--	103	134	402	548	771	2,086	3,120
Calcium, dissolved (mg/L as Ca)	1	58	0.02	1.3	1.7	11	46	65	173	660
Magnesium, dissolved (mg/L as Mg)	1	58	0.001	0.3	0.4	4.8	16	32	70	160
Sodium, dissolved (mg/L as Na)	1	58	0.1	7.4	14	47	110	200	610	710
Potassium, dissolved (mg/L as K)	1	58	0.1	0.6	0.7	1.1	1.9	3.0	5.6	14
Sulfate, dissolved (mg/L as SO_4)	1	58	0.2	3.2	12.8	26	62	120	648	1,300
Chloride, dissolved (mg/L as Cl)	1	58	0.1	3.6	9.4	23	45	120	629	970
Fluoride, dissolved (mg/L as F)	2	58	0.1	--	[1]0.05	0.2	0.3	0.5	1.3	2.2
Bromide, dissolved (mg/L as Br)	2	58	0.05	--	*0.025	0.09	0.2	0.5	2.1	3.7
Silica, dissolved (mg/L as SiO_2)	1	58	0.01	4.1	7.2	9.7	13	18	25	48
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	2	51	0.002	--	0.003	0.065	0.034	3.6	14	18
Nitrogen, ammonia, dissolved (mg/L as N)	2	51	--	‡0.01	N/A	N/A	0.018	0.32	0.91	1.4
Nitrogen, ammonia plus organic, total dissolved (mg/L as N)	2	51	0.2	--	N/A	N/A	N/A	N/A	N/A	1.7
Phosphorus, total dissolved (mg/L as P)	2	51	--	‡0.005	N/A	N/A	N/A	0.008	0.062	0.14
Phosphorus, orthophosphate dissolved (mg/L as P)	2	51	--	‡0.004	N/A	N/A	N/A	0.007	0.06	0.14
Arsenic, dissolved (µg/L as As)	3	58	1.0	--	N/A	N/A	N/A	N/A	N/A	4.7
Boron, dissolved (µg/L as B)	1	58	3.0	21	30	58	305	665	2,615	3,000
Iron, dissolved (µg/L as Fe)	2	58	--	‡4.0	N/A	5	10	42	530	650
Lithium, dissolved (µg/L as Li)	2	58	4.0	--	*2	5.8	10	20	41	90
Manganese, dissolved (µg/L as Mn)	2	58	0.2	--	*0.1	1.1	6.0	22	152	210
Strontium, dissolved (µg/L as) Sr	1	58	0.5	64	68	238	445	878	2,650	8,700
Carbon organic, total dissolved (mg/L as C)	2	51	--	‡0.5	N/A	N/A	N/A	0.6	2.6	4.1

[1]Value was estimated by using a log-probability regression to predict the values of data when the minimum value was less than the detection limit.

‡ Equipment-blank sample value greater than MRL, percentile values less than equipment-blank sample considered questionable and not available

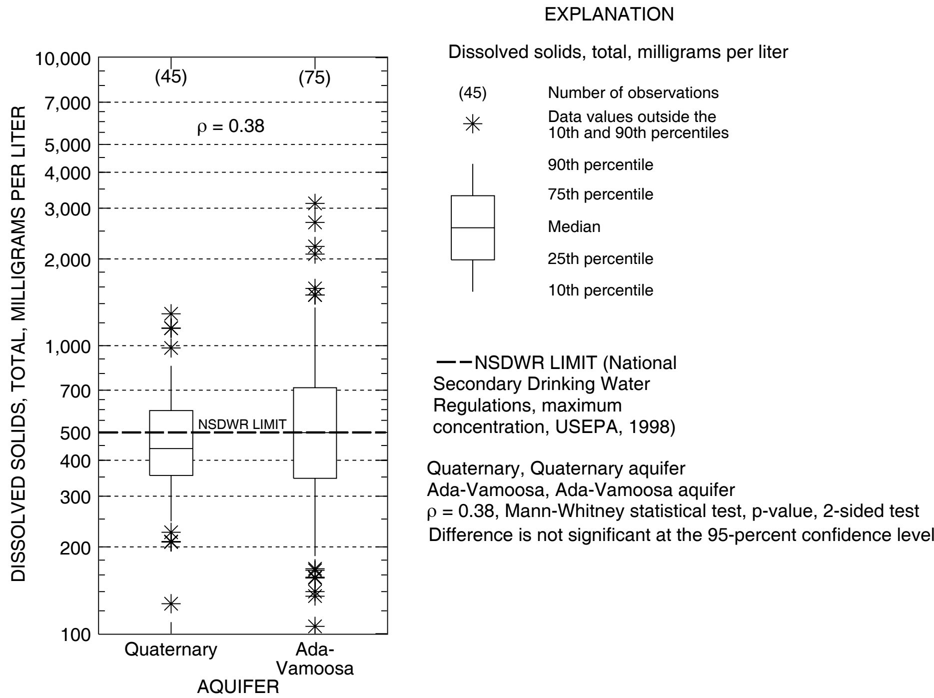


Figure 7. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, for dissolved solids, total.

Sodium, potassium, sulfate, and chloride are significantly different at the 95-percent confidence level (table 2). Sulfate in water containing calcium forms hard scale, particularly gypsum ($CaSO_4$) and barite ($BaSO_4$), in pipes and steam boilers. Large concentrations of sulfate in combination with other ions gives water a bitter taste and have a laxative effect on those unaccustomed to the water. Drinking water standards recommend that sulfate concentrations should not exceed a secondary regulation of 250 milligrams per liter (USEPA, 1998). Chloride in large amounts in combination with sodium and potassium gives a salty taste to water and in large quantities increases the corrosiveness of water. Drinking water standards recommend that chloride concentrations not exceed a secondary regulation of 250 milligrams per liter (USEPA, 1998).

Comparison of Ground-Water Quality From Freshwater Aquifer Wells Near Oil Wells to Freshwater Aquifer Wells Not Near Oil Wells

Summary statistics of the water-quality data for the subgroups of the Quaternary and Ada-Vamoosa aquifers are presented in tables 5-8. Water from the Quaternary aquifer wells within a quarter mile of an oil well were not significantly different from Quaternary aquifer wells not near an oil well. No r-values calculated by the Mann-Whitney test rejected the null hypothesis when comparing the subgroups of the Quaternary aquifer (table 2). This may be explained by the faster movement of water in the unconsolidated aquifer; thus the quarter-mile buffer zone may be inadequate. Further analysis is needed to determine factors controlling water quality in this aquifer.

Several constituents in samples from the Ada-Vamoosa-aquifer wells within a quarter mile of an oil well (Appendix 3) were significantly greater than from Ada-Vamoosa-aquifer wells not near oil wells. The r-values calculated by the Mann-Whitney test for the physical properties and constituents that rejected the null hypothesis (table 2) include specific conductance, dissolved solids, sodium, sulfate, chloride, bromide, and silica. These ions are probably derived from brine water from greater depths (Collins, 1975, Richter and Kreitler, 1991).

Three subgroups in figure 15 have median percentiles of dissolved-solids concentrations less than 500 milligrams per liter, the secondary regulation for dissolved solids. The Ada-Vamoosa aquifer near oil wells has greater median dissolved solids (fig. 15 and tables 7 and 8) than not near oil wells. The

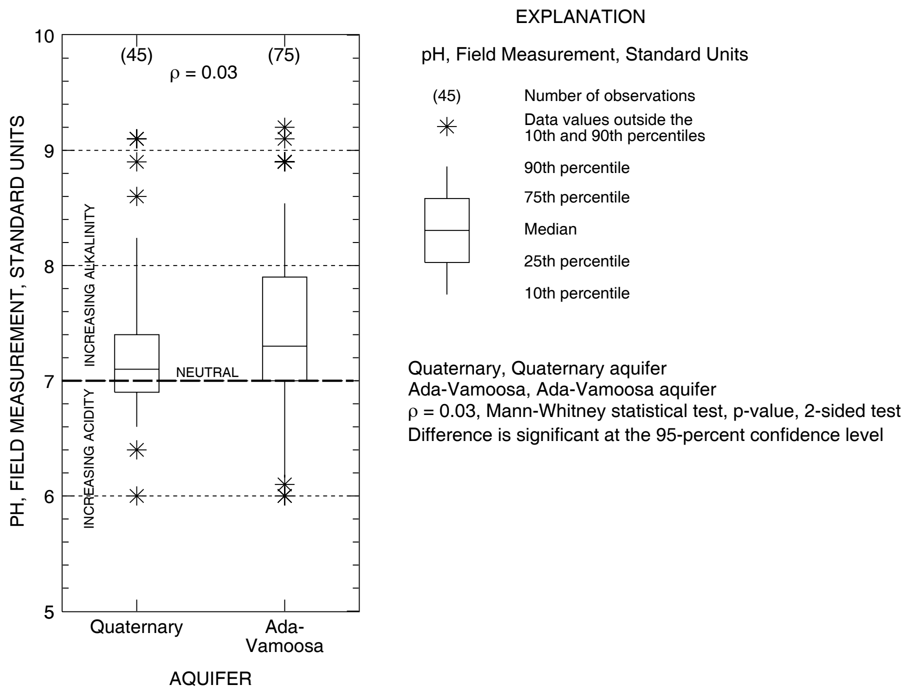


Figure 8. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, for pH.

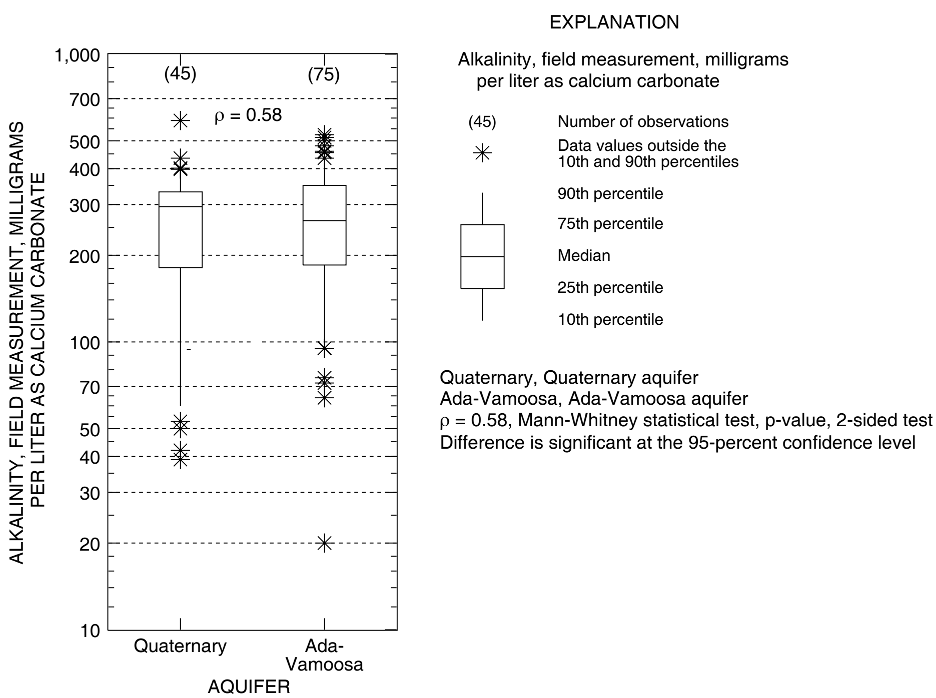


Figure 9. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, alkalinity, total field.

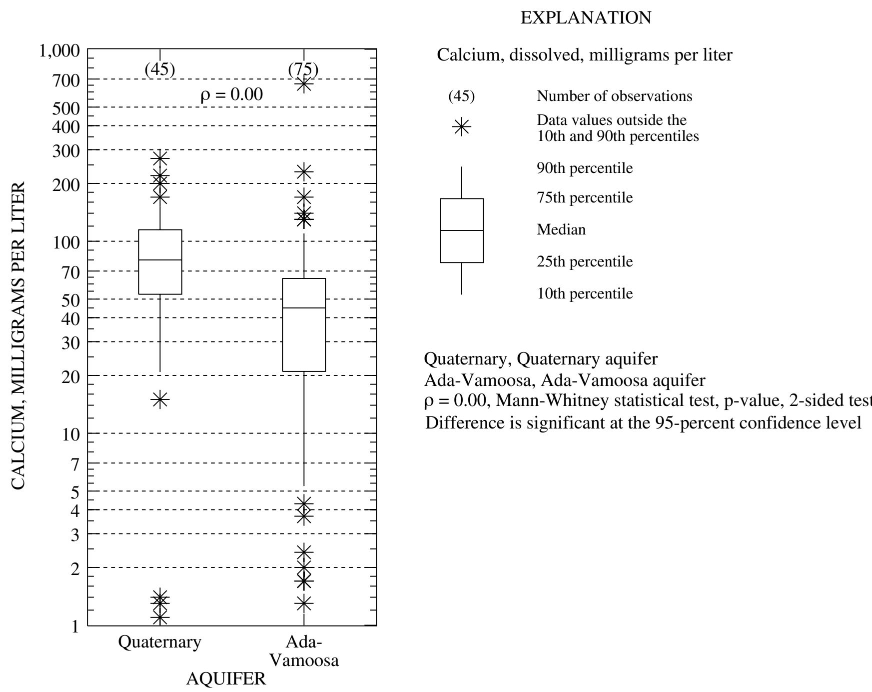


Figure 10. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, for calcium, dissolved.

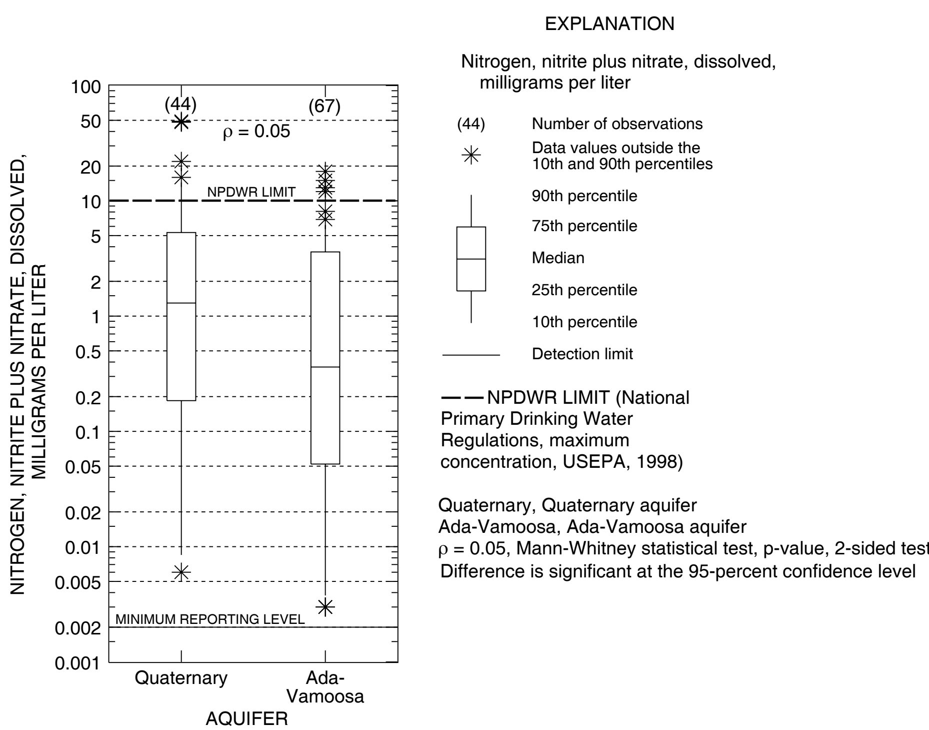


Figure 11. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, for nitrogen, nitrite plus nitrogen, dissolved.

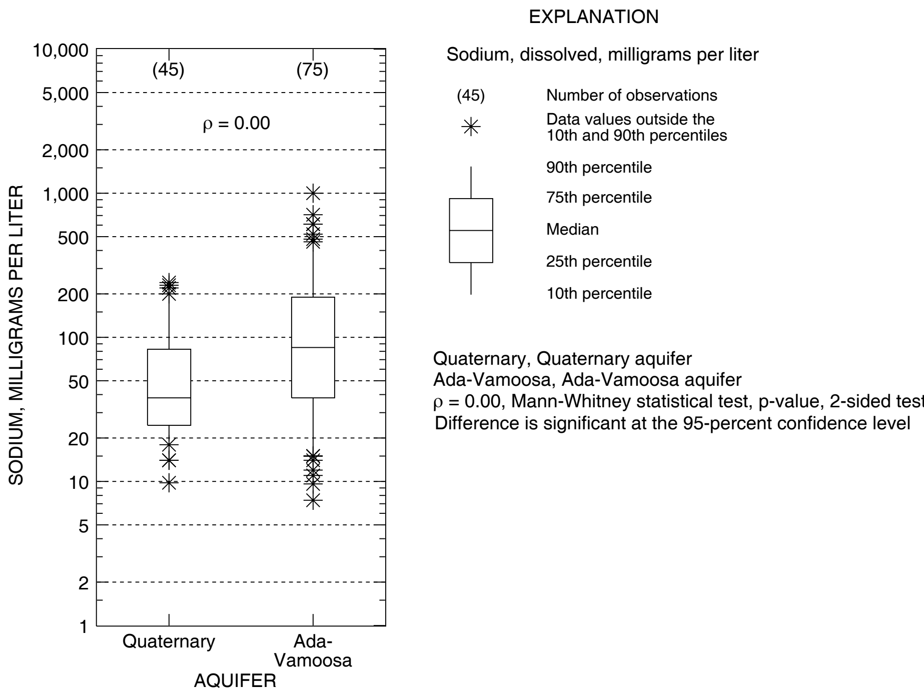


Figure 12. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, for sodium, dissolved.

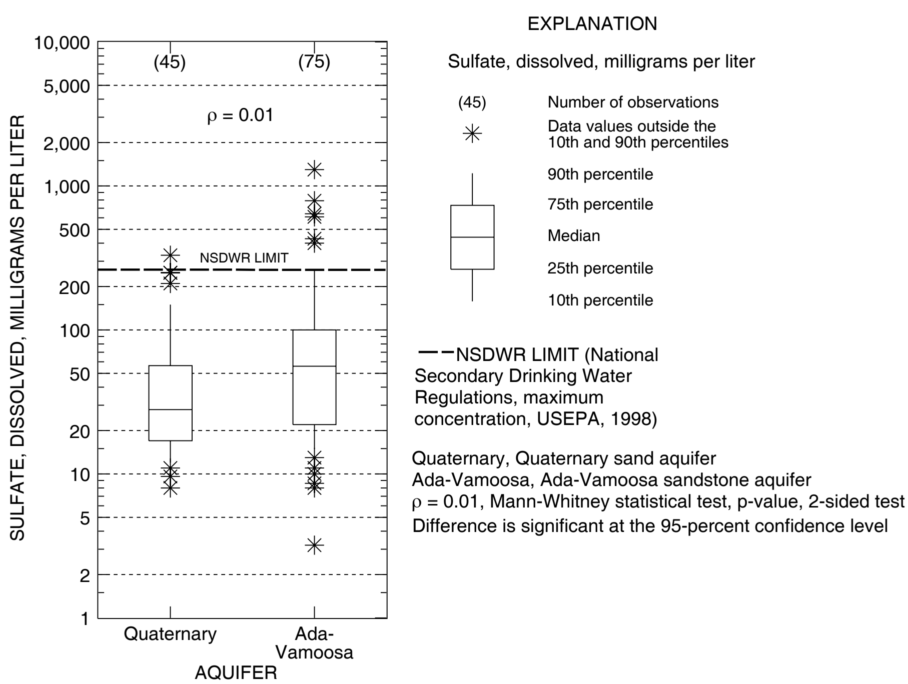


Figure 13. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, for sulfate, dissolved.

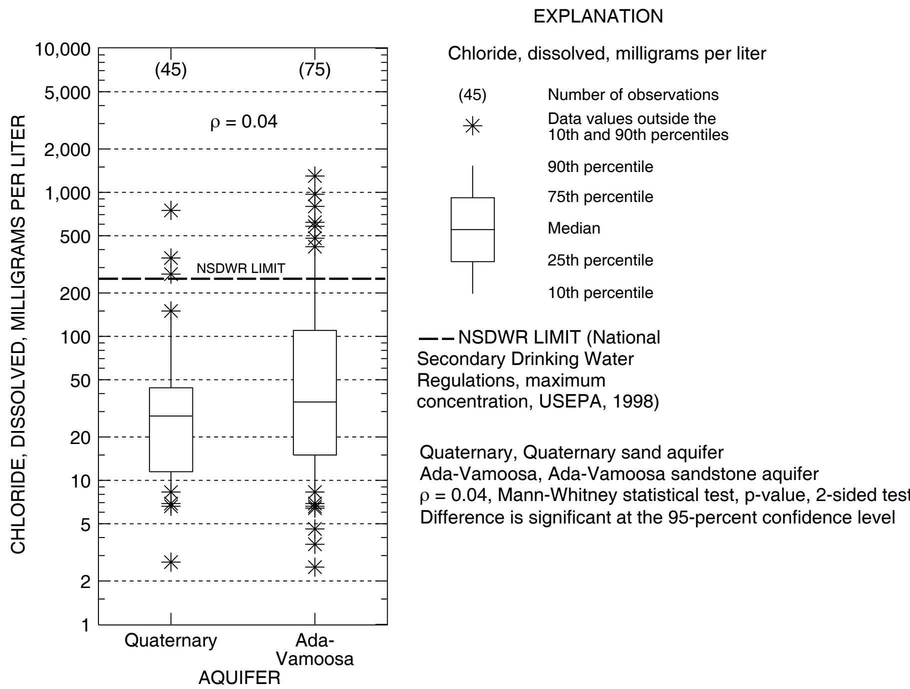


Figure 14. Comparison of ground-water quality from Quaternary and Ada-Vamoosa aquifers, for chloride, dissolved.

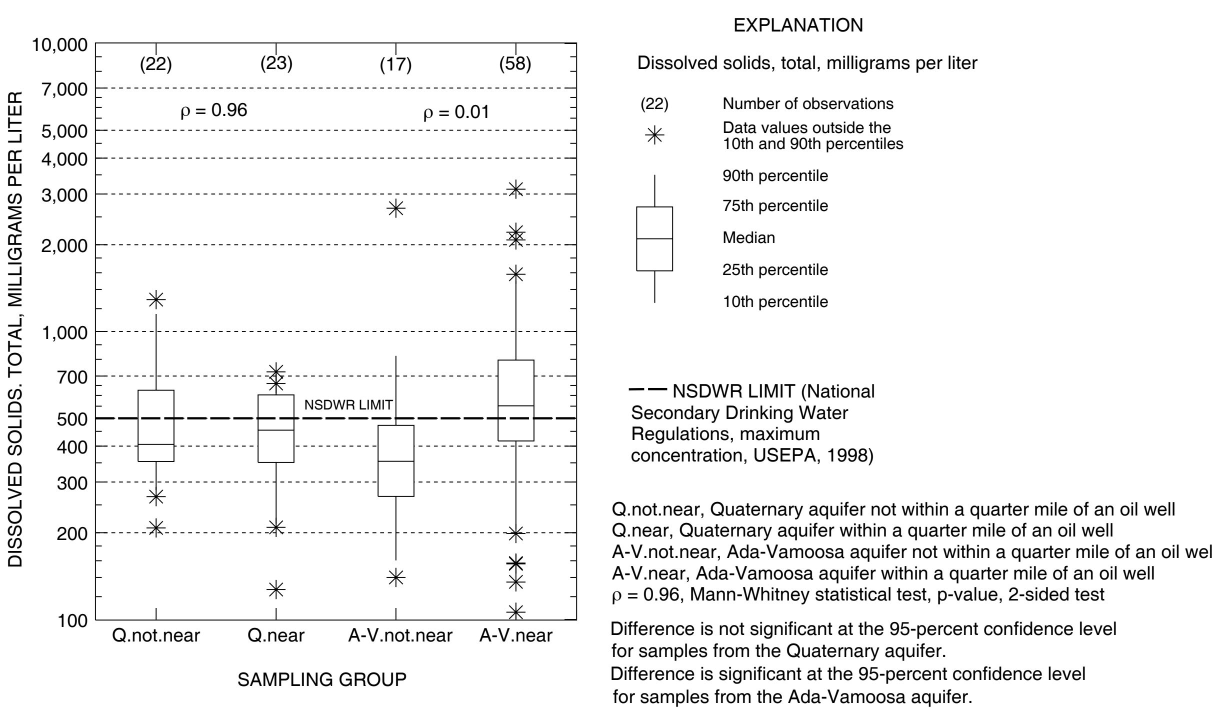


Figure 15. Comparison of ground-water quality from aquifers near oil wells and not near oil wells in the Osage Reservation, Oklahoma, for dissolved solids, total.

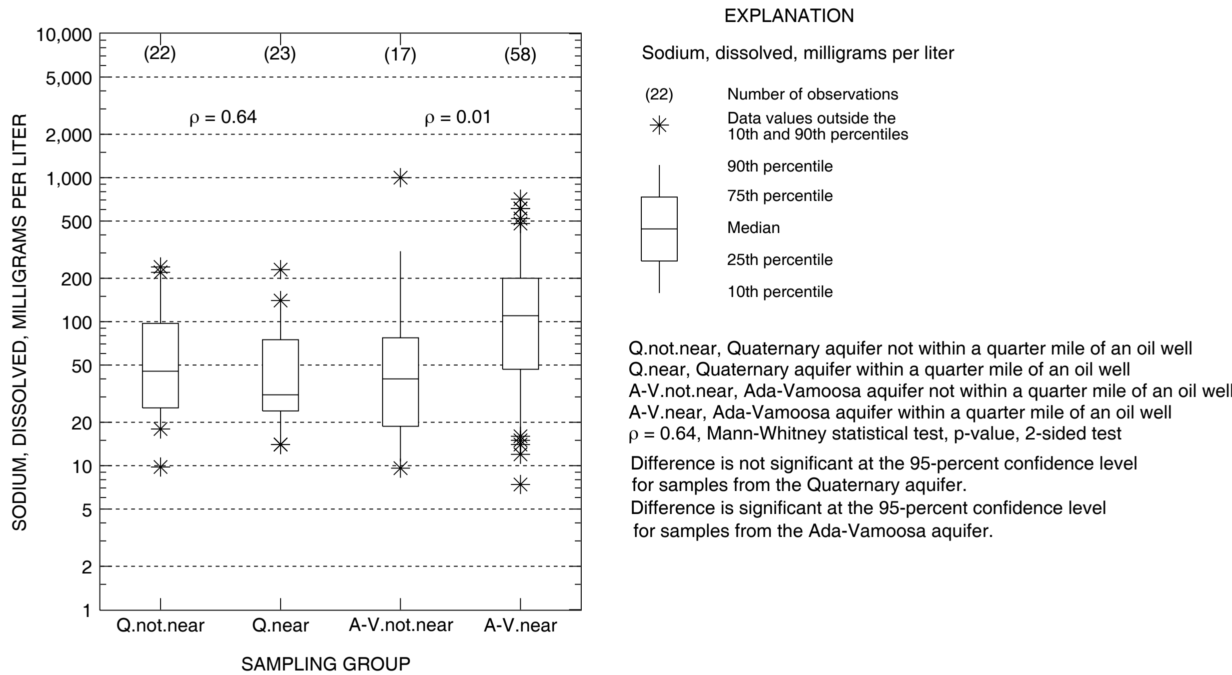


Figure 16. Comparison of ground-water quality from aquifers near oil wells and not near oil wells in the Osage Reservation, Oklahoma, for sodium, dissolved.

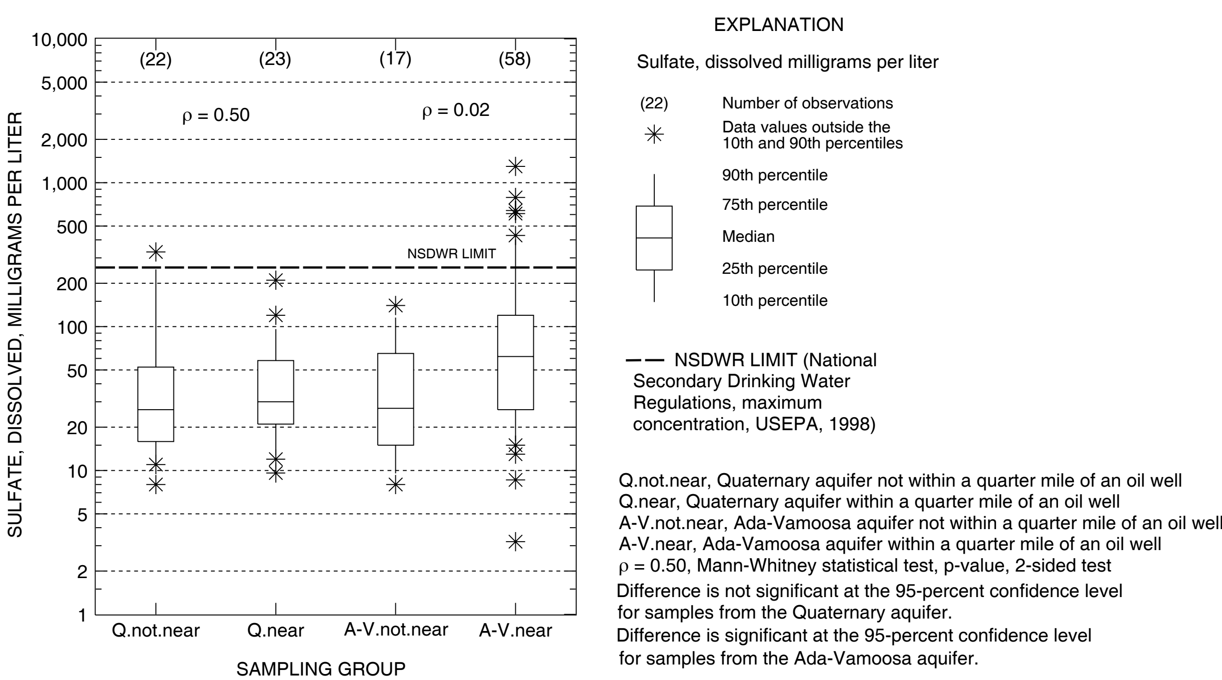


Figure 17. Comparison of ground-water quality from aquifers near oil wells and not near oil wells in the Osage Reservation, Oklahoma, for sulfate, dissolved.

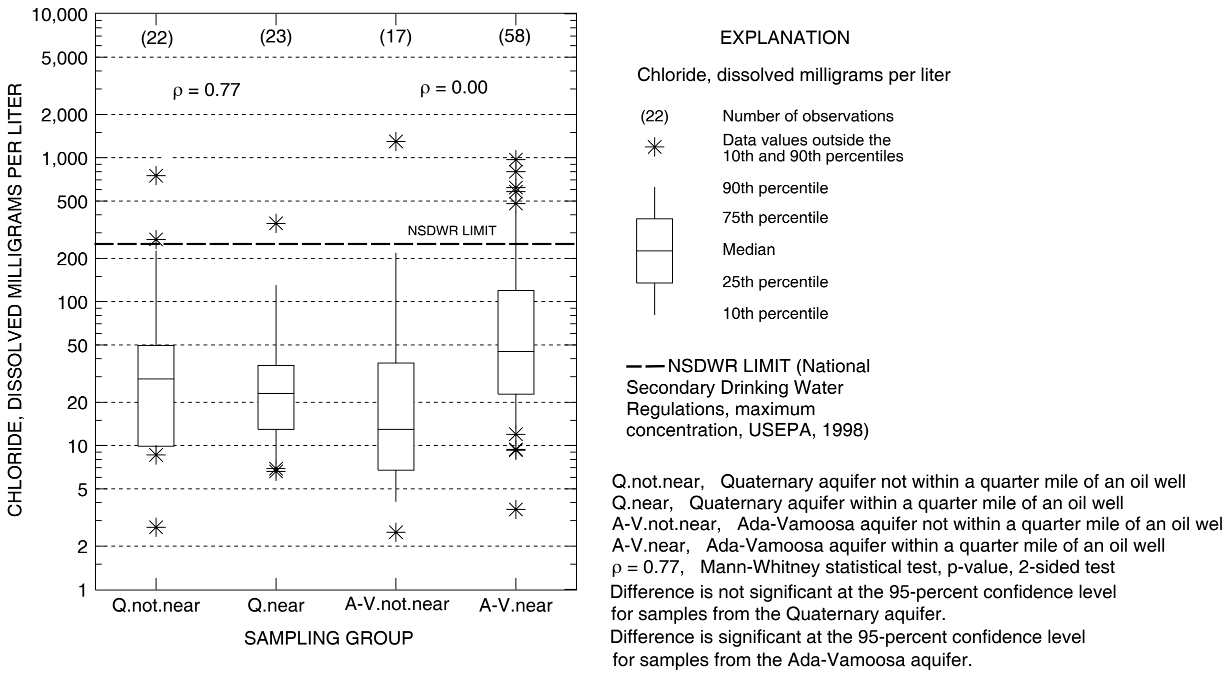


Figure 18. Comparison of ground-water quality from aquifers near oil wells and not near oil wells in the Osage Reservation, Oklahoma, for chloride, dissolved.

Mann-Whitney test (table 2) confirmed the apparent difference in water quality from the Ada-Vamoosa aquifer subgroups (fig. 15) is statistically different. Thirty-three of 58 samples from the Ada-Vamoosa near oil wells, 57 percent, of the subgroup near oil wells are of poorer quality than the secondary standards (USEPA, 1998) (Appendix 4) and 13 of 17 samples, 76 percent, of the subgroup not near an oil well are of better quality water than the secondary standards. The Quaternary aquifer subgroups near and not near oil wells have similar interquartile values for dissolved solids (tables 5 and 6) and similar box plots in figure 15. Seventy percent of the Quaternary samples near oil wells and 59 percent of the subgroup samples not near oil wells have dissolved solids less than the secondary regulation of 500 milligrams per liter (USEPA, 1998).

Sodium concentrations (fig. 16) are similar to dissolved-solids concentrations. The Ada-Vamoosa aquifer samples, near oil wells, are statistically different from samples not near oil wells. Median concentrations of sodium in samples from the Quaternary aquifer are similar to those from the Ada-Vamoosa aquifer not near oil wells.

Sulfate concentrations (fig. 17) are similar to dissolved-solids and sodium concentrations. The Ada-Vamoosa aquifer near oil wells has greater median concentration than for wells not near oil wells (tables 7 and 8). Median sulfate concentrations from the Quaternary aquifer are (tables 5 and 6) similar to the Ada-Vamoosa aquifer not near oil wells. Ninety-three percent of the Quaternary water-quality samples and 89 percent of the Ada-Vamoosa aquifer samples have sulfate concentrations less than the secondary regulation (USEPA, 1998) of 250 milligrams per liter (Appendix 4). Three water samples from the Quaternary aquifer not near oil wells and eight from the Ada-Vamoosa aquifer near oil wells exceeded the secondary regulations. No water samples from the alternate subgroups exceeded the secondary regulations.

Chloride concentrations (fig. 18) are similar to sodium and sulfate concentrations. The Ada-Vamoosa aquifer samples near oil wells have greater median chloride concentrations (table 8) than the subgroup not near oil wells (table 7). Median concentrations for chloride from the Quaternary aquifer subgroups are (tables 5 and 6) greater than from the Ada-Vamoosa aquifer not near oil wells. Ninety-three percent of the Quaternary water-quality samples and 87 percent of the Ada-Vamoosa aquifer samples (Appendix 4) have chloride concentrations less than the secondary regulation (USEPA, 1998) of 250 milligrams per liter (fig. 18).

Where no oil wells have been drilled through freshwater aquifers, the water quality of the Ada-Vamoosa aquifer is similar to the water quality of the Quaternary aquifer (figs. 15-18). The median concentrations of the major constituents (table 1) for water samples from wells completed in the Ada-Vamoosa aquifer not near oil wells (table 7) were less than or equal to median concentrations in water samples from the Quaternary aquifer not near oil wells (table 5) except for sulfate, which is slightly greater.

Major Ion Chemistry Distribution

Water-quality diagrams (Stiff, 1951) are a means of showing water-composition similarities and differences. A polygonal shape is created from three horizontal axes extending on either side of a vertical zero axis (Hem, 1989). The resulting points are connected to form an irregular polygonal shape. Cations are plotted on the left of the zero axis and anions are plotted on the right, both in milliequivalents per liter. The horizontal axis units are constant on the water-quality diagrams in figures 19 and 20. The diagram size is an indication of the dissolved-solids concentration, with greater horizontal distance from the zero axis representing greater constituent concentration. The number above the vertical axis is dissolved-solids concentrations in milligrams per liter (figs. 19 and 20). Diagrams represented in green indicate dissolved-solids concentrations greater than 500 milligrams per liter and diagrams represented in blue indicate less than 500 milligrams per liter.

Sixty-four percent of the Quaternary aquifer water-quality samples have dissolved-solids concentrations less than the secondary regulation (USEPA, 1998) of 500 milligrams per liter (fig. 19). Fifty-nine percent of the aquifer samples in the Quaternary aquifer subgroups not near oil wells and 70 percent of the samples near oil wells had dissolved solids less than 500 milligrams per liter. The water-quality diagrams indicate most of the water in the Quaternary aquifer with dissolved solids less than 500 milligrams per liter is calcium-bicarbonate-type, sodium+potassium-bicarbonate-type, or sodium+potassium+calcium-bicarbonate-type water.

Fifty-one percent of the water-quality samples from the Ada-Vamoosa aquifer have dissolved-solids concentrations less than the secondary regulation (USEPA, 1998) of 500 milligrams per liter (fig. 20). In the Ada-Vamoosa aquifer subgroups, 76 percent of the aquifer samples not near oil wells and 43 percent of the aquifer samples near oil wells had dissolved solids less than 500 milligrams per liter. The water-quality diagrams indicate much of the water in the Ada-Vamoosa aquifer with dissolved solids less than 500 milligrams per liter is calcium-bicarbonate-type or sodium-bicarbonate-type water. Water-quality samples from the Ada-Vamoosa aquifer with dissolved solids greater than 500 milligrams per liter are sodium+potassium-chloride-type, sodium+potassium+calcium-chloride-type, sodium+potassium-

sulfate-type, or calcium-chloride+sulfate-type water.

in water samples from the Quaternary Areas in the Ada-Vamoosa aquifer (fig. 20) near Hominy (fig. 1), Pershing, and Hula Lake have dissolved-solids concentrations greater than the secondary regulations. Many water-quality samples from the Quaternary aquifer with dissolved solids greater than 500 milligrams per liter are in these areas (fig. 19).

Summary and Conclusions

The project included documenting information for rural-domestic-water wells, collecting 120 water-quality samples from those wells, and comparing the water-quality to proximity to oil wells. Locating and sampling the wells was conducted from September to December 1997. The Osage Reservation, otherwise known as Osage County, consists of about 2,260 square miles. The Reservation is characterized by gently-rolling uplands with locally sharp cuestas formed by resistant sandstone and limestone ledges.

About 38,500 oil wells have been drilled in the Reservation since drilling began in 1896. About 17,600 oil wells were drilled before 1940 and 3,200 of these were dry and abandoned. In 1988 only about 12,680 oil wells were actively operated and 4,200 of these were classified as pressure maintenance, salt-water disposal, or water-flood injection wells. The remaining oil wells (about 26,000) are temporarily or permanently plugged and abandoned. About 1,480 square miles or 64 percent of the Reservation is within a quarter mile of an oil well. The term “oil well” is an industry well drilled through the fresh-water aquifers to oil and gas production depths; including oil and gas producers, nonproducing wells, injection wells, salt-water disposal wells, plugged wells, and abandoned wells.

Fresh ground-water aquifers on the Reservation consist of alluvial and terrace deposits of Quaternary age and sandstones of Pennsylvanian age. The Quaternary aquifer covers about 315 square miles or about 14 percent of the Reservation and consists of alluvial and terrace deposits of sand, silt, clay, and gravels. The Quaternary is an unconfined aquifer and is uncemented in most areas. The outcrop for the Pennsylvanian age Ada-Vamoosa aquifer system includes about 800 square miles or about 35 percent of the Reservation in a broad north-south band. The Ada Formation in the Reservation is about 400 feet thick and consists of interbedded limestone and shale units near the Kansas border grading into fine-grained sandstones interbedded with limestone and shale near the southern border of the Reservation. The Vamoosa Formation is about 630 feet thick and consists of alternating layers of shale and fine to coarse-grained sandstone with some limestone. The aquifer is mostly semiconfined or confined by the alternating lithologic units, except where the individual sandstones crop out. The sandstones are well cemented to semicemented with clay and calcite.

The Tallant, Barnsdall, Wann, and Chanute Formations comprise the minor Pennsylvanian aquifer; crop out in a north-south band along the eastern portion of the Reservation, and underlie the Ada-Vamoosa aquifer. The combined outcrop of these units covers about 480 square miles or about 21 percent of the Reservation. The formations consist of shale, fine to medium-grained sandstone, and thin limestone layers. Combined thickness of these units ranges from 127 to 600 feet. Fresh ground water from the Tallant, Barnsdall, Wann, and Chanute Formations also is reported but few ground-water wells are completed in the minor Pennsylvanian aquifer, possibly because of the limited amount of water available. The water-

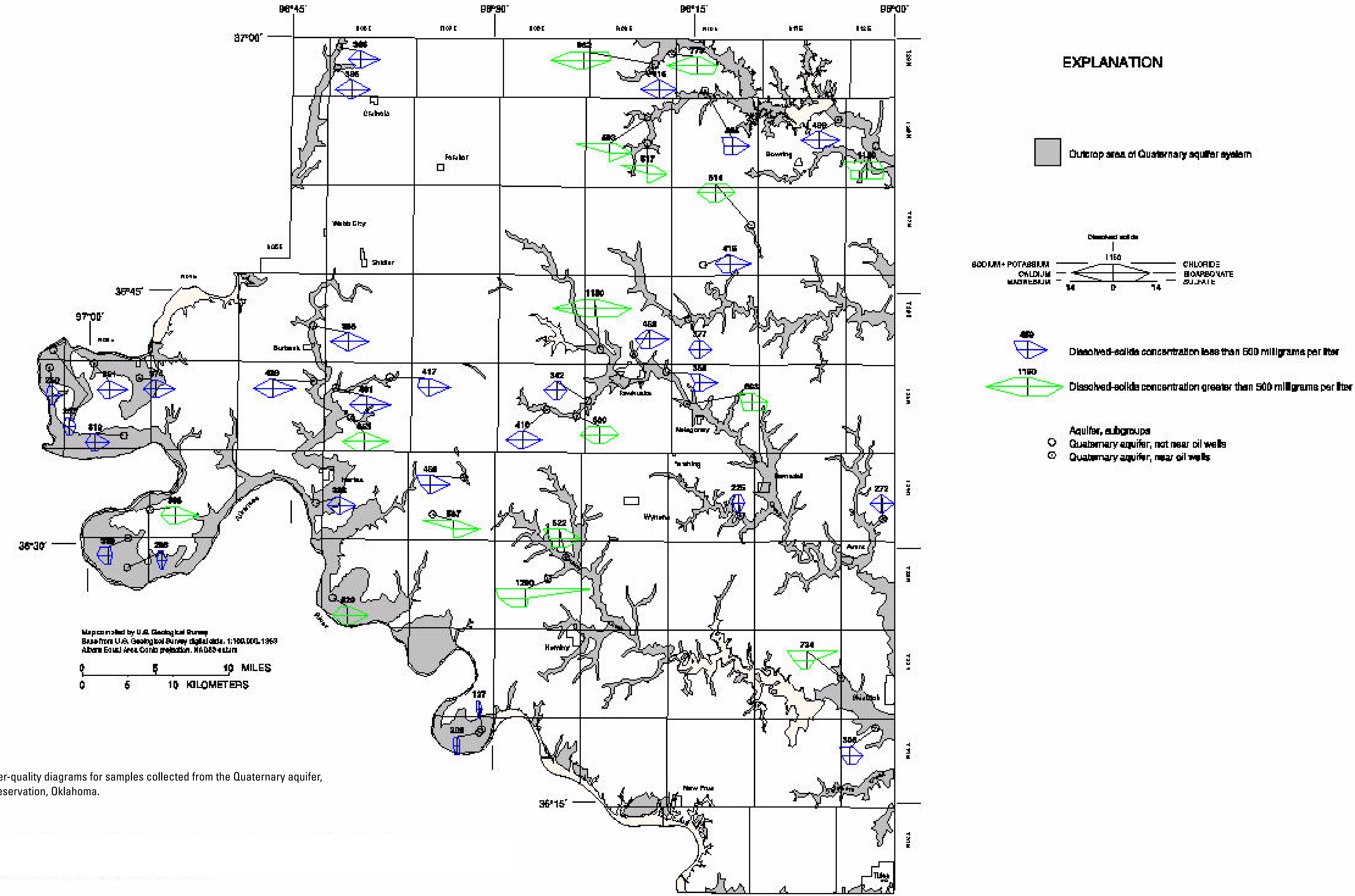


Figure 19. Water-quality diagrams for samples collected from the Quaternary aquifer, in the Osage Reservation, Oklahoma.

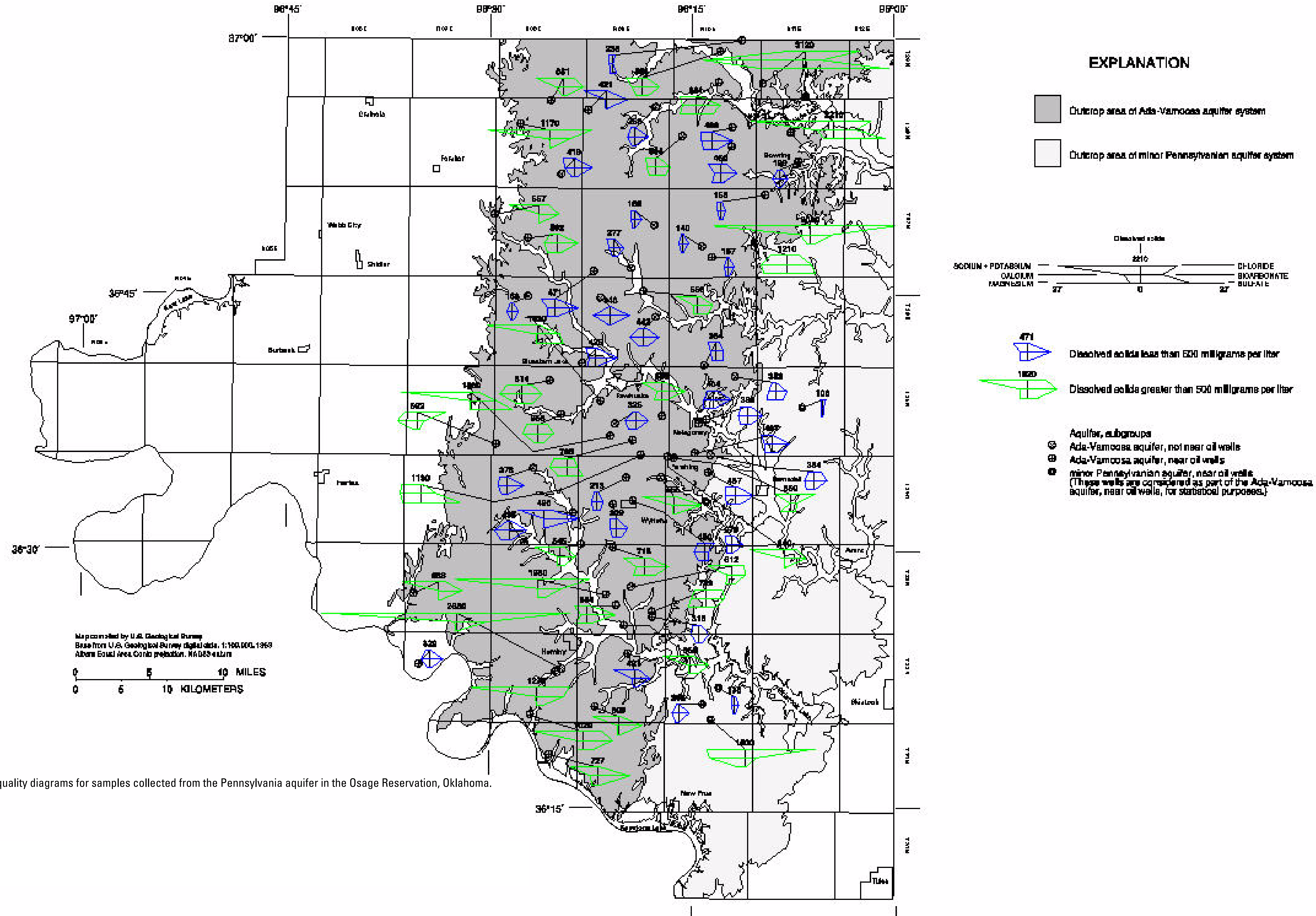


Figure 20. Water-quality diagrams for samples collected from the Pennsylvania aquifer in the Osage Reservation, Oklahoma.

quality samples from the minor Pennsylvanian aquifer are included with the Ada-Vamoosa aquifer samples for statistical and discussion purposes.

The ground-water-quality-sampling network was designed to randomly select sites to obtain a statistical representation of the water quality from areal subsets across the Reservation. No known method of site selection can remove all biases from a water-quality data set and ensure that sampling is representative of the ground-water quality in an aquifer. Existing water-supply wells commonly are located in areas that produce usable volumes of potable water. Thus, the use of water-supply wells introduces a bias that tends to minimize water-quality problems. All water-quality samples collected for this study were from existing domestic wells. Existing wells may not be equally distributed throughout the study area. Many wells were no longer functioning or supplied with power in areas where rural-water districts operate. The owner of a selected well may not want their well inventoried or sampled, which affects the areal distribution and random selection of sampled wells. Domestic-supply wells are designed for maximum available water collection and receive the combined input of all the strata contributing to the well.

The Mann-Whitney test was used because it is a nonparametric test that requires no assumptions about the population distributions and is resistant to data outliers. The comparison populations were the constituent concentrations in the water-quality samples from the:

- Quaternary aquifer and Ada-Vamoosa aquifer,
- Quaternary aquifer not near an oil well and Quaternary aquifer near an oil well,
- Ada-Vamoosa aquifer not near an oil well and Ada-Vamoosa aquifer near an oil well.

An arbitrary radial distance of a quarter mile was selected to define the buffer zone in which an oil well might affect the quality of water in the freshwater aquifers. About 1,480 square miles or 64 percent of the Reservation is within the quarter-mile buffer zones of the oil wells. Fifty-eight percent of the Quaternary aquifer, 69 percent of the outcrop area of the Ada-Vamoosa aquifer, and 78 percent of the outcrop area of the minor Pennsylvanian aquifer are near oil wells.

The quality of water from the unconfined Quaternary aquifer is significantly different from the quality of water from the confined Ada-Vamoosa aquifer for pH, calcium, sodium, potassium, sulfate, chloride, silica, nitrogen as nitrite plus nitrate, nitrogen as ammonia, total phosphorus, phosphorus as orthophosphate, boron, and lithium. No significant difference was determined for dissolved-solids concentration of the two aquifers at the 95 percent confidence level.

Water from the Quaternary aquifer wells within a quarter mile of an oil well were not significantly different from Quaternary aquifer wells not near an oil well. Several constituents in samples from the Ada-Vamoosa-aquifer wells within a quarter mile of an oil well were significantly greater than from Ada-Vamoosa aquifer wells not near oil wells. The constituents include specific conductance, dissolved solids, sodium, sulfate, chloride, bromide, and silica. These ions are probably derived from brine water from greater depths. Thirty-three of 58 samples from the Ada-Vamoosa near oil wells, 57 percent, of the subgroup near oil wells are of poorer quality than the secondary standards and 13 of 17 samples, 76 percent, of the subgroup not near an oil well are of better quality water than the secondary standards.

The water quality of the Ada-Vamoosa aquifer is similar to the water quality of the Quaternary aquifer where no oil wells have been drilled through freshwater aquifers. The median concentrations of the major constituents for water samples from wells completed in the Ada-Vamoosa aquifer not near oil wells were less than or equal to median concentrations in water samples from the Quaternary aquifer not near oil wells except for sulfate, which is slightly greater.

Sixty-four percent of the Quaternary aquifer water-quality samples have dissolved-solids concentrations less than the secondary regulation of 500 milligrams per liter. Fifty-nine percent of the aquifer samples in the Quaternary aquifer subgroups not near oil wells and 70 percent of the samples near oil wells had dissolved solids less than 500 milligrams per liter. The water-quality diagrams indicate most of the water in the Quaternary aquifer with dissolved solids less than 500 milligrams per liter is calcium-bicarbonate-type, sodium+potassium-bicarbonate-type, or sodium+potassium+calcium-bicarbonate-type water.

Fifty-one percent of the water-quality samples from the Ada-Vamoosa aquifer have dissolved-solids concentrations less than the secondary regulation of 500 milligrams per liter. In the Ada-Vamoosa aquifer subgroups, 76 percent of the aquifer samples not near oil wells and 43 percent of the aquifer samples near oil wells had dissolved solids less than 500 milligrams per liter. The water-quality diagrams indicate much of the water in the Ada-Vamoosa aquifer with dissolved solids less than 500 milligrams per liter is calcium-bicarbonate-type or sodium-bicarbonate-type water. Water-quality samples from the Ada-Vamoosa aquifer with dissolved solids greater than 500 milligrams per liter are sodium+potassium-chloride-type, sodium+potassium+calcium-chloride-type, sodium+potassium-sulfate-type, or calcium-chloride+sulfate-type water.

Areas in the Ada-Vamoosa aquifer near Hominy, Pershing, and Hula Lake have dissolved-solids concentrations greater than the secondary regulations. Many water-quality samples from the Quaternary aquifer with dissolved solids greater than 500 milligrams per liter are in these areas.

More detailed investigations of identified contaminated areas is recommended. This will likely require drilling of observation wells, surface geophysical investigations, and collection of historical oil production records. The Ada-Vamoosa aquifer should be the focus of such investigations unless additional data suggests the Quaternary aquifer should be included.

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Appendices

Appendix 1. Chemical analyses of quality-assurance samples from wells in the Osage Reservation, Oklahoma

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25° Celsius; specific conductance, pH, and alkalinity were measured in the field and the laboratory; --, indicates no data available; <, indicates concentration is less than the minimum reporting level; all samples were collected by the U.S. Geological Survey, Oklahoma District; laboratory analyses were done by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida]

Site identifier	Local number	Type sample	Hydrogeologic unit	Well classification	Latitude	Longitude	Date sampled	Time
*363025096230901	24N-09E-31 CCD 1	Duplicate	Ada-Vamoosa sandstone aquifer	Near oil well	363025	0962309	11/05/97	1246
363546096144601	25N-10E-32 DCA 1		Ada-Vamoosa sandstone aquifer	Not near oil well	363546	0961446	11/06/97	1046
363801096243901	25N-08E-23 ABC 1		Ada-Vamoosa sandstone aquifer	Near oil well	363801	0962439	11/06/97	1631
364015096114801	25N-10E-02 CAD 1		Ada-Vamoosa sandstone aquifer	Not near oil well	364015	0961148	12/17/97	0901
365053096093401	27N-11E-06 ACC 1		Ada-Vamoosa sandstone aquifer	Near oil well	365053	0960934	12/16/97	0831
Blank	--	Blank	--	--	--	--	10/20/97	1249
Blank	--		--	--	--	--	11/17/97	1200

Site identifier	Local number	Specific conductance, laboratory (µS/cm)	pH, laboratory whole water	Alkalinity, water dissolved, total, ANC laboratory (mg/L as $CaCo_3$)	Dissolved solids, calculated sum (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
363025096230901	24N-09E-31 CCD 1	910	8.3	268	547	11	8.0
363546096144601	25N-10E-32 DCA 1	752	7.7	290	467	48	29
363801096243901	25N-08E-23 ABC 1	966	7.6	252	568	99	16
364015096114801	25N-10E-02 CAD 1	567	7.9	180	352	45	35
365053096093401	27N-11E-06 ACC 1	299	7.3	91	155	21	5.1
Blank		--	5.4	3.5	--	.040	.002
Blank		6	5.3	3.5	--	.030	.001

Appendix 1. Chemical analyses of quality-assurance samples from wells in the Osage Reservation, Oklahoma—Continued

Site identifier	Local number	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)
363025096230901	24N-09E-31 CCD 1	180	1.5	89	67	.40	.20	12
363546096144601	25N-10E-32 DCA 1	77	2.6	100	15	.50	.080	17
363801096243901	25N-08E-23 ABC 1	83	4.2	87	110	.40	.20	15
364015096114801	25N-10E-02 CAD 1	22	1.4	110	9.7	.25	.050	15
365053096093401	27N-11E-06 ACC 1	31	1.1	30	11	.15	.050	7.2
Blank		1.0	<.10	<.20	<.10	<.10	<.050	<.010
Blank		<.10	<.10	<.20	<.10	<.10	<.050	<.010

Site identifier	Local number	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, total dissolved (mg/L as N)	Phosphoru s, total dissolved (mg/L as P)	Phosphoru s,ortho-phosphate dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)
363025096230901	24N-09E-31 CCD 1	3.60	.200	.22	<.002	.002	<1
363546096144601	25N-10E-32 DCA 1	.048	.012	<.20	.006	<.001	<1
363801096243901	25N-08E-23 ABC 1	.242	.004	<.20	.040	.040	<1
364015096114801	25N-10E-02 CAD 1	.541	<.002	<.20	.003	.002	<1
365053096093401	27N-11E-06 ACC 1	--	--	--	--	--	<1
Blank		.002	.010	<.20	.005	.004	<1
Blank		<.002	.002	<.20	.003	<.001	<1

Appendix 1. Chemical analyses of quality-assurance samples from wells in the Osage Reservation, Oklahoma—Continued

Site identifier	Local number	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon organic, total dissolved (mg/L as C)
363025096230901	24N-09E-31 CCD 1	450	3.0	10	4.1	290	.40
363546096144601	25N-10E-32 DCA 1	2000	90	10	26	1600	.20
363801096243901	25N-08E-23 ABC 1	90	20	6	8.1	940	1.5
364015096114801	25N-10E-02 CAD 1	95	1.0	10	<.20	180	.50
365053096093401	27N-11E-06 ACC 1	110	40	<4	1.1	150	--
Blank		10	4.0	<4	<.20	<.50	<.10
Blank		11	<1.0	<4	<.20	<.50	.50

*Hydrogeologic units are listed in Appendix 3.

Appendix 2. Relative percent difference between water-quality and duplicate samples collected from wells in the Osage Reservation, Oklahoma

[--, No calculation of relative percent difference because concentration reported in water-quality or duplicate sample was less than laboratory minimum reporting level]

Site identifier	Local number	Specific conductance	pH	Alkalinity	Dissolved solids	Calcium	Magnesium
*363025096230901	24N-09E-31 CCD 1	0.1	0.0	0.4	0.2	0.0	0.0
363546096144601	25N-10E-32 DCA 1	0.3	1.3	0.0	0.0	2.1	3.4
363801096243901	25N-08E-23 ABC 1	0.0	0.0	0.0	0.0	1.0	0.0
364015096114801	25N-10E-02 CAD 1	0.0	12.1	0.6	0.0	0.0	0.0
365053096093401	27N-11E-06 ACC 1	2.0	1.4	3.4	0.6	0.0	1.9

Site identifier	Local number	Sodium	Potassium	Sulfate	Chloride	Fluoride	Bromide	Silica
363025096230901	24N-09E-31 CCD 1	0.0	0.0	0.0	0.0	22.2	0.0	0.0
363546096144601	25N-10E-32 DCA 1	0.0	3.8	0.0	14.3	0.0	28.6	0.0
363801096243901	25N-08E-23 ABC 1	0.0	0.0	1.1	0.0	0.0	0.0	0.0
364015096114801	25N-10E-02 CAD 1	0.0	0.0	0.0	1.0	0.0	0.0	0.0
365053096093401	27N-11E-06 ACC 1	0.0	0.0	0.0	8.7	0.0	0.0	0.0

Site identifier	Local number	Nitrogen, nitrite plus nitrate	Nitrogen, ammonia	Nitrogen, ammonia plus organic, total	Phosphorus, total	Phosphorus, ortho phosphate	Arsenic
363025096230901	24N-09E-31 CCD 1	0.0	4.9	8.7	66.7	0.0	--
363546096144601	25N-10E-32 DCA 1	52.6	66.7	--	40.0	66.7	--
363801096243901	25N-08E-23 ABC 1	4.7	66.7	--	22.2	0.0	--
364015096114801	25N-10E-02 CAD 1	0.4	0.0	--	0.0	0.0	--
365053096093401	27N-11E-06 ACC 1	--	--	--	--	--	--

Site identifier	Local number	Boron	Iron	Lithium	Manganese	Strontium	Carbon organic, total
363025096230901	24N-09E-31 CCD 1	0.0	0.0	0.0	2.5	0.0	28.6
363546096144601	25N-10E-32 DCA 1	0.0	0.0	0.0	3.8	0.0	0.0
363801096243901	25N-08E-23 ABC 1	0.0	66.7	15.4	4.8	0.0	22.2
364015096114801	25N-10E-02 CAD 1	2.1	--	0.0	--	0.0	85.7
365053096093401	27N-11E-06 ACC 1	8.7	120.0	--	20.0	0.0	--

*Hydrogeologic units are listed in Appendix 3.

Appendix 3. Ground-water well information in the Osage Reservation, Oklahoma

near oil well, within one-quarter mile radius; not near oil well, greater than one-quarter mile radius]

Site identifier	Local number	Hydrogeologic unit	Well classification	Latitude	Longitude
361917096304101	21N-07E-01 CCA 1	Quaternary aquifer	Near oil well	361917	0963041
361906096305101	21N-07E-11 AAA 1	Quaternary aquifer	Near oil well	361906	0963051
361807096252701	21N-08E-14 BBC 1	Ada-Vamoosa sandstone aquifer	Near oil well	361807	0962527
361925096012801	21N-12E-04 CAA 1	Quaternary aquifer	Not near oil well	361925	0960128
362323096350601	22N-07E-17 BBC 1	Ada-Vamoosa sandstone aquifer	Near oil well	362323	0963506
362308096243201	22N-08E-14 ADD 1	Ada-Vamoosa sandstone aquifer	Not near oil well	362308	0962432
362259096250001	22N-08E-14 CAA 1	Ada-Vamoosa sandstone aquifer	Near oil well	362259	0962500
362026096265101	22N-08E-33 ACD 1	Ada-Vamoosa sandstone aquifer	Near oil well	362026	0962651
362402096193901	22N-09E-10 BDA 1	Ada-Vamoosa sandstone aquifer	Near oil well	362402	0961939
362055096220501	22N-09E-29 CCD 1	Ada-Vamoosa sandstone	Near oil well	362055	0962205
362202096125701	22N-10E-22 DBA 1	minor Pennsylvanian sandstone aquifer	Near oil well	362202	0961257
362105096140901	22N-10E-28 DBC 1	minor Pennsylvanian sandstone aquifer	Near oil well	362105	0961409
362011096133201	22N-10E-34 CBC 1	minor Pennsylvanian sandstone aquifer	Near oil well	362011	0961332
362222096040101	22N-11E-24 AAD 1	Quaternary aquifer	Near oil well	362222	0960401
363023096570101	23N-03E-02 ABB 1	Quaternary aquifer	Near oil well	363023	0965701
362839096570501	23N-03E-14 BAA 1	Quaternary aquifer	Not near oil well	362839	0965705
362659096414801	23N-06E-19 DCD 1	Quaternary aquifer	Not near oil well	362659	0964148
362731096352801	23N-07E-19 ACB 1	Ada-Vamoosa sandstone aquifer	Near oil well	362731	0963528
362926096242901	23N-08E-11 AAA 1	Quaternary aquifer	Near oil well	362926	0962429
362809096254801	23N-08E-15 DBA 1	Quaternary aquifer	Not near oil well	362809	0962548
363014096204601	23N-09E-04 BAD 1	Ada-Vamoosa sandstone aquifer	Near oil well	363014	0962046
362757096192601	23N-09E-15 DCB 1	Ada-Vamoosa sandstone aquifer	Not near oil well	362757	0961926
362729096211701	23N-09E-20 DAA 1	Ada-Vamoosa sandstone aquifer	Near oil well	362729	0962117
362629096175401	23N-09E-25 BCC 1	Ada-Vamoosa sandstone aquifer	Near oil well	362629	0961754
362611096175201	23N-09E-25 CCB 1	Ada-Vamoosa sandstone aquifer	Near oil well	362611	0961752

Appendix 3. Ground-water well information in the Osage Reservation, Oklahoma—Continued

near oil well, within one-quarter mile radius; not near oil well, greater than one-quarter mile radius]

Site identifier	Local number	Hydrogeologic unit	Well classification	Latitude	Longitude
362651096203301	23N-09E-28 ABB 1	Ada-Vamoosa sandstone aquifer	Near oil well	362651	0962033
362541096195701	23N-09E-34 BCC 1	Ada-Vamoosa sandstone aquifer	Near oil well	362541	0961957
363204096552601	24N-04E-30 BBB 1	Quaternary aquifer	Not near oil well	363204	0965526
363233096430501	24N-05E-24 DBB 1	Quaternary aquifer	Not near oil well	363233	0964305
363406096320501	24N-07E-10 DDB 1	Quaternary aquifer	Near oil well	363406	0963205
363155096342401	24N-07E-29 ACA 1	Quaternary aquifer	Near oil well	363155	0963424
363453096264101	24N-08E-04 DDA 1	Ada-Vamoosa sandstone aquifer	Not near oil well	363453	0962641
363216096234501	24N-08E-24 DCA 1	Ada-Vamoosa sandstone aquifer	Near oil well	363216	0962345
363033096272101	24N-08E-33 CDB 1	Ada-Vamoosa sandstone aquifer	Near oil well	363033	0962721
363419096195001	24N-09E-10 BCD 1	Ada-Vamoosa sandstone aquifer	Near oil well	363419	0961950
363421096171601	24N-09E-12 ACD 1	Ada-Vamoosa sandstone aquifer	Not near oil well	363421	0961716
363246096204701	24N-09E-21 BDA 1	Ada-Vamoosa sandstone aquifer	Near oil well	363246	0962047
363259096191901	24N-09E-22 ABA 1	Ada-Vamoosa sandstone aquifer	Near oil well	363259	0961919
363025096230901	24N-09E-31 CCD 1	Ada-Vamoosa sandstone aquifer	Near oil well	363025	0962309
363529096161801	24N-10E-06 ABB 1	Ada-Vamoosa sandstone aquifer	Near oil well	363529	0961618
363533096164601	24N-10E-06 BBB 1	Ada-Vamoosa sandstone aquifer	Near oil well	363533	0961646
363438096134601	24N-10E-09 AAA 1	Ada-Vamoosa sandstone aquifer	Near oil well	363438	0961346
363256096135501	24N-10E-21 ABA 1	minor Pennsylvanian sandstone aquifer	Near oil well	363256	0961355
363154096113101	24N-10E-26 AAD 1	Quaternary aquifer	Near oil well	363154	0961131
363143096005501	24N-12E-28 ADC 1	Quaternary aquifer	Near oil well	363143	0960055
364022097030001	25N-02E-02 DAA 1	Quaternary aquifer	Near oil well	364022	0970300
364039096594201	25N-03E-05 AAD 1	Quaternary aquifer	Near oil well	364039	0965942
363949096561801	25N-03E-12 BBA 1	Quaternary aquifer	Near oil well	363949	0965618
363625096572501	25N-03E-35 BB 1	Quaternary aquifer	Not near oil well	363625	0965725
363943096431901	25N-05E-12 BCA 1	Quaternary aquifer	Near oil well	363943	0964319

Appendix 3. Ground-water well information in the Osage Reservation, Oklahoma—Continued

near oil well, within one-quarter mile radius; not near oil well, greater than one-quarter mile radius]

Site identifier	Local number	Hydrogeologic unit	Well classification	Latitude	Longitude
364000096373901	25N-06E-02 CDD 1	Quaternary aquifer	Not near oil well	364000	0963739
363920096414001	25N-06E-07 DBD 1	Quaternary aquifer	Near oil well	363920	0964140
363735096403201	25N-06E-20 DAC 1	Quaternary aquifer	Near oil well	363735	0964032
364000096253001	25N-08E-03 DDC 1	Ada-Vamoosa sandstone aquifer	Near oil well	364000	0962530
363807096255901	25N-08E-22 BAB 1	Quaternary aquifer	Near oil well	363807	0962559
363801096243901	25N-08E-23 ABC 1	Ada-Vamoosa sandstone aquifer	Near oil well	363801	0962439
363745096234301	25N-08E-24 CAA 1	Quaternary aquifer	Near oil well	363745	0962343
363616096292701	25N-08E-31 BBD 1	Ada-Vamoosa sandstone aquifer	Near oil well	363616	0962927
364023096170401	25N-09E-01 ACC 1	Quaternary aquifer	Not near oil well	364023	0961704
363849096214401	25N-09E-17 BDB 1	Ada-Vamoosa sandstone aquifer	Near oil well	363849	0962144
363838096225301	25N-09E-18 CBA 1	Quaternary aquifer	Not near oil well	363838	0962253
363729096204001	25N-09E-21 CDB 1	Ada-Vamoosa sandstone aquifer	Not near oil well	363729	0962040
363756096171101	25N-09E-24 BDA 1	Ada-Vamoosa sandstone aquifer	Near oil well	363756	0961711
363631096192101	25N-09E-27 CDD 1	Ada-Vamoosa sandstone aquifer	Near oil well	363631	0961921
363646096210101	25N-09E-29 DAD 1	Ada-Vamoosa sandstone aquifer	Near oil well	363646	0962101
363539096184501	25N-09E-35 CCC 1	Ada-Vamoosa sandstone aquifer	Near oil well	363539	0961845
364015096114801	25N-10E-02 CAD 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364015	0961148
363829096153101	25N-10E-17 CBC 1	Quaternary aquifer	Near oil well	363829	0961531
363729096142801	25N-10E-20 DDA 1	Ada-Vamoosa sandstone aquifer	Near oil well	363729	0961428
363744096135401	25N-10E-21 DBB 1	Ada-Vamoosa sandstone aquifer	Near oil well	363744	0961354
363546096144601	25N-10E-32 DCA 1	Ada-Vamoosa sandstone aquifer	Near oil well	363546	0961446
363539096133501	25N-10E-33 DDC 1	Ada-Vamoosa sandstone aquifer	Not near oil well	363539	0961335
363827096064801	25N-11E-15 CBC 1	minor Pennsylvanian sandstone aquifer	Near oil well	363827	0960648
364125097024401	26N-02E-36 BCA 1	Quaternary aquifer	Not near oil well	364125	0970244
364300096432301	26N-05E-24 CBA1	Quaternary aquifer	Not near oil well	364300	0964323

Appendix 3. Ground-water well information in the Osage Reservation, Oklahoma—Continued

near oil well, within one-quarter mile radius; not near oil well, greater than one-quarter mile radius]

Site identifier	Local number	Hydrogeologic unit	Well classification	Latitude	Longitude
364455096270801	26N-08E-09 BCA 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364455	0962708
364515096183701	26N-09E-02 CCD 1	Ada-Vamoosa sandstone aquifer	Near oil well	364515	0961837
364451096214601	26N-09E-08 BDB 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364451	0962146
364343096174101	26N-09E-13 CBC 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364343	0961741
364101096230501	26N-09E-31 CCB 1	Ada-Vamoosa sandstone aquifer	Near oil well	364101	0962305
364140096215901	26N-09E-32 BBB 1	Quaternary aquifer	Not near oil well	364140	0962159
364124096192901	26N-09E-34 BDA 1	Quaternary aquifer	Near oil well	364124	0961929
364328096152601	26N-10E-17 CCC 1	Quaternary aquifer	Not near oil well	364328	0961526
364055096140501	26N-10E-33 CCA 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364055	0961405
364943096293701	27N-07E-12 DDA 1	Ada-Vamoosa sandstone aquifer	Near oil well	364943	0962937
364820096270901	27N-08E-21 BCD 1	Ada-Vamoosa sandstone aquifer	Near oil well	364820	0962709
364906096174801	27N-09E-14 ADD 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364906	0961748
364624096221601	27N-09E-31 DAB 1	Ada-Vamoosa sandstone aquifer	Near oil well	364624	0962216
364635096193101	27N-09E-34 BDB 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364635	0961931
364901096104501	27N-10E-13 DBB 1	Quaternary aquifer	Near oil well	364901	0961045
364752096141501	27N-10E-21 CDB 1	Ada-Vamoosa sandstone aquifer	Not near oil well	364752	0961415
364805096102101	27N-10E-24 DAD 1	minor Pennsylvanian sandstone aquifer	Near oil well	364805	0961021
364714096133201	27N-10E-28 DAA 1	Ada-Vamoosa sandstone aquifer	Near oil well	364714	0961332
364640096142001	27N-10E-33 BCA 1	Quaternary aquifer	Not near oil well	364640	0961420
365053096093401	27N-11E-06 ACC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365053	0960934
365623096252901	28N-08E-03 AAC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365623	0962529
365501096274501	28N-08E-08 DBD 1	Ada-Vamoosa sandstone aquifer	Near oil well	365501	0962745
365205096244201	28N-08E-35 ABB 1	Ada-Vamoosa sandstone aquifer	Not near oil well	365205	0962442
365601096174301	28N-09E-01 BCC 1	Ada-Vamoosa sandstone aquifer	Not near oil well	365601	0961743
365549096224301	28N-09E-06 CAD 1	Ada-Vamoosa sandstone aquifer	Near oil well	365549	0962243

Appendix 3. Ground-water well information in the Osage Reservation, Oklahoma—Continued

near oil well, within one-quarter mile radius; not near oil well, greater than one-quarter mile radius]

Site identifier	Local number	Hydrogeologic unit	Well classification	Latitude	Longitude
365522096183001	28N-09E-11 BAC 1	Quaternary aquifer	Not near oil well	365522	0961830
365350096183101	28N-09E-23 BAB 1	Quaternary aquifer	Not near oil well	365350	0961831
365420096120101	28N-10E-11 CDC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365420	0961201
365419096154301	28N-10E-18 ADD 1	Ada-Vamoosa sandstone aquifer	Not near oil well	365419	0961543
365342096120501	28N-10E-23 BAC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365342	0961205
365514096041601	28N-11E-12 BDD 1	Quaternary aquifer	Near oil well	365514	0960416
365431096074101	28N-11E-16 BAC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365431	0960741
365250096070801	28N-11E-28 AAC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365250	0960708
365341096012701	28N-12E-21 BBC 1	Quaternary aquifer	Not near oil well	365341	0960127
365924096413501	29N-06E-18 DBA 1	Quaternary aquifer	Not near oil well	365924	0964135
365811096414201	29N-06E-30 ABB 1	Quaternary aquifer	Not near oil well	365811	0964142
365830096175801	29N-09E-23 DBC 1	Quaternary aquifer	Not near oil well	365830	0961758
365906096164201	29N-09E-24 ABA 1	Quaternary aquifer	Not near oil well	365906	0961642
365806096182201	29N-09E-26 BBD 1	Quaternary aquifer	Near oil well	365806	0961822
365955096111901	29N-10E-14 ABA 1	Ada-Vamoosa sandstone aquifer	Near oil well	365955	0961119
365915096125601	29N-10E-15 CCA 1	Ada-Vamoosa sandstone aquifer	Near oil well	365915	0961256
365727096130201	29N-10E-27 CCC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365727	0961302
365657096141401	29N-10E-32 ADD 1	Quaternary aquifer	Near oil well	365657	0961414
365723096094601	29N-11E-30 CCC 1	Ada-Vamoosa sandstone aquifer	Near oil well	365723	0960946
365637096063501	29N-11E-34 CCB 1	Ada-Vamoosa sandstone aquifer	Near oil well	365637	0960635

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; specific conductance, pH, and alkalinity were measured in the field and the laboratory; --, indicates no data available; <, indicates concentration is less than the minimum reporting level; all samples were collected by the U.S. Geological Survey, Oklahoma District; laboratory analyses were done by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida]

Site-identification number	Local identifier	Date sampled	Time	Specific conductance, field (µS/cm)	pH, field, whole water (standard units)	Temperature water (°C)	Alkalinity, water dissolved, total incremental titration, field (mg/L as $CaCo_3$)
361917096304101	21N-07E-01 CCA 1	10/30/97	1255	167	7.1	--	53
361906096305101	21N-07E-11 AAA 1	10/30/97	1155	323	6.4	--	39
361807096252701	21N-08E-14 BBC 1	10/30/97	1355	1,170	7.3	--	514
361925096012801	21N-12E-04 CAA 1	10/28/97	1105	678	8.0	--	210
362323096350601	22N-07E-17 BBC 1	10/23/97	1045	496	7.1	--	201
362308096243201	22N-08E-14 ADD 1	10/29/97	1040	4,540	8.3	--	500
362259096250001	22N-08E-14 CAA 1	12/15/97	1120	2,370	8.2	16.0	435
362026096265101	22N-08E-33 ACD 1	10/30/97	1045	1,830	8.0	--	480
362402096193901	22N-09E-10 BDA 1	10/29/97	1330	732	8.0	--	262
362055096220501	22N-09E-29 CCD 1	12/15/97	1240	824	7.5	13.5	370
362202096125701	22N-10E-22 DBA 1	10/29/97	0940	202	6.3	--	72
362105096140901	22N-10E-28 DBC 1	10/29/97	0850	360	7.4	--	174
362011096133201	22N-10E-34 CBC 1	10/28/97	1650	2,990	7.3	--	194
362222096040101	22N-11E-24 AAD 1	10/23/97	0900	1,420	--	17.5	122
363023096570101	23N-03E-02 ABB 1	11/19/97	1815	744	6.7	12.5	65
362839096570501	23N-03E-14 BAA 1	11/19/97	1715	309	8.6	14.0	85
362659096414801	23N-06E-19 DCD 1	10/21/97	1025	843	7.1	--	330
362731096352801	23N-07E-19 ACB 1	10/23/97	0915	1,180	8.9	--	376
362926096242901	23N-08E-11 AAA 1	10/29/97	1140	1,060	7.1	--	356

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ^{o}C, degrees Celsius; specific conductance, pH, and alkalinity were measured in the field and the laboratory; --, indicates no data available; <, indicates concentration is less than the minimum reporting level; all samples were collected by the U.S. Geological Survey, Oklahoma District; laboratory analyses were done by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida]

Site-identification number	Local identifier	Date sampled	Time	Specific conductance, field (µS/cm)	pH, field, whole water (standard units)	Temperature water (^{o}C)	Alkalinity, water dissolved, total incremental titration, field (mg/L as $CaCo_3$)
362809096254801	23N-08E-15 DBA 1	12/15/97	1630	2,540	6.0	16.5	50
363014096204601	23N-09E-04 BAD 1	12/16/97	1000	1,150	7.6	16.0	395
362757096192601	23N-09E-15 DCB 1	12/15/97	1545	1,060	7.9	16.5	225
362729096211701	23N-09E-20 DAA 1	12/15/97	1400	2,840	8.1	8.5	400
362629096175401	23N-09E-25 BCC 1	12/15/97	1500	1,330	6.9	18.0	305
362611096175201	23N-09E-25 CCB 1	12/15/97	1520	525	7.8	14.0	160
362651096203301	23N-09E-28 ABB 1	12/15/97	1330	889	7.3	12.5	460
362541096195701	23N-09E-34 BCC 1	10/29/97	1415	921	8.0	--	300
363204096552601	24N-04E-30 BBB 1	11/19/97	1700	859	7.4	10.0	390
363233096430501	24N-05E-24 DBB 1	10/22/97	1450	608	7.3	--	274
363406096320501	24N-07E-10 DDB 1	10/22/97	1230	748	7.5	--	328
363155096342401	24N-07E-29 ACA 1	10/22/97	1000	756	9.1	--	424
363453096264101	24N-08E-04 DDA 1	10/22/97	1500	644	7.2	--	280
363216096234501	24N-08E-24 DCA 1	11/05/97	1145	830	8.9	15.0	264
363033096272101	24N-08E-33 CDB 1	12/15/97	1700	745	7.1	16.5	290
363419096195001	24N-09E-10 BCD 1	12/16/97	1045	383	6.6	16.0	100
363421096171601	24N-09E-12 ACD 1	12/16/97	1125	899	8.9	14.5	455
363246096204701	24N-09E-21 BDA 1	11/04/97	1500	440	7.6	17.0	176
363259096191901	24N-09E-22 ABA 1	11/05/97	1045	768	6.0	14.0	64
363025096230901	24N-09E-31 CCD 1	11/05/97	1245	909	8.3	18.0	264

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; specific conductance, pH, and alkalinity were measured in the field and the laboratory; --, indicates no data available; <, indicates concentration is less than the minimum reporting level; all samples were collected by the U.S. Geological Survey, Oklahoma District; laboratory analyses were done by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida]

Site-identification number	Local identifier	Date sampled	Time	Specific conductance, field (µS/cm)	pH, field, whole water (standard units)	Temperature water (°C)	Alkalinity, water dissolved, total incremental titration, field (mg/L as $CaCo_3$)
363529096161801	24N-10E-06 ABB 1	12/16/97	1230	1,260	6.0	14.0	110
363533096164601	24N-10E-06 BBB 1	12/16/97	1200	1,100	9.1	14.0	345
363438096134601	24N-10E-09 AAA 1	10/21/97	1700	780	7.6	--	304
363256096135501	24N-10E-21 ABA 1	10/21/97	1530	460	6.8	--	176
363154096113101	24N-10E-26 AAD 1	10/21/97	1445	372	6.9	--	110
363143096005501	24N-12E-28 ADC 1	10/21/97	1145	457	7.1	17.5	208
364022097030001	25N-02E-02 DAA 1	10/20/97	1250	415	7.1	--	147
364039096594201	25N-03E-05 AAD 1	10/22/97	1155	590	6.9	16.0	298
363949096561801	25N-03E-12 BBA 1	10/21/97	1515	621	7.1	17.0	300
363115096573601	25N-03E-35 BB 1	10/30/97	0820	540	7.2	--	238
363943096431901	25N-05E-12 BCA 1	10/21/97	1200	741	6.9	--	378
364000096373901	25N-06E-02 CDD 1	10/21/97	1350	706	7.2	--	346
363920096414001	25N-06E-07 DBD 1	10/21/97	0820	815	7.1	--	402
363735096403201	25N-06E-20 DAC 1	10/22/97	1000	1,050	6.8	--	398
364000096253001	25N-08E-03 DDC 1	11/06/97	1500	1,130	6.8	15.0	326
363807096255901	25N-08E-22 BAB 1	12/17/97	1145	724	7.2	15.0	320
363801096243901	25N-08E-23 ABC 1	11/06/97	1630	884	7.0	15.0	250
363745096234301	25N-08E-24 CAA 1	10/21/97	1230	1,150	7.1	18.0	308
363616096292701	25N-08E-31 BBD 1	11/19/97	1145	1,340	7.1	16.5	105
364023096170401	25N-09E-01 ACC 1	12/17/97	1030	626	8.0	11.0	295

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ^{o}C, degrees Celsius; specific conductance, pH, and alkalinity were measured in the field and the laboratory; --, indicates no data available; <, indicates concentration is less than the minimum reporting level; all samples were collected by the U.S. Geological Survey, Oklahoma District; laboratory analyses were done by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida]

Site-identification number	Local identifier	Date sampled	Time	Specific conductance, field (µS/cm)	pH, field, whole water (standard units)	Temperature water (^{o}C)	Alkalinity, water dissolved, total incremental titration, field (mg/L as $CaCo_3$)
363849096214401	25N-09E-17 BDB 1	12/17/97	1230	1,590	7.5	16.0	360
363838096225301	25N-09E-18 CBA 1	11/19/97	1000	617	6.8	15.5	160
363729096204001	25N-09E-21 CDB 1	12/17/97	1500	556	7.4	13.5	220
363756096171101	25N-09E-24 BDA 1	12/17/97	1425	935	7.9	8.0	370
363631096192101	25N-09E-27 CDD 1	11/05/97	0945	1,280	6.2	15.5	172
363646096210101	25N-09E-29 DAD 1	10/21/97	1810	2,260	8.3	--	408
363539096184501	25N-09E-35 CCC 1	11/06/97	0945	1,600	7.4	13.5	254
364015096114801	25N-10E-02 CAD 1	12/17/97	0900	571	8.0	15.5	185
363829096153101	25N-10E-17 CBC 1	12/16/97	1415	935	7.8	15.0	265
363729096142801	25N-10E-20 DDA 1	12/16/97	1300	734	7.5	14.0	280
363744096135401	25N-10E-21 DBB 1	12/16/97	1330	745	7.3	15.5	240
363546096144601	25N-10E-32 DCA 1	11/06/97	1045	869	7.0	15.5	280
363539096133501	25N-10E-33 DDC 1	11/06/97	1130	678	6.5	13.0	212
363827096064801	25N-11E-15 CBC 1	10/21/97	0930	180	6.1	12.0	20
364125097024401	26N-02E-36 BCA 1	11/19/97	1530	434	6.9	17.0	100
364300096432301	26N-05E-24 CBA1	10/22/97	0830	627	7.1	--	332
364455096270801	26N-08E-09 BCA 1	10/22/97	1415	286	--	18.0	100
364515096183701	26N-09E-02 CCD 1	10/22/97	1030	864	7.5	18.0	245
364451096214601	26N-09E-08 BDB 1	10/22/97	1315	608	--	17.5	310
364343096174101	26N-09E-13 CBC 1	10/21/97	1015	742	7.1	17.0	250

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; specific conductance, pH, and alkalinity were measured in the field and the laboratory; --, indicates no data available; <, indicates concentration is less than the minimum reporting level; all samples were collected by the U.S. Geological Survey, Oklahoma District; laboratory analyses were done by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida]

Site-identification number	Local identifier	Date sampled	Time	Specific conductance, field (µS/cm)	pH, field, whole water (standard units)	Temperature water (°C)	Alkalinity, water dissolved, total incremental titration, field (mg/L as $CaCo_3$)
364101096230501	26N-09E-31 CCB 1	10/21/97	1330	722	7.6	16.5	350
364140096215901	26N-09E-32 BBB 1	10/21/97	1430	1,680	6.8	16.5	588
364124096192901	26N-09E-34 BDA 1	11/19/97	0915	780	7.5	16.0	315
364328096152601	26N-10E-17 CCC 1	10/21/97	0915	648	7.1	16.5	205
364055096140501	26N-10E-33 CCA 1	12/17/97	1000	576	7.5	16.5	125
364943096293701	27N-07E-12 DDA 1	11/18/97	1430	985	9.2	19.0	320
364820096270901	27N-08E-21 BCD 1	11/18/97	1500	844	7.3	9.5	350
364906096174801	27N-09E-14 ADD 1	10/22/97	1215	263	--	17.0	120
364624096221601	27N-09E-31 DAB 1	10/20/97	1700	803	7.2	17.5	385
364635096193101	27N-09E-34 BDB 1	10/22/97	1115	430	--	15.0	155
364901096104501	27N-10E-13 DBB 1	10/22/97	0930	1,080	7.1	16.5	318
364752096141501	27N-10E-21 CDB 1	11/17/97	1415	218	6.6	12.5	95
364805096102101	27N-10E-24 DAD 1	10/22/97	0900	1,830	7.1	16.0	388
364714096133201	27N-10E-28 DAA 1	11/17/97	1330	246	6.4	14.0	95
364640096142001	27N-10E-33 BCA 1	11/17/97	1300	712	6.9	14.0	345
365053096093401	27N-11E-06 ACC 1	12/16/97	0830	291	7.2	14.0	75
365623096252901	28N-08E-03 AAC 1	11/18/97	1130	1,180	7.4	12.5	330
365501096274501	28N-08E-08 DBD 1	11/18/97	1345	2,200	8.9	10.0	320
365205096244201	28N-08E-35 ABB 1	10/20/97	1545	692	7.2	18.5	292
365601096174301	28N-09E-01 BCC 1	10/28/97	1130	453	7.7	15.5	220

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; specific conductance, pH, and alkalinity were measured in the field and the laboratory; --, indicates no data available; <, indicates concentration is less than the minimum reporting level; all samples were collected by the U.S. Geological Survey, Oklahoma District; laboratory analyses were done by the U.S. Geological Survey, Quality of Water Service Unit laboratory in Ocala, Florida]

Site-identification number	Local identifier	Date sampled	Time	Specific conductance, field (µS/cm)	pH, field, whole water (standard units)	Temperature water (°C)	Alkalinity, water dissolved, total incremental titration, field (mg/L as $CaCo_3$)
365549096224301	28N-09E-06 CAD 1	11/18/97	1230	716	8.9	16.0	350
365522096183001	28N-09E-11 BAC 1	10/28/97	1215	982	8.9	16.0	365
365350096183101	28N-09E-23 BAB 1	11/18/97	1700	507	9.1	13.5	320
365420096120101	28N-10E-11 CDC 1	10/28/97	1400	813	7.2	17.0	338
365419096154301	28N-10E-18 ADD 1	10/28/97	1315	813	7.6	17.0	235
365342096120501	28N-10E-23 BAC 1	10/29/97	1315	829	6.9	17.0	215
365514096041601	28N-11E-12 BDD 1	10/30/97	0930	821	6.9	16.5	221
365431096074101	28N-11E-16 BAC 1	10/29/97	1600	3,780	7.2	16.5	222
365250096070801	28N-11E-28 AAC 1	10/29/97	1500	359	7.9	16.0	222
365341096012701	28N-12E-21 BBC 1	10/30/97	1030	1,780	6.6	15.5	219
365924096413501	29N-06E-18 DBA 1	11/20/97	0915	620	7.4	15.5	315
365811096414201	29N-06E-30 ABB 1	11/19/97	1315	743	7.3	15.0	295
365830096175801	29N-09E-23 DBC 1	11/18/97	0900	1,750	7.1	10.0	435
365906096164201	29N-09E-24 ABA 1	10/28/97	1030	1,150	6.8	16.0	332
365806096182201	29N-09E-26 BBD 1	11/18/97	0945	690	6.6	14.5	285
365955096111901	29N-10E-14 ABA 1	10/28/97	0930	386	7.0	17.5	525
365915096125601	29N-10E-15 CCA 1	10/29/97	0900	940	7.4	17.5	298
365727096133501	29N-10E-27 CCC 1	10/29/97	1045	1,270	7.3	16.0	285
365657096141401	29N-10E-32 ADD 1	10/29/97	1115	782	7.5	16.0	282
365723096094601	29N-11E-30 CCC 1	10/29/97	1000	4,100	6.6	15.0	265
365637096063501	29N-11E-34 CCB 1	10/29/97	1215	3,440	7.2	16.5	220

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Dissolved solids, total (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as An)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
361917096304101	21N-07E-01 CCA 1	127	15	3.0	14	.90	9.6	6.6
361906096305101	21N-07E-11 AAA 1	209	26	7.0	21	1.4	29	18
361807096252701	21N-08E-14 BBC 1	727	49	21	200	.70	65	31
361925096012801	21N-12E-04 CAA 1	396	55	10	70	4.0	87	34
362323096350601	22N-07E-17 BBC 1	329	58	10	33	1.1	24	9.4
362308096243201	22N-08E-14 ADD 1	2,680	13	5.0	1,000	3.6	35	1,300
362259096250001	22N-08E-14 CAA 1	1270	7.1	3.0	480	2.5	110	370
362026096265101	22N-08E-33 ACD 1	1020	41	25	350	2.0	170	220
362402096193901	22N-09E-10 BDA 1	421	8.6	4.0	150	1.1	30	53
362055096220501	22N-09E-29 CCD 1	508	7.9	3.1	190	2.0	44	24
362202096125701	22N-10E-22 DBA 1	135	17	5.0	20	.80	8.6	17
362105096140901	22N-10E-28 DBC 1	206	43	12	12	.90	13	9.3
362011096133201	22N-10E-34 CBC 1	1,500	230	31	280	1.3	15	800
362222096040101	22N-11E-24 AAD 1	724	88	22	140	6.9	26	350
363023096570101	23N-03E-02 ABB 1	338	70	13	57	1.8	42	32
362839096570501	23N-03E-14 BAA 1	208	29	5.0	23	1.5	17	14
362659096414801	23N-06E-19 DCD 1	529	99	20	54	2.2	60	28
362731096352801	23N-07E-19 ACB 1	686	2.0	.80	270	1.1	42	76
362926096242901	23N-08E-11 AAA 1	622	56	33	120	2.4	120	63
362809096254801	23N-08E-15 DBA 1	1,290	170	57	220	1.9	27	750
363014096204601	23N-09E-04 BAD 1	715	50	43	150	2.9	160	57
362757096192601	23N-09E-15 DCB 1	612	30	22	170	3.6	65	140
362729096211701	23N-09E-20 DAA 1	1,580	6.8	2.3	610	1.9	120	580
362629096175401	23N-09E-25 BCC 1	789	93	68	77	3.3	140	190

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Dissolved solids, total (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as An)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
362611096175201	23N-09E-25 CCB 1	315	50	10	42	3.1	52	31
362651096203301	23N-09E-28 ABB 1	564	40	44	90	3.2	48	47
362541096195701	23N-09E-34 BCC 1	568	11	4.0	200	1.2	120	40
363204096552601	24N-04E-30 BBB 1	508	91	22	69	1.0	26	30
363233096430501	24N-05E-24 DBB 1	333	80	9.0	28	.70	11	8.6
363406096320501	24N-07E-10 DDB 1	459	66	7.0	100	1.0	43	30
363155096342401	24N-07E-29 ACA 1	587	1.1	.30	230	.50	66	23
363453096264101	24N-08E-04 DDA 1	378	56	20	49	1.6	20	6.9
363216096234501	24N-08E-24 DCA 1	490	1.7	.30	190	.80	60	62
363033096272101	24N-08E-33 CDB 1	435	93	32	15	.80	55	34
363419096195001	24N-09E-10 BCD 1	213	38	14	17	.80	56	13
363421096171601	24N-09E-12 ACD 1	555	8.5	2.9	230	1.1	15	14
363246096204701	24N-09E-21 BDA 1	329	43	18	46	1.6	76	13
363259096191901	24N-09E-22 ABA 1	450	66	24	50	1.3	64	110
363025096230901	24N-09E-31 CCD 1	546	11	8.0	180	1.5	89	67
363529096161801	24N-10E-06 ABB 1	650	65	40	110	1.8	72	280
363533096164601	24N-10E-06 BBB 1	640	2.4	1.1	260	1.0	16	140
363438096134601	24N-10E-09 AAA 1	467	61	32	63	2.1	73	35
363256096135501	24N-10E-21 ABA 1	278	33	16	45	1.7	27	30
363154096113101	24N-10E-26 AAD 1	225	35	8.0	30	.60	30	30
363143096005501	24N-12E-28 ADC 1	272	77	6.0	14	.40	23	6.9
364022097030001	25N-02E-02 DAA 1	260	44	8.0	29	1.7	17	16
364039096594201	25N-03E-05 AAD 1	351	76	18	25	.70	14	9.5
363949096561801	25N-03E-12 BBA 1	374	87	14	28	.30	22	14
363115096573601	25N-03E-35 BB 1	319	63	13	29	1.1	13	11

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Dissolved solids, total (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as An)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
363943096431901	25N-05E-12 BCA 1	439	120	15	21	1.0	16	13
364000096373901	25N-06E-02 CDD 1	417	77	9.0	72	.10	17	17
363920096414001	25N-06E-07 DBD 1	481	110	17	51	1.8	21	8.3
363735096403201	25N-06E-20 DAC 1	653	140	31	41	.70	58	29
364000096253001	25N-08E-03 DDC 1	814	140	24	110	1.0	180	120
363807096255901	25N-08E-22 BAB 1	410	110	14	24	.80	12	36
363801096243901	25N-08E-23 ABC 1	568	98	16	83	4.2	88	110
363745096234301	25N-08E-24 CAA 1	660	130	23	73	5.6	63	130
363616096292701	25N-08E-31 BBD 1	692	130	15	93	1.0	25	330
364023096170401	25N-09E-01 ACC 1	358	31	28	70	2.2	27	9.6
363849096214401	25N-09E-17 BDB 1	1,030	4.3	1.5	370	1.5	400	29
363838096225301	25N-09E-18 CBA 1	342	84	15	18	2.2	48	37
363729096204001	25N-09E-21 CDB 1	325	66	26	15	.80	27	24
363756096171101	25N-09E-24 BDA 1	555	30	31	150	3.8	65	34
363631096192101	25N-09E-27 CDD 1	765	110	34	91	5.1	260	83
363646096210101	25N-09E-29 DAD 1	1,500	6.1	2.0	520	1.9	640	71
363539096184501	25N-09E-35 CCC 1	1,130	130	69	140	4.5	610	42
364015096114801	25N-10E-02 CAD 1	352	45	35	22	1.4	110	9.6
363829096153101	25N-10E-17 CBC 1	603	68	30	91	3.9	210	19
363729096142801	25N-10E-20 DDA 1	404	58	38	38	2.2	37	50
363744096135401	25N-10E-21 DBB 1	399	60	29	48	2.1	57	38
363546096144601	25N-10E-32 DCA 1	467	49	30	77	2.7	100	13
363539096133501	25N-10E-33 DDC 1	384	60	30	38	1.5	23	79
363827096064801	25N-11E-15 CBC 1	106	10	4.0	16	.60	3.2	34
364125097024401	26N-02E-36 BCA 1	267	44	10	26	1.6	30	21

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Dissolved solids, total (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as An)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
364300096432301	26N-05E-24 DBA 1	365	120	9.0	9.8	.20	12	2.7
364455096270801	26N-08E-09 BCA 1	168	37	4.0	16	.50	16	9.8
364515096183701	26N-09E-02 CCD 1	550	29	12	150	2.6	170	21
364451096214601	26N-09E-08 BDB 1	346	110	9.0	11	1.2	15	2.5
364343096174101	26N-09E-13 CBC 1	442	91	18	40	.90	65	40
364101096230501	26N-09E-31 CCB 1	425	44	31	71	2.2	17	20
364140096215901	26N-09E-32 BBB 1	1,150	270	33	97	1.0	330	46
364124096192901	26N-09E-34 BDA 1	453	91	31	31	1.1	43	34
364328096152601	26N-10E-17 CCC 1	377	71	17	36	2.7	13	42
364055096140501	26N-10E-33 CCA 1	354	37	15	55	2.2	100	35
364943096293701	27N-07E-12 DDA 1	557	1.3	.40	220	.90	21	110
364820096270901	27N-08E-21 BCD 1	502	82	38	47	1.2	73	23
364906096174801	27N-09E-14 ADD 1	166	21	7.0	29	.90	10	4.6
364624096221601	27N-09E-31 DAB 1	471	47	28	98	2.2	22	19
364635096193101	27N-09E-34 BDB 1	277	33	7.0	54	1.4	50	8.3
364901096104501	27N-10E-13 DBB 1	614	120	24	75	2.2	55	130
364752096141501	27N-10E-21 CDB 1	140	25	6.9	9.6	.50	8.0	6.6
364805096102101	27N-10E-24 DAD 1	1,210	170	91	120	4.4	430	140
364714096133201	27N-10E-28 DAA 1	157	28	9.0	7.4	.60	20	3.6
364640096142001	27N-10E-33 BCA 1	415	96	27	23	.70	28	8.7
365053096093401	27N-11E-06 ACC 1	156	21	5.2	31	1.1	30	12
365623096252901	28N-08E-03 AAC 1	681	47	5.4	200	1.0	44	120
365501096274501	28N-08E-08 DBD 1	1,170	3.7	1.0	460	1.7	16	480
365205096244201	28N-08E-35 ABB 1	419	60	12	82	.90	55	13
365601096174301	28N-09E-01 BCC 1	258	47	13	30	1.1	11	6.4

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Dissolved solids, total (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as An)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
365549096224301	28N-09E-06 CAD 1	421	1.7	.40	160	.80	22	15
365522096183001	28N-09E-11 BAC 1	583	1.3	.30	240	.80	18	87
365350096183101	28N-09E-23 BAB 1	517	1.4	.30	200	.80	50	61
365420096120101	28N-10E-11 CDC 1	499	64	31	73	3.4	88	15
365419096154301	28N-10E-18 ADD 1	504	60	26	73	3.8	140	32
365342096120501	28N-10E-23 BAC 1	460	38	32	85	4.6	53	75
365514096041601	28N-11E-12 BDD 1	499	120	16	28	.40	29	12
365431096074101	28N-11E-16 BAC 1	2080	64	13	710	3.9	80	970
365250096070801	28N-11E-28 AAC 1	199	48	8.0	14	2.5	18	23
365341096012701	28N-12E-21 BBC 1	1,150	100	61	180	1.8	250	150
365924096413501	29N-06E-18 DBA 1	366	77	16	23	4.5	8.0	9.3
365811096414201	29N-06E-30 ABB 1	386	110	15	27	.70	24	10
365830096175801	29N-09E-23 DBC 1	982	220	27	98	1.0	23	270
365906096164201	29N-09E-24 ABA 1	773	200	22	38	1.3	250	37
365806096182201	29N-09E-26 BBD 1	416	120	6.0	20	.60	44	23
365955096111901	29N-10E-14 ABA 1	235	24	11	24	14	59	22
365915096125601	29N-10E-15 CCA 1	558	62	19	110	2.7	100	66
365727096133501	29N-10E-27 CCC 1	831	89	63	120	3.0	260	43
365657096141401	29N-10E-32 ADD 1	454	51	29	73	1.9	69	47
365723096094601	29N-11E-30 CCC 1	3,120	660	160	120	8.4	1,300	620
365637096063501	29N-11E-34 CCB 1	2,210	110	39	610	5.5	790	420

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, total dissolved (mg/L as N)
361917096304101	21N-07E-01 CCA 1	.10	<.050	35	2.30	.009	<.20
361906096305101	21N-07E-11 AAA 1	.10	<.050	33	8.70	.004	<.20
361807096252701	21N-08E-14 BBC 1	1.3	.30	33	3.80	.006	<.20
361925096012801	21N-12E-04 CAA 1	.20	.20	12	.182	1.60	1.6
362323096350601	22N-07E-17 BBC 1	.40	.10	48	5.40	.009	<.20
362308096243201	22N-08E-14 ADD 1	2.0	9.2	7.8	.004	1.00	.97
362259096250001	22N-08E-14 CAA 1	.90	1.8	7.7	6.00	.095	<.20
362026096265101	22N-08E-33 ACD 1	.70	.90	9.3	.106	.200	.24
362402096193901	22N-09E-10 BDA 1	.40	.20	13	1.00	.220	.31
362055096220501	22N-09E-29 CCD 1	.49	.060	13	.003	.560	.34
362202096125701	22N-10E-22 DBA 1	.20	.10	18	1.00	.020	<.20
362105096140901	22N-10E-28 DBC 1	.10	.050	17	.052	.005	<.20
362011096133201	22N-10E-34 CBC 1	<.10	2.1	16	1.70	.005	<.20
362222096040101	22N-11E-24 AAD 1	.20	.90	9.5	1.10	.012	.64
363023096570101	23N-03E-02 ABB 1	.10	.20	34	49.0	.016	<.20
362839096570501	23N-03E-14 BAA 1	.10	.20	34	7.30	.005	<.20
362659096414801	23N-06E-19 DCD 1	.40	.30	35	7.40	.004	<.20
362731096352801	23N-07E-19 ACB 1	1.8	<.050	8.6	.012	.350	.30
362926096242901	23N-08E-11 AAA 1	.40	.30	15	.220	.011	<.20
362809096254801	23N-08E-15 DBA 1	<.10	2.6	22	2.10	.009	<.20
363014096204601	23N-09E-04 BAD 1	.36	.10	13	--	--	--

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, total dissolved (mg/L as N)
362757096192601	23N-09E-15 DCB 1	.35	.30	12	6.90	.010	<.20
362729096211701	23N-09E-20 DAA 1	2.2	2.6	8.1	<.002	.620	.41
362629096175401	23N-09E-25 BCC 1	.19	.50	14	3.80	.110	<.20
362611096175201	23N-09E-25 CCB 1	.36	.20	4.1	5.80	.004	<.20
362651096203301	23N-09E-28 ABB 1	.33	.20	14	.148	<.002	<.20
362541096195701	23N-09E-34 BCC 1	.40	.20	11	.022	.260	<.20
363204096552601	24N-04E-30 BBB 1	.40	.20	22	2.60	.006	<.20
363233096430501	24N-05E-24 DBB 1	.20	<.050	21	2.10	.003	<.20
363406096320501	24N-07E-10 DDB 1	.40	.10	14	.261	.028	<.20
363155096342401	24N-07E-29 ACA 1	1.0	.090	9.3	.141	.110	<.20
363453096264101	24N-08E-04 DDA 1	.20	<.050	21	<.002	.200	<.20
363216096234501	24N-08E-24 DCA 1	.40	.30	9.5	.070	.210	<.20
363033096272101	24N-08E-33 CDB 1	.28	.060	14	3.60	<.002	<.20
363419096195001	24N-09E-10 BCD 1	.13	.070	14	--	--	--
363421096171601	24N-09E-12 ACD 1	.19	.10	9.8	--	--	--
363246096204701	24N-09E-21 BDA 1	.40	.10	18	.076	.033	<.20
363259096191901	24N-09E-22 ABA 1	<.10	.40	14	13.0	.018	.52
363025096230901	24N-09E-31 CCD 1	.50	.20	12	3.60	.210	.24
363529096161801	24N-10E-06 ABB 1	.11	1.2	13	--	--	--
363533096164601	24N-10E-06 BBB 1	1.2	.60	8.7	--	--	--
363438096134601	24N-10E-09 AAA 1	.20	.090	16	.124	.008	<.20
363256096135501	24N-10E-21 ABA 1	.20	.10	22	.134	.006	<.20
363154096113101	24N-10E-26 AAD 1	.20	.20	22	.866	.006	<.20

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, total dissolved (mg/L as N)
363143096005501	24N-12E-28 ADC 1	.20	<.050	15	.528	.005	<.20
364022097030001	25N-02E-02 DAA 1	.20	.10	31	5.10	.004	<.20
364039096594201	25N-03E-05 AAD 1	.40	<.050	24	.686	.006	<.20
363949096561801	25N-03E-12 BBA 1	.50	<.050	27	.107	.012	<.20
363115096573601	25N-03E-35 BB 1	.30	.060	22	5.30	.006	<.20
363943096431901	25N-05E-12 BCA 1	.30	.10	26	.002	.150	<.20
364000096373901	25N-06E-02 CDD 1	.30	.090	15	1.20	.006	<.20
363920096414001	25N-06E-07 DBD 1	.40	.10	14	.100	.047	.94
363735096403201	25N-06E-20 DAC 1	.30	<.050	16	22.0	.006	.20
364000096253001	25N-08E-03 DDC 1	.30	.70	19	4.20	.004	.24
363807096255901	25N-08E-22 BAB 1	.17	.20	14	1.40	<.002	<.20
363801096243901	25N-08E-23 ABC 1	.40	.20	15	.231	.002	<.20
363745096234301	25N-08E-24 CAA 1	.20	.50	26	5.30	.005	<.20
363616096292701	25N-08E-31 BBD 1	<.10	1.0	20	3.00	.006	<.20
364023096170401	25N-09E-01 ACC 1	.57	.070	12	.071	.010	<.20
363849096214401	25N-09E-17 BDB 1	.26	.10	8.9	.065	.420	.28
363838096225301	25N-09E-18 CBA 1	.20	.20	20	4.60	.009	.35
363729096204001	25N-09E-21 CDB 1	.40	.070	18	3.80	<.002	<.20
363756096171101	25N-09E-24 BDA 1	.56	.10	15	.420	<.002	<.20
363631096192101	25N-09E-27 CDD 1	.30	.30	11	15.0	.008	.78
363646096210101	25N-09E-29 DAD 1	1.0	.30	8.7	.086	.390	.38
363539096184501	25N-09E-35 CCC 1	.10	.20	19	.044	.780	.73

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, total dissolved (mg/L as N)
364015096114801	25N-10E-02 CAD 1	.25	.050	15	.543	<.002	<.20
363829096153101	25N-10E-17 CBC 1	.14	<.050	19	--	--	--
363729096142801	25N-10E-20 DDA 1	.24	.20	12	--	--	--
363744096135401	25N-10E-21 DBB 1	.18	.20	20	--	--	--
363546096144601	25N-10E-32 DCA 1	.50	.060	17	.028	.006	<.20
363539096133501	25N-10E-33 DDC 1	.20	.20	15	.982	.002	<.20
363827096064801	25N-11E-15 CBC 1	<.10	.10	21	.617	.010	<.20
364125097024401	26N-02E-36 BCA 1	.20	.090	31	9.50	.004	<.20
364300096432301	26N-05E-24 DBA 1	.40	<.050	12	.164	.005	<.20
364455096270801	26N-08E-09 BCA 1	.20	<.050	17	1.70	.004	<.20
364515096183701	26N-09E-02 CCD 1	.20	.10	15	.336	.530	.49
364451096214601	26N-09E-08 BDB 1	.20	<.050	11	.019	.004	<.20
364343096174101	26N-09E-13 CBC 1	.40	.20	20	3.60	.013	<.20
364101096230501	26N-09E-31 CCB 1	.30	.10	19	.224	.016	<.20
364140096215901	26N-09E-32 BBB 1	.20	.40	16	.350	.008	<.20
364124096192901	26N-09E-34 BDA 1	.40	.20	20	2.50	.012	<.20
364328096152601	26N-10E-17 CCC 1	.30	.30	18	12.0	.005	<.20
364055096140501	26N-10E-33 CCA 1	.14	.20	18	3.70	<.002	<.20
364943096293701	27N-07E-12 DDA 1	.60	.50	10	.003	.019	.31
364820096270901	27N-08E-21 BCD 1	.29	.090	13	3.00	<.002	<.20
364906096174801	27N-09E-14 ADD 1	.10	<.050	21	<.002	.130	<.20
364624096221601	27N-09E-31 DAB 1	.20	.070	21	.352	.005	<.20
364635096193101	27N-09E-34 BDB 1	.20	<.050	22	1.60	.230	<.20

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, total dissolved (mg/L as N)
364901096104501	27N-10E-13 DBB 1	.30	.30	15	.252	.009	<.20
364752096141501	27N-10E-21 CDB 1	.20	.080	23	.708	.004	<.20
364805096102101	27N-10E-24 DAD 1	.30	.40	20	.013	.410	.41
364714096133201	27N-10E-28 DAA 1	.10	<.050	25	1.40	.002	<.20
364640096142001	27N-10E-33 BCA 1	.30	.20	22	.002	.110	<.20
365053096093401	27N-11E-06 ACC 1	.15	<.050	7.2	--	--	--
365623096252901	28N-08E-03 AAC 1	.80	.50	9.8	12.0	.290	.37
365501096274501	28N-08E-08 DBD 1	.70	2.1	9.4	.698	.005	<.20
365205096244201	28N-08E-35 ABB 1	.30	<.050	12	1.60	.002	<.20
365601096174301	28N-09E-01 BCC 1	.20	.050	17	.090	.006	<.20
365549096224301	28N-09E-06 CAD 1	.60	.080	8.9	.013	.320	.34
365522096183001	28N-09E-11 BAC 1	.90	.40	8.8	.002	.380	.36
365350096183101	28N-09E-23 BAB 1	.66	.30	8.9	.012	.300	.33
365420096120101	28N-10E-11 CDC 1	.40	<.050	18	.220	.360	<.20
365419096154301	28N-10E-18 ADD 1	.30	.10	21	.002	.760	.86
365342096120501	28N-10E-23 BAC 1	.20	.60	10	.074	.006	<.20
365514096041601	28N-11E-12 BDD 1	.20	<.050	21	16.0	.006	<.20
365431096074101	28N-11E-16 BAC 1	1.0	3.7	9.8	.260	1.10	1.1
365250096070801	28N-11E-28 AAC 1	.20	<.050	6.2	.362	.004	.29
365341096012701	28N-12E-21 BBC 1	.20	.50	21	48.0	.009	<.20
365924096413501	29N-06E-18 DBA 1	.20	.60	17	.192	8.60	6.6
365811096414201	29N-06E-30 ABB 1	.20	.080	21	.006	.006	<.20

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia plus organic, total dissolved (mg/L as N)
365830096175801	29N-09E-23 DBC 1	.30	1.3	21	13.0	.020	.21
365906096164201	29N-09E-24 ABA 1	.20	.080	13	2.60	.005	<.20
365806096182201	29N-09E-26 BBD 1	.20	.10	21	2.10	.014	<.20
365955096111901	29N-10E-14 ABA 1	.20	.080	12	8.10	.003	<.20
365915096125601	29N-10E-15 CCA 1	.20	.20	18	.044	.420	.47
365727096133501	29N-10E-27 CCC 1	.40	.10	12	1.70	.005	<.20
365657096141401	29N-10E-32 ADD 1	.30	.10	11	.381	.008	<.20
365723096094601	29N-11E-30 CCC 1	.30	1.3	9.2	18.0	.025	<.20
365637096063501	29N-11E-34 CCB 1	.40	1.7	12	.005	1.40	1.7

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Phosphorus, total dissolved (mg/L as P)	Phosphorus, ortho phosphate dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)
361917096304101	21N-07E-01 CCA 1	.070	.070	<1	27	4.0	<4
361906096305101	21N-07E-11 AAA 1	.050	.050	<1	68	2.0	<4
361807096252701	21N-08E-14 BBC 1	.080	.090	<1	25	20	7
361925096012801	21N-12E-04 CAA 1	.400	.320	1	110	5.0	<4
362323096350601	22N-07E-17 BBC 1	.140	.140	<1	51	40	<4
362308096243201	22N-08E-14 ADD 1	.004	.004	<1	3,400	130	30
362259096250001	22N-08E-14 CAA 1	.009	.010	5	1,800	9.0	20
362026096265101	22N-08E-33 ACD 1	.007	.006	<1	1,200	<1.0	10
362402096193901	22N-09E-10 BDA 1	.006	.006	2	350	2.0	8
362055096220501	22N-09E-29 CCD 1	.003	.004	3	1,100	10	10
362202096125701	22N-10E-22 DBA 1	.030	.020	<1	30	10	<4
362105096140901	22N-10E-28 DBC 1	.003	.004	<1	34	20	5
362011096133201	22N-10E-34 CBC 1	.004	.001	<1	46	90	20
362222096040101	22N-11E-24 AAD 1	.080	.040	<1	610	7.0	20
363023096570101	23N-03E-02 ABB 1	.060	.070	<1	25	10	7
362839096570501	23N-03E-14 BAA 1	.080	.100	<1	23	10	<4
362659096414801	23N-06E-19 DCD 1	.090	.090	<1	40	2.0	7
362731096352801	23N-07E-19 ACB 1	.010	.007	<1	1,500	20	7
362926096242901	23N-08E-11 AAA 1	.010	.008	<1	340	10	10
362809096254801	23N-08E-15 DBA 1	.010	.001	<1	30	230	20
363014096204601	23N-09E-04 BAD 1	--	--	<1	530	30	20
362757096192601	23N-09E-15 DCB 1	.002	.001	<1	650	20	20

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Phosphorus, total dissolved (mg/L as P)	Phosphorus, ortho phosphate dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)
362729096211701	23N-09E-20 DAA 1	.005	.004	<1	3,000	220	20
362629096175401	23N-09E-25 BCC 1	<.002	<.001	<1	160	530	10
362611096175201	23N-09E-25 CCB 1	.007	.006	<1	59	3.0	<4
362651096203301	23N-09E-28 ABB 1	<.002	<.001	<1	240	5.0	30
362541096195701	23N-09E-34 BCC 1	.010	.010	<1	650	5.0	9
363204096552601	24N-04E-30 BBB 1	.090	.110	<1	150	3.0	10
363233096430501	24N-05E-24 DBB 1	.040	.040	<1	46	2.0	5
363406096320501	24N-07E-10 DDB 1	.002	<.001	<1	290	3.0	6
363155096342401	24N-07E-29 ACA 1	.010	.010	<1	690	6.0	6
363453096264101	24N-08E-04 DDA 1	<.002	<.001	<1	80	170	<4
363216096234501	24N-08E-24 DCA 1	.007	.003	<1	490	20	7
363033096272101	24N-08E-33 CDB 1	.003	.002	<1	67	5.0	7
363419096195001	24N-09E-10 BCD 1	--	--	<1	39	3.0	7
363421096171601	24N-09E-12 ACD 1	--	--	<1	830	2.0	10
363246096204701	24N-09E-21 BDA 1	.002	<.001	<1	140	5.0	7
363259096191901	24N-09E-22 ABA 1	.010	<.001	<1	38	650	<4
363025096230901	24N-09E-31 CCD 1	.004	.002	<1	450	3.0	10
363529096161801	24N-10E-06 ABB 1	--	--	<1	43	290	<4
363533096164601	24N-10E-06 BBB 1	--	--	<1	1,600	7.0	10
363438096134601	24N-10E-09 AAA 1	<.002	<.001	<1	280	10	10
363256096135501	24N-10E-21 ABA 1	<.002	<.001	<1	130	40	8
363154096113101	24N-10E-26 AAD 1	<.002	<.001	<1	32	5.0	4
363143096005501	24N-12E-28 ADC 1	.002	<.001	<1	52	4.0	<4

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Phosphorus, total dissolved (mg/L as P)	Phosphorus, ortho phosphate dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)
364022097030001	25N-02E-02 DAA 1	.080	.080	<1	26	10	5
364039096594201	25N-03E-05 AAD 1	.100	.090	<1	60	20	<4
363949096561801	25N-03E-12 BBA 1	.050	.050	<1	70	5.0	7
363115096573601	25N-03E-35 BB 1	.100	.100	1	97	5.0	5
363943096431901	25N-05E-12 BCA 1	.100	.008	1	67	1,900	5
364000096373901	25N-06E-02 CDD 1	.003	.002	<1	65	<1.0	<4
363920096414001	25N-06E-07 DBD 1	.010	.010	<1	110	190	<4
363735096403201	25N-06E-20 DAC 1	.030	.030	<1	87	<1.0	7
364000096253001	25N-08E-03 DDC 1	.003	.002	<1	660	7.0	4
363807096255901	25N-08E-22 BAB 1	<.002	<.001	<1	37	<1.0	<4
363801096243901	25N-08E-23 ABC 1	.050	.040	<1	90	40	7
363745096234301	25N-08E-24 CAA 1	.040	.050	<1	40	7.0	6
363616096292701	25N-08E-31 BBD 1	<.002	.020	<1	37	10	<4
364023096170401	25N-09E-01 ACC 1	<.002	<.001	<1	370	1.0	20
363849096214401	25N-09E-17 BDB 1	.004	.004	<1	850	6.0	20
363838096225301	25N-09E-18 CBA 1	.010	.030	<1	52	30	<4
363729096204001	25N-09E-21 CDB 1	.020	.020	<1	68	20	6
363756096171101	25N-09E-24 BDA 1	<.002	.001	<1	1,000	6.0	20
363631096192101	25N-09E-27 CDD 1	.040	.030	<1	53	20	<4
363646096210101	25N-09E-29 DAD 1	.008	.007	<1	2,900	10	20
363539096184501	25N-09E-35 CCC 1	.004	<.001	<1	450	330	20
364015096114801	25N-10E-02 CAD 1	.003	.002	<1	93	<1.0	10
363829096153101	25N-10E-17 CBC 1	--	--	<1	260	640	10
363729096142801	25N-10E-20 DDA 1	--	--	<1	110	6.0	20

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Phosphorus, total dissolved (mg/L as P)	Phosphorus, ortho phosphate dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)
363744096135401	25N-10E-21 DBB 1	--	--	<1	80	6.0	7
363546096144601	25N-10E-32 DCA 1	.004	.002	<1	2,000	90	10
363539096133501	25N-10E-33 DDC 1	.003	<.001	<1	64	10	9
363827096064801	25N-11E-15 CBC 1	.002	<.001	<1	21	240	5
364125097024401	26N-02E-36 BCA 1	.090	.120	<1	76	<1.0	<4
364300096432301	26N-05E-24 DBA 1	<.002	<.001	<1	42	9.0	<4
364455096270801	26N-08E-09 BCA 1	.006	.006	<1	29	2.0	<4
364515096183701	26N-09E-02 CCD 1	.002	<.001	<1	330	9.0	20
364451096214601	26N-09E-08 BDB 1	<.002	<.001	<1	31	3.0	<4
364343096174101	26N-09E-13 CBC 1	.002	.004	<1	52	30	5
364101096230501	26N-09E-31 CCB 1	<.002	<.001	<1	460	6.0	6
364140096215901	26N-09E-32 BBB 1	.010	<.001	<1	180	460	<4
364124096192901	26N-09E-34 BDA 1	.060	.080	<1	150	8.0	5
364328096152601	26N-10E-17 CCC 1	.008	.005	<1	43	20	9
364055096140501	26N-10E-33 CCA 1	.005	.003	<1	39	6.0	6
364943096293701	27N-07E-12 DDA 1	.010	.020	<1	490	1.0	9
364820096270901	27N-08E-21 BCD 1	.003	.001	<1	130	<1.0	10
364906096174801	27N-09E-14 ADD 1	.010	.010	<1	98	170	6
364624096221601	27N-09E-31 DAB 1	<.002	<.001	<1	190	2.0	10
364635096193101	27N-09E-34 BDB 1	.020	.006	<1	190	30	9
364901096104501	27N-10E-13 DBB 1	.003	<.001	<1	400	30	10
364752096141501	27N-10E-21 CDB 1	.020	.030	<1	26	20	6
364805096102101	27N-10E-24 DAD 1	.002	<.001	<1	390	510	20

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Phosphorus, total dissolved (mg/L as P)	Phosphorus, ortho phosphate dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)
364714096133201	27N-10E-28 DAA 1	.010	.040	<1	36	50	<4
364640096142001	27N-10E-33 BCA 1	.002	.002	2	84	470	<4
365053096093401	27N-11E-06 ACC 1	--	--	<1	120	10	<4
365623096252901	28N-08E-03 AAC 1	.006	.005	<1	440	<1.0	10
365501096274501	28N-08E-08 DBD 1	.008	.008	<1	680	20	20
365205096244201	28N-08E-35 ABB 1	.007	.004	<1	220	5.0	6
365601096174301	28N-09E-01 BCC 1	<.002	.002	<1	76	1.0	9
365549096224301	28N-09E-06 CAD 1	.005	.005	<1	680	20	10
365522096183001	28N-09E-11 BAC 1	.007	.008	<1	1,100	30	10
365350096183101	28N-09E-23 BAB 1	.008	.006	<1	720	3.0	10
365420096120101	28N-10E-11 CDC 1	.002	.002	<1	590	20	20
365419096154301	28N-10E-18 ADD 1	.004	.002	<1	550	4,000	20
365342096120501	28N-10E-23 BAC 1	<.002	.001	<1	95	540	10
365514096041601	28N-11E-12 BDD 1	.030	.030	<1	85	7.0	9
365431096074101	28N-11E-16 BAC 1	<.002	.002	<1	1,900	5.0	40
365250096070801	28N-11E-28 AAC 1	<.002	.001	<1	52	<1.0	<4
365341096012701	28N-12E-21 BBC 1	.010	.020	<1	300	10	20
365924096413501	29N-06E-18 DBA 1	2.60	2.30	7	300	80	10
365811096414201	29N-06E-30 ABB 1	.080	.100	<1	100	<1.0	6
365830096175801	29N-09E-23 DBC 1	.010	.040	<1	190	40	20
365906096164201	29N-09E-24 ABA 1	.006	.006	<1	100	4.0	8
365806096182201	29N-09E-26 BBD 1	.030	.050	<1	52	3.0	<4
365955096111901	29N-10E-14 ABA 1	.010	.008	<1	42	4.0	<4

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Phosphorus, total dissolved (mg/L as P)	Phosphorus, ortho phosphate dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)	Iron, dissolved (μg/L as Fe)	Lithium, dissolved (μg/L as Li)
365915096125601	29N-10E-15 CCA 1	.003	.003	<1	260	120	10
365727096133501	29N-10E-27 CCC 1	<.002	.002	<1	450	40	10
365657096141401	29N-10E-32 ADD 1	<.002	.001	<1	120	4.0	20
365723096094601	29N-11E-30 CCC 1	.002	.001	<1	450	80	90
365637096063501	29N-11E-34 CCB 1	.003	.002	<1	2,600	160	60

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon organic, total dissolved (mg/L as C)
361917096304101	21N-07E-01 CCA 1	1.5	100	<.10
361906096305101	21N-07E-11 AAA 1	<.20	260	.20
361807096252701	21N-08E-14 BBC 1	.30	370	.70
361925096012801	21N-12E-04 CAA 1	500	330	2.9
362323096350601	22N-07E-17 BBC 1	.60	290	.60
362308096243201	22N-08E-14 ADD 1	5.8	660	.20
362259096250001	22N-08E-14 CAA 1	1.9	260	.40
362026096265101	22N-08E-33 ACD 1	4.9	470	<.10
362402096193901	22N-09E-10 BDA 1	8.8	200	<.10
362055096220501	22N-09E-29 CCD 1	24	190	.50
362202096125701	22N-10E-22 DBA 1	.60	68	.20
362105096140901	22N-10E-28 DBC 1	15	300	<.10
362011096133201	22N-10E-34 CBC 1	1.8	510	.30
362222096040101	22N-11E-24 AAD 1	92	1,200	6.2
363023096570101	23N-03E-02 ABB 1	2.7	400	.40
362839096570501	23N-03E-14 BAA 1	1.0	180	.70
362659096414801	23N-06E-19 DCD 1	6.8	490	.80
362731096352801	23N-07E-19 ACB 1	1.4	160	<.10
362926096242901	23N-08E-11 AAA 1	7.7	860	.20
362809096254801	23N-08E-15 DBA 1	290	1,200	.10
363014096204601	23N-09E-04 BAD 1	22	700	--
362757096192601	23N-09E-15 DCB 1	18	2,200	.90

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon organic, total dissolved (mg/L as C)
362729096211701	23N-09E-20 DAA 1	5.6	380	.40
362629096175401	23N-09E-25 BCC 1	16	2,600	1.6
362611096175201	23N-09E-25 CCB 1	<.20	380	2.2
362651096203301	23N-09E-28 ABB 1	2.3	490	.30
362541096195701	23N-09E-34 BCC 1	38	160	<.10
363204096552601	24N-04E-30 BBB 1	2.0	630	.70
363233096430501	24N-05E-24 DBB 1	.50	330	<.10
363406096320501	24N-07E-10 DDB 1	2.2	400	<.10
363155096342401	24N-07E-29 ACA 1	1.0	52	<.10
363453096264101	24N-08E-04 DDA 1	19	13,200	<.10
363216096234501	24N-08E-24 DCA 1	3.4	70	.10
363033096272101	24N-08E-33 CDB 1	<.20	770	.40
363419096195001	24N-09E-10 BCD 1	120	150	--
363421096171601	24N-09E-12 ACD 1	97	110	--
363246096204701	24N-09E-21 BDA 1	4.7	390	.60
363259096191901	24N-09E-22 ABA 1	55	380	3.2
363025096230901	24N-09E-31 CCD 1	4.0	290	.30
363529096161801	24N-10E-06 ABB 1	9.1	520	--
363533096164601	24N-10E-06 BBB 1	2.4	110	--
363438096134601	24N-10E-09 AAA 1	10	1,200	<.10
363256096135501	24N-10E-21 ABA 1	43	540	.20
363154096113101	24N-10E-26 AAD 1	.40	190	.10
363143096005501	24N-12E-28 ADC 1	<.20	380	<.10

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon organic, total dissolved (mg/L as C)
364022097030001	25N-02E-02 DAA 1	.40	380	<.10
364039096594201	25N-03E-05 AAD 1	.30	650	.60
363949096561801	25N-03E-12 BBA 1	5.5	630	.70
363115096573601	25N-03E-35 BB 1	.50	400	<.10
363943096431901	25N-05E-12 BCA 1	240	670	.80
364000096373901	25N-06E-02 CDD 1	<.20	310	<.10
363920096414001	25N-06E-07 DBD 1	15	720	2.8
363735096403201	25N-06E-20 DAC 1	.60	1,100	.80
364000096253001	25N-08E-03 DDC 1	6.4	860	1.6
363807096255901	25N-08E-22 BAB 1	.30	770	.50
363801096243901	25N-08E-23 ABC 1	8.5	940	1.2
363745096234301	25N-08E-24 CAA 1	1.5	930	.90
363616096292701	25N-08E-31 BBD 1	<.20	250	.40
364023096170401	25N-09E-01 ACC 1	3.9	270	.50
363849096214401	25N-09E-17 BDB 1	6.9	730	.20
363838096225301	25N-09E-18 CBA 1	160	690	1.7
363729096204001	25N-09E-21 CDB 1	3.0	1,600	.50
363756096171101	25N-09E-24 BDA 1	.30	1,100	.20
363631096192101	25N-09E-27 CDD 1	21	380	4.1
363646096210101	25N-09E-29 DAD 1	3.0	790	<.10
363539096184501	25N-09E-35 CCC 1	81	3,600	.60
364015096114801	25N-10E-02 CAD 1	<.20	180	.20
363829096153101	25N-10E-17 CBC 1	89	2,200	--
363729096142801	25N-10E-20 DDA 1	.30	540	--

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon organic, total dissolved (mg/L as C)
363744096135401	25N-10E-21 DBB 1	53	460	--
363546096144601	25N-10E-32 DCA 1	27	1,600	.20
363539096133501	25N-10E-33 DDC 1	.80	830	.40
363827096064801	25N-11E-15 CBC 1	10	67	.10
364125097024401	26N-02E-36 BCA 1	<.20	420	.60
364300096432301	26N-05E-24 DBA 1	21	540	.60
364455096270801	26N-08E-09 BCA 1	<.20	90	<.10
364515096183701	26N-09E-02 CCD 1	26	1,000	<.10
364451096214601	26N-09E-08 BDB 1	.60	460	.20
364343096174101	26N-09E-13 CBC 1	12	340	.40
364101096230501	26N-09E-31 CCB 1	<.20	8,700	<.10
364140096215901	26N-09E-32 BBB 1	1,400	1,100	.60
364124096192901	26N-09E-34 BDA 1	16	550	1.3
364328096152601	26N-10E-17 CCC 1	2.0	160	.20
364055096140501	26N-10E-33 CCA 1	<.20	170	.90
364943096293701	27N-07E-12 DDA 1	1.8	100	.20
364820096270901	27N-08E-21 BCD 1	1.2	990	1.1
364906096174801	27N-09E-14 ADD 1	120	170	<.10
364624096221601	27N-09E-31 DAB 1	<.20	670	<.10
364635096193101	27N-09E-34 BDB 1	220	360	<.10
364901096104501	27N-10E-13 DBB 1	11	810	.20
364752096141501	27N-10E-21 CDB 1	.60	57	.10
364805096102101	27N-10E-24 DAD 1	200	1,500	<.10

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon organic, total dissolved (mg/L as C)
364714096133201	27N-10E-28 DAA 1	1.4	75	.20
364640096142001	27N-10E-33 BCA 1	750	460	.40
365053096093401	27N-11E-06 ACC 1	.90	150	--
365623096252901	28N-08E-03 AAC 1	19	320	.90
365501096274501	28N-08E-08 DBD 1	.50	260	.30
365205096244201	28N-08E-35 ABB 1	.40	630	<.10
365601096174301	28N-09E-01 BCC 1	.20	310	<.10
365549096224301	28N-09E-06 CAD 1	6.7	64	.20
365522096183001	28N-09E-11 BAC 1	3.7	47	<.10
365350096183101	28N-09E-23 BAB 1	6.8	53	.20
365420096120101	28N-10E-11 CDC 1	22	1,400	<.10
365419096154301	28N-10E-18 ADD 1	54	1,300	.30
365342096120501	28N-10E-23 BAC 1	9.6	430	.50
365514096041601	28N-11E-12 BDD 1	.60	670	.40
365431096074101	28N-11E-16 BAC 1	100	800	.10
365250096070801	28N-11E-28 AAC 1	<.20	300	1.3
365341096012701	28N-12E-21 BBC 1	1.0	920	1.0
365924096413501	29N-06E-18 DBA 1	780	1,400	4.5
365811096414201	29N-06E-30 ABB 1	<.20	840	.50
365830096175801	29N-09E-23 DBC 1	4.1	1,700	.90
365906096164201	29N-09E-24 ABA 1	.30	580	.30
365806096182201	29N-09E-26 BBD 1	.60	410	.50
365955096111901	29N-10E-14 ABA 1	2.1	160	1.1

Appendix 4. Chemical analyses of ground-water samples from wells in the Osage Reservation, Oklahoma—Continued

Site-identification number	Local identifier	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Carbon organic, total dissolved (mg/L as C)
365915096125601	29N-10E-15 CCA 1	150	580	.30
365727096133501	29N-10E-27 CCC 1	.80	930	.10
365657096141401	29N-10E-32 ADD 1	5.3	370	<.10
365723096094601	29N-11E-30 CCC 1	210	2,100	1.0
365637096063501	29N-11E-34 CCB 1	28	2,400	<.10