Prepared in cooperation with the
OSAGE TRIBAL COUNCIL AND BUREAU OF INDIAN AFFAIRS

Aquifer Characteristics, Water Availability, and Water Quality of the Quaternary Aquifer, Osage County, Northeastern Oklahoma, 2001-2002

Water-Resources Investigations Report 03–4235

Photograph of Arkansas River taken by Chris Neel, U.S. Geological Survey.

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
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)

Multiply	By	To obtain
Volume		
acre-foot (acre-ft)	1,233	cubic meter (m^3)
Flow rate		
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
centimeter per second (cm/s)	2834.6	foot per day (ft/d)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Transmissivity*		
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

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).

Aquifer Characteristics, Water Availability, and Water Quality of the Quaternary Aquifer, Osage County, Northeastern Oklahoma, 2001-2002

By Shana L. Mashburn, Caleb C. Cope, and Marvin M. Abbott

Abstract

Additional sources of water are needed on the Osage Reservation for future growth and development. The Quaternary aquifer along the Arkansas River in the Osage Reservation may represent a substantial water resource, but limited amounts of hydrogeologic data were available for the aquifer. The study area is about 116 square miles of the Quaternary aquifer in the Arkansas River valley and the nearby upland areas along the Osage Reservation. The study area included the Arkansas River reach downstream from Kaw Lake near Ponca City, Oklahoma to upstream from Keystone Lake near Cleveland, Oklahoma.

Electrical conductivity logs were produced for 103 test holes. Water levels were determined for 49 test holes, and 105 water samples were collected for water-quality field analyses at 46 test holes. Water-quality data included field measurements of specific conductance, pH, water temperature, dissolved oxygen, and nitrate (nitrite plus nitrate as nitrogen). Sediment cores were extracted from 20 of the 103 test holes.

The Quaternary aquifer consists of alluvial and terrace deposits of sand, silt, clay, and gravel. The measured thickness of the alluvium ranged from 13.7 to 49.8 feet. The measured thickness of the terrace sediments ranged from 7 to 93.8 feet. The saturated thickness of all sediments ranged from 0 to 38.2 feet with a median of 24.8 feet. The weighted-mean grain size for cores from the alluvium ranged from 3.69 to 0.64 ϕ, (0.08-0.64 millimeter), and ranged from 4.02 to 2.01 ϕ (0.06-0.25 millimeter) for the cores from terrace deposits. The mean of the weighted-mean grain sizes for cores from the alluvium was 1.67 ϕ (0.31 millimeter), and the terrace deposits was 2.73 ϕ (0.15 millimeter). The hydraulic conductivity calculated from grain size of the alluvium ranged from 2.9 to 6,000 feet per day and of the terrace deposits ranged from 2.9 to 430 feet per day. The calculated transmissivity of the alluvium ranged from 2,000 to 26,000 feet squared per day with a median of 5,100 feet squared per day. Water in storage in the alluvium was estimated to be approximately 200,000 acre-feet. The amount of water annually recharging the aquifer was estimated to be approximately 4,800 acre-feet.

Specific conductance for all water samples ranged from 161 to 6,650 microsiemens per centimeter. Median specific conductance for the alluvium was 683 microsiemens per centimeter and for the terrace deposits was 263 microsiemens per centimeter. Dissolved-solids concentrations, estimated from specific conductance, for water samples from the aquifer ranged from 88 to 3,658 milligrams per liter. Estimated median dissolved-solids concentration for the alluvium was 376 milligrams per liter and for the terrace deposits was 145 milligrams per liter. More than half of the samples from the Quaternary aquifer were estimated to contain less than 500 milligrams per liter dissolved solids. Field-screened nitrate concentrations for the sampling in December 2001-August 2002 ranged from 0 to 15 milligrams per liter. The field-screened nitrate concentrations for the second sampling in September 2002 were less than corresponding laboratory reported values.

Introduction

Additional sources of water are needed on the Osage Reservation for future growth and development. The Quaternary aquifer along the Arkansas River in the Osage Reservation may represent a substantial water resource, but limited amounts of hydrogeologic data were available for the aquifer. The U.S. Geological Survey (USGS), in cooperation with the Osage Tribe and the Bureau of Indian Affairs, conducted a study to assess the availability and quality of ground water in the Quaternary aquifer in the Osage Reservation, Osage County, northeastern Oklahoma. The study area is about 116 square miles of the Quaternary aquifer in the Arkansas River valley and the nearby upland areas along the Osage Reservation. The study area included the Arkansas River reach downstream from Kaw Lake near Ponca City, Oklahoma to upstream from Keystone Lake near Cleveland, Oklahoma (fig. 1). The field work was conducted from December 2001 to September 2002 and 103 test holes were driven in the aquifer during that time. Saturated thickness of the aquifer was determined by measuring water levels in the test holes. Data collected included electrical conductivity logs, sediment cores, and water-quality field measurements of specific conductance, pH, water temperature, dissolved oxygen, and nitrite plus nitrate as nitrogen (referred to as nitrate in this report).

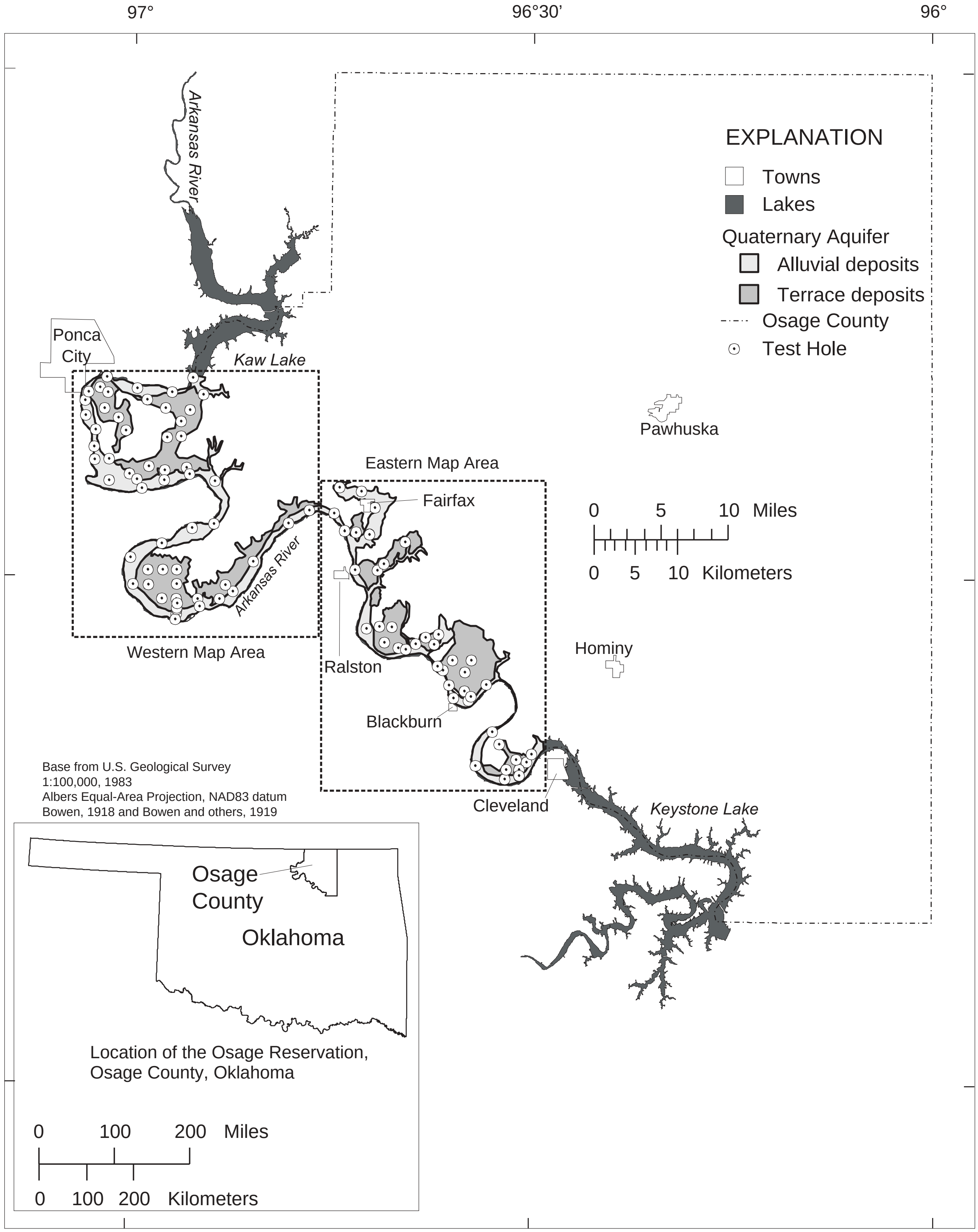


Figure 1. Location of the study area, Quaternary aquifer, and site locations, western Osage County, Oklahoma.

Purpose and Scope

This report describes aquifer characteristics, water availability, and water quality for the Quaternary aquifer in Osage County based on data collected in 2001-2002. This report presents the measured sediment thickness, saturated thickness, sediment grain-size, net sand, and calculated hydraulic conductivity and transmissivity. This report also presents potential water availability for the Quaternary aquifer. Summary statistics for aquifer characteristics and water-quality data are included.

Acknowledgments

The authors thank the farmers, ranchers, and landowners for providing access to their land. Thanks to Greg McMahn, Chesapeake Energy, for scanning the large-scale maps of the study area into digital format (Bowen, 1918 and Bowen and others, 1919). Special thanks are extended to the Osage Tribal Council and the Osage Environmental Council. The authors also thank U.S. Geological Survey colleagues Scott Christenson for technical support, Mike Sughru for creating the illustrations, and Scott Strong for field assistance.

Description of Study Area

The Osage Reservation, comprising Osage County, contains about 2,260 square miles (fig. 1). The Reservation is characterized by gently rolling uplands with sharp cuestas formed by resistant sandstone and limestone ledges. The Arkansas River borders the Reservation on the south and southwest (fig. 1). The western part of the Reservation, known informally as the Bluestem Hills, is mostly open savanna. The altitude of the surface of the alluvium ranges from 945 feet above NAVD 88 below the dam on Kaw Lake near Ponca City, Oklahoma to 725 feet west of Cleveland. The distance along the Arkansas River is about 94 miles. Mean annual precipitation across the study area ranged from 34 inches near Ponca City to 37 inches near Cleveland during the period 1971 to 2000 (Oklahoma Climatological Survey, 2002).

Description of Quaternary Aquifer

The Quaternary aquifer (figs. 1, 2, and 3) consists of alluvial and terrace deposits of sand, silt, clay, and gravel of Quaternary age (Bingham and Bergman, 1980, plates 1 and 2). The contact between the alluvial and the terrace deposits, for this study, is located where the slope in the Arkansas River valley changes from a low angle on the alluvium to a greater angle on the terrace deposits (fig. 4). The alluvium was deposited by the Arkansas River and the lesser tributary streams. The terrace deposits were deposited by the Arkansas River at a time when it flowed at a higher level. The material was later reworked by the prevailing wind from the southwest, and deposited on the upland areas generally north of the Arkansas River valley (Oakes, 1952, p. 95-96). The Quaternary aquifer is unconfined and uncemented in most areas. Recharge to the alluvial and terrace deposits in the Reservation is mostly from precipitation. Recharge in the study area is about 1.5 inches per year (Pettyjohn and others, 1983, p. 42-43).

Maps of the study area in this report will be presented in the format shown in figures 2 and 3. The western area will be presented first and then the eastern area, because of the scale needed to see closely-spaced test holes.

Methods

Test hole locations were distributed across the alluvial and terrace deposits on private land and along road rights-of-way. Data from these 103 test holes were used to characterize the Quaternary aquifer. Electrical conductivity log data were used to define the sediment in the aquifer. Water-level measurements were used to describe the saturated thickness of the aquifer. Water samples were collected from test holes and used to measure water-quality properties. Sediment cores were analyzed for grain size and used to calculate hydraulic conductivity and transmissivity. Net sand and saturated thickness were mapped to provide a tool for evaluating potential water availability of the Quaternary aquifer.

Site Selection

Test holes were placed on private land and along road rights-of-way underlain by alluvial and terrace deposits. Test hole locations depended on landowner permission and road accessibility. The 103 test holes were distributed across the alluvial and terrace deposits (figs. 2 and 3). Geologic sections X-X' and Y-Y' were constructed from test-hole data obtained along two transects of closely-spaced test holes that extended from the terrace deposits to the alluvium near the river channel (figs. 2 and 3). These transects were located to investigate changes in the sediment type, water level, and water quality across the aquifer. Site locations were determined using a global positioning system with a horizontal accuracy of about 30 feet. Each site was assigned a local identifier number made up of a site sequence number and a letter identifying alluvium (A) or terrace deposit (T).

Field Procedures

A truck-mounted Geoprobe was used to make 103 temporary test holes. No materials were permanently installed in the aquifer. Electrical conductivity logs were produced for each test hole to define the aquifer thickness and to estimate sediment grain size. Water levels were determined for 49 test holes, and water samples were collected for water-quality field analyses at 46 test holes yielding enough water to sample. Sediment cores were extracted from 20 of the 103 test holes for sieve analyses

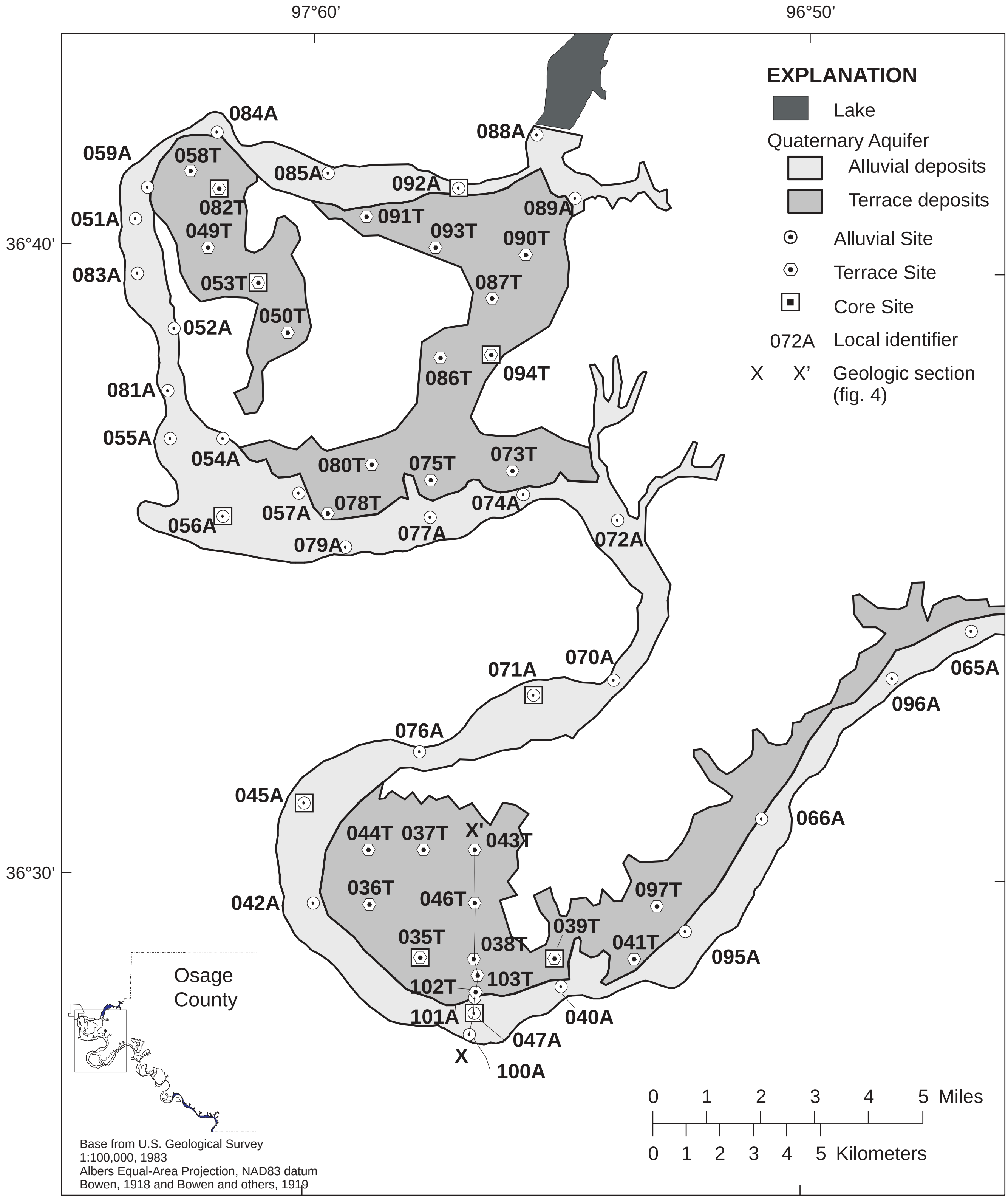


Figure 2. Quaternary aquifer and site locations, western map of the study area, western Osage County, Oklahoma.

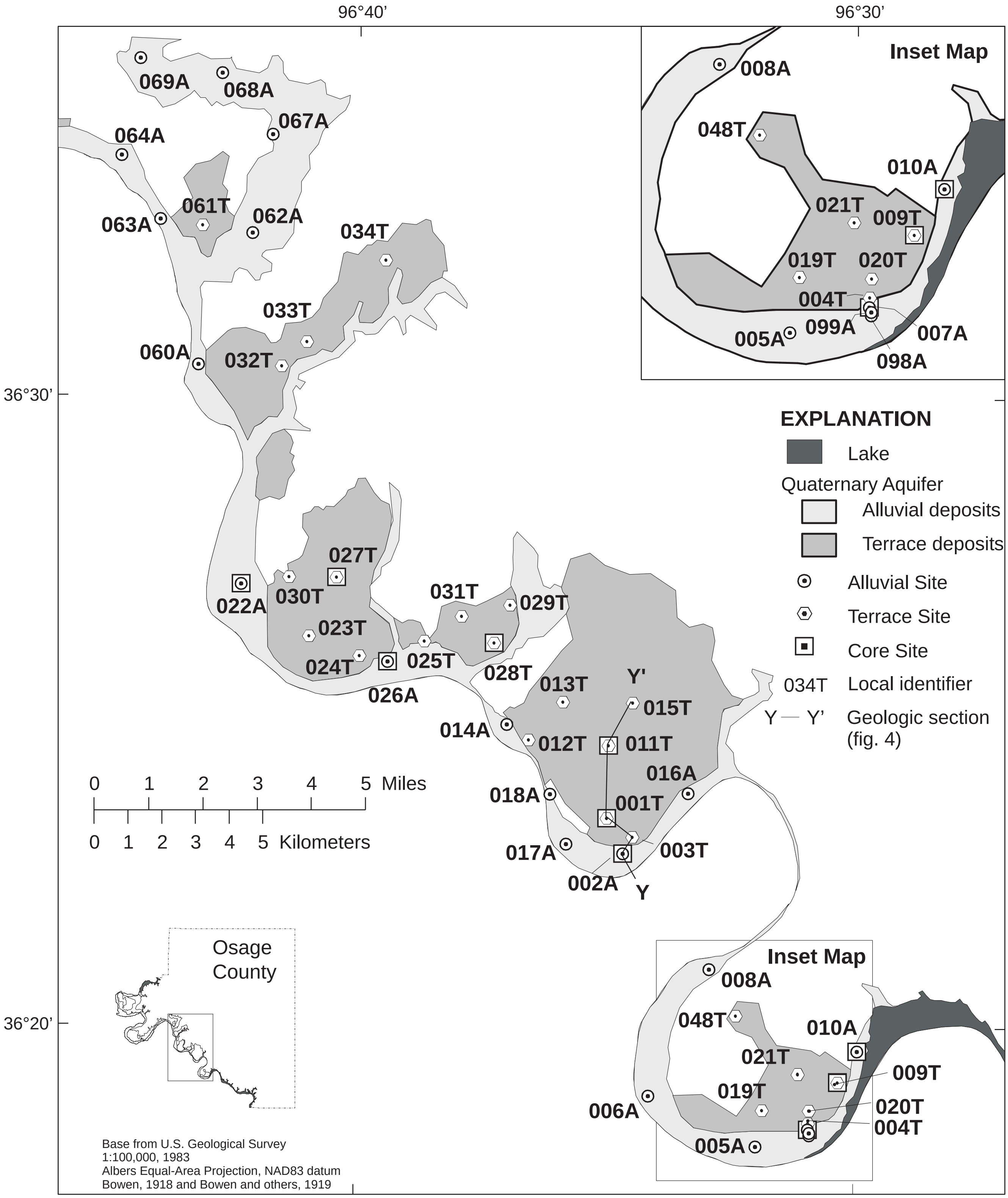


Figure 3. Quaternary aquifer and site locations, eastern map of the study area, western Osage County, Oklahoma.

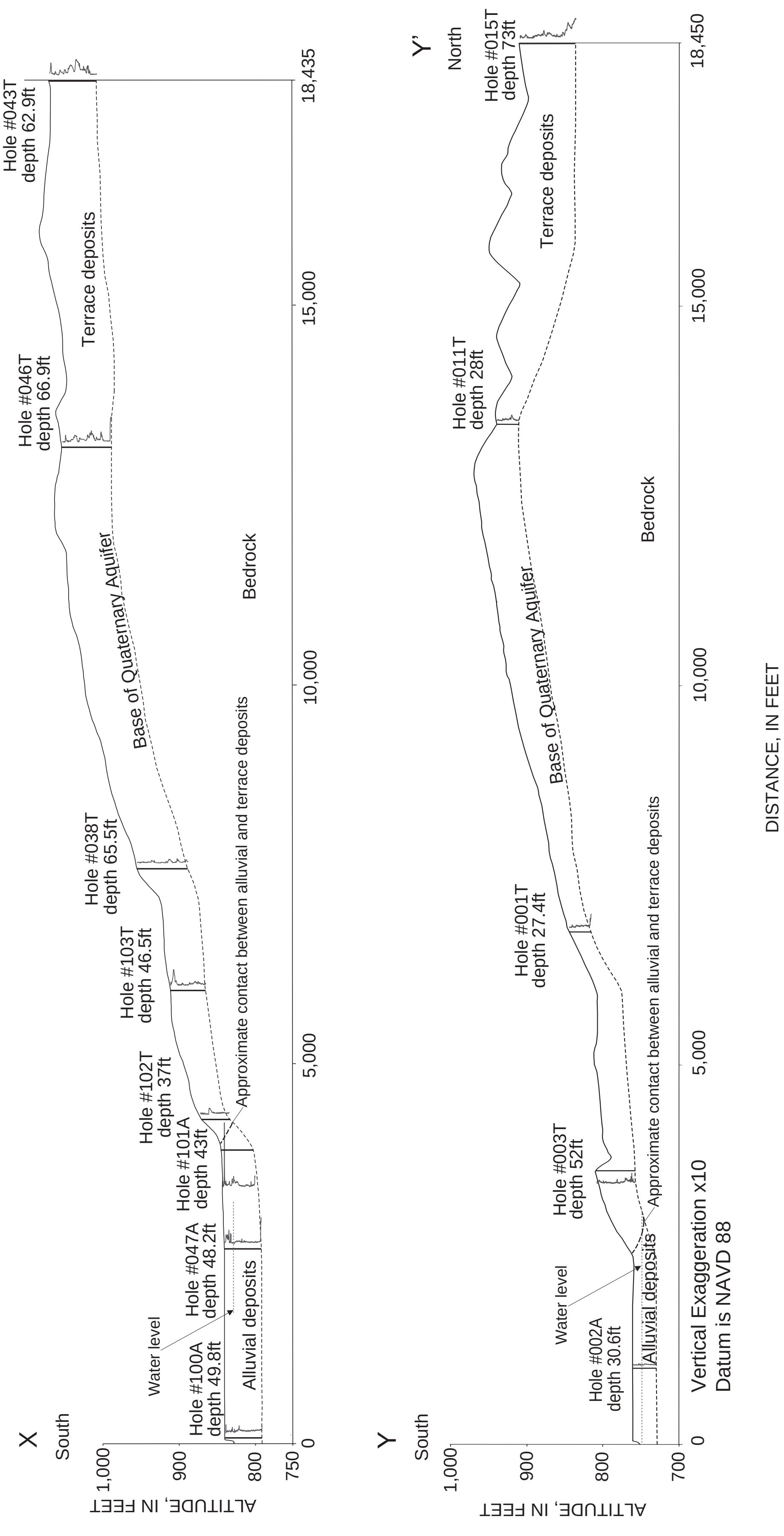


Figure 4. Geologic sections X-X' and Y-Y' based on electrical conductivity log profiles of the Quaternary aquifer, western Osage County, Oklahoma.

of grain size and interpretation of sediment grain size from the electrical conductivity logs.

Electrical Conductivity Logs

An electrical conductivity probe, 15 inches long and 1.5 inches in diameter, was used to measure the electrical conductivity of the alluvial and terrace deposits in a vertical profile. Conductivity log data were relayed through a coaxial cable to a computer at the surface as the probe advanced into the ground. The depth where the probe penetration slowed markedly was assumed to be bedrock at the base of the Quaternary aquifer.

Water Levels and Water Samples

A 1-foot long stainless steel screen of 1.25-inch diameter was driven down into the aquifer to make a hole for water-level measurements and water samples. Extraction of the conductivity probe out of the test hole disturbed the aquifer sediments and the possibility of collecting water samples from discrete zones; therefore, a new hole was created within 6 inches of the hole used for conductivity measurements. An electric water-level sounding device was lowered into the new test hole to measure the depth to water from land surface. Measurements were recorded to the nearest 0.1 foot.

Water samples were collected using polyethylene tubing and a peristaltic pump. Water samples were collected at three depth intervals, where possible. The sample depth listed in Appendix 2 was the deepest depth of the screened interval. The objective was to sample at shallow, medium, and deep intervals below the water table. Designations of shallow, medium, and deep intervals below the water table in this report were arbitrarily chosen as 0 to 10 feet, greater than 10 to 20 feet, and greater than 20 feet. Water was pumped for at least 2 minutes at each sample level or until the water visually cleared of turbidity before sampling. Specific conductance, pH, and water temperature were measured using electrometric meters. Dissolved oxygen and nitrate were measured using field screening colorimetric methods. The dissolved-oxygen concentrations were measured using the indigo carmine method, with a minimum reporting limit of 1 milligram per liter (mg/L) (CHEMetrics, CHEMets kit, K-7512). The nitrate concentrations were measured using cadmium-reduction/azo dye formation method, with a minimum reporting limit of 2.5 mg/L (CHEMetrics, vacuettes kit, K-6902D). Ten test holes were sampled a second time to evaluate changes in nitrate concentrations with time and to compare field-screened nitrate concentrations with laboratory analyses. The USGS National Water Quality Laboratory in Lakewood, Colorado, analyzed the 10 nitrate samples using a cadmium-reduction colorimetry method with a laboratory reporting limit of 0.06 mg/L. At the same time the 10 nitrate samples were collected for the laboratory analyses, water samples were collected and tested using the field screening colorimetric method for comparison of results.

Laboratory Core Analysis

Sediment cores were collected from 20 of the 103 test holes, (figs. 2 and 3). Ten cores each were collected from the alluvium and from the terrace deposits. The cores were collected for the entire thickness of the aquifer in 4-foot intervals inside 1.5-inch diameter plastic sleeves. The cores were kept vertical until completely dried to maintain the stratification of the sediments. After drying, the sediment cores were divided into units based on visual interpretation of gross grain size. Sediment samples weighing about 100 grams each were collected from each of the units. A series of 10 wire-mesh sieves with openings ranging in size from 16 to 0.045 millimeters (mm) were stacked in descending order with the largest size on top. Each sediment sample was placed in the top sieve and then shaken for about 12 minutes in a Rotap sieving machine. This process separated the sediment sample into 10 units by grain size. The amount of sediment collected in each sieve was weighed using a digital scale. Weight percent of each sieve size was plotted against cumulative weight percent to produce a cumulative frequency curve for each sample (fig. 5).

Grain sizes shown on the cumulative frequency curves are expressed in phi (ϕ) values. The ϕ value is a logarithmic scale that allows grain size data to be expressed in units of equal value for the purpose of graphical plotting and statistical calculations. Particle size, expressed in millimeters, decreases with increasing ϕ values and increases with decreasing ϕ values (Boggs, 1995, p. 80). The relation of phi to a diameter in millimeters is expressed by:

$$\phi = -\log_2 d \qquad (1)$$

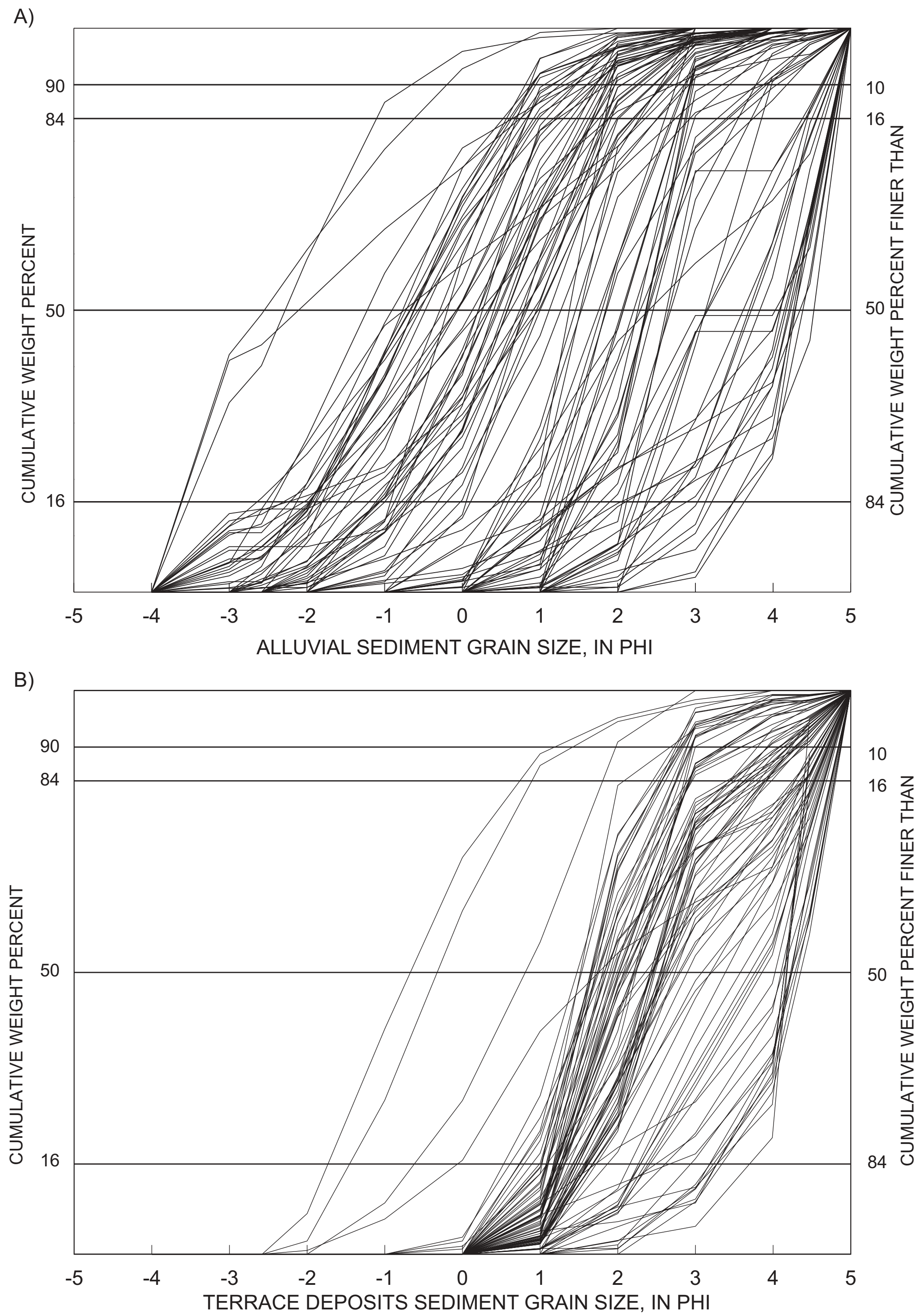
where “d” is the diameter of the sediment grains.

The weighted-mean grain size for each core was determined by the following method:

1. Cumulative frequency curves (fig. 5A and 5B) for each sample were plotted.
2. The 16, 50, and 84 percentile ϕ values were averaged to get the sample-interval mean grain size, in phi units (Folk, 1968, p. 45).
3. The sample-interval mean grain size was multiplied by the sample-interval thickness, in feet, to get an interval-thickness-mean grain size, in phi units.
4. The interval-thickness-mean grain size values were summed and divided by the total thickness, in feet, of the core to get a weighted-mean grain size, in phi units.

Aquifer Characteristics

Aquifer characteristics determined for this report include sediment thickness, saturated thickness, sediment grain size, and net sand. The sediment thickness defines how much sediment was present at each test hole site. The saturated thickness



Pebble	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Coarse Silt

(Udden, 1914, Wentworth, 1922)

Figure 5. Cumulative frequency plots of sediment grain size from the Quaternary aquifer, western Osage County, Oklahoma.

establishes how much water was present in the aquifer at the time of the study. The sediment grain size distribution provided data for calculating the hydraulic conductivity and transmissivity. The net sand data describes how much aquifer material was present to transmit water readily. These aquifer characteristics were used to calculate hydraulic conductivity and transmissivity and evaluate the potential water availability of the Quaternary aquifer.

Sediment Thickness

The total sediment thickness at each test hole was determined from the depth penetrated by the electrical conductivity probe. The measured thickness of the alluvium ranged from 13.7 to 49.8 feet (fig. 4, and Appendix 1). The measured thickness of the terrace sediments ranged from 7 to 93.8 feet (fig. 4, and Appendix 1).

Saturated Thickness

Water levels were determined for 42 of the 52 test holes in alluvial deposits, and for 7 of the 51 test holes in terrace deposits. All test holes in the alluvial deposits contained water, but water levels were not measured for 10 of the 52 alluvial test holes because of complications in the field. Water levels were measured from June to September 2002. Although most of the test holes in terrace deposits were dry, five of the test holes contained sufficient water for sampling. Water levels could not be measured for 1 of these 5 test holes in terrace deposits because of complications in the field. The saturated thickness of all sediments ranged from 0 to 38.2 feet with a median of 24.8 feet, (figs. 6, 7, and Appendix 1).

Sediment Grain Size

The weighted-mean grain size for cores from the alluvial deposits ranged from 3.69 to 0.64 ϕ, (0.08-0.64 mm), and ranged from 4.02 to 2.01 ϕ (0.06-0.25 mm) for the cores from terrace deposits. The mean of the weighted-mean grain sizes for cores from the alluvial deposits was 1.67 ϕ (0.31 mm), and the terrace deposits was 2.73 ϕ (0.15 mm). Two cores, 028T and 039T (figs. 2 and 3), were located in areas of increased slope near the boundary of the alluvium and the terrace deposits and initially were designated as terrace deposits. Samples taken from the base of these cores are represented by the four anomalous curves on the left in figure 5B. These coarse sediments indicated in the curves for these samples are more representative of alluvial deposits than terrace deposits and were not included in the grain-size calculations for the terrace deposits.

Net Sand

Electrical conductivity logs were compared to the core data of the alluvial and the terrace deposits to determine log responses for sand-gravel intervals and for silt-clay intervals. The electrical conductivity of the sand and gravel intervals was typically less than 30 millisiemens per meter. The silt and clay intervals were generally greater than 30 millisiemens per meter (fig. 8). The net sand (figs. 6, 7, and Appendix 1), which includes both sand and gravel, was estimated for each test hole from electrical conductivity logs (fig. 8). The net sand of the alluvium ranged from 0.7 to 47.5 feet with a median of 24.5 feet. The net sand of the terrace deposits ranged from 0.1 to 85.3 feet with a median of 30.9 feet.

Calculated Hydraulic Conductivity and Transmissivity

Hydraulic conductivity is the rate at which water moves through a porous medium under a unit head gradient (Fetter, 1988, p. 571). Hydraulic conductivity was calculated from grain size at which 10 percent of the grains are finer by weight (Fetter, 1988, p. 81). This grain size for each sample is equivalent to the 90 percent cumulative weight percent shown in figure 5. Grain size values of low permeability, such as clays, were eliminated from the hydraulic conductivity calculation. The hydraulic conductivity was calculated for each sieve sample by squaring the 10 percent finer grain size, in centimeters, and multiplying by a constant of 80 to get centimeters per second (cm/s) (Fetter, 1988, p. 81). The hydraulic conductivity in cm/s was converted to feet per day (ft/d) (Appendix 3). Then the hydraulic conductivity in ft/day was averaged for each core. The calculated hydraulic conductivity of the alluvium ranged from 2.9 ft/d to 6,000 ft/d and the terrace deposits ranged from 2.9 ft/d to 430 ft/d. The mean of these hydraulic conductivity values for the alluvium was 290 ft/d and the mean for the terrace deposits was 30 ft/d.

Transmissivity is defined as the amount of water that can be transmitted horizontally by a fully saturated thickness of the aquifer under a unit hydraulic gradient (Fetter, 1988, p. 578). The standard unit for transmissivity is cubic feet per day per square foot multiplied by the feet of saturated thickness of the aquifer, which reduces to feet squared per day, (ft^2/d).

Transmissivity values for each cored test hole was calculated by multiplying the mean hydraulic conductivity value for the test hole and the saturated thickness for the test hole. The transmissivity of the six cored test holes in the alluvial deposits ranged from 2,000 ft^2/d to 26,000 ft^2/d and the median was 5,100 ft^2/d.

Water Availability

Water availability was evaluated by mapping net sand and saturated thickness of the Quaternary aquifer (figs. 6 and 7). These maps depict only estimates of water availability for the aquifer. The most accurate way to evaluate water availability is to drill wells and perform aquifer tests. Zones that will produce more water are those that have greater sand thickness and greater saturated thickness if water-transmitting characteristics

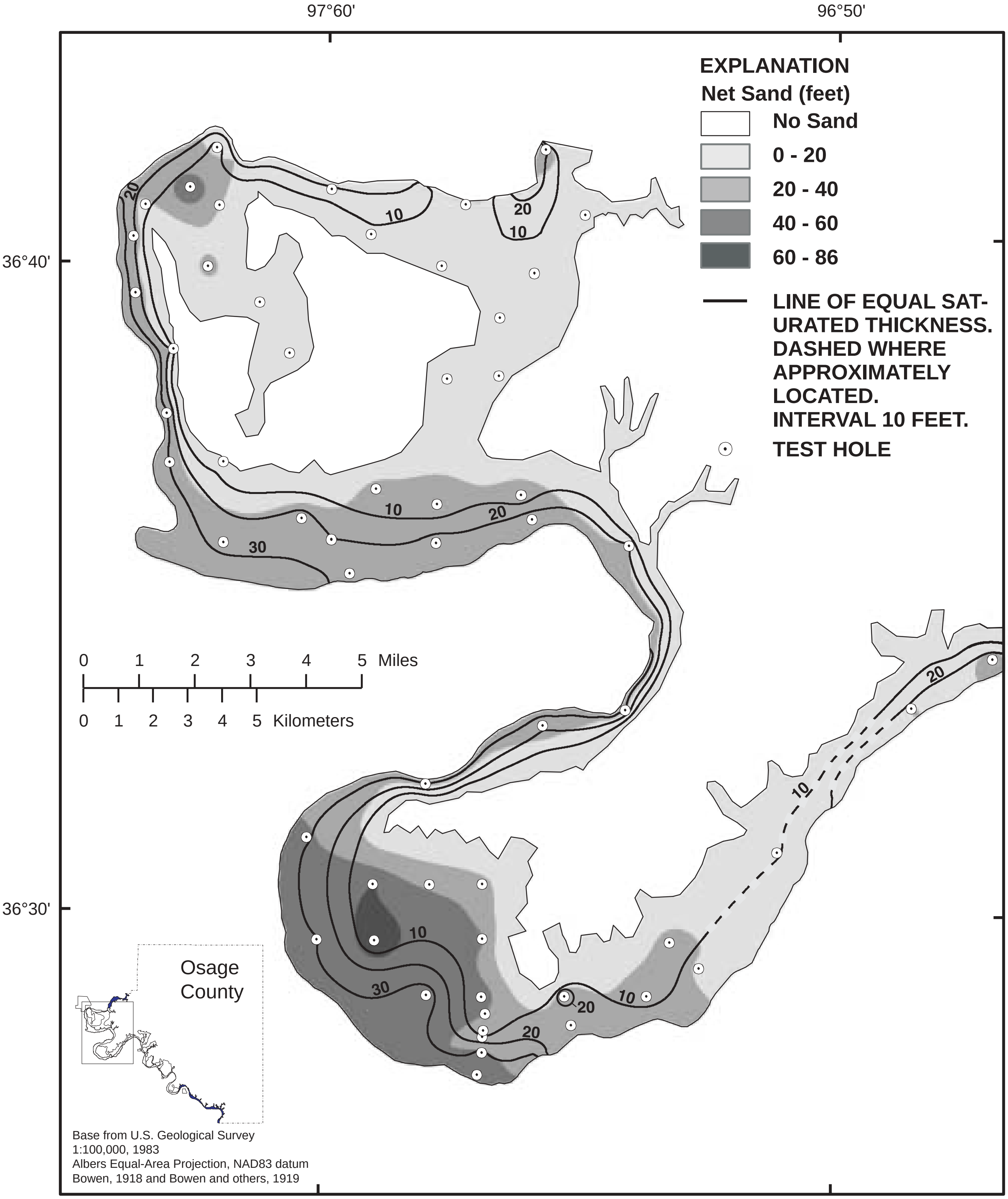


Figure 6. Net sand and saturated thickness, western map of the study area, western Osage County, Oklahoma; water levels for saturated thickness measured June to September 2002.

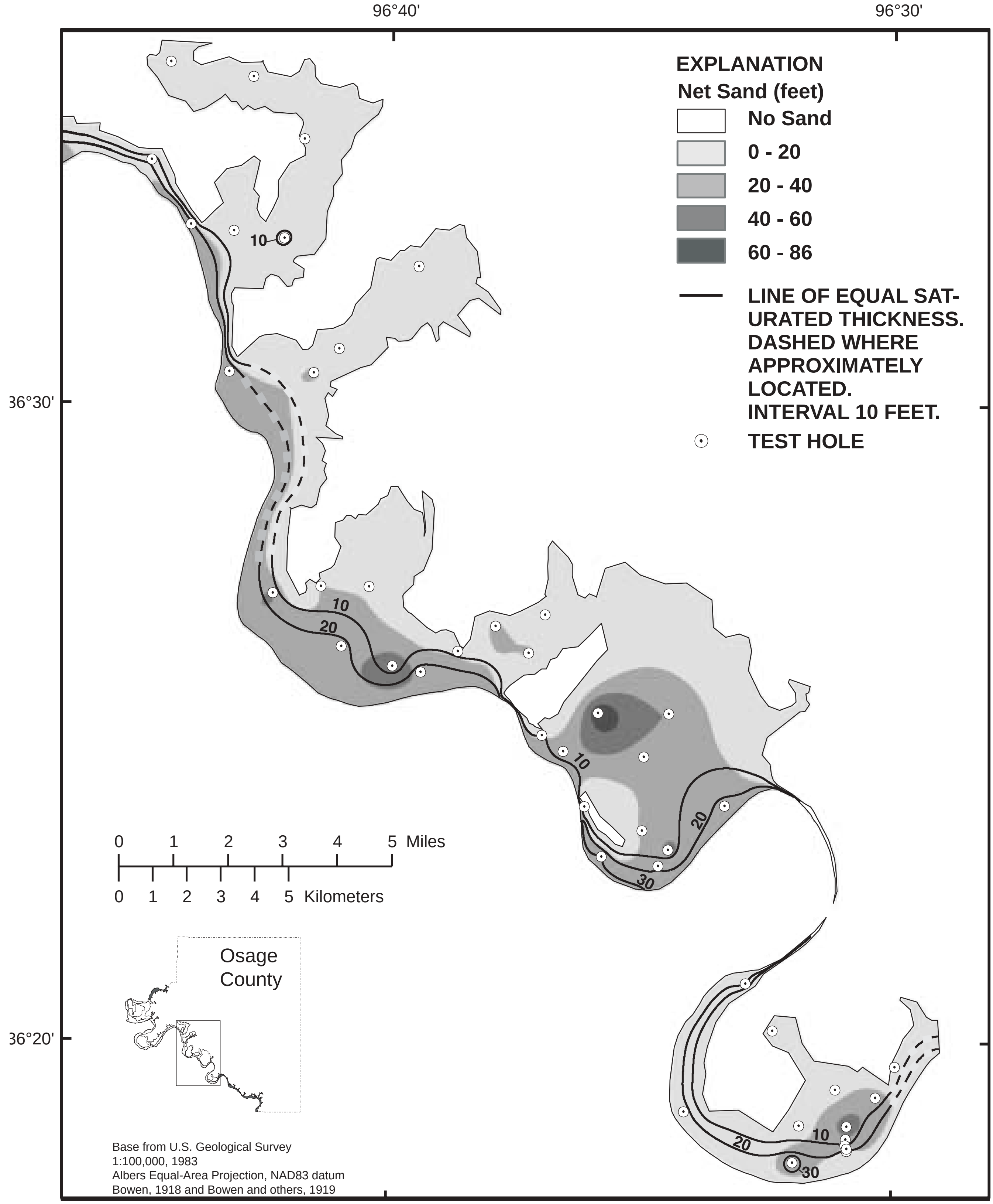


Figure 7. Net sand and saturated thickness, eastern map of the study area, western Osage County, Oklahoma; water levels for saturated thickness measured June to September 2002.

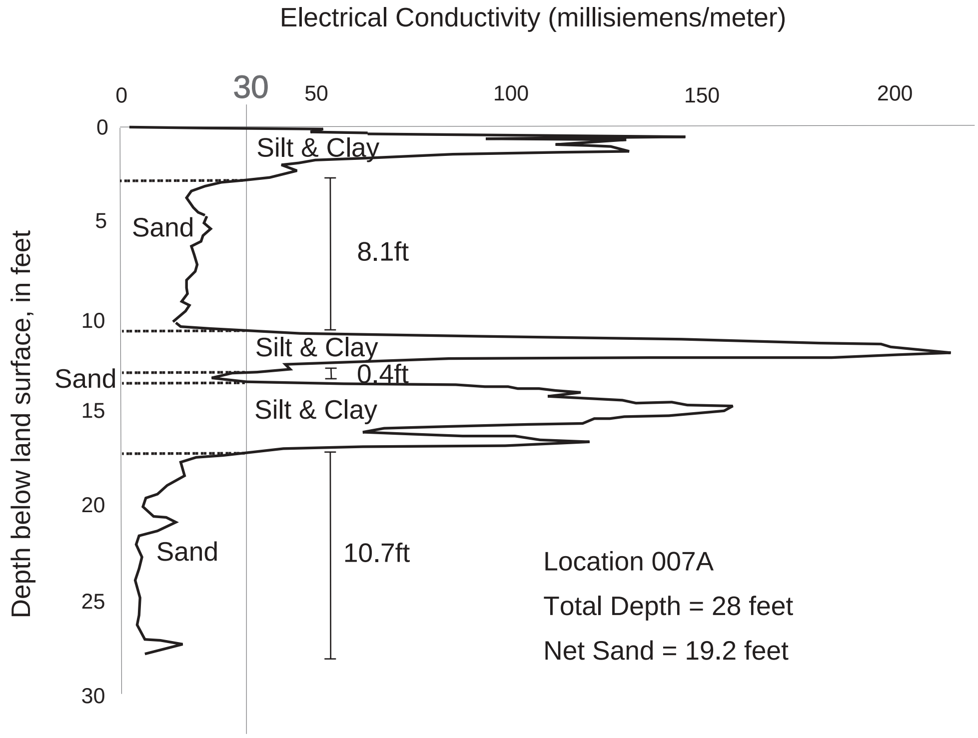


Figure 8. Electrical conductivity log profile with a 30 millisiemens arbitrary limit for estimating net sand.

are similar. Water levels were measured from June to September 2002 to determine saturated thickness. Saturated thickness varies according to the amount of seasonal precipitation and river levels for parts of the aquifer near the river, adding some variability to estimated saturated thickness (figs. 6 and 7). Given a specific yield of 20 percent (Walton, 1970), 38,450 acres of alluvial deposits in the study area, and an average saturated thickness of 25 feet, water in storage in the alluvium was estimated to be approximately 200,000 acre-feet. The amount of water annually recharging the aquifer is approximately 4,800 acre-feet, given an estimated annual recharge of 1.5 inches per year (Pettyjohn and others, 1983, p.42-43) and 38,450 acres of alluvial deposits in the study area. These storage and recharge estimates would change during development of the aquifer. Development of pumping well fields would likely induce leakage from the adjoining Arkansas River and underlying bedrock units, potentially providing more water than what is available in the alluvial and terrace sediments.

Water Quality

Water-quality data from the Quaternary aquifer included field measurements of specific conductance, pH, water temperature, dissolved oxygen, and nitrate. One hundred five water-quality samples were analyzed from the 46 test holes that produced enough water to sample (Appendix 2). Water samples were collected from December 2001 to August 2002. Ninety-eight samples were from the alluvial deposits and seven were from the terrace deposits. The terrace deposit locations that contained ground water were few, but were distributed across the study area (figs. 9, 10, 11, and 12).

The National Primary Drinking Water Regulations and National Secondary Drinking Water Standards are used to evaluate health risks and drinking water quality (U.S. Environmental Protection Agency [USEPA], 2002). The primary regulations are enforceable for public water systems based on health risks, while the secondary standards are guidelines for the aesthetic quality of drinking water.

Specific conductance is a measure of the ability of fluid to transmit an electric current (Hem, 1992, p. 66). Specific conductance for all samples ranged from 161 to 6,650 microsiemens per centimeter (µS/cm). The median specific conductance for the alluvium was 683 µS/cm and the median for the terrace deposits was 263 µS/cm.

Specific conductance is directly proportional to dissolved-solids concentration. Greater specific conductance values indicate greater dissolved solids. Dissolved-solids concentration in

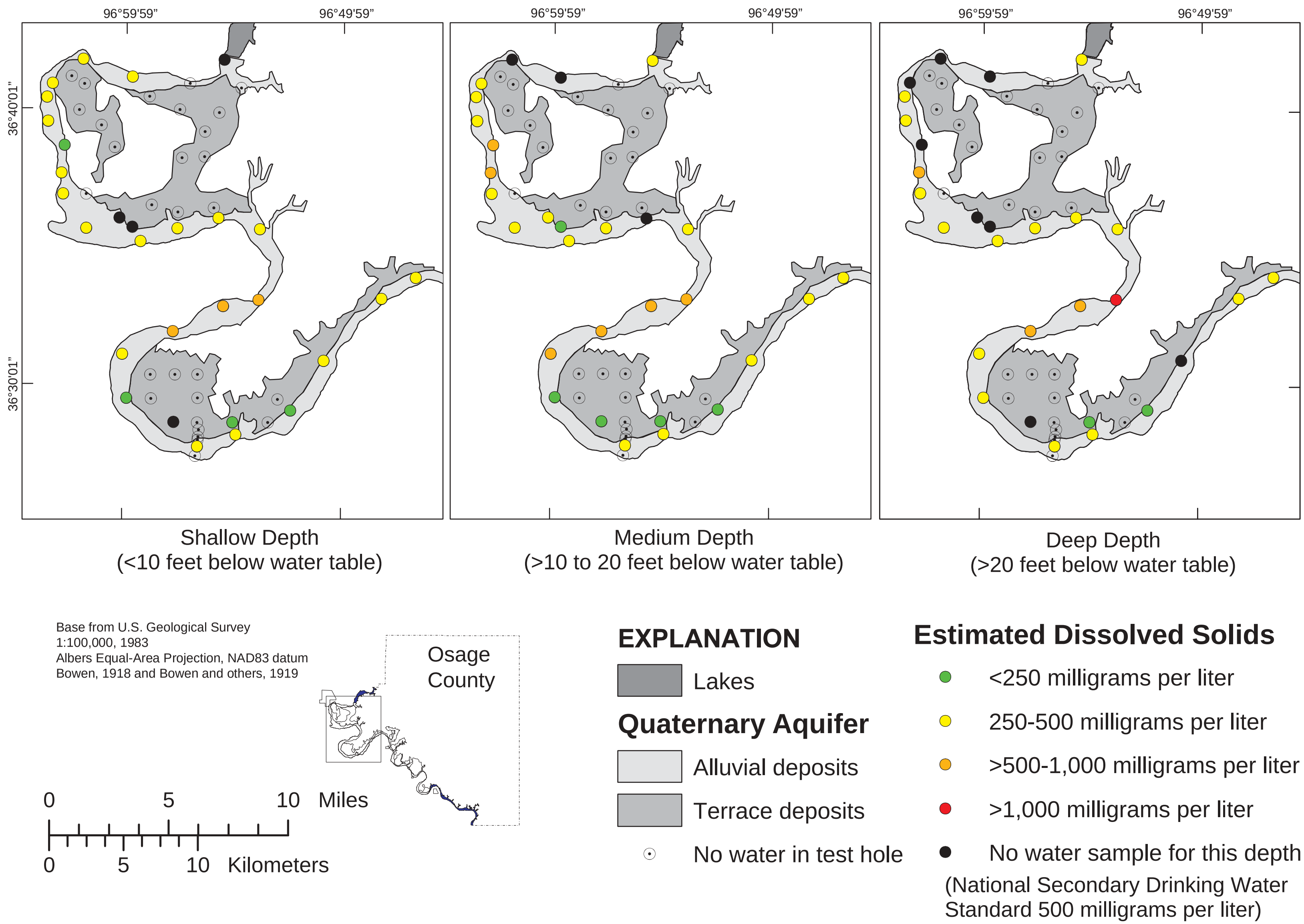


Figure 9. Estimated dissolved-solids concentrations, eastern map of the study area, western Osage County, Oklahoma; sampled December 2001 to August 2002.

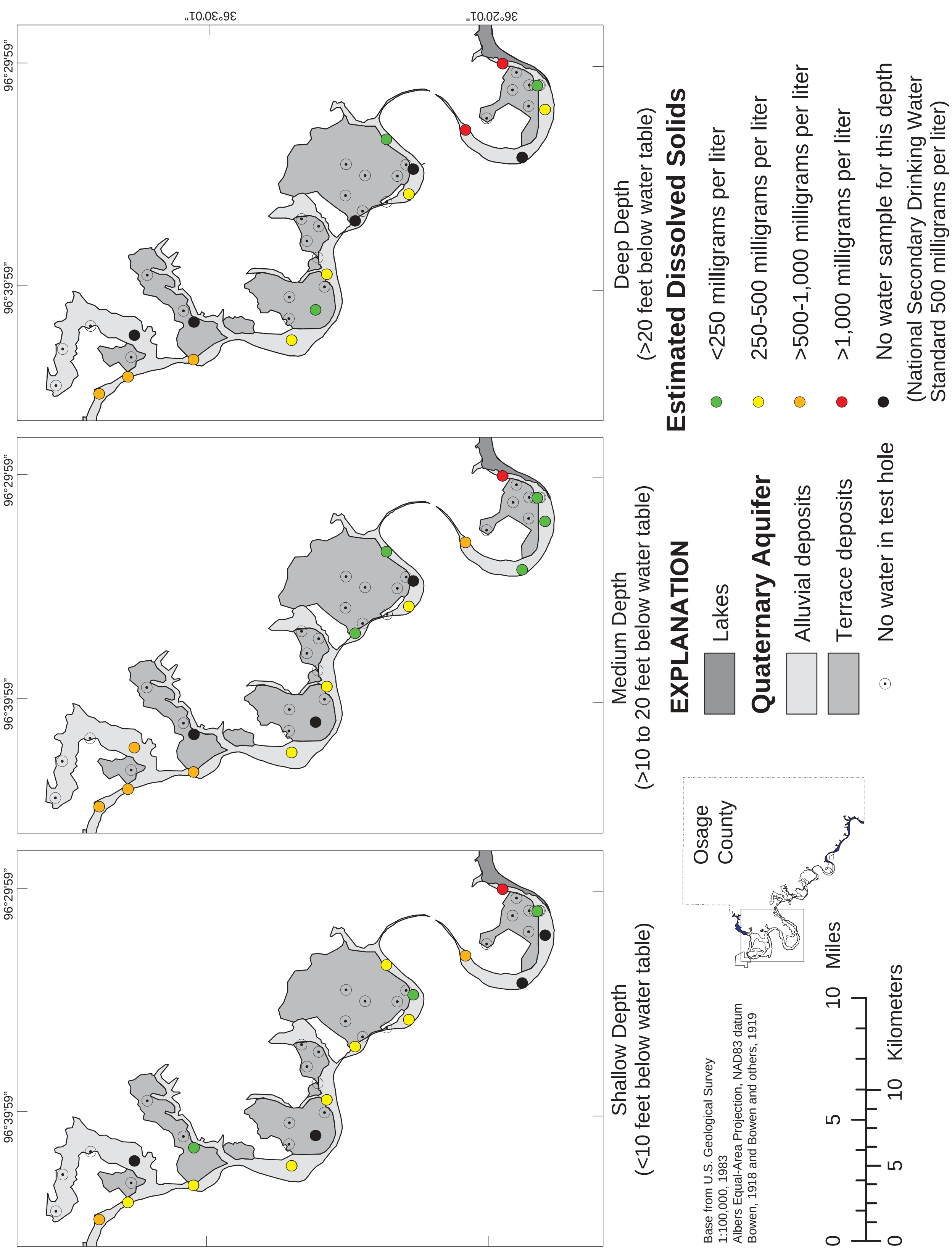


Figure 10. Estimated dissolved-solids concentrations, eastern map of the study area, western Osage County, Oklahoma; sampled December 2001 to August 2002.

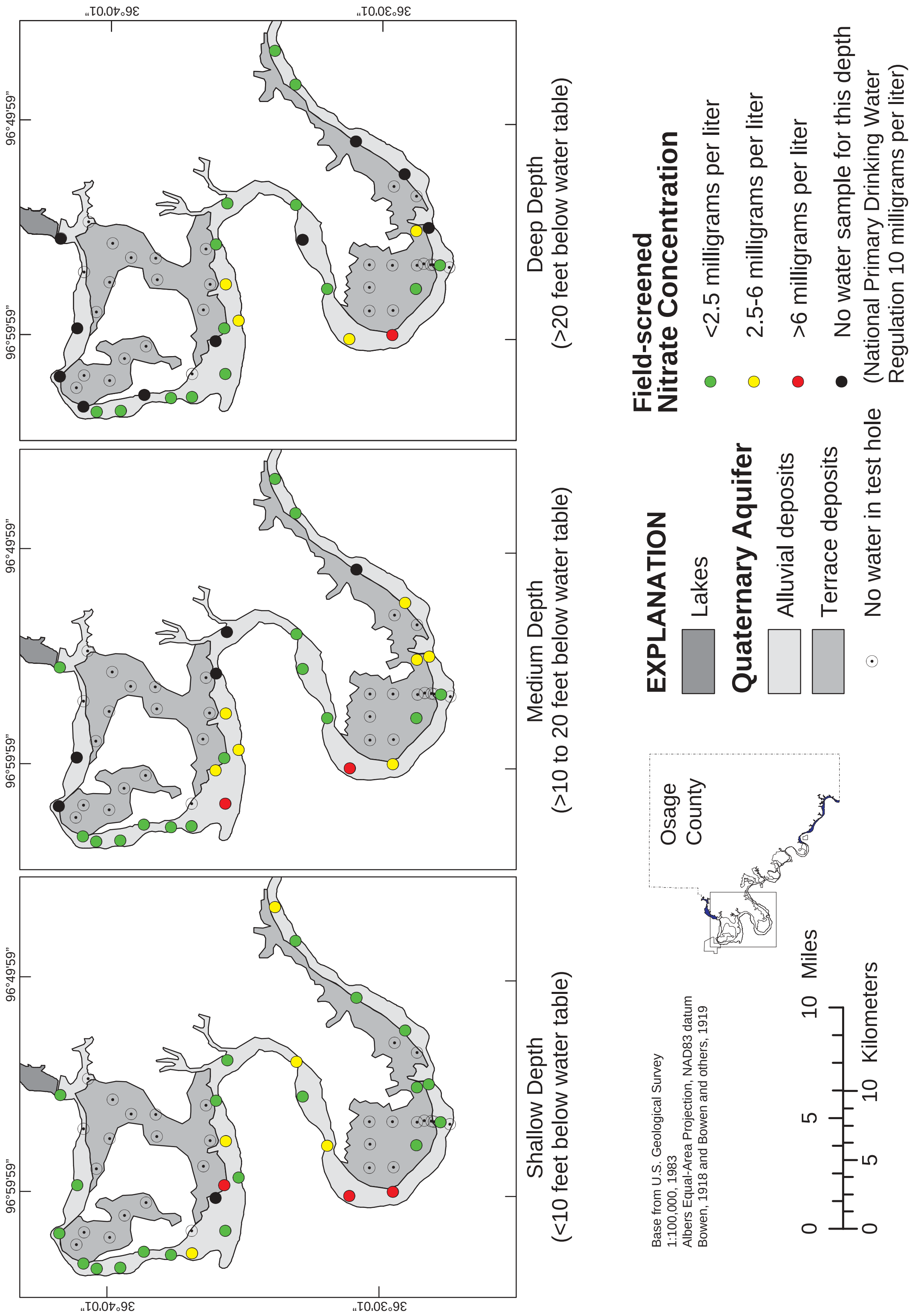


Figure 11. Field-screened nitrate concentrations, western map of the study area, western Osage County, Oklahoma; sampled December 2001 to August 2002.

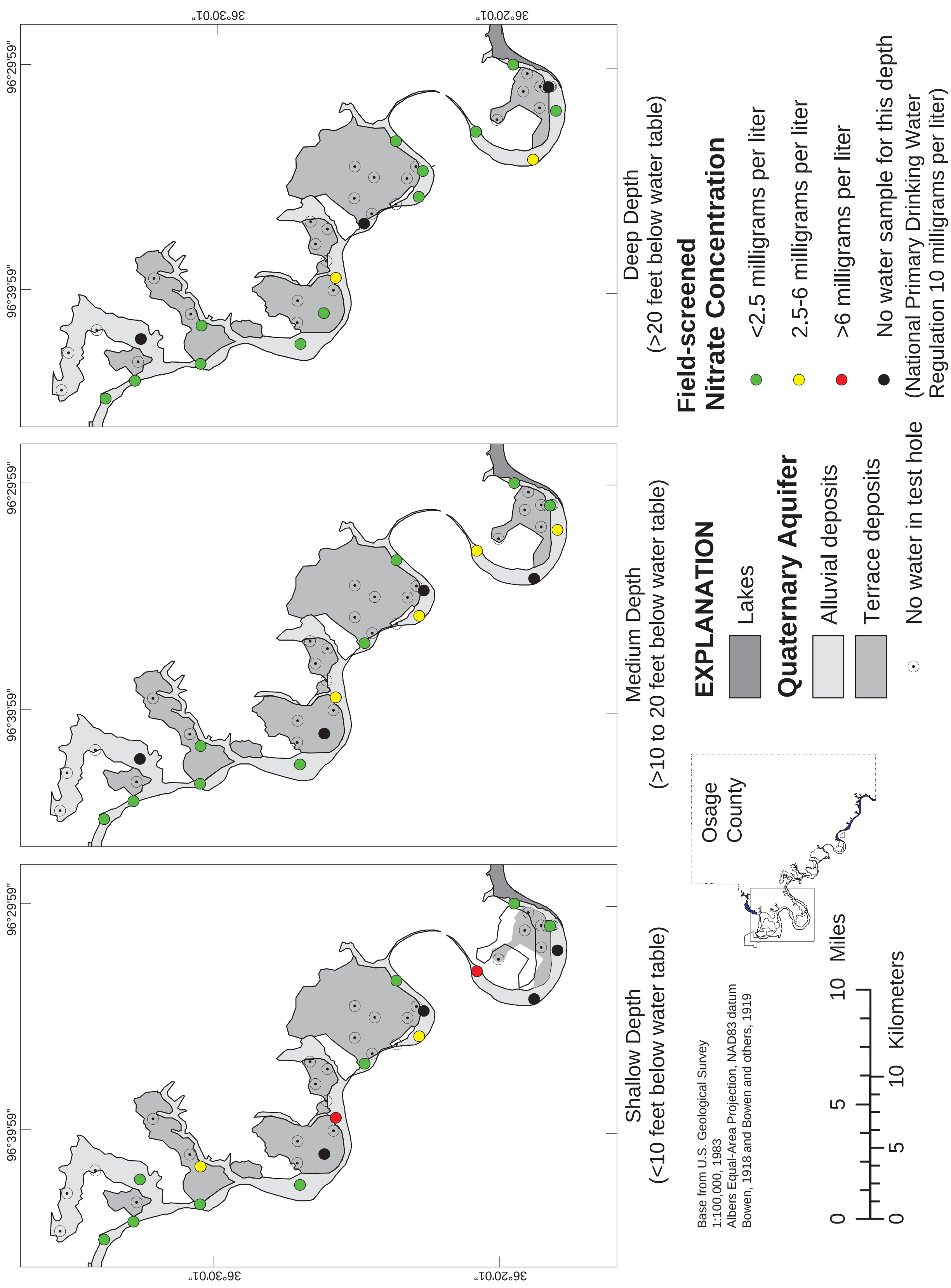


Figure 12. Field-screened nitrate concentrations, eastern map of the study area, western Osage County, Oklahoma; sampled December 2001 to August 2002.

milligrams per liter were estimated for the Quaternary aquifer by multiplying the specific conductance values by 0.55. This constant was determined by linear regression from water-quality data from domestic wells in the Quaternary aquifer in the Osage Reservation (Abbott, 2000). Estimated dissolved-solids concentration for the aquifer ranged from 88 to 3,658 mg/L (Appendix 2). Estimated median dissolved-solids concentration for the alluvium was 376 mg/L and for the terrace deposits was 145 mg/L. More than half of the samples from the Quaternary aquifer were estimated to contain less than the Secondary Drinking Water Standards recommendation of 500 mg/L for dissolved solids (figs. 9 and 10).

A pH of 7.0 indicates a neutral solution (Hem, 1992, p. 63). A pH greater than 7.0 indicates increasing alkalinity and less than 7.0 indicates increasing acidity. Corrosiveness of water generally increases with decreasing pH; however, excessively alkaline water also may attack metals. The National Secondary Drinking Water Standard recommends pH values in the range of 6.5 to 8.5. The median pH in the aquifer was 6.9 and ranged from 6.0 to 7.4 (Appendix 2).

Water-temperature values ranged from 12.0 to 28.1 degrees Celsius (°C), with a mean of 20 °C. Fifty percent of the water-temperature values were between 18 and 21 °C.

Dissolved-oxygen concentrations ranged from 0.5 to 6.0 mg/L. More than fifty percent of the concentrations were between 1.0 and 3.0 mg/L (Appendix 2). Median dissolved-oxygen concentration for the alluvium was 1.5 mg/L and for the terrace deposits was 4.5 mg/L. Water recharging the aquifer can contain oxygen similar to surface water in contact with the atmosphere, which ranges from 7 to 13 mg/L (Hem, 1992, p.155-156). Concentrations of dissolved oxygen less than 7 mg/L are probably the result of microbial consumption of oxygen or the reaction with organic matter or oxidizable minerals in the aquifer (Hem, 1992, p.155-158).

Nitrogen is commonly associated with fertilizer, domestic sewage, and animal waste contamination. Biochemical processes in treatment plants and soil convert ammonia and organic nitrogen, the reduced forms of nitrogen found in fertilizer and animal waste, to nitrite and nitrate (Becker and others, 2003). The National Primary Drinking Water Regulations maximum contaminant level (MCL) for nitrate is 10 mg/L (U.S. Environmental Protection Agency, 2002). Nitrate concentration greater than the MCL can cause methemoglobinemia, (blue-baby syndrome), an often fatal disease in infants, and water with nitrate concentrations greater than the MCL should not be used in infant feeding, by pregnant women, or by nursing mothers (U.S. Environmental Protection Agency, 2002).

Field-screened nitrate concentrations of the 105 water-quality samples ranged from 0 to 15 mg/L (Appendix 2). Median field-screened nitrate concentration for the alluvium was 0.5 mg/L and for the terrace deposits was 3.0 mg/L. Nitrate concentrations greater than 6 mg/L occurred mostly in the shallow and medium depths below the water table (figs. 11, 12, and Appendix 2). At site 008A the nitrate concentration decreased from 15.0 to 2.5 mg/L.

Ten of the 46 test holes were sampled a second time in September 2002 to compare the field-screened nitrate values with laboratory analyses from the USGS, National Water Quality Laboratory (table 1) and to evaluate changes in the nitrate concentration with time. Hypothesis testing was used to determine if the water-quality samples from the first field screening, second field screening, or the laboratory analysis were statistically different. The Wilcoxon rank sum test (Wilcoxon, 1945, P-STAT, Inc., 1990), also called the Mann-Whitney test (Mann, 1945), was used because it is a nonparametric test that requires no assumptions about the population distributions and is resistant to data outliers. The null hypothesis for the Wilcoxon rank sum test is that the two data sets have the same median and distribution. The null hypothesis is rejected if the probability (p-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.

There was no statistically significant difference between the first field screening, second field screening, or the laboratory analysis. The p-value was 0.32 between the first and second field screening. This indicates that the values for the first and second field screening were similar. The p-value was 0.57 between the first field screening and the laboratory analysis, indicating that the values for the first field screening and the laboratory analysis were similar. The p-value was 0.18 between the second field screening and the laboratory analysis. If the p-value was less than or equal to 0.05, then the field screening methods would have been inconsistent with what the laboratory reported and the two sample sets could not be compared. However, the field screening methods remained consistent to what the laboratory reported and the two sample sets can be compared.

The field-screened nitrate concentrations for the second sampling in September 2002 were less than the corresponding laboratory reported concentrations for every sample pair. This difference indicates the field-screened nitrate concentrations were probably less than a laboratory analysis would report. To quantify this difference, a linear regression of the two data sets was created. The linear regression indicates a field-screened concentration of about 6.2 mg/L would be approximately equivalent to a laboratory analysis of 10 mg/L or the Primary Drinking Water Regulation MCL (fig. 13). Therefore, any field-screened nitrate concentration greater than 6.0 mg/L could be near the MCL or could be exceeding the MCL. During the initial sampling, five sample sites had nitrate concentrations greater than 6.0 mg/L (table 1). Nine sites had similar nitrate concentration values at both the initial and second samplings (table 1).

Water-quality results indicate water in the Quaternary aquifer could be suitable for drinking and/or irrigation supply. Most areas in the aquifer contained nitrate and dissolved-solids concentrations less than the MCL for drinking water regulations and standards. Water in these areas could be used for public or domestic drinking water supply. Isolated areas exist where concentrations of nitrate and dissolved solids exceed the MCL for

Table 1. Comparison of field-screening data and laboratory data for nitrite plus nitrate as nitrogen concentration from the Quaternary aquifer, western Osage County, Oklahoma

[A, alluvium; T, terrace deposits; measurement in milligrams per liter]

Local identifier (figs. 2 and 3)	Site identifier	1st sampling		2nd sampling		
		Date	Field screening	Date	Field screening	Laboratory
005A	361807096315705	01/09/02	5.0	09/24/02	2.0	4.3
008A	362055096325408	01/18/02	15.0	09/24/02	3.0	5.7
022A	362701096421922	03/01/02	0.0	09/26/02	0.0	0.8
026A	362547096392226	03/19/02	10.0	09/26/02	10.0	14.3
039T	362842096545839	05/30/02	4.0	09/26/02	4.0	7.3
042A	362933096594942	06/05/02	15.0	09/25/02	16.0	22.6
047A	362749096563447	06/07/02	4.0	09/26/02	4.0	5.4
056A	363541097014356	06/26/02	8.0	09/25/02	6.0	7.4
078T	363544096593778	07/24/02	7.5	09/25/02	7.5	16.4
079A	363513096591579	07/24/02	4.0	09/25/02	2.5	5.6

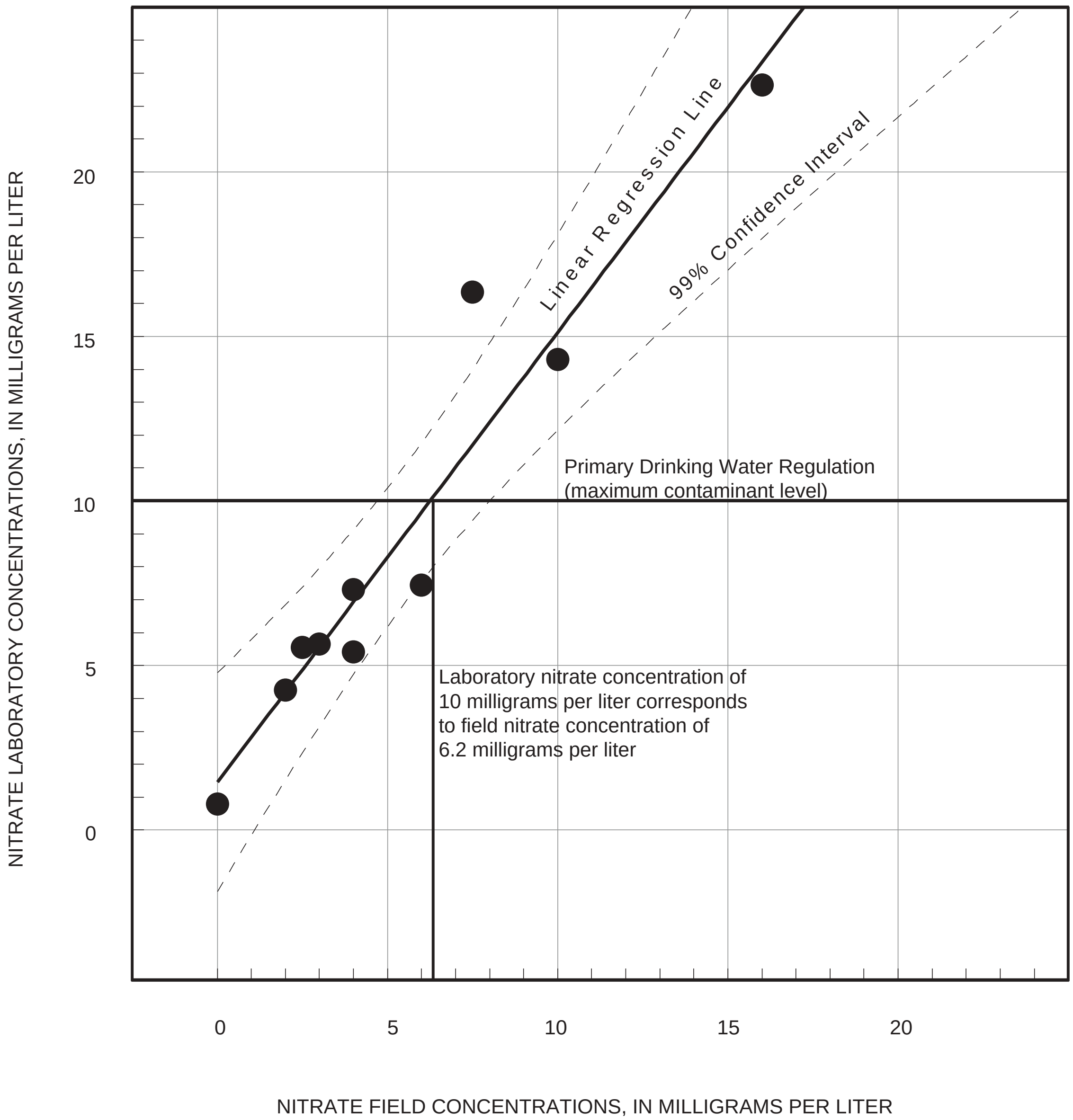


Figure 13. Comparison of field data and laboratory analysis for nitrate concentrations form the Quaternary aquifer, western Osage County, Oklahoma, September 2002.

drinking water regulations and standards. Water in those areas could be used for irrigation and stock supply.

Summary

Additional sources of water are needed on the Osage Reservation for future growth and development. The Quaternary aquifer along the Arkansas River in the Osage Reservation may represent a substantial water resource, but limited amounts of hydrogeologic data were available for the aquifer. The Quaternary aquifer covers about 116 square miles in the study area along the Arkansas River in western Osage County. It consists of alluvial and terrace deposits of sand, silt, clay, and gravel. The contact between the alluvial and the terrace deposits, for this report, is located where the slope changes from a low angle on the alluvial deposits to a greater angle on the terrace deposits. Recharge to the Quaternary aquifer in the Osage Reservation is about 1.5 inches per year. Thickness of the alluvium ranges from 13.7 to 49.8 feet. Thickness of the terrace deposits at the sites ranges from 7 to 93.8 feet.

Data collected from 103 test holes included electrical conductivity logs, sediment cores, and water-quality measurements of field parameters. Water levels were determined for 42 of the 52 test holes in the alluvial deposits, and for 7 of the 51 test holes in terrace deposits. All test holes in the alluvial deposits contained water, but water levels were not measured for 10 of the 52 alluvial test holes because of complications in the field. Although most of the test holes in terrace deposits were dry, five of the test holes contained sufficient water for sampling.

The weighted-mean grain size for cores from the alluvium ranged from 3.69 to 0.64 ϕ, (0.08-0.64 millimeters) and ranged from 4.02 to 2.01 ϕ (0.06-0.25 millimeters) for cores from the terrace deposits. The mean of the weighted-mean grain sizes for the cores from the alluvium was 1.67 ϕ (0.31 millimeters), and the terrace deposits was 2.73 ϕ (0.15 millimeters). The net sand of the alluvium ranged from 0.7 to 47.5 feet with a median of 24.5 feet. The net sand of the terrace deposits ranged from 0.1 to 85.3 feet with a median of 30.9 feet. The calculated hydraulic conductivity of the alluvium ranged from 2.9 to 6,000 feet per day, and of the terrace deposits ranged from 2.9 to 430 feet per day. The calculated transmissivity of the alluvium ranged from 2,000 to 26,000 feet squared per day, with a median of 5,100 feet squared per day. Given a specific yield of 20 percent, 38,450 acres of alluvial deposits in the study area, and an average saturated thickness of 25 feet, water in storage in the alluvium was estimated to be approximately 200,000 acre-feet. The amount of water annually recharging the aquifer is approximately 4,800 acre-feet, given an estimated annual recharge of 1.5 inches per year and 38,450 acres of alluvium in the study area.

Water-quality data from the Quaternary aquifer included field measurements of specific conductance, pH, water temperature, dissolved oxygen, and nitrate (nitrite plus nitrate as nitrogen). One hundred five water-quality samples were analyzed from the 46 test holes that produced water.

Specific conductance ranged from 161 to 6,650 microsiemens per centimeter with a median of 683 microsiemens per centimeter. Specific conductance is directly proportional to dissolved-solids concentration. The estimated dissolved-solids concentration for the aquifer ranged from 88 to 3,658 milligrams per liter. Estimated median dissolved-solids concentration for the alluvial deposits determined by a relation to specific conductance was 376 milligrams per liter and for the terrace deposits was 145 milligrams per liter. More than half of the samples from the Quaternary aquifer were estimated to contain less than the secondary drinking water standard of 500 milligrams per liter dissolved solids.

Field-screened nitrate concentration values of the 105 water-quality samples ranged from 0 to 15 milligrams per liter. Median field-screened nitrate concentration for the alluvial deposits was 0.5 milligram per liter and for the terrace deposits was 3.0 milligrams per liter. At site 008A the nitrate concentration decreased from 15.0 to 2.5 milligrams per liter.

The field-screened nitrate concentrations were less than corresponding laboratory reported values. A linear regression of the two data sets indicates a field-screened value of about 6.2 milligrams per liter would be approximately equivalent to a laboratory analysis of 10 milligrams per liter or the maximum contaminant level (MCL) for the Primary Drinking Water Regulation. Therefore, any field-screened nitrate concentration greater than 6.0 milligrams per liter could be at or greater than the MCL. During the initial sampling, five sample sites had nitrate concentrations greater than 6.0 milligrams per liter. Nine sites had similar nitrate concentration values at both the initial and later samplings.

Water quality results indicate water in the Quaternary aquifer could be suitable for drinking and/or irrigation supply. Most areas in the aquifer contained nitrate and dissolved-solids concentrations less than the MCL or National Drinking Water Regulations and Secondary Drinking Water Standards. Water in these areas could be used for public or domestic drinking water supply. Isolated areas exist where concentrations of nitrate and dissolved solids exceed the MCL for National Drinking Water Regulations and Standards. Water in those areas could be used for irrigation and stock supply.

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Appendices

Appendix 1. Test hole data for the Quaternary aquifer, western Osage County, Oklahoma

[T, terrace deposits; A, alluvium; ddmmss.sss, degrees degrees minutes minutes seconds seconds decimal seconds seconds seconds; NAD 83, North American Datum of 1983; bls, below land surface; nw, no water; --, data not available]

Local identifier (figs. 2 and 3)	Site identifier	Local number	Latitude (ddmmss.sss) (NAD 83)	Longitude (ddmmss.sss) (NAD 83)	Hydrogeologic unit	Total depth (feet bls)	Depth to water (feet bls)	Cored sites	Saturated thickness/ net sand/ total depth (feet)
001T	362320096345801	22N-07E-17 BBC 1	362319.860	-963458.020	Terrace	27.4	nw	Yes	0 / 25.9 / 27.4
002A	362246096343802	22N-07E-17 CDD 1	362246.180	-963438.818	Alluvium	30.6	11.7	Yes	18.9 / 28.1 / 30.6
003T	362301096342703	22N-07E-17 ACC 1	362301.725	-963427.248	Terrace	52.0	nw	No	0 / 46.5 / 52.0
004T	361829096305404	21N-07E-11 DDB 1	361829.479	-963054.010	Terrace	41.0	nw	No	0 / 37.2 / 41.0
005A	361807096315705	21N-07E-15 AAA 1	361807.331	-963157.402	Alluvium	36.2	6	No	30.2 / 34.3 / 36.2
006A	361855096340606	21N-07E-09 CAA 1	361855.174	-963406.769	Alluvium	29.9	4	No	25.9 / 10.7 / 29.9
007A	361823096305407	21N-07E-11 DDD 1	361823.591	-963054.432	Alluvium	28.2	--	Yes	--[1] / 19.2 / 28.2
008A	362055096325408	22N-07E-03 CBC 1	362055.747	-963254.090	Alluvium	37.0	10.7	No	26.3 / 16.3 / 37.0
009T	361908096301809	21N-07E-01 CDD 1	361908.710	-963018.920	Terrace	41.0	nw	Yes	0 / 40.3 / 41.0
010A	361937096295510	21N-07E-01 DAC 1	361937.830	-962955.910	Alluvium	32.0	--	Yes	--[1] / 9.4 / 32.0
011T	362428096345611	22N-07E-05 CCD 1	362428.630	-963456.530	Terrace	28.0	nw	Yes	0 / 26.4 / 28.0
012T	362433096363212	22N-06E-01 DCA 1	362433.630	-963632.660	Terrace	40.5	39.1	No	1.4 / 32.0 / 40.5
013T	362510096355113	22N-07E-06 BAD 1	362510.230	-963551.390	Terrace	93.8	nw	No	0 / 85.3 / 93.8
014A	362448096365814	22N-06E-01 CAD 1	362448.631	-963658.409	Alluvium	25.0	12.3	No	12.7 / 20.3 / 25.0
015T	362509096342715	22N-07E-05 ABA 1	362509.678	-963427.226	Terrace	73.0	nw	No	0 / 40.2 / 73.0
016A	362343096332016	22N-07E-09 DCA 1	362343.551	-963320.247	Alluvium	37.0	13.4	No	23.6 / 37.0 / 37.0
017A	362255096354617	22N-07E-18 CAB 1	362255.030	-963546.680	Alluvium	48.0	16.2	No	31.8 / 36.7 / 48.0
018A	362342096360618	22N-07E-07 CCC 1	362342.180	-963606.780	Alluvium	21.9	15.2	No	6.7 / 1.1 / 21.9
019T	361842096314919	21N-07E-11 CBA 1	361842.120	-963149.660	Terrace	8.0	nw	No	0 / 8.0 / 8.0
020T	361841096305220	21N-07E-11 DAA 1	361841.490	-963052.740	Terrace	56.3	nw	No	0 / 56.3 / 56.3

Appendix 1. Test hole data for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; ddmmss.sss, degrees degrees minutes minutes seconds seconds decimal seconds seconds seconds; NAD 83, North American Datum of 1983; bls, below land surface; nw, no water; --, data not available]

Local identifier (figs. 2 and 3)	Site identifier	Local number	Latitude (ddmmss.sss) (NAD 83)	Longitude (ddmmss.sss) (NAD 83)	Hydrogeologic unit	Total depth (feet bls)	Depth to water (feet bls)	Cored sites	Saturated thickness/ net sand/ total depth (feet)
021T	361916096310621	21N-07E-02 DDC 1	361916.362	-963106.493	Terrace	8.0	nw	No	0 / 6.8 / 8.0
022A	362701096421922	23N-06E-19 CDC 1	362701.480	-964219.280	Alluvium	44.5	--	Yes	--[1] / 44.5 / 44.5
023T	362611096405723	23N-06E-29 DCD 1	362611.952	-964057.113	Terrace	37.8	12.7	No	25.1 / 36.1 / 37.8
024T	362553096395624	23N-06E-33 BAD 1	362553.210	-963956.270	Terrace	63.0	nw	No	0 / 54.9 / 63.0
025T	362607096383825	23N-06E-27 DCD 1	362607.630	-963838.215	Terrace	23.0	17.1	No	5.9 / 17.8 / 23.0
026A	362547096392226	23N-06E-33 ADA 1	362547.940	-963922.400	Alluvium	40.5	13.8	Yes	26.0 / 37.8 / 40.5
027T	362708096402427	23N-06E-21 CCB 1	362708.082	-964024.509	Terrace	33.8	nw	Yes	0 / 17.3 / 33.8
028T	362606096371428	23N-06E-26 DDD 1	362606.227	-963714.334	Terrace	43.0	nw	Yes	0 / 24.5 / 43.0
029T	362642096365529	23N-06E-25 BAC 1	362642.423	-963655.086	Terrace	16.0	nw	No	0 / 1.4 / 16.0
030T	362708096412130	23N-06E-20 CCA 1	362708.341	-964121.990	Terrace	44.2	nw	No	0 / 24.1 / 44.2
031T	362631096375331	23N-06E-26 CAA 1	362631.393	-963753.537	Terrace	42.0	nw	No	0 / 32.6 / 42.0
032T	363029096413232	24N-06E-32 CCC 1	363029.190	-964132.450	Terrace	37.0	--	No	--[1] / 28.5 / 37.0
033T	363052096410233	24N-06E-32 BDD 1	363052.170	-964102.090	Terrace	23.2	nw	No	0 / 2.4 / 23.2
034T	363210096392734	24N-06E-28 AAA 1	363210.080	-963927.670	Terrace	7.0	nw	No	0 / 0.1 / 7.0
035T	362842096574035	23N-03E-10 DDD 1	362842.150	-965740.470	Terrace	55.0	16.8	Yes	38.2 / 43.5 / 55.0
036T	362932096584236	23N-03E-10 BBB 1	362932.620	-965842.080	Terrace	80.2	nw	No	0 / 70.4 / 80.2
037T	363025096573737	23N-03E-02 BBB 1	363025.184	-965737.674	Terrace	73.8	nw	No	0 / 37.3 / 73.8
038T	362841096563538	23N-03E-14 AAA 1	362841.080	-965635.390	Terrace	65.5	nw	No	0 / 55.5 / 65.5
039T	362842096545839	23N-04E-07 CDD 1	362842.506	-965458.603	Terrace	44.0	21.2	Yes	22.8 / 36.4 / 44.0
040A	362815096545040	23N-04E-18 ACC 1	362815.674	-965450.088	Alluvium	30.6	15.8	No	14.8 / 21.3 / 30.6
041T	362842096532241	23N-04E-08 DDD 1	362842.909	-965322.234	Terrace	33.0	nw	No	0 / 32.0 / 33.0
042A	362933096594942	23N-03E-08 AAA 1	362933.265	-965949.837	Alluvium	44.5	13.4	No	31.1 / 40.4 / 44.5

Appendix 1. Test hole data for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; ddmmss.sss, degrees degrees minutes minutes seconds seconds decimal seconds seconds seconds; NAD 83, North American Datum of 1983; bls, below land surface; nw, no water; --, data not available]

Local identifier (figs. 2 and 3)	Site identifier	Local number	Latitude (ddmmss.sss) (NAD 83)	Longitude (ddmmss.sss) (NAD 83)	Hydrogeologic unit	Total depth (feet bls)	Depth to water (feet bls)	Cored sites	Saturated thickness/ net sand/ total depth (feet)
043T	363025096563543	23N-03E-35 DDD 1	363025.945	-965635.512	Terrace	62.9	nw	No	0 / 30.9 / 62.9
044T	363024096584444	23N-03E-03 BBB 1	363024.907	-965844.104	Terrace	92.5	nw	No	0 / 62.3 / 92.5
045A	363108096000245	24N-03E-32 AAD 1	363108.402	-970002.571	Alluvium	41.9	10.1	Yes	31.8 / 41.6 / 41.9
046T	362935096563546	23N-03E-02 DDD 1	362935.067	-965635.029	Terrace	66.9	nw	No	0 / 45.8 / 66.9
047A	362749096563447	23N-03E-14 DDD 1	362749.329	-965634.544	Alluvium	48.2	15.0	Yes	33.1 / 42.6 / 48.2
048T	362011096322148	24N-07E-34 DCA 1	362011.363	-963221.848	Terrace	19.8	nw	No	0 / 11.7 / 19.8
049T	363957097020549	25N-02E-12 AAB 1	363957.503	-970205.889	Terrace	73.6	nw	No	0 / 30.2 / 73.6
050T	363837097002850	25N-03E-17 BDC 1	363837.789	-970028.362	Terrace	51.4	nw	No	0 / 0.7 / 51.4
051A	364024097033451	25N-02E-02 DBB 1	364024.779	-970334.063	Alluvium	39.2	14.4	No	24.8 / 38.8 / 39.2
052A	363840097024552	25N-02E-13 BCD 1	363840.549	-970245.660	Alluvium	30.5	9.7	No	20.8 / 21.4 / 30.5
053T	363924097010453	25N-03E-07 DBD 1	363924.955	-970104.470	Terrace	45.5	nw	Yes	0 / 0.3 / 45.5
054A	363655097014454	25N-03E-30 CBB 1	363655.919	-970144.946	Alluvium	44.3	35.3	No	9.0 / 17.6 / 44.3
055A	363655097024855	25N-02E-25 CBB 1	363655.235	-970248.666	Alluvium	40.9	10.3	No	30.6 / 28.6 / 40.9
056A	363541097014356	25N-03E-31 CCB 1	363541.364	-970143.923	Alluvium	37.8	11.1	Yes	26.7 / 31.8 / 37.8
057A	363604097001257	25N-03E-32 ACC 1	363604.272	-970012.672	Alluvium	35.0	9.8	No	25.2 / 33.0 / 35.0
058T	364110097022758	26N-02E-36 CAA 1	364110.811	-970227.718	Terrace	75.6	nw	No	0 / 62.7 / 75.6
059A	364054097031959	26N-02E-35 DBD 1	364054.609	-970319.854	Alluvium	20.2	8.3	No	11.9 / 17.9 / 20.2
060A	363030096431260	24N-05E-36 CDD 1	363030.190	-964312.922	Alluvium	38.9	9.1	No	29.8 / 35.7 / 38.9
061T	363242096430861	24N-05E-24 ACB 1	363242.587	-964308.781	Terrace	49.4	nw	No	0 / 11.5 / 49.4
062A	363235096420862	24N-06E-19 BDD 1	363235.931	-964208.682	Alluvium	35.0	19.5	No	15.5 / 6.4 / 35.0
063A	363248096440063	24N-05E-14 DCC 1	363248.456	-964400.050	Alluvium	40.7	12.4	No	28.3 / 38.6 / 40.7
064A	363349096444764	24N-05E-15 AAA 1	363349.332	-964447.496	Alluvium	30.0	12.0	No	18.0 / 18.7 / 30.0

Appendix 1. Test hole data for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; ddmmss.sss, degrees degrees minutes minutes seconds seconds decimal seconds seconds seconds; NAD 83, North American Datum of 1983; bls, below land surface; nw, no water; --, data not available]

Local identifier (figs. 2 and 3)	Site identifier	Local number	Latitude (ddmmss.sss) (NAD 83)	Longitude (ddmmss.sss) (NAD 83)	Hydrogeologic unit	Total depth (feet bls)	Depth to water (feet bls)	Cored sites	Saturated thickness/ net sand/ total depth (feet)
065A	363358096463965	24N-05E-09 CCD 1	363358.652	-964639.416	Alluvium	35.2	7.4	No	27.8 / 31.9 / 35.2
066A	363057096505001	24N-04E-35 BDD 1	363057.745	-965050.079	Alluvium	18.9	11.0	No	7.9 / 12.9 / 18.9
067A	363409096414501	24N-06E-07 DAD 1	363409.616	-964145.230	Alluvium	29.0	nw	No	0 / 2.1 / 29.0
068A	363508096424601	24N-05E-01 DAB 1	363508.146	-964246.608	Alluvium	24.5	nw	No	0 / 2.2 / 24.5
069A	363521096442501	24N-05E-02 BDB 1	363521.937	-964425.491	Alluvium	33.9	nw	No	0 / 5.4 / 33.9
070A	363308096535001	24N-04E-17 DDB 1	363308.827	-965350.073	Alluvium	47.2	13.6	No	33.6 / 21.2 / 47.2
071A	363253096552701	24N-04E-19 BBC 1	363253.709	-965527.129	Alluvium	38.0	16.2	Yes	21.8 / 29.4 / 38.0
072A	363541096534701	25N-04E-32 DCB 1	363541.628	-965347.334	Alluvium	37.0	14.2	No	22.8 / 25.4 / 37.0
073T	363627096555401	25N-03E-36 ABB 1	363627.750	-965554.621	Terrace	64.1	nw	No	0 / 40.8 / 64.1
074A	363604096554101	25N-03E-36 ACD 1	363604.930	-965541.813	Alluvium	41.0	13.0	No	28.0 / 37.4 / 41.0
075T	363618096573301	25N-03E-35 BBC 1	363618.278	-965733.063	Terrace	66.6	nw	No	0 / 41.7 / 66.6
076A	363158096574301	24N-03E-27 AAC 1	363158.728	-965743.698	Alluvium	43.8	10.6	No	33.2 / 23.6 / 43.8
077A	363542096573301	25N-03E-35 CCC 1	363542.489	-965733.706	Alluvium	43.0	17.3	No	25.7 / 28.7 / 43.0
078T	363544096593778	25N-03E-33 CCC 1	363544.978	-965937.079	Terrace	31.3	11.3	No	20.0 / 26.2 / 31.3
079A	363513096591579	24N-03E-04 BDD 1	363513.546	-965915.077	Alluvium	43.7	13.8	No	29.9 / 39.8 / 43.7
080T	363632096584501	25N-03E-28 DDD 1	363632.175	-965845.022	Terrace	64.8	nw	No	0 / 35.1 / 64.8
081A	363740097025201	25N-02E-24 CBB 1	363740.881	-970252.416	Alluvium	48.8	14	No	34.8 / 42.4 / 48.8
082T	364054097015201	26N-03E-31 CCC 1	364054.108	-970152.820	Terrace	42.3	nw	Yes	0 / 21.0 / 42.3
083A	363932097033001	25N-02E-11 BDD 1	363932.374	-970330.566	Alluvium	36.9	11	No	25.9 / 34.2 / 36.9
084A	364148097015601	26N-02E-25 DDD 1	364148.085	-970156.371	Alluvium	15.7	12.7	No	3.0 / 15.7 / 15.7
085A	364110096594101	26N-03E-33 CBC 1	364110.053	-965941.037	Alluvium	28.1	12.1	No	16.0 / 21.9 / 28.1
086T	363815096572201	25N-03E-14 CCD 1	363815.148	-965722.998	Terrace	15.1	nw	No	0 / 0.2 / 15.1

Appendix 1. Test hole data for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; ddmmss.sss, degrees degrees minutes minutes seconds seconds decimal seconds seconds seconds; NAD 83, North American Datum of 1983; bls, below land surface; nw, no water; --, data not available]

Local identifier (figs. 2 and 3)	Site identifier	Local number	Latitude (ddmmss.sss) (NAD 83)	Longitude (ddmmss.sss) (NAD 83)	Hydrogeologic unit	Total depth (feet bls)	Depth to water (feet bls)	Cored sites	Saturated thickness/ net sand/ total depth (feet)
087T	363912096562101	25N-03E-12 CCA 1	363912.520	-965621.187	Terrace	16.1	nw	No	0 / 0.5 / 16.1
088A	364148096552901	26N-03E-25 DDA 1	364148.740	-965529.700	Alluvium	43.7	20.7	No	23.0 / 43.1 / 43.7
089A	364048096544201	25N-04E-06 ABB 1	364048.190	-965442.610	Alluvium	13.7	nw	No	0 / 1.0 / 13.7
090T	363954096554101	25N-03E-12 ABB 1	363954.060	-965541.710	Terrace	10.0	nw	No	0 / 0.2 / 10.0
091T	364028096585401	25N-03E-03 BCB 1	364028.680	-965854.080	Terrace	60.7	10.7	No	8.1 / 19.8 / 60.7
092A	364056096570201	26N-03E-35 DDD 1	364056.930	-965702.860	Alluvium	18.8	nw	Yes	0 / 0.7 / 18.8
093T	363959096573001	25N-03E-02 CCC 1	363959.910	-965730.570	Terrace	26.0	nw	No	0 / 0.1 / 26.0
094T	363818096562101	25N-03E-13 CCC 1	363818.330	-965621.690	Terrace	20.8	nw	Yes	0 / 0.1 / 20.8
095A	362909096522101	23N-04E-09 ADC 1	362909.370	-965221.100	Alluvium	27.5	11.0	No	16.5 / 17.2 / 27.5
096A	363312096481301	24N-05E-18 DDB 1	363312.710	-964813.680	Alluvium	33.8	10.9	No	22.9 / 21.2 / 33.8
097T	362933096525597	23N-04E-09 BAB 1	362933.150	-965255.510	Terrace	56.7	nw	No	0 / 34.4 / 56.7
098A	361818096305201	21N-07E-11 DDC 1	361818.160	-963052.670	Alluvium	35.3	10.2	No	25.1 / 17.5 / 35.3
099A	361820096305201	21N-07E-11 DDC 1	361820.410	-963052.820	Alluvium	28.5	11.1	No	17.4 / 15.0 / 28.5
100A	362729096563901	23N-03E-23 ADD 1	362729.060	-965639.850	Alluvium	49.8	--	No	--[1] / 47.5 / 49.8
101A	362804096563301	23N-03E-13 CBC 1	362804.160	-965633.780	Alluvium	43.0	--	No	--[1] / 29.6 / 43.0
102T	362809096563201	23N-03E-13 CBC 1	362809.980	-965632.800	Terrace	37.0	nw	No	0 / 34.4 / 37.0
103T	362825096563001	23N-03E-13 BCB 1	362825.570	-965630.790	Terrace	46.5	nw	No	0 / 39.1 / 46.5

[1]depth to water not measured

Appendix 2. Water-quality data for the Quaternary aquifer, western Osage County, Oklahoma, 2001-2002

[A, alluvium; T, terrace deposits; Sample depth, deepest depth of screened interval during sampling; bls, below land surface; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; nitrates are from first sampling, before September, 2002]

Local identifier (figs. 2 and 3)	Site identifier	Date sampled	Sample depth (feet bls)	pH (standard units)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Estimated dissolved solids (mg/L)	Nitrate dissolved (mg/L)
002A	362246096343802	12/20/01	15.0	6.9	18.0	311	1.0	171	0.0
005A	361807096315705	01/09/02	22.0	7.2	20.1	244	3.0	134	5.0
005A	361807096315705	01/09/02	36.0	7.3	25.3	487	2.0	268	0.0
006A	361855096340606	01/10/02	29.9	6.9	15.5	298	4.0	164	2.5
007A	361823096305407	01/18/02	18.0	7.0	13.5	242	1.0	133	0.0
007A	361823096305407	01/18/02	28.2	6.9	14.3	161	2.5	88	1.0
008A	362055096325408	01/18/02	14.0	6.6	12.2	1,235	1.5	679	15
008A	362055096325408	01/18/02	22.0	7.2	12.0	1,312	1.0	722	2.5
008A	362055096325408	01/18/02	37.0	7.1	13.4	1,824	2.0	1,003	0.0
010A	361937096295510	01/21/01	12.0	6.5	17.9	6,650	5.0	3,658	0.0
010A	361937096295510	01/21/01	20.0	6.8	17.8	3,434	0.5	1,889	0.0
010A	361937096295510	01/21/01	32.0	6.2	15.4	2,411	2.5	1,326	0.0
014A	362448096365814	02/13/02	15.0	6.8	15.3	522	1.5	287	0.0
014A	362448096365814	02/13/02	25.0	6.6	15.1	384	1.0	211	0.0
016A	362343096332016	02/22/02	16.0	7.0	15.1	523	0.5	288	0.0
016A	362343096332016	02/22/02	26.0	7.2	16.7	423	0.5	233	0.0
016A	362343096332016	02/22/02	37.8	7.3	15.8	431	0.5	237	0.0
017A	362255096354617	02/25/02	20.0	7.0	12.5	600	6.0	330	5.0

Appendix 2. Water-quality data for the Quaternary aquifer, western Osage County, Oklahoma, 2001-2002—Continued.

[A, alluvium; T, terrace deposits; Sample depth, deepest depth of screened interval during sampling; bls, below land surface; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; nitrates are from first sampling, before September, 2002]

Local identifier (figs. 2 and 3)	Site identifier	Date sampled	Sample depth (feet bls)	pH (standard units)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Estimated dissolved solids (mg/L)	Nitrate dissolved (mg/L)
017A	362255096354617	02/25/02	33.0	7.0	14.2	693	0.5	381	3.5
017A	362255096354617	02/25/02	48.0	7.1	15.0	683	1.0	376	0.0
022A	362701096421922	04/01/02	22.0	6.8	20.0	755	1.0	415	0.0
022A	362701096421922	04/01/02	34.0	7.0	21.7	805	1.0	443	0.0
022A	362701096421922	04/01/02	45.5	7.0	21.2	822	1.0	452	0.0
023T	362611096405723	04/01/02	37.8	6.6	19.0	230	5.0	127	0.5
026A	362547096392226	04/19/02	16.0	6.7	19.3	717	3.5	394	10.0
026A	362547096392226	04/19/02	28.0	7.1	20.1	628	1.5	345	5.0
026A	362547096392226	04/19/02	40.0	7.1	22.1	598	0.5	329	2.5
032T	363029096413232	05/15/02	14.0	6.3	17.8	247	3.0	136	2.5
035T	362842096574035	05/30/02	24.0	6.0	18.9	281	4.0	155	5.0
039T	362842096545839	05/30/02	26.0	6.7	24.4	264	4.5	145	4.0
039T	362842096545839	05/30/02	34.0	6.8	28.0	260	5.0	143	2.5
039T	362842096545839	05/30/02	42.0	6.8	24.7	279	4.0	154	3.0
040A	362815096545040	05/28/02	24.0	6.7	17.5	643	1.0	354	2.5
040A	362815096545040	05/28/02	30.6	6.7	17.9	726	1.0	399	2.5
042A	362933096594942	06/05/02	14.0	6.3	21.0	433	3.0	238	15.0
042A	362933096594942	06/05/02	26.0	6.9	20.3	395	3.0	217	5.0
042A	362933096594942	06/05/02	44.0	7.3	20.1	487	3.0	268	7.5

Appendix 2. Water-quality data for the Quaternary aquifer, western Osage County, Oklahoma, 2001-2002—Continued.

[A, alluvium; T, terrace deposits; Sample depth, deepest depth of screened interval during sampling; bls, below land surface; ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; nitrates are from first sampling, before September, 2002]

Local identifier (figs. 2 and 3)	Site identifier	Date sampled	Sample depth (feet bls)	pH (standard units)	Water temperature (^{o}C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Estimated dissolved solids (mg/L)	Nitrate dissolved (mg/L)
045A	363108096000245	06/06/02	10.0	7.1	17.5	638	3.0	351	8.0
045A	363108096000245	06/06/02	26.0	7.2	17.5	962	1.0	529	7.0
045A	363108096000245	06/06/02	41.9	7.3	18.4	900	1.0	495	3.0
047A	362749096563447	06/07/02	14.0	7.3	18.7	698	4.0	384	4.0
047A	362749096563447	06/07/02	36.0	7.1	21.2	534	0.5	294	0.0
047A	362749096563447	06/07/02	46.0	7.0	20.6	560	0.5	308	0.0
051A	364024097033451	06/24/02	18.0	6.8	19.0	600	1.0	330	2.5
051A	364024097033451	06/24/02	30.0	6.8	21.1	486	0.5	268	0.0
051A	364024097033451	06/24/02	40.0	6.8	21.2	503	0.5	277	0.0
052A	363840097024552	06/24/02	14.0	6.8	19.6	337	3.0	185	2.0
052A	363840097024552	06/24/02	22.0	7.0	19.5	980	0.5	539	0.0
055A	363655097024855	06/25/02	18.0	7.2	17.7	636	1.0	350	0.0
055A	363655097024855	06/25/02	30.0	7.2	17.9	702	1.0	386	0.0
055A	363655097024855	06/25/02	38.0	7.2	17.9	899	1.0	494	0.0
056A	363541097014356	06/26/02	10.0	7.1	20.9	825	3.0	454	6.0
056A	363541097014356	06/26/02	22.0	6.8	20.5	850	0.5	468	8.0
056A	363541097014356	06/26/02	34.0	7.2	20.1	743	1.5	409	1.0
057A	363604097001257	06/26/02	22.0	6.7	28.1	506	3.0	278	3.0
059A	364054097031959	06/27/02	10.0	7.0	18.2	621	6.0	342	2.5

Appendix 2. Water-quality data for the Quaternary aquifer, western Osage County, Oklahoma, 2001-2002—Continued.

[A, alluvium; T, terrace deposits; Sample depth, deepest depth of screened interval during sampling; bls, below land surface; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; nitrates are from first sampling, before September, 2002]

Local identifier (figs. 2 and 3)	Site identifier	Date sampled	Sample depth (feet bls)	pH (standard units)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Estimated dissolved solids (mg/L)	Nitrate dissolved (mg/L)
059A	364054097031959	06/27/02	20.2	7.3	17.4	593	0.5	326	0.0
060A	363030096431260	07/02/02	14.0	6.6	19.0	643	1.0	354	1.0
060A	363030096431260	07/02/02	26.0	6.8	19.9	1,165	1.0	641	0.0
060A	363030096431260	07/02/02	38.0	6.8	19.3	1,292	1.0	711	0.0
062A	363235096420862	07/08/02	26.0	7.1	20.8	1,433	1.0	788	0.0
063A	363248096440063	07/08/02	18.0	6.8	20.6	909	4.5	500	1.5
063A	363248096440063	07/08/02	28.0	6.8	23.6	1,072	1.0	590	0.0
063A	363248096440063	07/08/02	38.0	7.2	25.3	1,201	1.0	661	0.0
064A	363349096444764	07/08/02	14.0	6.9	20.8	1,041	1.0	573	0.0
064A	363349096444764	07/08/02	22.0	7.0	20.0	942	1.0	518	0.0
064A	363349096444764	07/08/02	28.7	7.0	18.8	937	1.0	515	0.0
065A	363358096463965	07/09/02	14.0	6.9	21.2	709	1.0	390	0.0
065A	363358096463965	07/09/02	24.0	7.0	20.2	722	1.5	397	0.0
065A	363358096463965	07/09/02	34.0	6.8	20.9	732	1.0	403	0.0
066A	363057096505001	07/09/02	14.0	6.8	21.4	582	2.0	346	0.5
070A	363308096535001	07/12/02	22.0	6.8	19.3	1,137	1.5	625	0.0
070A	363308096535001	07/12/02	34.0	6.5	19.6	1,528	1.5	840	0.0
070A	363308096535001	07/12/02	46.0	6.5	19.6	1,913	1.5	1,052	0.0
071A	363253096552701	07/18/02	18.0	6.9	19.3	1,056	1.5	644	1.0

Appendix 2. Water-quality data for the Quaternary aquifer, western Osage County, Oklahoma, 2001-2002—Continued.

[A, alluvium; T, terrace deposits; Sample depth, deepest depth of screened interval during sampling; bls, below land surface; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; nitrates are from first sampling, before September, 2002]

Local identifier (figs. 2 and 3)	Site identifier	Date sampled	Sample depth (feet bls)	pH (standard units)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Estimated dissolved solids (mg/L)	Nitrate dissolved (mg/L)
071A	363253096552701	07/18/02	34.0	7.3	19.7	1,486	1.0	817	0.0
072A	363541096534701	07/18/02	14.0	6.8	23.1	617	3.5	336	3.0
072A	363541096534701	07/18/02	34.0	7.1	25.0	652	4.0	359	1.0
074A	363604096554101	07/23/02	14.0	6.8	21.4	621	2.0	342	2.5
074A	363604096554101	07/23/02	38.0	7.1	26.8	813	3.5	447	2.0
076A	363158096574301	07/23/02	18.0	6.8	18.4	1,464	2.0	805	0.0
076A	363158096574301	07/23/02	30.0	6.8	18.1	1,625	1.0	894	0.0
076A	363158096574301	07/23/02	42.0	7.4	18.1	1,691	1.0	930	0.0
077A	363542096573301	07/23/02	18.0	6.8	19.5	595	4.0	327	0.0
077A	363542096573301	07/23/02	30.0	6.8	18.8	771	2.5	424	2.5
077A	363542096573301	07/23/02	42.0	7.0	22.5	754	2.0	415	3.5
078T	363544096593778	07/24/02	26.0	6.8	19.9	388	5.0	213	7.5
079A	363513096591579	07/24/02	14.0	6.8	21.0	588	3.0	323	4.0
079A	363513096591579	07/24/02	30.0	7.2	26.7	581	1.0	320	3.5
079A	363513096591579	07/24/02	42.0	7.2	23.2	688	2.0	378	3.0
081A	363740097025201	07/25/02	14.0	7.2	20.6	639	4.0	351	2.0
081A	363740097025201	07/25/02	30.0	7.3	21.6	957	0.5	526	0.0
081A	363740097025201	07/25/02	46.0	7.4	21.0	994	0.5	547	0.0
083A	363932097033001	07/26/02	14.0	6.8	19.9	740	1.0	407	2.5

Appendix 2. Water-quality data for the Quaternary aquifer, western Osage County, Oklahoma, 2001-2002—Continued.

[A, alluvium; T, terrace deposits; Sample depth, deepest depth of screened interval during sampling; bls, below land surface; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; nitrates are from first sampling, before September, 2002]

Local identifier (figs. 2 and 3)	Site identifier	Date sampled	Sample depth (feet bls)	pH (standard units)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Estimated dissolved solids (mg/L)	Nitrate dissolved (mg/L)
083A	363932097033001	07/26/02	24.0	7.2	20.0	679	1.0	373	1.0
083A	363932097033001	07/26/02	34.0	7.2	21.0	737	1.0	405	0.5
084A	364148097015601	07/26/02	14.0	6.8	20.7	688	3.0	378	3.0
085A	364110096594101	08/16/02	16.0	6.8	20.1	736	1.0	405	1.0
088A	364148096552901	08/26/02	24.0	7.0	24.7	638	1.0	351	2.0
088A	364148096552901	08/26/02	40.0	7.1	22.9	661	2.0	364	0.0
095A	362909096522101	08/28/02	20.0	6.7	21.4	392	1.5	215	2.5
095A	362909096522101	08/28/02	24.0	7.0	21.2	369	2.0	203	2.5
096A	363312096481301	08/28/02	20.0	6.9	22.4	851	4.5	468	1.0
096A	363312096481301	08/28/02	26.0	7.0	20.5	765	3.5	421	1.0
096A	363312096481301	08/28/02	32.0	6.8	21.5	801	2.0	441	0.0

Appendix 3. Sieve data and calculated hydraulic conductivity for the Quaternary aquifer, western Osage County, Oklahoma

[T, terrace deposits; A, alluvium; *, data not included because of small grain size; Φ^{10}, negative $\log_2$ of the grain size in millimeters of the 10 percentile finer by weight; Diameter^{10}, diameter of the 10 percentile finer by weight; cm, centimeters; ft/d, feet per day]

Local identifier (figs. 2 and 3)	Sample depth (feet)	Φ^{10}	Diameter^{10} (cm)	Hydraulic conductivity (ft/d)
001T	1.0	4.6	0.00412	3.9
001T	3.0	4.4	0.00474	5.1
001T	5.0	4.7	0.00385	3.4
001T	7.0	4.7	0.00385	3.4
001T	10.0	3.8	0.00718	12
001T	11.0	4.2	0.00544	6.7
001T	13.0	3.6	0.00825	15
001T	15.0	4.8	0.00359	2.9
001T	17.0	4.7	0.00385	3.4
001T	19.0	3.8	0.00718	12
001T	20.0	4.8	0.00359	2.9
001T	23.0	3.8	0.00718	12
001T	24.0	3.8	0.00718	12
002A	2.0	4.7	0.00385	3.4
002A	6.0	4.8	0.00359	2.9
002A	9.5	4.6	0.00412	3.9
002A	13.0	3.6	0.00825	15
002A	15.0	4.0	0.00625	8.9
002A	16.0	3.4	0.00947	20
002A	20.0	1.8	0.02872	190
002A	22.0	3.0	0.01250	35
002A	22.5	3.8	0.00718	12
002A	23.0	0.8	0.05743	750
002A	24.0	1.3	0.04061	370
002A	28.0	2.0	0.02500	140
007A	4.5	4.6	0.00412	3.9
007A	20.0	3.9	0.00670	10
007A	24.0	0.9	0.05359	650
007A	28.0	1.8	0.02872	190
009T	0.5	4.7	0.00385	3.4
009T	1.5	4.7	0.00385	3.4
009T	8.0	2.8	0.01436	47

Appendix 3. Sieve data and calculated hydraulic conductivity for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; *, data not included because of small grain size; Φ^{10}, negative $\log_2$ of the grain size in millimeters of the 10 percentile finer by

Local identifier (figs. 2 and 3)	Sample depth (feet)	Φ^{10}	Diameter[10] (cm)	Hydraulic conductivity (ft/d)
009T	12.0	2.8	0.01436	47
009T	16.0	2.8	0.01436	47
009T	22.0	3.4	0.00947	20
009T	24.0	3.7	0.00769	13
009T	26.5	2.8	0.01436	47
009T	30.5	3.0	0.01250	35
010A	14.0	3.8	0.00718	12
010A	16.0	2.6	0.01649	62
010A	20.0	2.3	0.02031	93
010A	22.0	0.9	0.05359	650
011T	1.0	4.3	0.00508	5.8
011T	3.0	4.7	0.00385	3.4
011T	5.0	4.8	0.00359	2.9
011T	9.0	4.6	0.00412	3.9
011T	14.0	4.6	0.00412	3.9
011T	19.0	4.7	0.00385	3.4
011T	24.0	3.5	0.00884	18
011T	28.0	2.6	0.01649	62
022A	3.0	4.8	0.00359	2.9
022A	4.0	4.6	0.00412	3.9
022A	8.0	2.9	0.01340	41
022A	12.0	3.8	0.00718	12
022A	15.0	2.9	0.01340	41
022A	16.0	2.2	0.02176	110
022A	20.0	1.7	0.03078	210
022A	24.0	1.9	0.02679	160
022A	28.0	1.3	0.04061	370
022A	35.0	-0.4	0.13195	3,900
022A	40.0	1.5	0.03536	280
022A	44.0	1.3	0.04061	370
026A	6.0	3.0	0.01250	35
026A	14.0	2.5	0.01768	71

Appendix 3. Sieve data and calculated hydraulic conductivity for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; *, data not included because of small grain size; Φ^{10}, negative $\log_2$ of the grain size in millimeters of the 10 percentile finer by

Local identifier (figs. 2 and 3)	Sample depth (feet)	Φ^{10}	Diameter[10] (cm)	Hydraulic conductivity (ft/d)
026A	20.0	2.9	0.01340	41
026A	28.0	1.9	0.02679	160
026A	32.0	1.6	0.03299	250
026A	38.0	1.6	0.03299	250
027T	4.0	4.2	0.00544	6.7
027T	8.0	3.4	0.00947	20
027T	12.0	3.0	0.01250	35
027T	17.0	3.0	0.01250	35
027T	23.0	3.4	0.00947	20
028T	1.0	4.6	0.00412	3.9
028T	4.0	2.8	0.01436	47
028T	12.0	4.1	0.00583	7.7
028T	16.0	3.4	0.00947	20
028T	24.0	2.9	0.01340	41
028T	35.7	3.7	0.00769	13
028T	38.0	1.2	0.04353	430
028T	39.7	1.4	0.03789	330
035T	1.0	4.6	0.00412	3.9
035T	4.0	2.7	0.01539	54
035T	8.0	2.9	0.01340	41
035T	12.0	3.7	0.00769	13
035T	16.0	4.3	0.00508	5.8
035T	23.0	4.0	0.00625	8.9
035T	24.0	4.0	0.00625	8.9
035T	28.0	4.4	0.00474	5.1
035T	32.0	3.6	0.00825	15
035T	40.0	4.6	0.00412	3.9
035T	44.0	3.3	0.01015	23
035T	47.0	3.8	0.00718	12
035T	50.0	3.0	0.01250	35
039T	4.0	4.1	0.00600	8.2
039T	8.0	4.8	0.00359	2.9

Appendix 3. Sieve data and calculated hydraulic conductivity for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; *, data not included because of small grain size; Φ^{10}, negative $\log_2$ of the grain size in millimeters of the 10 percentile finer by

Local identifier (figs. 2 and 3)	Sample depth (feet)	Φ^{10}	Diameter[10] (cm)	Hydraulic conductivity (ft/d)
039T	13.0	4.4	0.00474	5.1
039T	20.0	4.1	0.00583	7.7
039T	24.0	2.8	0.01436	47
039T	28.0	4.1	0.00583	7.7
039T	32.0	2.9	0.01340	41
039T	36.0	2.9	0.01340	41
039T	40.0	2.0	0.02500	140
045A	1.5	3.8	0.00718	12
045A	4.0	2.7	0.01539	54
045A	8.0	2.9	0.01340	41
045A	16.0	1.8	0.02872	190
045A	20.0	2.6	0.01649	62
045A	22.0	4.4	0.00474	5.1
045A	28.0	1.7	0.03078	210
045A	32.0	0.9	0.05359	650
045A	41.9	1.0	0.05000	570
047A	1.0	4.6	0.00412	3.9
047A	20.0	2.9	0.01340	41
047A	16.0	2.6	0.01649	62
047A	26.0	1.7	0.03078	210
047A	35.5	2.9	0.01340	41
047A	39.0	1.2	0.04353	430
047A	42.0	0.9	0.05359	650
047A	44.0	1.9	0.02679	160
047A	47.8	1.7	0.03078	210
053T	*	*	*	*
056A	8.0	2.9	0.01340	41
056A	12.0	3.1	0.01166	31
056A	16.0	2.3	0.02031	94
056A	23.0	-0.7	0.16245	6,000
056A	24.0	2.9	0.01340	41
056A	33.0	2.8	0.01436	47

Appendix 3. Sieve data and calculated hydraulic conductivity for the Quaternary aquifer, western Osage County, Oklahoma—Continued.

[T, terrace deposits; A, alluvium; *, data not included because of small grain size; Φ^{10}, negative $\log_2$ of the grain size in millimeters of the 10 percentile finer by

Local identifier (figs. 2 and 3)	Sample depth (feet)	Φ^{10}	Diameter[10] (cm)	Hydraulic conductivity (ft/d)
056A	37.0	2.8	0.01436	47
071A	1.0	4.1	0.00583	7.7
071A	4.0	4.7	0.00385	3.4
071A	16.0	3.4	0.00947	20
071A	20.0	2.0	0.02500	140
071A	24.0	2.6	0.01649	62
071A	28.0	2.3	0.02031	94
071A	38.0	1.4	0.03789	330
082T	1.0	4.4	0.00474	5.1
082T	4.0	4.2	0.00544	6.7
082T	24.0	3.8	0.00718	12
082T	28.0	2.9	0.01340	41
092A	*	*	*	*
094T	*	*	*	*