



Prepared in cooperation with the Oklahoma Department of Environmental Quality

Comparison of Ground-Water Quality in Samples From Selected Shallow and Deep Wells in the Central Oklahoma Aquifer, 2003–2005



Scientific Investigations Report 2006–5084

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

On the cover: Photographs on the cover (clockwise starting upper left) show activities that occur above the Central Oklahoma aquifer: urban setting of Oklahoma City, Oklahoma; livestock and oil tanks; agriculture; and urban fertilizing. Photographs were taken by U.S. Geological Survey employees.

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By Carol J. Becker

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

U.S. Department of the Interior
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U.S. Geological Survey
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Conversion Factors and Datums

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m ³)

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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 or below NAVD 88.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), milliliters (mL), or micrograms per liter ($\mu\text{g}/\text{L}$).

Comparison of Ground-Water Quality in Samples from Selected Shallow and Deep Wells in the Central Oklahoma Aquifer, 2003–2005

By Carol J. Becker

Abstract

The aquifer units of the Central Oklahoma aquifer underlie about 2,890 square miles of central Oklahoma and are used extensively to supply water for municipal, domestic, industrial, and agricultural needs. The Central Oklahoma aquifer also is commonly referred to as the Garber-Wellington aquifer because the Garber Sandstone and Wellington Formation yield the greatest quantities of usable water for domestic and high-capacity wells.

The major water-quality concerns for the Central Oklahoma aquifer described by the U.S. Geological Survey National Water Quality Assessment Program (1987 to 1992) were elevated concentrations of nitrate nitrogen in shallow water and the occurrence of arsenic, chromium, and selenium in parts of the aquifer. The quality of water from deep public-water supply wells in the Central Oklahoma aquifer is monitored by the State of Oklahoma. The chemical quality of water from shallow domestic wells is not monitored, and, therefore, there is a concern that well owners may be unknowingly ingesting water with nitrate nitrogen, arsenic, chromium, selenium, and other chemical constituents at concentrations that are considered harmful. As a result of this concern, the Oklahoma Department of Environmental Quality and the U.S. Geological Survey collaborated on a study to sample water during June 2003 through August 2005 from 23 shallow wells (less than 200 feet in depth) and 28 deep wells (200 feet or greater in depth) completed in the bedrock aquifer units of the Central Oklahoma aquifer. The objectives of the study were to describe the chemical quality of water from shallow and deep wells and to determine if the differences in constituent concentrations are statistically significant.

Water from shallow wells had significantly higher concentrations of calcium, magnesium, bicarbonate, sulfate, chloride, and nitrate nitrogen than water from deep wells. There were no significant differences between concentrations of dissolved solids, sodium, and fluoride in water from shallow and deep wells. Water from 9 shallow wells had nitrate nitrogen concentrations greater than 2 milligrams per liter, suggesting nitrogen sources at land surface have had an effect

on water from these wells. Water from three shallow wells (13 percent) exceeded the nitrate nitrogen maximum contaminant level of 10 milligrams per liter in drinking water.

Water from shallow wells had significantly lower concentrations of arsenic, chromium, iron, and selenium than water from deep wells, whereas, concentrations of barium, copper, manganese, and zinc were similar. Water-quality data indicate that arsenic frequently occurs in shallow ground water from the Central Oklahoma aquifer, but at low concentrations (<10 micrograms per liter). The occurrence of chromium and selenium in water from shallow wells was infrequent and at low concentrations in this study.

It does not appear that the quality of water from a shallow well can be predicted based on the quality of water from a nearby deep well. The results show that in general terms, shallow ground water has significantly higher concentrations of most major ions and significantly lower concentrations of arsenic, chromium, and selenium than water from deep wells.

Introduction

The Central Oklahoma aquifer (COA) underlies about 2,890 square miles of central Oklahoma (fig. 1) and is used extensively to supply water for municipal, domestic, industrial, and agricultural needs (Tortorelli, 2004). The COA also is commonly referred to as the Garber-Wellington aquifer because the Garber Sandstone and Wellington Formation yield the greatest quantities of usable water for domestic and public-supply wells (fig. 2).

The bedrock aquifer units of the COA and overlying alluvial deposits along the major rivers were sampled between 1987 and 1992 as part of the National Water Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS). The major water-quality concerns were elevated concentrations of nitrate nitrogen in shallow water and the occurrence of arsenic, chromium, and selenium in parts of the COA (Christenson, 1998). Elevated concentrations of nitrate nitrogen were measured in shallow ground water near areas where nitrogen compounds in fertilizers commonly were

2 Comparison of Ground-Water Quality in Samples from Selected Shallow and Deep Wells in the Central Oklahoma Aquifer, 2003–2005

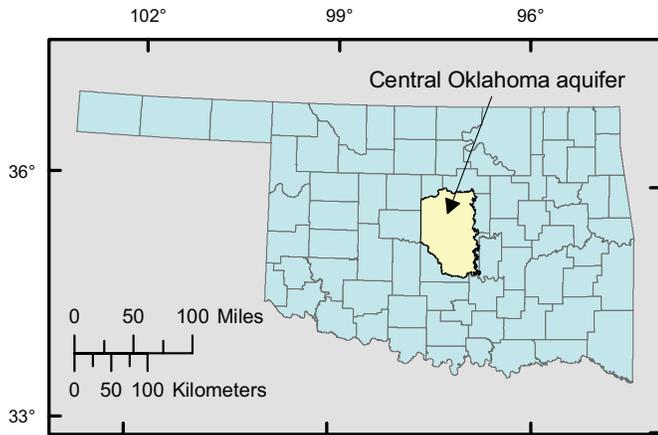


Figure 1. Location of the Central Oklahoma aquifer in Oklahoma.

used. In parts of the COA, water from deep bedrock layers is affected by naturally occurring dissolved concentrations of arsenic, chromium, and selenium in exceedance of the maximum contaminant levels (MCL) for drinking-water (Parkhurst and others, 1993) (U.S. Environmental Protection Agency, 2003b).

The quality of water from deep public-water supply wells in the COA is monitored by the State of Oklahoma as required by the U.S. Environmental Protection Agency (EPA). The EPA regulates the concentrations in public-drinking water of certain chemical constituents that can be harmful at elevated concentrations, including arsenic, chromium, selenium, and nitrate nitrogen. The maximum contaminant levels (MCL) are concentrations that are not to be exceeded and are referred to as primary standards (table 1). For some non-toxic constituents, such as chloride, fluoride, and iron, the EPA recommends a concentration level referred to as a secondary maximum contaminant level (SMCL) because of the undesirable cosmetic or aesthetic effects that occur at elevated concentrations. These recommendations, referred to as secondary standards, are guidelines for public-water systems and are not legally enforceable (U.S. Environmental Protection Agency, 2003b). The State of Oklahoma follows the EPA primary and secondary standards used for public-supply water systems and has a monitoring program that checks water quality to ensure public safety (Mike Houts, Oklahoma Dept. of Environmental Quality, oral commun., 2004).

The chemical quality of water from shallow domestic wells is not monitored by the EPA or the State of Oklahoma and, therefore, there is a concern that well owners may be unknowingly ingesting water with nitrate nitrogen, arsenic, chromium, and selenium or other chemical constituents at concentrations that are considered harmful. As a result of this concern, the Oklahoma Department of Environmental Quality (ODEQ) and the USGS collaborated on a study to sample water from 23 shallow wells and 28 deep wells completed in the bedrock aquifer units of the COA from June 2003 through August 2005 to compare the quality of water from the

two groups. A better understanding about the occurrence of undesirable and potentially hazardous chemical constituents in shallow ground water would help well owners and operators make informed decisions about appropriate water use.

The objectives of the study were (1) to describe the chemical quality of water from shallow and deep wells completed in the bedrock aquifer units of the COA and (2) to determine if the differences in constituent concentrations in ground-water samples from shallow and deep wells are statistically significant.

Purpose and Scope

The purpose of this report is to describe ground-water-quality data collected from 23 shallow wells (less than 200 feet deep) and 28 deep wells (200 feet or greater) completed in the bedrock aquifer units of the COA and to provide the results from statistical tests used to determine if differences in constituent concentrations are statistically significant between the shallow and deep well samples. The 51 wells sampled for this project ranged in depth from 40 to 805 feet and were completed in the bedrock aquifer units of the COA and not the Hennessey Group or the unconsolidated alluvial deposits along the major rivers in the COA study area.

The scope of the project entailed the sampling of 30 domestic wells and 21 high-capacity wells. The domestic wells were sampled by USGS personnel and consisted of 23 shallow wells and 7 deep wells; 28 wells were sampled on five occasions, one well was sampled four times, and one well was sampled once. A total of 145 water samples were collected and analyzed from domestic wells sampled at about 12-week intervals over a 1-year period from June 2003 to June 2004. Water properties and acid neutralizing capacity (ANC) of water from domestic wells were measured in the field. The 21 high-capacity wells were sampled by well operators and all were completed at depths of 200 feet or greater; 17 wells were sampled three times, two wells four times, one well twice, and one well once—all from June 2004 through May 2005; a total of 62 water samples were analyzed. Water properties and ANC of water from high-capacity wells were not measured. All ground-water samples were analyzed for dissolved solids, major ions, nitrite plus nitrate nitrogen, and nine trace elements (table 1) at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality in Oklahoma City, Oklahoma. For the purposes of this report, nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen.

Description of the Central Oklahoma Aquifer

The geology, petrology, and water chemistry of the COA have been studied and described in depth by the USGS National Water Quality Assessment Program. This section provides a general overview of some of the important attributes describing the COA and ground-water quality.

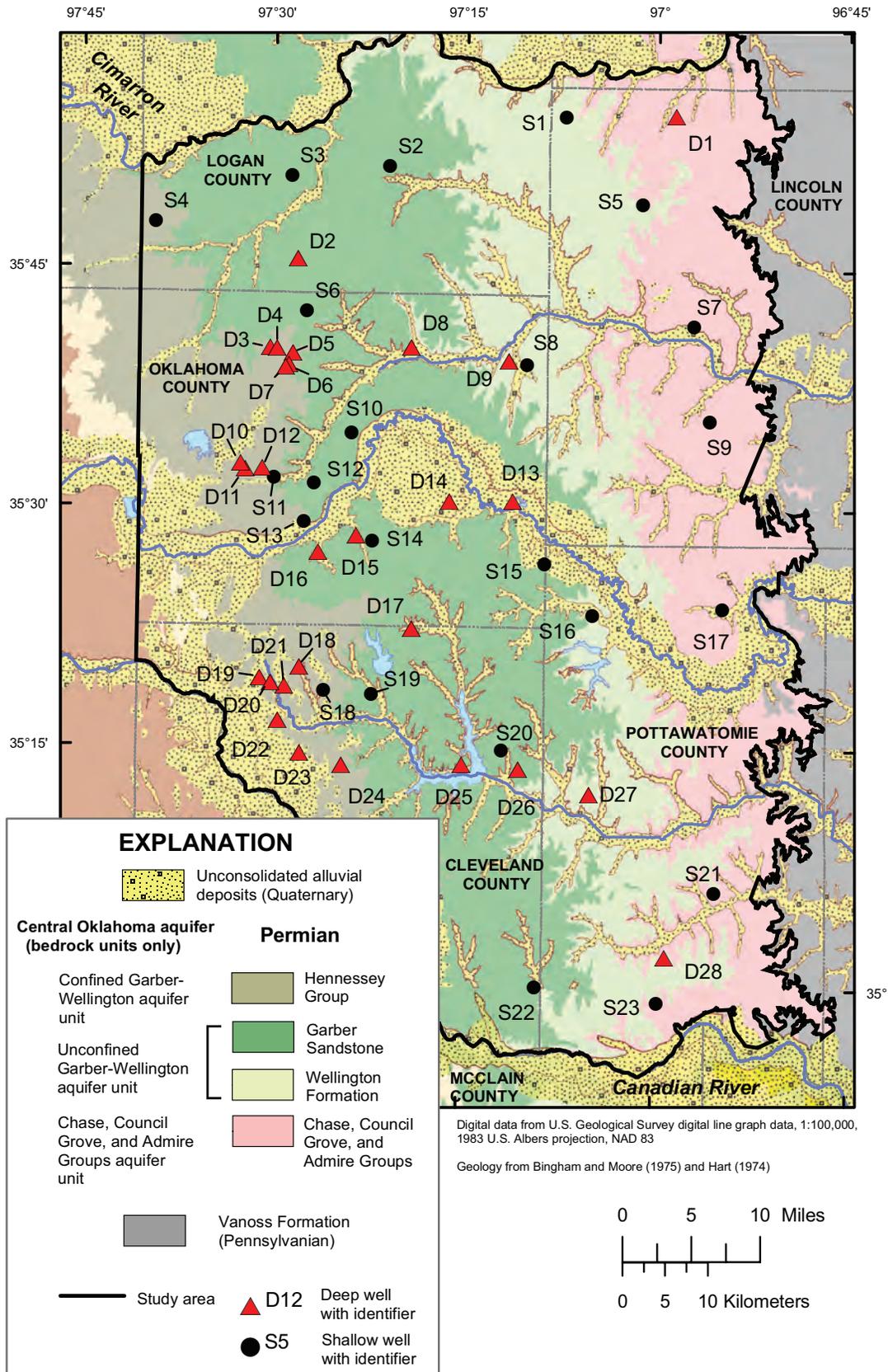


Figure 2. Surficial geology map showing bedrock aquifer units and locations of shallow and deep wells sampled in the Central Oklahoma aquifer, 2003–2005.

Table 1. Analysis methodology, method references, and minimum reporting levels for water properties and chemical constituents measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005

[EPA, U.S. Environmental Protection Agency; $\mu\text{S}/\text{cm}$, microsiemens per centimeter; $^{\circ}\text{C}$, degree Celsius; —, not applicable; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; CaCO_3 , calcium carbonate; N, nitrogen; ICP, inductively coupled plasma; AES, atomic emission spectroscopy; MS, mass spectrometry]

Water properties ¹ and chemical constituents ² (units)	Maximum Contaminant Level	Secondary Maximum Contaminant Level	Analysis methodology (EPA method)	Method references	Minimum reporting level ³ (domestic / high capacity)
Specific conductance, field ($\mu\text{S}/\text{cm}$ at 25°C)	—	—	—	Wilde and Radtke (1998)	3 significant digits
pH, field (standard units)	—	6.5–8.5	—	Wilde and Radtke (1998)	0.1 standard units
Water temperature, field ($^{\circ}\text{C}$)	—	—	—	Wilde and Radtke (1998)	0.5 $^{\circ}\text{C}$
Oxygen, dissolved, field (mg/L)	—	—	—	Wilde and Radtke (1998)	0.1 mg/L
Acid neutralizing capacity, field (mg/L as CaCO_3)	—	—	—	Rounds and Wilde (2001)	3 significant digits
Dissolved solids, total (mg/L)	—	500	(160.1) Residue, filterable, 180°C	EPA (1983)	10 mg/L
Calcium, total (mg/L)	—	—	(200.7) ICP/AES without digestion	EPA (1994)	1 mg/L
Magnesium, total (mg/L)	—	—	(200.7) ICP/AES without digestion	EPA (1994)	1 mg/L
Sodium, total (mg/L)	—	—	(200.7) ICP/AES without digestion	EPA (1994)	1 mg/L
Potassium, total (mg/L)	—	—	(200.7) ICP without digestion	EPA (1994)	1 mg/L
Bicarbonate, total, field (mg/L)	—	—	—	Rounds and Wilde (2001)	3 significant digits
Sulfate, total, (mg/L)	—	250	(375.4) Barium sulfate turbidity	EPA (1983)	10 mg/L
Chloride, total (mg/L)	—	250	(325.2) Colorimetric, ferricyanide	EPA (1983)	10 mg/L

Table 1. Analysis methodology, method references, and minimum reporting levels for water properties and chemical constituents measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005—Continued

[EPA, U.S. Environmental Protection Agency; $\mu\text{S}/\text{cm}$, microsiemens per centimeter; $^{\circ}\text{C}$, degree Celsius; —, not applicable; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; CaCO_3 , calcium carbonate; N, nitrogen; ICP, inductively coupled plasma; AES, atomic emission spectroscopy; MS, mass spectrometry]

Water properties ¹ and chemical constituents ² (units)	Maximum Contaminant Level	Secondary Maximum Contaminant Level	Analysis methodology (EPA method)	Method references	Minimum reporting level ³ (domestic / high capacity)
Fluoride, total (mg/L)	—	2.0	(300.1A) / (300) Ion chromatography	EPA (2000)	0.1 mg/L
Nitrate nitrogen, total (mg/L as N)	10	—	(353.2) Colorimetric, automated, cadmium reduction	EPA (1983)	0.05 / 0.05-0.1 mg/L ⁴
Arsenic, total ($\mu\text{g}/\text{L}$)	10	—	(200.8) ICP/MS / (200.7) ICP/AES without digestion	EPA (1994)	2 / 10 $\mu\text{g}/\text{L}$
Barium, total ($\mu\text{g}/\text{L}$)	2,000	—	(200.8) ICP/MS / (200.7) ICP/AES without digestion	EPA (1994)	10 / 5 $\mu\text{g}/\text{L}$
Cadmium, total ($\mu\text{g}/\text{L}$)	5	—	(200.8) ICP/MS / (200.7) ICP/AES without digestion	EPA (1994)	2 / 5 $\mu\text{g}/\text{L}$
Chromium, total ($\mu\text{g}/\text{L}$)	100	—	(200.8) ICP/MS / (200.7) ICP/AES without digestion	EPA (1994)	10 / 5 $\mu\text{g}/\text{L}$
Copper, total ($\mu\text{g}/\text{L}$)	1,300	—	(200.8) ICP/MS / (200.7) ICP/AES without digestion	EPA (1994)	10 / 5 $\mu\text{g}/\text{L}$
Iron, total ($\mu\text{g}/\text{L}$)	—	300	(200.7) ICP/AES without digestion	EPA (1994)	10 / 20 $\mu\text{g}/\text{L}$
Manganese, total ($\mu\text{g}/\text{L}$)	—	500	(200.7) ICP/AES without digestion	EPA (1994)	10 / 5 $\mu\text{g}/\text{L}$
Selenium, total ($\mu\text{g}/\text{L}$)	50	—	(200.8) ICP/MS / (200.7) ICP/AES without digestion	EPA (1994)	10 / 10 $\mu\text{g}/\text{L}$
Zinc, total ($\mu\text{g}/\text{L}$)	5,000	—	(200.8) ICP/MS / (200.7) ICP/AES without digestion	EPA (1994)	10 / 5 $\mu\text{g}/\text{L}$

¹ Water properties in water from domestic wells were measured in the field by U.S. Geological Survey personnel.

² Chemical constituents were analyzed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality in Oklahoma City, Oklahoma.

³ The minimum reporting level for some chemical constituents was different for domestic and high-capacity wells.

⁴ The minimum reporting level changed for domestic wells from 0.05 to 0.1 mg/L , February 2005.

Location and Physiography

The COA lies within all or parts of Cleveland, Lincoln, Logan, Payne, Oklahoma, and Pottawatomie Counties (fig. 3). The COA is bordered by the Cimarron River on the north and the Canadian River on the south (fig. 2). The aquifers ability to yield water decreases beyond these borders and generally does not yield enough water for large volume wells. The western edge is defined as the western Cleveland, Logan, and Oklahoma County lines. West of this boundary the concentration of dissolved solids in ground water exceeds 5,000 milligrams per liter (mg/L) (Christenson, 1998, fig. 9). The eastern boundary is defined by the contact between the Chase, Council Grove, and Admire Groups with the underlying Vanoss Formation at land surface. The base of the COA is considered to be the base of the fresh water, which is defined as where the concentration of dissolved solids in ground water is equal to 5,000 mg/L (Hart, 1966). Depth to the base of fresh water ranges from about 1,000 feet in south-central Oklahoma County to about 100 feet below land surface at the north, south, and eastern aquifer boundaries (Christenson, 1998, fig. 8).

Land Use, Population, and Water Use

Land use information for 1992 shows that about 25 percent of the land overlying the COA was used for agricultural land uses, which includes pasture, hay, row crops, and small grains and about 8 percent was developed for residential, commercial, industrial, and transportation uses (fig. 3) (U.S. Environmental Protection Agency, 2003a). Areas dominated by tree cover (forested upland) and grasses (herbaceous upland) covered the greatest percentage of land in the study area, at 26.08 and 37.54 percent, respectively.

The number of people residing within the Oklahoma City metropolitan statistical area in 2003 is estimated to have been about 1.25 million (Lexico Publishing Group, 2006). The Oklahoma City metropolitan statistical area includes the study area.

In 2000, the two largest users of water from the COA were municipalities and domestic well owners. Estimated ground-water withdrawals in 2000 totaled about 41.82 million gallons per day from the COA (table 2) (Tortorelli, 2004). The greatest volume of water was withdrawn for public-water supply; 25.65 million gallons per day. Public-water supplies for the two largest metropolitan areas, Oklahoma City and Norman, are primarily from surface-water reservoirs, whereas, most of the smaller municipalities rely on ground water. The second greatest use of ground water from the COA was for domestic well owners, who withdrew 7.31 million gallons per day. Other uses of ground water include commercial, industrial and mining, irrigation, livestock, aquaculture, and thermoelectric power.

Table 2. Estimated ground-water withdrawals for the Central Oklahoma aquifer in 2000 (Tortorelli, 2004)

Water Use	Amounts in million of gallons per day
Domestic	7.31
Commercial	1.57
Industrial and mining	0.82
Irrigation	5.25
Livestock and aquaculture	1.09
Public-water supply	25.65
Thermoelectric power	0.13
Total	41.82

Aquifer Units

The bedrock aquifer units that make up the COA are the Garber Sandstone, Wellington Formation, and the Chase, Council Grove, and Admire Groups. The Hennessey Group is a low permeability shale and mudstone that overlies the Garber Sandstone in the western one-quarter of the COA study area. Even though the Hennessey Group may yield small quantities of water in isolated areas, it is not considered part of the COA for this study. The Garber Sandstone and Wellington Formation are considered one aquifer unit for this report and are referred to as the Garber-Wellington aquifer unit (GWAU). Where the GWAU is overlain by the Hennessey Group it is referred to as the confined GWAU. Where the GWAU is exposed at land surface, it is referred to as the unconfined GWAU. The Chase, Council Grove, and Admire Groups also are considered one aquifer unit in this report and are referred to as the Chase, Council Grove, and Admire Groups aquifer unit (CCAAU).

The bedrock aquifer units of the COA were deposited during the Permian age in fluvial, deltaic, and marginal marine environments (Tanner, 1959) when central Oklahoma was near the equator (Ziegler, 1990). Fluctuations in the sea level caused large changes in depositional environment that resulted in the rock units varying lithologically over short distances. As a result, the Garber Sandstone and Wellington Formation consist of fine-grained, crossbedded sandstone interbedded with siltstone and mudstone (Breit, 1998). The upper part of the GWAU, the Garber Sandstone, contains more sandstone than the underlying Wellington Formation, although the amount in both units varies from 25 to 75 percent (Breit, 1998). The thickness of a full section of the Garber Sandstone and Wellington Formation ranges from 1,165 to 1,600 feet (Christenson and others, 1992). Underlying the Wellington Formation is the Chase, Council Grove, and Admire Groups. These units have similar lithology consisting of mudstone, fine-grained sandstone, and conglomerates (Breit, 1998). The combined thickness of the Chase, Council Grove, and Admire Groups ranges from 570 to 940 feet (Christenson and others, 1992).

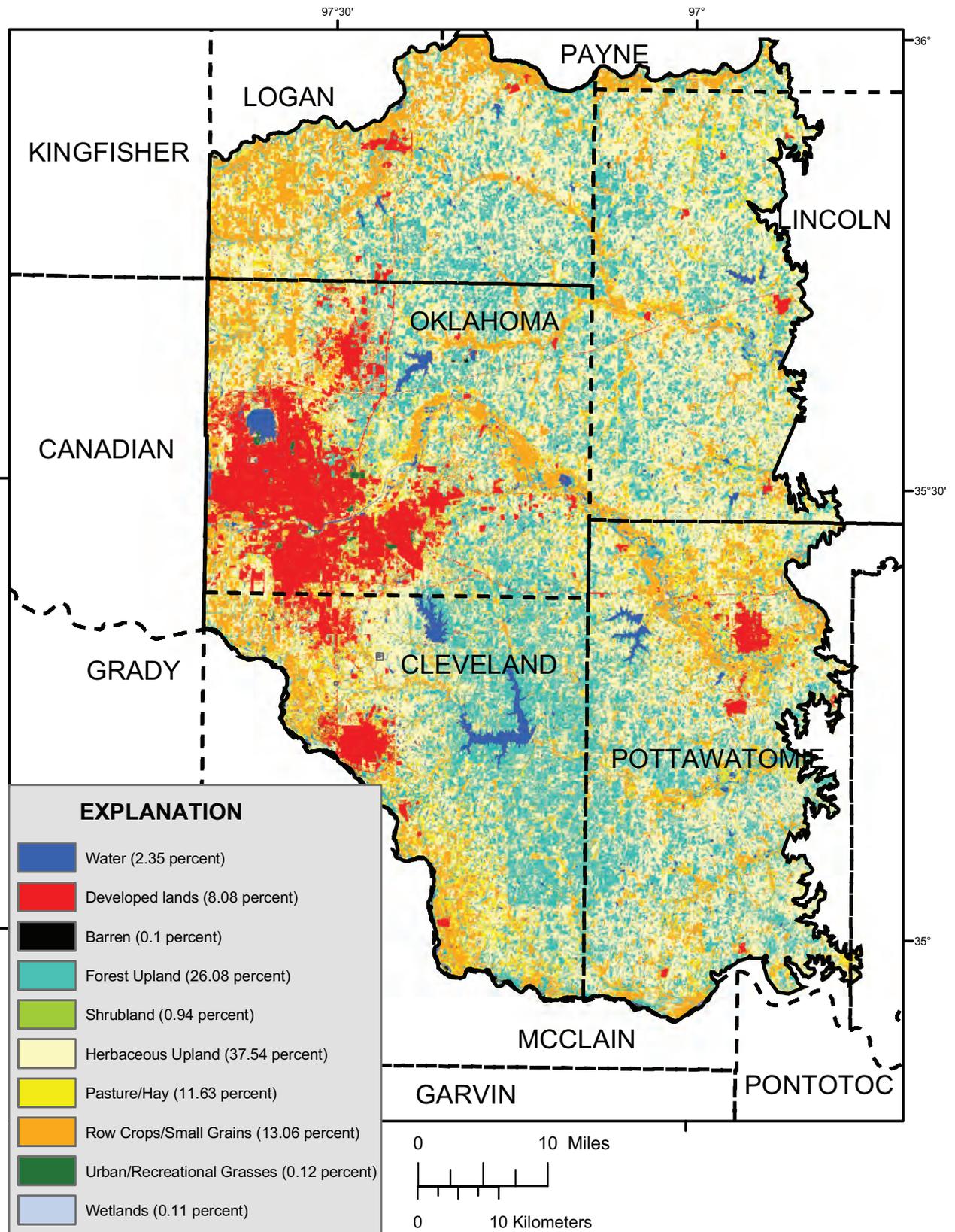


Figure 3. Land use overlying the Central Oklahoma aquifer, 1992 (U.S. Environmental Protection Agency, 2003a).

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The aquifer units of the COA dip to the west at approximately 50 feet per mile.

Previous Study — National Water Quality Assessment Program

The most comprehensive study of the COA ground-water quality to date was the USGS NAWQA Program from 1987–1992. The NAWQA Program described ground-water quality throughout the aquifer and the location, nature, and causes of selected water-quality problems. These water-quality problems include elevated concentrations of nitrate nitrogen and the trace elements arsenic, chromium, and selenium in parts of the COA (Christenson, 1998).

Elevated concentrations of nitrate nitrogen were most commonly found in water from shallow wells completed in the bedrock aquifer units of the COA (Christenson, 1998, table 6) and were described as resulting from shallow sources for nitrate such as nitrogen-based fertilizer or septic-tank effluent. The NAWQA Program also established that the trace elements arsenic, chromium, and selenium occur naturally in various mineralogical forms throughout rocks of the COA. The highest dissolved concentrations of these trace elements were found by Schlottmann and others (1998) in water from the deep parts of the confined GWAU (table 3).

Christenson (1998) reported that the proportion of major ions in ground water varies widely in the COA, but that certain major-ion compositions or water types are associated with the aquifer units. In the unconfined GWAU, calcium, magnesium, and bicarbonate are the dominant ions in ground water. Whereas, in the confined GWAU and the CCAAU, sodium and bicarbonate were the dominant ions (Christenson, 1998).

The calcium and bicarbonate ions originate from recharge water absorbing carbon dioxide as it moves down through the unsaturated zone into the aquifer and from the dissolution of calcite in the rocks (Christenson and others, 1998). In the deep confined GWAU where water has resided for longer periods of time, the calcium (and magnesium) cations are removed and replaced with sodium from the interbedded clays in the rocks in a process called ion exchange (Christenson and others, 1998). This geochemical alteration of the water, in addition to the dissolution of dolomite, causes the pH of ground water to increase. When the pH exceeds 8.5, arsenic sorbed onto grain coatings in the rocks is released (Parkhurst and others, 1996). Figure 4 shows the relation between arsenic concentrations and pH measured in ground water mostly from high-capacity wells producing water from the confined GWAU in Cleveland County. This portion of the COA has concentrations of arsenic in water from high-capacity wells that exceed the EPA MCL of 10 micrograms per liter ($\mu\text{g/L}$) for drinking water (Smith, 2005).

Table 3. Summary of dissolved arsenic, chromium, and selenium distribution in the Central Oklahoma aquifer from historical data and data collected from 1987–90 for the U.S. Geological Survey National Ground-Water-Quality Assessment of the Central Oklahoma aquifer program (modified from Schlottmann and others, 1998). The definition for shallow and deep wells is based on Schlottmann and others, 1998

[Shallow is less than 300 feet; Deep is greater than or equal to 300 feet; Unconfined is outside confined part of the aquifer; Confined, within confined part of the aquifer; \geq , greater than or equal to; $\mu\text{g/L}$, microgram per liter; Rare, Less common, and Common indicate overall proportion of analyses that exceed concentration in data sets; Rare, fewer than 10 percent exceeded concentration; Less common, fewer than 20 percent exceeded concentration; Common, 20 percent or more exceeded concentration; —, indicates no analyses from category exceeded concentration]

Trace elements and concentration	Garber-Wellington aquifer unit				Chase, Council Grove, and Admire Groups aquifer unit		Near base of	
	Shallow unconfined	Shallow confined	Deep unconfined	Deep confined	Shallow	Deep	Hennessey Formation	Fresh water
Arsenic								
$\geq 50 \mu\text{g/L}$	Rare	Rare	Rare	Common	—	—	Yes	Yes
Chromium								
$\geq 50 \mu\text{g/L}$	Rare	—	Less common	Common	—	—	—	Yes
$\geq 100 \mu\text{g/L}$	—	—	Rare	Rare	—	—	—	Yes
Selenium								
$\geq 10 \mu\text{g/L}$	Rare	Less common	Less common	Common	Rare	Common	Yes	Yes
$\geq 50 \mu\text{g/L}$	Rare	—	Rare	Common	—	—	Yes	Yes

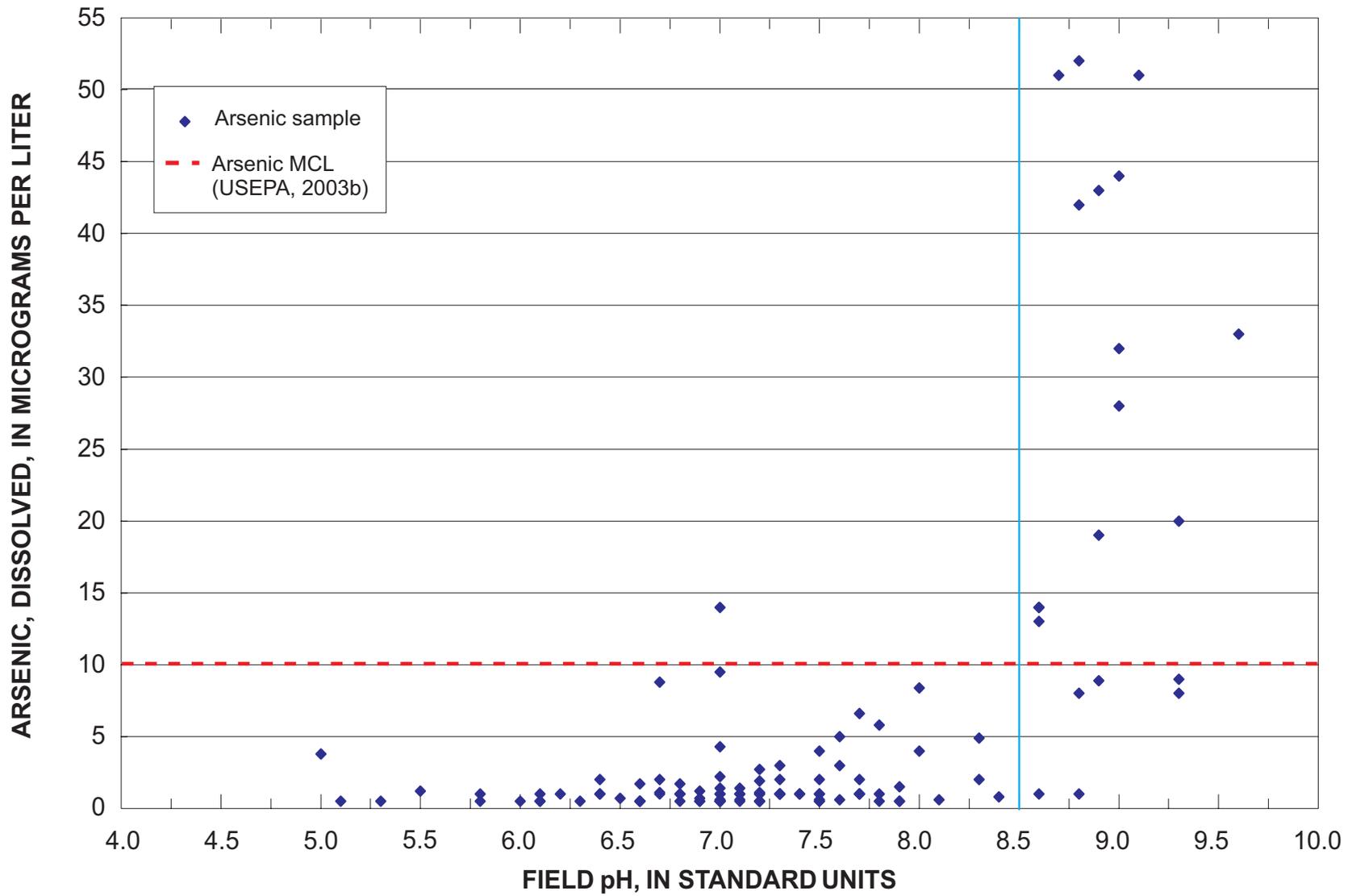


Figure 4. Relation between dissolved arsenic concentration and pH measured in ground water mostly from public-supply wells producing water from the confined Garber-Wellington aquifer in Cleveland County, Oklahoma. Modified from Smith (2005).

Acknowledgments

The author thanks Mike Houts and Jay Wright with ODEQ and personnel at the ODEQ State Environmental Laboratory. Gratitude also is expressed to the many well owners who graciously allowed USGS personnel to access their well for the collection of water samples and to USGS personnel; Lee Ann Alf, Monica Allen, Rick Hanlon, Royce Johnson, Shana Mashburn, and Jerrod Smith.

Methods

This section of the report describes the shallow and deep wells and the criteria used for selection. Water samples were collected from domestic wells by several teams of USGS personnel using methods consistent with USGS protocol. These methods are described below in addition to techniques used to analyze the water-quality data.

Description of Wells

Fifty-one wells were sampled throughout the COA study area. Seventeen wells produced water from the confined GWAU, 26 wells produced water from the unconfined GWAU, and eight wells produced water from the CCAAU (fig. 2 and table 4). Wells ranged in depth from 40 to 805 feet; 23 wells were completed at depths less than 200 feet deep, 10 wells were completed at depths between 200 and 399 feet, 8 wells were completed at depths between 400 and 599 feet, and 10 wells were completed at depths 600 feet or greater.

Twenty-one of the 51 wells were high-capacity wells and all were completed at depths of 200 feet or more. Thirty of the 51 wells were domestic wells and ranged in depth from 40 to 430 feet.

Site Selection

Twenty-three of the 30 domestic wells sampled for this study were previously sampled by the USGS for the NAWQA Program and were randomly selected using methods described by Scott (1990). An additional seven domestic wells were subsequently selected in the study area. Criteria for selecting domestic wells were: knowledge of the well construction including total depth, completion in the bedrock aquifer units, an operational existing pump, and a spigot location where untreated ground water could be sampled. The high-capacity wells were randomly selected by ODEQ from a list of wells routinely monitored for water-quality constituents (Jay Wright, Oklahoma Dept. of Environmental Quality, oral commun., 2005).

Sample Collection and Analytical Methods

Water from domestic wells was collected by USGS personnel at about 12-week intervals over a 1-year period from June 2003 to June 2004. Twenty-eight wells were sampled on five occasions, one well was sampled four times, and one well was sampled once for a total of 145 samples (appendixes 1 and 2). Water from high-capacity wells was collected by well operators from June 2004 to May 2005. Seventeen wells were sampled three times, two wells four times, one well twice, and one well once, for a total of 62 samples (appendix 2).

Sampling a domestic well consisted of measuring depth to water, purging the well, measurement of water properties, sampling, and sample preservation. The equipment used to sample a domestic well consisted of a plastic Y-connector with a garden hose adapter, a polypropylene adaptor (connects Y-connector to water spigot), and plastic tubing. Each domestic well was purged of at least three standing well-casing volumes of water before sampling. The water properties: specific conductance, pH, temperature, and dissolved oxygen were measured continuously during the purging process using a flow-through chamber with a multi-probe meter. The meter calibrations were performed every morning before use. The specific conductance and pH calibrations used standard solutions that bracketed the expected values. Domestic wells were sampled after purging and when the water properties specific conductance, pH, and dissolved oxygen had stabilized. Some well pumps were operating when the sampling team arrived. These wells were sampled after verifying that the volume of water purged was sufficient and the water properties had stabilized. Unfiltered water was collected in two 1-liter polyethylene bottles in an enclosed sampling chamber to prevent wind-borne contamination. The sample for trace element analysis was preserved by acidification with 2 milliliters (mL) of nitric acid to a pH of 2 or less. The samples were chilled on ice and delivered to the State Environmental Laboratory at the ODEQ by USGS personnel within 48 hours of collection. Water-quality samples were collected and processed using established USGS protocol described in Wilde and others (2003a, 2003b).

Water samples from high-capacity wells were collected by well operators from spigots at the point-of entry into the water distribution system. The high-capacity wells were operating and had been purged of any standing well-casing water before samples were collected. The spigot was turned on and water was run freely for 2 to 5 minutes then the flow of water was reduced. Two 1-liter polyethylene bottles were filled, capped, and delivered to the State Environmental Laboratory, as soon as possible. The sample for trace elements was preserved by acidification with 2 mL of nitric acid by laboratory personnel at the State Environmental Laboratory within 5 days after collection of the sample (Oklahoma Department of Environmental Quality, 2004). The water properties (specific conductance, pH, temperature, and dissolved oxygen) and acid neutralizing capacity (ANC) of water from high-capacity wells were not measured.

Table 4. Site information for shallow and deep wells sampled in the Central Oklahoma aquifer, 2003–2005

[USGS, U.S. Geological Survey; ID, identification; Well type, H is domestic, P is public-water supply (high-capacity well); GWAU, Garber Sandstone and Wellington Formation aquifer unit; Chase, Council Grove, and Admire Groups aquifer unit, CCAAU]

Well identifier	USGS ID number	Well type	Aquifer unit	Well depth in feet
Shallow wells				
S1	355444097071301	H	unconfined GWAU	141
S2	355134097211101	H	unconfined GWAU	194
S3	355052097284301	H	unconfined GWAU	180
S4	354755097392001	H	confined GWAU	81
S5	354914097010901	H	CCAAU	114
S6	354221097272501	H	unconfined GWAU	180
S7	354143096564301	H	CCAAU	89
S8	353909097100101	H	unconfined GWAU	101
S9	353539096554701	H	CCAAU	120
S10	353446097241101	H	unconfined GWAU	156
S11	353155097294601	H	unconfined GWAU	141
S12	353145097263801	H	unconfined GWAU	108
S13	352910097272501	H	unconfined GWAU	109
S14	352759097220201	H	unconfined GWAU	80
S15	352639097083401	H	unconfined GWAU	160
S16	352326097044801	H	unconfined GWAU	97
S17	352351096544001	H	CCAAU	80
S18	351839097254301	H	confined GWAU	165
S19	351823097215701	H	unconfined GWAU	125
S20	351450097114201	H	unconfined GWAU	65
S21	350603096550801	H	CCAAU	40
S22	350003097090102	H	unconfined GWAU	125
S23	345908096593101	H	CCAAU	84
Deep wells				
D1	355446096583601	H	CCAAU	227
D2	354538097280901	P	unconfined GWAU	212
D3	353939097301901	P	confined GWAU	544
D4	353959097294301	P	confined GWAU	600
D5	353948097283501	P	confined GWAU	544
D6	353900097284001	P	confined GWAU	451
D7	353850097290001	P	confined GWAU	467
D8	354008097190901	H	unconfined GWAU	220
D9	353925097113101	P	unconfined GWAU	200
D10	353218097321801	P	confined GWAU	550
D11	353224097320401	P	confined GWAU	705
D12	353229097304301	P	confined GWAU	800

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Table 4. Site information for shallow and deep wells sampled in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; ID, identification; Well type, H is domestic, P is public-water supply (high-capacity well); GWAU, Garber Sandstone and Wellington Formation aquifer unit; Chase, Council Grove, and Admire Groups aquifer unit, CCAAU]

Well identifier	USGS ID number	Well type	Aquifer unit	Well depth in feet
D13	353032097110701	P	unconfined GWAU	400
D14	353028097161901	P	unconfined GWAU	418
D15	352819097232501	P	unconfined GWAU	736
D16	352717097261601	P	unconfined GWAU	750
D17	352232097190201	H	unconfined GWAU	220
D18	352001097273601	P	confined GWAU	803
D19	351918097304001	P	confined GWAU	805
D20	351904097294201	H	confined GWAU	430
D21	351853097284701	P	confined GWAU	783
D22	351637097291301	H	confined GWAU	295
D23	351437097273101	P	confined GWAU	634
D24	351357097242001	P	confined GWAU	748
D25	351359097145401	P	unconfined GWAU	345
D26	351344097102801	P	unconfined GWAU	240
D27	351212097045601	H	unconfined GWAU	240
D28	350202096585901	H	CCAAU	300

All water samples were analyzed at the ODEQ State Environmental Laboratory for the major ions (calcium, magnesium, sodium, potassium, sulfate, chloride, and fluoride) in addition to dissolved solids and nitrate nitrogen. Water samples also were analyzed for the trace elements arsenic, barium, cadmium, chromium, copper, iron, manganese, selenium, and zinc (table 1). The minimum reporting level (MRL) for a constituent is the smallest measured concentration that can be reliably reported using a given analytical method (Timme, 1995). The MRL for nitrogen and all trace elements, except for selenium, was not the same in water analyzed from domestic and high-capacity wells, resulting in two MRLs for these constituents. The MRLs for constituent concentrations are shown on table 1.

The ANC of water from domestic wells was measured in the field by using incremental titrations of sulfuric acid. Because ANC was measured five times for each domestic well, an effort was made to use the same volume of water and acid strength each time a titration was performed. Depending on the ANC concentration, 50 mL of water was used with 0.16-normal standardized sulfuric acid or 100 to 150 mL of water was used with 1.6-normal standardized sulfuric acid. The ANC was measured in the field except on a few occasions when the titration was performed 4 to 6 hours later at the office. In these instances, a 250-mL bottle was filled to the top

leaving no air space, tightly capped, and chilled until the titration was performed.

Quality Control

The equipment for domestic well sampling was cleaned at the Oklahoma City USGS office using a non-phosphate detergent and plastic brush, then rinsed with tap water followed by deionized water. The equipment was then rinsed with an acid solution consisting of 5 percent hydrochloric acid and 95 percent trace-metal-free blank water and rinsed again with deionized water. Equipment was air dried, then wrapped in new plastic bags and used one time between each cleaning.

Ten percent of samples from domestic wells were quality-control samples consisting of five equipment blanks and 10 duplicate samples. Ten percent of samples from high-capacity wells were quality-control samples; three equipment blanks and three duplicate samples. An equipment blank sample was collected before each of the five domestic well sampling events to check if samples were contaminated by the sampling equipment or bottles. Three equipment blank samples were collected during June 2004 to check bottles, used for high-capacity wells, for existing contamination. Blank samples

indicated that there was no contamination from sampling equipment or bottles (appendix 3).

Duplicate samples are an extra set of samples collected at the same time as the environmental samples to determine the precision of laboratory analytical procedures. Duplicate samples were collected from two of the 30 domestic wells each sampling period. Duplicate samples from domestic wells were collected immediately following the environmental samples without using a splitting device. Three duplicate samples were collected from high-capacity wells by well operators. The duplicate samples were collected following the environmental samples without using a splitting device.

The analytical precision is calculated as the relative percent difference (RPD) of constituent concentrations between the environmental and duplicate samples using the equation below:

$$RPD = [(C_1 - C_2) / ((C_1 + C_2) / 2)] * 100$$

Where;

C_1 = largest of the two concentrations

C_2 = smaller of the two concentrations

If either of the constituent concentrations was less than the MRL the RPD was not calculated.

The RPD values for major ions measured in water from domestic wells ranged from 0 to 18.2 percent and in water from high-capacity wells, 0 to 9.8 percent. The RPD values for nitrate nitrogen concentrations ranged from 0 to 27.4 percent in water from domestic wells and 0 to 9.5 percent in water from high-capacity wells. For trace elements measured in water from domestic wells, the RPD values ranged from 0 to 48.4 percent and for high-capacity wells ranged from 0 to 20 percent. Five RPD values for iron were greater than 15 percent and may indicate that the analytical technique is problematic. The large RPD values also may be the result of sequential and not simultaneous collection of environmental and duplicate samples, and the prevalence of particulate material in the samples. Large RPD values also can be caused by small concentrations reported with few significant figures. For example, concentrations of 2 and 3 would give an RPD of 50 percent, whereas, if the concentrations were reported with more significant figures, such as 2.4 and 2.6, the RPD would be 8 percent. The analytical RPD are shown in appendix 4.

Ground-water samples from both shallow and deep wells were measured in unfiltered water and not digested prior to analysis. ODEQ analyzes non-digested whole water samples to better evaluate what is consumed. Unfortunately, constituent concentrations from unfiltered water are not considered ideal for statistical analysis, because particulate matter can be randomly introduced by wells and cause samples to be less representative of water from the aquifer. While sampling domestic wells, iron flakes from old well casing, sand, and other sediment were commonly seen in the flow-through chamber and occasionally in sample bottles.

Data Analysis

The 51 wells were divided into two groups based on total depth of well. The 23 shallow wells were labeled S1 through S23 and had a total depth of less than 200 feet. The 28 deep wells were labeled D1 through D28 and had a total depth of 200 feet or greater. The cutoff depth between the shallow and deep well groups was the midpoint depth of the shallow, intermediate, and deep well categories used by the NAWQA Program (Christenson, 1998).

Because multiple samples were collected from each well (except for two wells), median concentrations for each water property, major ion, and nitrate nitrogen, (not trace elements) were used to construct boxplots and describe water quality unless otherwise noted. The median was used because it represents the central trend of a constituent concentration and reduces spurious data that may be caused by laboratory error or contamination from particulate matter in the water sample.

The Mann-Whitney test (MathSoft Inc., 1999; Helsel and Hirsch, 1992) was used to statistically test populations of constituent concentrations in water from shallow and deep wells to determine if the differences are statistically significant within a 95 percent confidence of the relation. The Mann-Whitney test (also referred to as the Wilcoxon rank sum test) is a nonparametric test and requires no assumptions about population distribution and is not affected by spurious data. The Mann-Whitney test ranks the data from lowest to highest and uses the median rank of each population to determine if the populations are similar, instead of the actual constituent concentrations. If the two populations tested against each other had the same MRL, the censored data were assigned a -1 value and were ranked equally. If the two populations tested against each other had the same MRL, the censored data were assigned a -1 value. If the two populations tested had different MRLs, all censored data and all concentrations below the highest MRL were assigned a value of -1 (Dennis Helsel, USGS, written commun., 2006). The p-values for tests comparing some trace element concentrations were calculated using a small number of concentrations because of the large number of censored data.

The null hypothesis is that the two data sets have similar medians and distributions. The null hypothesis was rejected if the p-value (probability) is less than 0.05, which is equal to 95 percent confidence of the relation. The alternate hypothesis was that the differences in the populations of constituent concentrations are statistically significant. Constituent concentrations from all ground-water samples (not medians) were used to statistically test populations.

Comparison of Ground-Water Quality from Shallow and Deep Wells

Comparisons and descriptions of water properties and constituent concentrations, measured in water from shallow

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and deep wells, are shown using boxplots and statistical summaries. Constituent concentrations also were tested using the Mann-Whitney test to determine if differences in the shallow and deep well populations were statistically significant.

Boxplots show ranges of dissolved solids, sulfate, and chloride concentrations, which have an SMCL in drinking water, in addition to nitrate nitrogen, which has an MCL in drinking water (U.S. Environmental Protection Agency, 2003b). The median water property values and median concentrations from each well sampled were used to construct boxplots. For deep well D11, which had two water samples collected, the average concentration was used, whereas, for the wells S13 and D10 that had one water sample collected, the single constituent concentrations were used. Boxplots were not constructed for calcium, magnesium, sodium, potassium, bicarbonate, and fluoride. Boxplots also were not constructed for the trace elements because all concentrations were either considerably above the MCLs in drinking water or the large number of censored data made the construction of boxplots not possible. The descriptions of range, minimum, median, and maximum water property values and major-ion concentrations, refer to the median or other value described above and are shown on table 5.

The Mann-Whitney tests used all constituent concentrations (not medians) in water from each well. The descriptions of range, minimum, median, and maximum trace element concentrations, refer to all concentrations measured in water from shallow and deep wells and are shown on table 6.

Water Properties

Boxplots in figure 5 show ranges in median values of specific conductance, pH, and dissolved oxygen in water from 23 shallow wells and 7 deep wells. Water properties were only measured in water from domestic wells not high-capacity wells.

Specific conductance is a measure of the ability of water to conduct an electrical current and can be used to estimate the dissolved solids concentration of water. The specific conductance of water increases as the concentration of ions (chemical constituents) in water increases (Hem, 1992). Specific conductance in water from shallow wells ranged from 126 to 1,890 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) with a median of 697 $\mu\text{S}/\text{cm}$ (fig. 5 and table 5). Specific conductance in water from deep wells ranged from 279 to 3,230 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) with a median of 574 $\mu\text{S}/\text{cm}$. The lowest specific conductance, 126 $\mu\text{S}/\text{cm}$, was measured in water from well S20 (total depth 65 feet) and the highest specific conductance 3,230 was measured in water from well D8 (total depth 220 feet), both wells are located in the unconfined GWAU.

The EPA recommends that pH of drinking water ranges from 6.5 to 8.5; water having pH less than 6.5 is acidic, can have a bitter metallic taste and be corrosive to metal (U.S. Environmental Protection Agency, 2005a). Water having pH values greater than 8.5 is alkaline, can feel slippery, and leave

mineral precipitates on pipes and fixtures (U.S. Environmental Protection Agency, 2005a).

Water from deep wells had higher pH values than water from shallow wells (fig. 5). The pH in shallow wells ranged from 6.0 to 9.0 standard units with a median pH of 7.1 (table 5). Water from well S17 had an elevated pH of 9 and arsenic concentrations ranging from 6 to 9 $\mu\text{g}/\text{L}$. The pH of ground water from deep wells ranged from 6.5 to 9.2 and had a median of 7.7. The highest pH of 9.2 was measured in water from well D22, which also had elevated arsenic concentrations ranging from 44 to 51 $\mu\text{g}/\text{L}$.

Dissolved oxygen in ground water is made available through recharge and from the contact of water with oxygen in the unsaturated zone. Oxygen is used in ground water when oxidation reactions occur to organic materials and the minerals pyrite and siderite (Hem, 1992). Dissolved oxygen concentrations were highest in water from shallow wells and ranged from 0.7 to 9.0 mg/L with a median of 7.1 (fig. 5 and table 5). In deep wells, dissolved oxygen concentrations ranged from 2.9 to 8.8 mg/L with a median of 3.9.

Major Ions and Nitrate Nitrogen

Boxplots show that water from shallow wells had higher concentrations of sulfate, chloride, and nitrate nitrogen than water from deep wells. Mann-Whitney test results indicate that concentrations of calcium, magnesium, bicarbonate, sulfate, chloride, and nitrate nitrogen are significantly different in the two well populations (p -values < 0.05); concentrations of these constituents are highest in water from shallow wells. Test results indicate that concentrations of dissolved solids, sodium, and fluoride were not significantly different in water from shallow and deep wells (p -values > 0.05) (table 7).

Dissolved solids represent the sum of all constituent concentrations in water. The EPA recommends that the dissolved solids concentration in drinking water not exceed the SMCL of 500 mg/L (U.S. Environmental Protection Agency, 1992). Dissolved solids concentrations were not significantly different in water from shallow and deep wells (p -value = 0.11). Dissolved solids ranged from 80 to 1,270 mg/L, with a median of 380 mg/L in water from shallow wells and from 140 mg/L to 1,900 mg/L with a median of 300 mg/L in water from deep wells (fig. 6 and table 5). Water from five shallow wells (about 22 percent of shallow wells) exceeded 500 mg/L: S4 (1,270 mg/L), S13 (640 mg/L), S17 (540 mg/L), S18 (630 mg/L), and S21 (760 mg/L). Wells S4 and S18 are located in the confined GWAU, S13 is located in the unconfined GWAU, and S9 and S21 are located in the CCAAU. Water from five deep wells (about 18 percent of deep wells) exceeded the SMCL of 500 mg/L: D8 (1,900 mg/L), D10 (970 mg/L), D11 (1,165 mg/L), D12 (580 mg/L), and D13 (840). The well D8 and D13 are located in the unconfined GWAU, whereas, the other three are in the confined GWAU.

Sulfate concentrations in water from shallow wells were significantly different than concentrations in water from deep

Table 5. Summary statistics of median values of water properties and concentrations of chemical constituents measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005

[mg/L, milligram per liter; µS/cm, microsiemens per centimeter; °C, degree Celsius; —, not applicable; MRL, minimum reporting level; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; <, less than; N, nitrogen; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen]

Water properties and chemical constituents	Number of median values	MRL	Concentration at indicated percentiles					Number of wells exceeding MCL or SMCL
			Minimum	25	50 Median	75	Maximum	
Shallow wells (23 wells)								
Specific conductance, field (µS/cm at 25°C)	23	—	126	517	697	835	1,890	—
pH, field (standard units)	23	—	6.0	6.7	7.1	7.2	9.0	3 (13 percent)
Oxygen, dissolved, field (mg/L)	23	—	0.7	3.4	7.1	8.4	9.0	—
Dissolved solids, total (mg/L)	23	10 mg/L	80	290	380	460	1,270	4 (22 percent)
Calcium, total (mg/L)	23	1 mg/L	1	35	51	72	189	—
Magnesium, total (mg/L)	23	1 mg/L	< 1	15	31	38	60	—
Sodium, total (mg/L)	23	1 mg/L	4	18	40	66	235	—
Potassium, total (mg/L)	23	1 mg/L	¹ < 1	< 1	1	2	4	—
Bicarbonate, total, field (mg/L)	23	10 mg/L	56	231	362	423	579	—
Sulfate, total, (mg/L)	23	10 mg/L	< 10	10	20	20	400	1 (4 percent)
Chloride, total (mg/L)	23	10 mg/L	< 10	< 10	30	60	170	0
Fluoride, total (mg/L)	23	0.1 mg/L	< 0.1	0.2	0.2	0.3	0.5	0
Nitrate nitrogen (mg/L as N)	23	0.05 mg/L	< 0.05	0.47	1.04	4.60	25	3 (13 percent)
Deep wells (28 wells)								
Specific conductance, field (µS/cm at 25°C)	7	—	279	362	574	784	3,230	—
pH, field (standard units)	7	—	6.5	7.2	7.7	8.1	9.2	1
Oxygen, dissolved, field (mg/L)	7	—	2.9	3.2	3.9	5.4	8.8	—
Dissolved solids, total (mg/L)	28	10 mg/L	140	240	300	430	1,900	5 (18 percent)
Calcium, total (mg/L)	28	1 mg/L	< 1	17	36	46	103	—

Table 5. Summary statistics of median values of water properties and concentrations of chemical constituents measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005—Continued

[mg/L, milligram per liter; μ S/cm, microsiemens per centimeter; °C, degree Celsius; —, not applicable; MRL, minimum reporting level; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; <, less than; N, nitrogen; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen]

Water properties and chemical constituents	Number of median values	MRL	Minimum	Concentration at indicated percentiles				Number of wells exceeding MCL or SMCL
				25	50 Median	75	Maximum	
Magnesium, total (mg/L)	28	1 mg/L	< 1	12	20	24	82	—
Sodium, total (mg/L)	28	1 mg/L	6	19	47	120	741	—
Potassium, total (mg/L)	28	1 mg/L	< 1	¹ 1	1	2	4	—
Bicarbonate, total, field (mg/L)	7	10 mg/L	136	177	315	341	417	—
Sulfate, total, (mg/L)	28	10 mg/L	< 10	< 10	10	20	210	0
Chloride, total (mg/L)	28	10 mg/L	< 10	< 10	< 10	20	810	3 (11 percent)
Fluoride, total (mg/L)	28	0.1 mg/L	< 0.1	0.2	0.2	0.2	1.8	0
Nitrate nitrogen (mg/L as N)	28	0.05 mg/L	0.08	0.26	0.39	0.61	6.42	0

¹ The significant difference occurs in the 25th percentile and below (Dennis Helsel, U.S. Geological Survey, written commun., 2006).

Table 6. Summary statistics for all concentrations of chemical constituents measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005 and for statistical comparison using the Mann-Whitney test

[mg/L, milligram per liter; µg/L, microgram per liter; MRL, minimum reporting level; <, less than; N, nitrogen; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen]

Chemical constituents	Number of censored data	MRL	Concentration at indicated percentiles				
			Minimum	25	50 Median	75	Maximum
Shallow wells (23 wells 111 samples)							
Dissolved solids, total (mg/L)	0	10 mg/L	60	290	380	460	1,600
Calcium, total (mg/L)	0	1 mg/L	1	30	51	73	252
Magnesium, total (mg/L)	5	1 mg/L	<1	14	29	39	65
Sodium, total (mg/L)	0	1 mg/L	3	17	37	65	246
Potassium, total (mg/L)	44	1 mg/L	<1	<1	1	2	4
Bicarbonate, total, field (mg/L)	0	10 mg/L	51	206	362	405	590
Sulfate, total, (mg/L)	16	10 mg/L	<10	10	20	20	490
Chloride, total (mg/L)	34	10 mg/L	<10	<10	30	60	280
Fluoride, total (mg/L)	5	0.1 mg/L	<0.1	0.1	0.2	0.3	0.6
Nitrate nitrogen, total (mg/L as N)	10	0.05 mg/L	<0.05	0.43	1.03	4.19	25.9
Arsenic, total (µg/L)	83	2 µg/L	<2	<2	<2	<2	9
Barium, total (µg/L)	0	10 µg/L	40	130	210	430	960
Cadmium, total (µg/L)	111	2 µg/L	<2	<2	<2	<2	<2
Chromium, total (µg/L)	107	10 µg/L	<10	<10	<10	<10	10
Copper, total (µg/L)	101	5 µg/L	<10	<10	<10	<10	60
Iron, total (µg/L)	53	10 mg/L	<10	<10	10	110	4,290
Manganese, total (µg/L)	94	10 µg/L	<10	<10	<10	<10	650
Selenium, total (µg/L)	101	10 µg/L	<10	<10	<10	<10	20
Zinc, total (µg/L)	82	10 µg/L	<10	<10	<10	10	150
Deep wells (28 wells 96 samples, except for bicarbonate 7 wells 34 samples)							
Dissolved solids, total (mg/L)	0	10 mg/L	130	230	320	440	3,400
Calcium, total (mg/L)	5	1 mg/L	<1.0	11	34	46	103
Magnesium, total (mg/L)	8	1 mg/L	<1	8	19	24	82
Sodium, total (mg/L)	0	1 mg/L	5	18	44	138	1,360
Potassium, total (mg/L)	18	1 mg/L	<1	1	1	2	4
Bicarbonate, total, field (mg/L)	0	10 mg/L	129	171	308	341	511
Sulfate, total, (mg/L)	43	10 mg/L	<10	<10	10	20	400
Chloride, total (mg/L)	49	10 mg/L	<10	<10	<10	20	1,570
Fluoride, total (mg/L)	5	0.1 mg/L	<0.1	0.2	0.2	0.2	2.0
Nitrate nitrogen, total (mg/L as N)	4	0.05 / 0.10 mg/L	<0.05	0.26	0.42	0.68	6.56

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Table 6. Summary statistics for all concentrations of chemical constituents measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005 and for statistical comparison using the Mann-Whitney test—Continued

[mg/L, milligram per liter; µg/L, microgram per liter; MRL, minimum reporting level; <, less than; N, nitrogen; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen]

Chemical constituents	Number of censored data	MRL	Concentration at indicated percentiles				
			Minimum	25	50 Median	75	Maximum
Arsenic, total (µg/L)	68	2/10 µg/L	<2	<10	<10	<10	51
Barium, total (µg/L)	0	10 µg/L	30	100	260	380	1,020
Cadmium, total (µg/L)	96	2 / 5 µg/L	<2	<2	<5	<5	<5
Chromium, total (µg/L)	50	5/10 µg/L	<5	<5	<10	20	70
Copper, total (µg/L)	78	5 µg/L	<5	<5	<10	<10	180
Iron, total (µg/L)	64	10/20 mg/L	<10	<20	<20	30	1,930
Manganese, total (µg/L)	83	5/10 µg/L	<5	<5	<5	<10	520
Selenium, total (µg/L)	68	10 µg/L	<10	<10	<10	11	130
Zinc, total (µg/L)	69	5/10 µg/L	<5	<5	<10	10	80

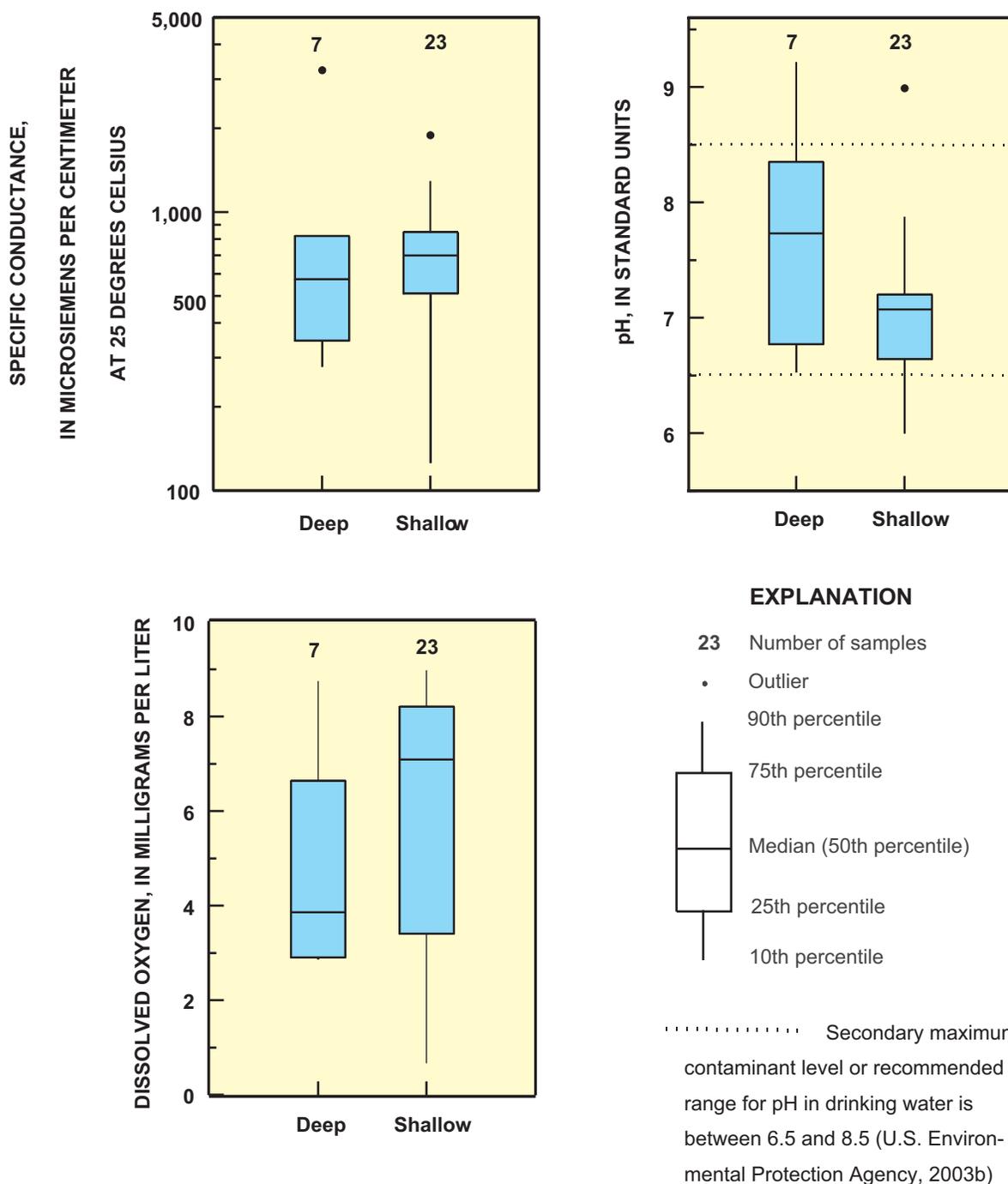


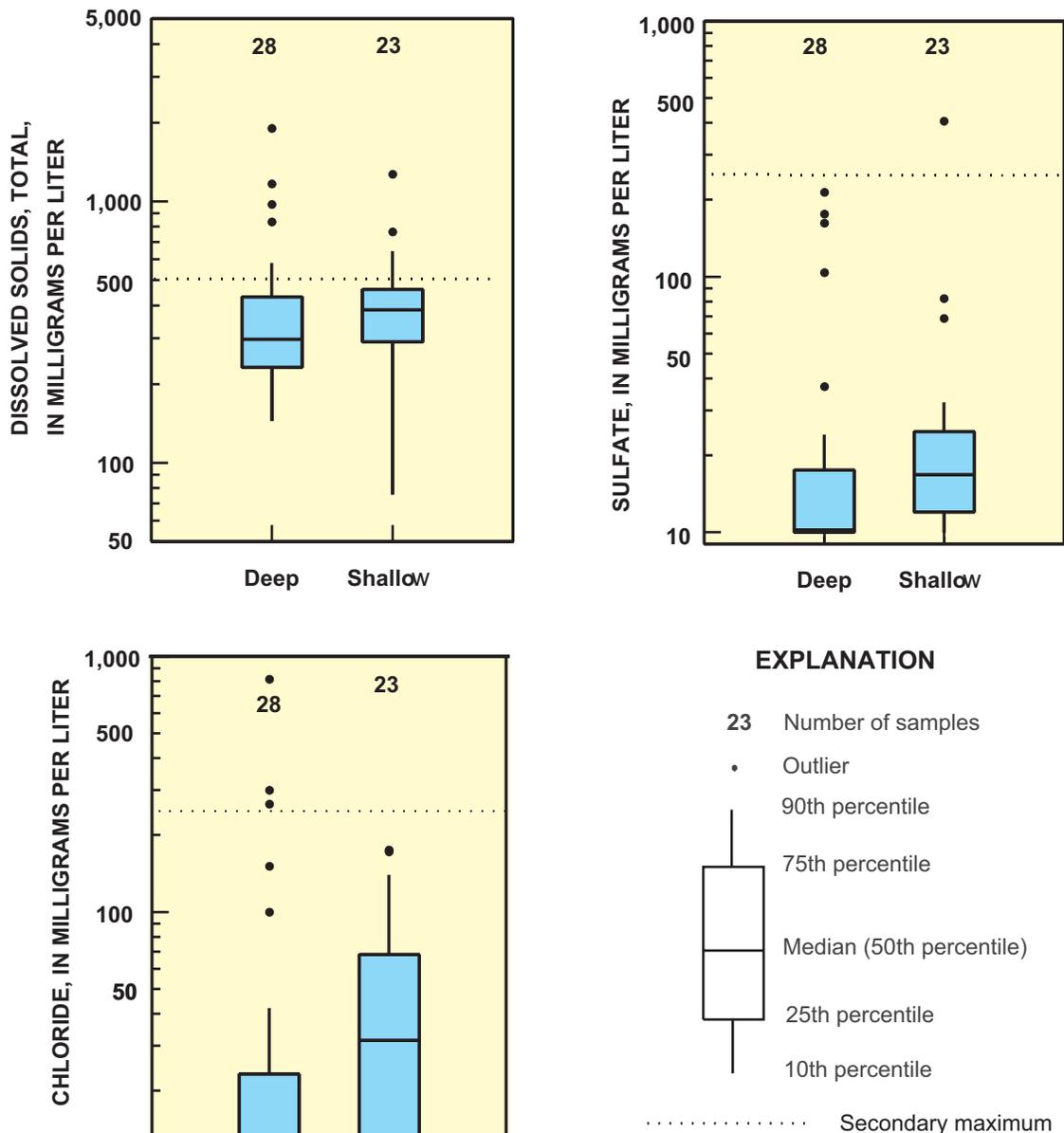
Figure 5. Ranges of water properties measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005. Values used to construct boxplots are the median (or average for wells having 2 analyses) of multiple measurements from each well.

Table 7. Results of the Mann-Whitney tests, p-values, used to compare concentrations of chemical constituents measured in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005

[p-values are decimal percentages; Nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; —, not calculated; The null hypothesis is that chemical constituents in ground-water-quality samples from the two populations tested have similar concentrations. Underlined p-values (< 0.05) indicate constituent concentrations are significantly different between the comparison populations at the 95 percent confidence level]

Chemical constituents	p-value	Well population having highest concentrations
Dissolved solids, total	0.11	Similar
Calcium	<u>0.00</u>	Shallow
Magnesium	<u>0.00</u>	Shallow
Sodium	0.07	Similar
Potassium	¹ <u>0.01</u>	Deep
Bicarbonate	<u>0.03</u>	Shallow
Sulfate	<u>0.00</u>	Shallow
Chloride	<u>0.00</u>	Shallow
Fluoride	0.15	Similar
Nitrate nitrogen	<u>0.00</u>	Shallow
Arsenic	<u>0.00</u>	Deep
Barium	0.16	Similar
Cadmium	—	—
Chromium	<u>0.00</u>	Deep
Copper	0.90	Similar
Iron	<u>0.03</u>	Deep
Manganese	0.73	Similar
Selenium	<u>0.00</u>	Deep
Zinc	0.40	Similar

¹ The significant difference occurs in the 25th percentile and below (Dennis Helsel, U.S. Geological Survey, written commun., 2006). See table 5.



contaminant level is 500 milligrams per liter for dissolved solids and 250 milligrams per liter for sulfate and chloride. Results from Mann-Whitney tests show dissolved solids concentrations are similar (p-value = 0.11) and chloride and sulfate concentrations are significantly different (p-values = 0.00) in water from shallow and deep wells

Figure 6. Ranges in dissolved solids, sulfate, and chloride concentrations in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005. Values used to construct boxplots are the median (or average for wells having 2 analyses) of multiple measurements from each well.

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wells (p -value = 0.00). Concentrations were highest in water from shallow wells and ranged from less than 10 mg/L to 400 mg/L, with a median sulfate concentration of 20 mg/L. One shallow well, S4 located in the confined GWAU, had a sulfate concentration (400 mg/L) greater than the SMCL of 250 mg/L in drinking water. In water from deep wells, sulfate concentrations ranged from less than 10 mg/L to 210 mg/L, with a median concentration of 10 mg/L (fig. 6 and table 5).

Chloride concentrations in water from shallow wells were significantly higher than concentrations in water from deep wells (p -value = 0.00). Chloride concentrations ranged from less than 10 mg/L to 170 mg/L with a median of 30 mg/L in water from shallow wells and from less than 10 mg/L to 810 mg/L, with a median of less than 10 mg/L in water from deep wells (fig. 6 and table 5). Water from three deep wells, D8, D10, and D11 had chloride concentrations exceeding the SMCL of 250 mg/L in drinking water (810 mg/L, 300 mg/L, and 265 mg/L, respectively).

Fluoride in water is associated with the development of healthy teeth and the reduction of tooth decay. The optimal fluoride concentration in drinking water is considered to be 0.7 to 1.2 mg/L (Centers for Disease Control and Prevention, 2001). Fluoride concentrations above the EPA SMCL of 2 mg/L in drinking water can cause mottling and discoloration of tooth enamel (U.S. Environmental Protection Agency, 1992). Fluoride concentrations were not significantly different in water from shallow and deep wells. Fluoride concentrations ranged from less than 0.1 mg/L to 0.5 mg/L, with a median

concentration of 0.2 mg/L in water from shallow wells and from less than 0.1 mg/L to 1.8 mg/L with a median of 0.2 mg/L in water from deep wells (table 5).

The NAWQA Program (Christenson, 1998) reported that the highest percentage of water samples having nitrate nitrogen concentrations exceeding the MCL of 10 mg/L in drinking water (U.S. Environmental Protection Agency, 2003b) were from shallow wells. Common anthropogenic sources of nitrate nitrogen for water are nitrogen-based fertilizers, septic tanks, and livestock. Nitrate nitrogen also occurs naturally in ground water, usually at concentrations less than 2 mg/L; concentrations greater than 2 mg/L are considered an indication of anthropogenic sources (Mueller and Helsel, 1996, pgs. 14-15).

Concentrations of nitrate nitrogen were significantly different in water from shallow and deep wells (p -value = 0.00). Similar to findings from the NAWQA Program, nitrate nitrogen concentrations were highest in water from shallow wells (fig. 7). Concentrations in water from shallow wells ranged from less than 0.05 to 25 mg/L, with a median of 1.04 mg/L (table 5). Water from 9 shallow wells had concentrations greater than 2 mg/L, indicating nitrogen sources at land surface have had an effect on water from these wells. Water from three shallow wells—S2, S3, and S4—had concentrations of nitrate nitrogen, 12.9, 25, and 13.1 mg/L, respectively, exceeding the MCL of 10 mg/L for drinking water. All three wells are located in rural areas; well S3 is located near an abandoned dairy and well S4 is located near pens for livestock.

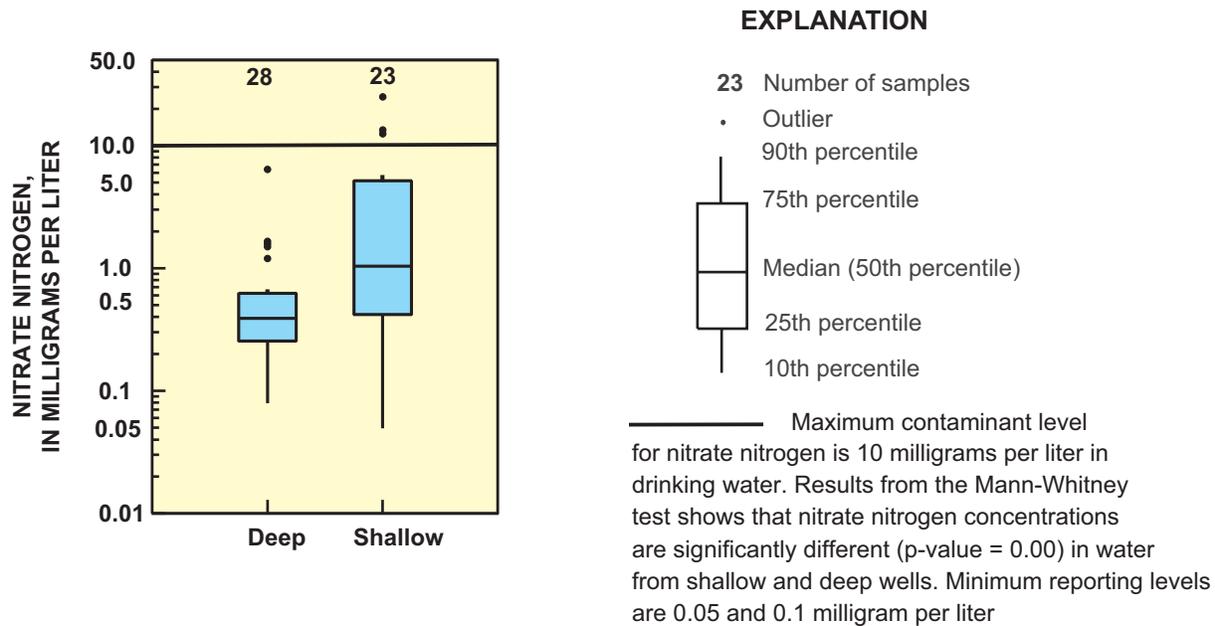


Figure 7. Ranges in nitrate nitrogen concentrations in water from shallow and deep wells in the Central Oklahoma aquifer, 2003–2005. Values used construct boxplots are the median (or average for wells having 2 analyses) of multiple measurements from each well.

Nitrate nitrogen concentrations in water from deep wells were significantly lower than water from shallow wells and only one well exceeded 2 mg/L, well D27 (6.42 mg/L), indicating that nitrogen sources at land surface have had less effect on water from deep wells. Concentrations of nitrate nitrogen in water from deep wells ranged from 0.08 to 6.42 mg/L, with a median of 0.39 mg/L. Well D27 is a domestic well with a total depth of 240 feet and is located in a rural area where cattle have been kept.

Trace Elements

Overall, the occurrence of trace elements was low in ground water from shallow and deep wells collected for this study. Seventy-three percent of trace element concentrations in water from shallow wells and 67 percent of trace element concentrations in water from deep wells were below the largest minimum reporting level (table 1).

Arsenic can cause various health effects from long-term consumption including skin disorders; irritation of the stomach, intestines, and lungs; neurological disturbances; and cancer (U.S. Environmental Protection Agency, 2005d). The EPA MCL of 10 µg/L for arsenic in drinking water was adopted January 2001, a decrease from the previous MCL of 50 µg/L. Public-water supply systems were required to comply with the 10 µg/L MCL by January 2006 (U.S. Environmental Protection Agency, 2005c).

Concentrations of arsenic were significantly different in water from shallow and deep wells (p -values < 0.05). Arsenic concentrations were significantly lower in water from shallow wells and ranged from less than 2 µg/L to 9 µg/L, with a median of less than 2 µg/L (table 6). Arsenic was measured in water from 11 shallow wells at concentrations ranging from 2 to 9 µg/L. There were no arsenic concentrations in water from shallow wells that exceeded the MCL of 10 µg/L (appendix 1). The highest arsenic concentrations (6 to 9 µg/L) were measured in water from well S17 located in the CCAAU. The median pH of water from well S17 was 9, above the 8.5 pH when elevated arsenic concentrations tend to occur in ground water (fig. 4).

Arsenic concentrations in water from deep wells ranged from less than 2 µg/L to 51 µg/L (table 6). Of the 96 water samples analyzed, 28 had measurable concentrations of arsenic. Of the 28 deep wells, nine wells (32 percent) had at least one arsenic concentration exceeding the MCL of 10 µg/L. Seven wells are located in the confined GWAU whereas, the other two are located in the unconfined GWAU. The MRL for arsenic was 10 µg/L in water from high-capacity wells and as a result, water with arsenic concentrations near the MCL of 10 µg/L would have been under-reported. The highest arsenic concentrations, measured in wells D22 and D23, ranged from 41 to 51 µg/L. As in the shallow well S17, the median pH of water from D22 (a domestic well) was 9.2, above the pH of 8.5 where elevated arsenic concentrations tend to occur in ground water (fig. 4)

Barium is found in ground water at small concentrations throughout the COA and is considered undesirable in drinking water at concentrations above 2,000 µg/L (U.S. Environmental Protection Agency, 2003b). The range in concentrations of barium in water from shallow and deep wells was similar (p -value = 0.16) and all concentrations were below 2,000 µg/L. In water from shallow wells, barium concentrations ranged from 40 to 960 µg/L with a median of 210 µg/L, and in water from deep wells concentrations ranged from 30 to 1,020 µg/L with a median of 260 µg/L (table 6).

The MCL for cadmium is 5 µg/L in drinking water (U.S. Environmental Protection Agency, 2003b). Cadmium was not measured above the MRLs of 2 µg/L and 5 µg/L in water from shallow or deep wells, respectively.

The MCL for chromium is 100 µg/L in drinking water (U.S. Environmental Protection Agency, 2003b). Short term potential effects from ingesting chromium at concentrations above the MCL are skin irritation or ulceration. Chronic effects from a lifetime of exposure at elevated concentrations include damage to the liver, kidneys, and nervous system (U.S. Environmental Protection Agency, 2005a). Concentrations of chromium were significantly different in water from shallow and deep wells (p -value = 0.00). Chromium concentrations were lower in water from shallow wells; 10 µg/L was measured in water from 3 wells (13 percent) (table 6). Of the 111 water samples from shallow wells, 4 had measurable concentrations of chromium. Chromium concentrations were highest in water from deep wells and ranged from less than 5 µg/L to 70 µg/L (table 6). Water from 15 of the 28 deep wells (54 percent) had measurable concentrations of chromium. Water from D18 and D21 had concentrations of chromium exceeding 50 µg/L.

Copper was measured in water from six shallow wells and six deep wells and all concentrations were less than the MCL of 1,300 µg/L in drinking water (U.S. Environmental Protection Agency, 2003b). There was no significant difference between copper concentrations in water from shallow and deep wells (p -value = 0.90). Copper concentrations in water from shallow wells ranged from less than 10 µg/L to 60 µg/L and in water from deep wells concentrations ranged from less than 5 µg/L to 180 µg/L (table 6).

Iron and manganese have SMCLs of 300 µg/L and 500 µg/L, respectively, in drinking water because of aesthetic effects such as staining and poor taste that occurs at elevated concentrations (U.S. Environmental Protection Agency, 2003a). Iron concentrations were significantly lower in water from shallow wells than deep wells (p -value = 0.03) and ranged from less than 10 µg/L to 4,290 µg/L, with a median concentration of 10 µg/L. Iron concentrations exceeded the SMCL in seven shallow wells. However, iron concentrations may not reflect accurate aquifer conditions because water samples were not filtered and may have contained particulate iron from well casings. This would explain why some wells did not have consistently high iron concentrations. Concentrations of iron in water from deep wells ranged from less than 10 µg/L to

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1,930 $\mu\text{g/L}$. Iron concentrations exceeded the SMCL in three deep wells (D11, D13, D19).

There was no significant difference between manganese concentrations in water from shallow and deep wells (p -value = 0.73). Concentrations in water from shallow wells ranged from less than 10 to 650 $\mu\text{g/L}$ whereas, in water from deep wells, concentrations ranged from less than 5 to 520 $\mu\text{g/L}$ (table 6). Manganese concentrations exceeded the SMCL in one deep well (D13) and one shallow well (S23).

Selenium is an essential nutrient at low levels; however, at elevated concentrations the short term effects are damage to the peripheral nervous system, fatigue, and irritability (U.S. Environmental Protection Agency, 2005b). The MCL for selenium is 50 $\mu\text{g/L}$ in drinking water (U.S. Environmental Protection Agency, 2003b). Concentrations of selenium were significantly different in water from shallow and deep wells (p -values = 0.00). Concentrations of selenium were lowest in water from shallow wells and ranged from less than 10 $\mu\text{g/L}$ to 20 $\mu\text{g/L}$, with a median concentration of less than 10 $\mu\text{g/L}$. Measurable concentrations of selenium were measured in water from three shallow wells (13 percent) (appendix 1). In water from deep wells, concentrations of selenium ranged from less than 10 $\mu\text{g/L}$ to 130 $\mu\text{g/L}$ with a median of less than 10 $\mu\text{g/L}$. Measurable concentrations of selenium were measured in water from 10 deep wells (36 percent). Well D8 was the only well sampled in the study with selenium concentrations exceeding the MCL of 50 $\mu\text{g/L}$ in drinking water. Concentrations ranged from 60 to 130 $\mu\text{g/L}$ in the five samples from well D8.

There was no significant difference in zinc concentrations in water from shallow and deep wells (p -value = 0.40). Concentrations ranged from less than 10 $\mu\text{g/L}$ to 150 $\mu\text{g/L}$, with a median of less than 10 $\mu\text{g/L}$, in water from shallow wells and ranged from less than 5 $\mu\text{g/L}$ to 80 $\mu\text{g/L}$ in water from deep wells (table 6). Zinc was measured in water from 12 shallow wells and 16 deep wells and all concentrations were less than the MCL of 5,000 $\mu\text{g/L}$ for drinking water (U.S. Environmental Protection Agency, 2003b).

Implications of the Ground-Water Quality Comparison

Water-quality samples collected for this study indicate: (1) that for consumers of shallow ground water the greatest health concern is nitrate nitrogen and the greatest aesthetic concern is dissolved solids, (2) shallow ground water contains significantly higher concentrations of calcium, magnesium, bicarbonate, sulfate, chloride, and nitrate nitrogen than water from deep wells, (3) there was no significant difference in concentrations of dissolved solids, sodium, fluoride, barium, copper, manganese, and zinc in water from shallow and deep wells, (4) that the concentration in shallow ground water of arsenic, chromium, and selenium is very low, and (5) that in

water from deep wells arsenic, chromium, and selenium occur more frequently and at higher concentrations.

The majority of shallow wells sampled produced water that met drinking water standards. Five shallow wells exceeded the SMCL of 500 mg/L for dissolved solids. The highest median dissolved solids was measured in well S4 (1,270 mg/L) that also had the only median sulfate concentration (400 mg/L) exceeding the SMCL of 250 mg/L . There were no shallow wells that exceeded the SMCL for chloride. Christenson (1998) reported that the largest concentrations of chloride tend to occur in the shallow, confined GWAU and the largest concentrations of sulfate tend to occur to in the southern part of the confined GWAU.

Water from shallow wells had significantly higher concentrations of calcium, magnesium, bicarbonate, chloride, and sulfate than water from the deep wells sampled; concentrations of dissolved solids, sodium, and fluoride were not significantly different between the two populations. The major source of ions to shallow ground water may be anthropogenic sources at land surface. Precipitation from recharge is the major source of water to the COA. Parkhurst and others (1996) reported that even after concentration from evaporation and evapotranspiration, rainfall is deficient in the quantity of ions needed to equal what is measured in shallow water. Land use can affect ground-water quality of the COA. Rea and others (2001) showed that the frequency of pesticide and volatile organic compound detections in ground-water samples were higher in densely populated areas compared to rural areas. Other water-quality studies have shown that chemical compounds used at land surface affected ground-water quality (Shedlock and others, 1993; Masoner and Mashburn, 2004).

Nitrate nitrogen concentrations also were significantly higher in water from shallow wells. Water from three wells (13 percent) exceeded the nitrate nitrogen MCL of 10 mg/L in drinking water. The NAWQA Program showed that water from 12 percent of wells less than 98 feet and 8.6 percent of wells between 98 and 299 feet, exceeded 10 mg/L of nitrate nitrogen (Christenson, 1998, table 6). The high concentrations in shallow ground water were attributed to anthropogenic sources of nitrogen at land surface (Christenson, 1998). Common sources include septic tanks, nitrogen-based fertilizers, and livestock. The results from this study could be biased because domestic wells sampled were adjacent to homes or other structures where sources of nitrogen (and major ions) were present. To test potential bias it would be necessary to sample ground water at similar depths in pristine areas not affected by human activities.

Water from shallow wells had significantly lower concentrations of arsenic, chromium, iron, and selenium than water from deep wells, whereas concentrations of barium, copper, manganese, and zinc were similar. Water-quality data from this study and the NAWQA Program indicate that arsenic frequently occurs in shallow ground water from the COA, but at low concentrations (<10 $\mu\text{g/L}$). Water from 11 of 23 shallow wells (48 percent) had measurable concentrations of arsenic; however, all were below the MCL of 10 $\mu\text{g/L}$. Christenson

(1998, tables 2 and 3) reported that arsenic was measured at concentrations between 0.5 and 6 µg/L in water from 50 percent of wells less than 98 feet deep and between 1 and 9 µg/L in water from 50 percent of wells between 98 and 299 feet deep.

Water from deep wells contained significantly higher concentrations of potassium, chromium, and selenium than water from shallow wells. The occurrence of chromium and selenium in water from shallow wells was infrequent and at low concentrations in this study. Results were similar from the NAWQA Program; of the 70 wells less than 299 feet deep that were sampled, there were no concentrations of chromium or selenium that exceeded the MCLs of 100 µg/L and 50 µg/L, respectively (Christenson, 1998, tables 2 and 3).

It does not appear that the quality of water from shallow wells can be predicted based on the quality of water from nearby deep wells. The results show that in general terms, shallow ground water has significantly higher concentrations of most major ions including nitrate nitrogen and significantly lower concentrations of arsenic, chromium, and selenium than water from deep wells.

Summary

The bedrock aquifer units of the Central Oklahoma aquifer underlie about 2,890 square miles of central Oklahoma and are used extensively to supply water for municipal, domestic, industrial, and agricultural needs. The Central Oklahoma aquifer also is commonly referred to as the Garber Wellington aquifer because the Garber Sandstone and Wellington Formation yield the greatest quantities of usable water for domestic and high-capacity wells.

The major water-quality concerns for the Central Oklahoma aquifer described by the USGS NAWQA Program (1987 to 1992) were elevated concentrations of nitrate nitrogen in shallow water and the occurrence of arsenic, chromium, and selenium in parts of the aquifer. The chemical quality of water from shallow domestic wells is not monitored and, therefore, there is a concern that well owners may be unknowingly ingesting water with nitrate nitrogen, arsenic, chromium, selenium, and other chemical constituents at concentrations that are considered harmful. As a result of this concern, the Oklahoma Department of Environmental Quality and the USGS collaborated on a study to sample water during June 2003 through August 2005 from 23 shallow wells (less than 200 feet in depth) and 28 deep wells (200 feet or greater in depth) completed in the bedrock aquifer units of the Central Oklahoma aquifer. The objectives of the study were to describe the chemical quality of water from shallow and deep wells and to determine if the differences in constituent concentrations are statistically significant.

Analysis of the data show that water from shallow wells had significantly higher concentrations of calcium, magnesium, bicarbonate, sulfate, chloride, and nitrate nitrogen than

water from deep wells (p-values < 0.05). There were no significant differences between concentrations of dissolved solids, sodium, and fluoride in water from shallow and deep wells (p-values > 0.05). Water from 9 shallow wells had nitrate nitrogen concentrations greater than 2 mg/L, indicating nitrogen sources at land surface have had an effect on water from these wells. Water from three shallow wells (13 percent) exceeded the nitrate nitrogen maximum contaminant level of 10 mg/L in drinking water. The major source of ions to shallow ground water may be anthropogenic sources at land surface. However, the results could be biased because domestic wells sampled were adjacent to homes or other structures where sources of nitrogen (and major ions) were present. To test potential bias it would be necessary to sample ground water at similar depths in pristine areas not affected by human activities.

Water from shallow wells had significantly lower concentrations of arsenic, chromium, iron, and selenium than water from deep wells, whereas, concentrations of barium, copper, manganese, and zinc were similar. Water-quality data indicate that arsenic frequently occurs in shallow ground water from the Central Oklahoma aquifer, but at low concentrations (<10 µg/L). The occurrence of chromium and selenium in water from shallow wells was infrequent and at low concentrations in this study.

It does not appear that the quality of water from a shallow well can be predicted based on the quality of water from a nearby deep well. The results show that in general terms, shallow ground water has significantly higher concentrations of most major ions and significantly lower concentrations of arsenic, chromium, and selenium than water from deep wells.

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Appendix

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
S1	355444097071301	Jun 19, 2003	693	7.5	20	11.4	325	380	55	31	60	1	395	M
S1	355444097071301	Aug 21, 2003	696	7.5	19.4	8.3	314	370	49	29	56	1	381	1
S1	355444097071301	Nov 5, 2003	697	7.6	17	7.6	329	380	49	29	59	1	400	M
S1	355444097071301	Feb 25, 2004	775	7.3	13.8	6.6	326	410	53	33	68	1	396	M
S1	355444097071301	Jun 3, 2004	856	7.2	18.1	7.7	318	420	51	31	64	1	387	M
S1	355444097071301	MEDIAN	697	7.5	18.1	7.7	325	380	51	31	60	1	395	—
S2	355134097211101	Jun 20, 2003	540	7.5	18.8	9.1	196	470	50	24	23	<1	238	M
S2	355134097211101	Aug 20, 2003	498	7.5	18.8	9	184	290	46	22	21	<1	224	M
S2	355134097211101	Nov 5, 2003	510	7.5	17	8.7	172	300	44	23	22	<1	209	M
S2	355134097211101	Feb 25, 2004	519	7.5	16.8	8.7	164	280	45	23	22	<1	199	M
S2	355134097211101	May 20, 2004	494	7.6	17.8	9.4	168	280	44	21	20	<1	203	M
S2	355134097211101	MEDIAN	510	7.5	17.8	9	172	290	45	23	22	<1	209	—
S3	355052097284301	Jun 20, 2003	786	7	19.7	8.1	228	200	97	27	19	<1	277	M
S3	355052097284301	Aug 21, 2003	760	7	19.1	8.2	228	470	90	27	18	<1	278	M
S3	355052097284301	Nov 3, 2003	749	7.1	18	8.5	220	460	93	26	19	<1	268	M
S3	355052097284301	Feb 17, 2004	754	7.1	16.6	6.7	223	510	92	26	19	<1	272	M
S3	355052097284301	May 12, 2004	771	7.1	17.9	8.6	222	450	87	25	18	<1	271	M
S3	355052097284301	MEDIAN	760	7.1	18	8.2	223	460	92	26	19	<1	272	—
S4	354755097392001	Jun 26, 2003	2,150	7	17.6	6	347	1,600	252	40	186	2	422	M
S4	354755097392001	Aug 20, 2003	1,780	7	17.9	4.2	354	1,200	158	33	170	2	E 431	M
S4	354755097392001	Nov 3, 2003	1,790	7	17.3	4.2	333	1,270	187	37	177	2	405	M
S4	354755097392001	Feb 17, 2004	1,890	7.1	16.5	3.4	333	1,270	194	39	186	2	405	M
S4	354755097392001	May 20, 2004	1,900	7	17.9	5.7	341	1,310	189	37	185	2	416	M
S4	354755097392001	MEDIAN	1,890	7	17.6	4.2	341	1,270	189	37	185	2	416	—
S5	354914097010901	Jun 18, 2003	831	7.2	18	8.1	360	420	66	48	40	3	438	M

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
S5	354914097010901	Aug 27, 2003	777	7.2	18.4	10.3	320	450	62	46	38	3	389	M
S5	354914097010901	Nov 6, 2003	806	7.2	16.9	6.5	367	420	59	45	39	3	447	M
S5	354914097010901	Feb 27, 2004	824	7.2	16.8	4.4	361	420	61	45	40	3	440	M
S5	354914097010901	Jun 3, 2004	843	7.2	17.8	7.6	361	440	60	46	40	3	439	M
S5	354914097010901	MEDIAN	824	7.2	17.8	7.6	361	420	61	46	40	3	439	—
S6	354221097272501	Jun 2, 2003	750	7.2	17.8	8.3	291	440	76	32	32	<1	E 354	M
S6	354221097272501	Aug 18, 2003	681	7.3	18.1	—	276	390	71	29	27	<1	E 336	M
S6	354221097272501	Oct 29, 2003	763	7.2	17.5	8.6	287	440	66	30	37	<1	350	M
S6	354221097272501	Feb 10, 2004	767	7.1	16.9	8.9	294	410	71	33	36	<1	358	M
S6	354221097272501	May 12, 2004	777	7.2	17.3	8.8	286	420	74	31	34	<1	348	M
S6	354221097272501	MEDIAN	763	7.2	17.5	8.7	287	420	71	31	34	<1	350	—
S7	354143096564301	Jun 18, 2003	770	7.9	17.6	3.4	360	400	16	9	157	2	437	M
S7	354143096564301	Aug 27, 2003	729	7.9	18.1	3.5	306	440	14	8	149	2	370	2
S7	354143096564301	Nov 6, 2003	764	7.9	17.1	2.8	299	420	15	9	154	2	362	2
S7	354143096564301	Feb 24, 2004	809	7.8	16.9	0.7	287	450	18	11	153	2	343	3
S7	354143096564301	Jun 1, 2004	765	7.9	17.8	4.6	301	430	16	10	153	2	362	2
S7	354143096564301	MEDIAN	765	7.9	17.6	3.4	301	430	16	9	153	2	362	—
S8	353909097100101	Jun 17, 2003	373	6.7	18.9	9.3	152	210	43	16	8	1	185	<0.1
S8	353909097100101	Aug 19, 2003	346	6.7	18.1	8.3	159	190	40	15	7	1	194	M
S8	353909097100101	Nov 4, 2003	346	6.7	17.2	8.4	154	180	40	16	7	1	188	<0.1
S8	353909097100101	Feb 26, 2004	351	6.8	17	8.5	152	170	38	15	7	1	185	<0.1
S8	353909097100101	Jun 1, 2004	345	6.7	17.5	8.9	151	190	38	15	7	1	184	M
S8	353909097100101	MEDIAN	346	6.7	17.5	8.5	152	190	40	15	7	1	185	—
S9	353539096554701	Jun 18, 2003	716	7.1	18	2	440	370	57	39	49	2	537	M
S9	353539096554701	Aug 27, 2003	680	7.1	19.5	3	330	400	51	36	47	1	402	M

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
S9	353539096554701	Nov 6, 2003	692	7.2	17.2	2.2	370	360	49	35	47	2	450	M
S9	353539096554701	Feb 26, 2004	692	7.1	17.3	2	362	350	49	35	48	2	452	M
S9	353539096554701	Jun 10, 2004	681	6.9	17.7	3	367	370	49	34	45	2	448	M
S9	353539096554701	MEDIAN	692	7.1	17.7	2.2	367	370	49	35	47	2	450	—
S10	353446097241101	Jun 16, 2003	862	6.6	17.4	3.6	273	450	71	38	31	<1	333	M
S10	353446097241101	Aug 20, 2003	835	6.6	18.5	3	291	460	72	36	41	<1	355	M
S10	353446097241101	Oct 29, 2003	858	6.7	18.4	3.3	289	510	66	35	52	<1	352	M
S10	353446097241101	Feb 10, 2004	905	6.8	17	2.2	319	500	75	35	66	2	389	<0.1
S10	353446097241101	May 11, 2004	817	6.6	17.1	4	E 287	460	71	36	42	<1	E 394	M
S10	353446097241101	MEDIAN	858	6.6	17.4	3.3	289	460	71	36	42	<1	355	—
S11	353155097294601	Jun 26, 2003	846	7.3	16.9	6.2	312	450	74	45	31	3	380	M
S11	353155097294601	Aug 19, 2003	834	7.2	17	6.5	333	450	74	45	31	3	406	M
S11	353155097294601	Oct 30, 2003	849	7.2	16.8	6.1	316	470	63	42	32	4	385	M
S11	353155097294601	Feb 26, 2004	853	7.2	15.6	6.5	303	430	69	44	33	4	369	M
S11	353155097294601	Jun 3, 2004	820	7	17	6.1	333	460	70	44	30	3	405	M
S11	353155097294601	MEDIAN	846	7.2	16.9	6.2	316	450	70	44	31	3	385	—
S12	353145097263801	Jun 26, 2003	616	7.2	16.5	9.1	296	350	66	33	17	<1	360	M
S12	353145097263801	Aug 19, 2003	603	7.2	16.7	8.8	309	340	64	32	17	<1	377	M
S12	353145097263801	Oct 30, 2003	617	7.2	16.6	8.5	281	340	55	30	18	<1	342	M
S12	353145097263801	Feb 24, 2004	619	7.2	16.1	8.8	305	320	62	32	17	<1	371	M
S12	353145097263801	May 11, 2004	614	7.1	16.4	9.3	303	320	62	31	17	<1	368	M
S12	353145097263801	MEDIAN	616	7.2	16.5	8.8	303	340	62	32	17	<1	368	—
S13	352910097272501	Jun 26, 2003	675	7	18	3.3	408	640	93	44	72	3	497	M
S14	352759097220201	Jun 19, 2003	526	6.5	18.5	7.2	204	300	51	25	24	1	249	<0.1
S14	352759097220201	Aug 18, 2003	513	6.5	19.9	8	209	300	47	24	22	1	255	<0.1

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
S14	352759097220201	Nov 4, 2003	523	6.5	18.9	9.2	E302	290	45	24	24	1	E 368	<0.1
S14	352759097220201	Jan 28, 2004	523	6.5	17.8	8.6	190	290	48	25	25	1	232	M
S14	352759097220201	Jun 3, 2004	527	6.7	18.1	8	210	290	47	24	22	1	256	M
S14	352759097220201	MEDIAN	523	6.5	18.5	8	209	290	47	24	24	1	255	—
S15	352639097083401	Jun 19, 2003	315	6.6	18.2	7	110	170	32	14	9	1	134	<0.1
S15	352639097083401	Aug 19, 2003	307	6.5	17.9	8.1	115	170	30	14	8	1	140	<0.1
S15	352639097083401	Nov 5, 2003	320	6.6	16.8	7.7	108	170	29	14	9	2	131	<0.1
S15	352639097083401	Jan 28, 2004	309	6.6	16.2	8.6	113	180	30	14	9	2	137	M
S15	352639097083401	May 26, 2004	307	6.7	17.9	7.4	106	170	29	13	9	1	129	<0.1
S15	352639097083401	MEDIAN	309	6.6	17.9	8.1	110	170	30	14	9	1	134	—
S16	352326097044801	Jun 18, 2003	575	6.8	17.4	7.7	210	290	49	22	44	1	256	M
S16	352326097044801	Aug 20, 2003	548	6.8	17.4	8.6	207	300	43	19	39	1	253	<0.1
S16	352326097044801	Nov 5, 2003	558	6.8	16.7	7.8	161	290	42	19	39	1	196	M
S16	352326097044801	Feb 23, 2004	561	6.8	16.9	7.2	205	290	42	19	41	1	250	M
S16	352326097044801	May 26, 2004	551	6.8	17.4	7.7	209	320	43	19	41	1	255	M
S16	352326097044801	MEDIAN	558	6.8	17.4	7.7	207	290	43	19	41	1	253	—
S17	352351096544001	Jun 25, 2003	856	9	17.9	3.9	383	540	1	<1	233	<1	430	18
S17	352351096544001	Aug 21, 2003	902	9	18	0.2	389	540	1	<1	235	<1	453	10
S17	352351096544001	Nov 5, 2003	919	9	17.2	0.7	315	530	1	<1	235	<1	368	8
S17	352351096544001	Mar 5, 2004	899	9	17.1	0.3	379	540	1	<1	246	<1	404	28
S17	352351096544001	Jun 10, 2004	903	8.8	17.6	2	374	500	1	<1	243	<1	432	12
S17	352351096544001	MEDIAN	902	9	17.6	0.7	379	540	1	<1	235	<1	430	—
S18	351839097254301	Jun 18, 2003	1,250	7.2	18.4	6.3	420	640	83	65	98	4	512	M
S18	351839097254301	Aug 18, 2003	1,220	7.2	18.7	7	434	310	75	58	86	4	530	M
S18	351839097254301	Nov 3, 2003	1,240	7.1	18	6.7	392	870	77	60	87	3	478	M

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
S18	351839097254301	Feb 26, 2004	1,180	7.2	17.7	6.9	410	610	75	60	95	4	499	M
S18	351839097254301	May 18, 2004	1,240	7	18.1	7.1	411	630	72	57	89	4	501	M
S18	351839097254301	MEDIAN	1,240	7.2	18.1	6.9	411	630	75	60	89	4	501	—
S19	351823097215701	Jun 18, 2003	722	7.1	17.7	0.9	308	370	80	42	15	1	376	<0.1
S19	351823097215701	Aug 20, 2003	708	7.1	17.2	0.8	320	380	73	39	13	<1	390	<0.1
S19	351823097215701	Nov 3, 2003	712	7	17.7	2.6	312	390	73	39	14	<1	380	M
S19	351823097215701	Feb 25, 2004	697	7.1	16.9	1.2	309	360	71	39	14	1	376	M
S19	351823097215701	May 24, 2004	704	7.1	17.3	3.1	306	430	69	38	14	1	372	M
S19	351823097215701	MEDIAN	708	7.1	17.3	1.2	309	380	73	39	14	1	376	—
S20	351450097114201	Jun 18, 2003	139	6	16.5	8.6	48	90	12	6	4	2	E59	<0.1
S20	351450097114201	Aug 19, 2003	129	6	16.6	8.4	48	80	11	6	3	2	E59	<0.1
S20	351450097114201	Nov 12, 2003	125	6	16.8	7.4	46	80	10	6	4	2	56	<0.1
S20	351450097114201	Feb 23, 2004	126	6	16.6	8.4	46	70	10	5	4	2	57	<0.1
S20	351450097114201	May 24, 2004	119	6	16.6	8.9	42	60	10	6	4	3	51	<0.1
S20	351450097114201	MEDIAN	126	6	16.6	8.4	46	80	10	6	4	2	56	—
S21	350603096550801	Jun 25, 2003	1,270	6.9	17.7	6.1	475	780	121	55	96	<1	579	M
S21	350603096550801	Aug 21, 2003	1,380	6.9	18.7	2.4	485	810	120	55	101	<1	590	M
S21	350603096550801	Nov 14, 2003	1,340	6.9	16.3	4.5	479	760	114	54	101	<1	583	M
S21	350603096550801	Mar 5, 2004	1,290	6.9	15	3.3	471	750	113	52	98	<1	573	M
S21	350603096550801	Jun 10, 2004	1,280	6.7	17.7	3.4	462	750	112	51	93	<1	562	M
S21	350603096550801	MEDIAN	1,290	6.9	17.7	3.4	475	760	114	54	98	<1	579	—
S22	350003097090102	Jun 25, 2003	200	6.9	16.8	2.4	88	300	18	9	10	<1	107	<0.1
S22	350003097090102	Aug 27, 2003	218	6	18.1	3.4	95	160	19	9	11	<1	115	<0.1
S22	350003097090102	Nov 13, 2003	211	6.2	17.4	4	92	120	18	9	11	<1	112	<0.1
S22	350003097090102	Feb 26, 2004	210	6.2	16	8	90	120	18	9	12	<1	109	<0.1

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
S22	350003097090102	Jun 14, 2004	209	6.1	17.3	7.3	90	130	19	9	11	<1	110	<0.1
S22	350003097090102	MEDIAN	210	6.2	17.3	4	90	130	18	9	11	<1	110	—
S23	345908096593101	Jun 25, 2003	317	6.6	19.5	7.1	144	230	19	9	48	<1	176	<0.1
S23	345908096593101	Aug 27, 2003	375	6.1	18.7	4.8	157	220	19	9	42	<1	191	<0.1
S23	345908096593101	Nov 13, 2003	357	6.5	19	6.8	147	190	15	7	55	1	180	<0.1
S23	345908096593101	Feb 26, 2004	345	6.8	18.5	10.2	147	190	14	6	55	1	180	<0.1
S23	345908096593101	Jun 14, 2004	327	6.3	18.6	9.6	147	190	18	8	42	<1	179	<0.1
S23	345908096593101	MEDIAN	345	6.5	18.7	7.1	147	190	18	8	48	<1	180	—

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Hydroxide (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic ($\mu\text{g}/\text{L}$)	Barium ($\mu\text{g}/\text{L}$)	Cadmium ($\mu\text{g}/\text{L}$)	Chromium ($\mu\text{g}/\text{L}$)	Copper ($\mu\text{g}/\text{L}$)	Iron ($\mu\text{g}/\text{L}$)	Manganese ($\mu\text{g}/\text{L}$)	Selenium ($\mu\text{g}/\text{L}$)	Zinc ($\mu\text{g}/\text{L}$)
S1	355444097071301	Jun 19, 2003	—	20	30	0.4	0.50	3	260	<2	<10	<10	1,860	10	<10	140
S1	355444097071301	Aug 21, 2003	—	20	30	0.4	0.47	3	250	<2	<10	10	1,890	20	<10	150
S1	355444097071301	Nov 5, 2003	—	20	30	0.4	0.65	<2	210	<2	<10	<10	550	<10	<10	80
S1	355444097071301	Feb 25, 2004	—	30	40	0.6	1.25	<2	260	<2	<10	<10	30	<10	<10	130
S1	355444097071301	Jun 3, 2004	—	30	40	0.5	1.22	<2	280	<2	<10	<10	20	<10	<10	90
S1	355444097071301	MEDIAN	—	20	30	0.4	0.65	—	—	—	—	—	—	—	—	—
S2	355134097211101	Jun 20, 2003	—	20	<10	0.3	12.9	<2	220	<2	<10	<10	10	<10	<10	<10
S2	355134097211101	Aug 20, 2003	—	20	<10	0.4	11.7	<2	220	<2	<10	<10	<10	<10	<10	<10
S2	355134097211101	Nov 5, 2003	—	20	<10	0.4	13.4	<2	180	<2	<10	<10	<10	<10	<10	<10
S2	355134097211101	Feb 25, 2004	—	20	<10	0.5	13	<2	180	<2	<10	<10	10	<10	<10	<10
S2	355134097211101	May 20, 2004	—	20	<10	0.4	11.8	<2	210	<2	<10	<10	<10	<10	<10	<10
S2	355134097211101	MEDIAN	—	20	<10	0.4	12.9	—	—	—	—	—	—	—	—	—
S3	355052097284301	Jun 20, 2003	—	20	30	0.2	24	<2	440	<2	<10	<10	<10	<10	<10	30
S3	355052097284301	Aug 21, 2003	—	20	30	0.2	24.6	<2	400	<2	<10	<10	<10	<10	<10	10
S3	355052097284301	Nov 3, 2003	—	20	30	0.2	25	<2	340	<2	<10	<10	<10	<10	<10	20
S3	355052097284301	Feb 17, 2004	—	20	30	0.2	25.9	<2	390	<2	<10	<10	<10	<10	<10	80
S3	355052097284301	May 12, 2004	—	20	30	0.2	25.7	<2	400	<2	<10	<10	<10	<10	<10	<10
S3	355052097284301	MEDIAN	—	20	30	0.2	25	—	—	—	—	—	—	—	—	—
S4	354755097392001	Jun 26, 2003	—	490	180	0.1	14.6	4	60	<2	<10	<10	20	<10	<10	<10
S4	354755097392001	Aug 20, 2003	—	290	180	0.1	12.3	4	60	<2	<10	<10	<10	<10	<10	<10
S4	354755097392001	Nov 3, 2003	—	340	170	0.1	12.6	5	40	<2	10	<10	30	<10	<10	<10
S4	354755097392001	Feb 17, 2004	—	400	180	0.1	13.1	4	50	<2	<10	<10	40	<10	<10	<10
S4	354755097392001	May 20, 2004	—	420	170	0.1	14.2	5	50	<2	<10	<10	50	<10	<10	<10
S4	354755097392001	MEDIAN	—	400	170	0.1	13.1	—	—	—	—	—	—	—	—	—
S5	354914097010901	Jun 18, 2003	—	10	30	0.2	5.28	<2	420	<2	<10	<10	330	<10	<10	20
S5	354914097010901	Aug 27, 2003	—	10	30	0.3	5.45	<2	390	<2	<10	<10	330	<10	<10	30

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Hydroxide (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic ($\mu\text{g}/\text{L}$)	Barium ($\mu\text{g}/\text{L}$)	Cadmium ($\mu\text{g}/\text{L}$)	Chromium ($\mu\text{g}/\text{L}$)	Copper ($\mu\text{g}/\text{L}$)	Iron ($\mu\text{g}/\text{L}$)	Manganese ($\mu\text{g}/\text{L}$)	Selenium ($\mu\text{g}/\text{L}$)	Zinc ($\mu\text{g}/\text{L}$)
S9	353539096554701	Jun 10, 2004	—	<10	<10	0.3	1.1	<2	730	<2	<10	<10	<10	<10	<10	10
S9	353539096554701	MEDIAN	—	<10	<10	0.3	1.04	—	—	—	—	—	—	—	—	—
S10	353446097241101	Jun 16, 2003	—	30	70	<0.1	4.52	<2	180	<2	<10	<10	<10	<10	<10	<10
S10	353446097241101	Aug 20, 2003	—	30	80	0.1	3.47	<2	190	<2	<10	20	<10	<10	<10	20
S10	353446097241101	Oct 29, 2003	—	30	90	0.2	3.94	<2	180	<2	<10	<10	<10	<10	<10	10
S10	353446097241101	Feb 10, 2004	—	40	80	0.3	1.98	<2	150	<2	<10	<10	<10	<10	<10	<10
S10	353446097241101	May 11, 2004	—	30	70	0.2	4.33	<2	170	<2	<10	<10	<10	<10	<10	<10
S10	353446097241101	MEDIAN	—	30	80	0.2	3.94	—	—	—	—	—	—	—	—	—
S11	353155097294601	Jun 26, 2003	—	20	80	0.2	0.85	<2	100	<2	<10	<10	30	<10	<10	<10
S11	353155097294601	Aug 19, 2003	—	20	70	0.2	0.76	<2	130	<2	<10	<10	<10	<10	<10	<10
S11	353155097294601	Oct 30, 2003	—	20	80	0.2	0.8	<2	120	<2	10	<10	20	<10	<10	<10
S11	353155097294601	Feb 26, 2004	—	20	90	0.3	0.9	<2	110	<2	<10	<10	20	<10	<10	20
S11	353155097294601	Jun 3, 2004	—	20	70	0.2	0.82	<2	150	<2	<10	<10	30	<10	<10	20
S11	353155097294601	MEDIAN	—	20	80	0.2	0.82	—	—	—	—	—	—	—	—	—
S12	353145097263801	Jun 26, 2003	—	<10	<10	0.2	1.44	<2	590	<2	<10	<10	100	<10	<10	<10
S12	353145097263801	Aug 19, 2003	—	<10	<10	0.1	1.55	<2	460	<2	<10	<10	10	<10	<10	<10
S12	353145097263801	Oct 30, 2003	—	10	<10	0.2	1.52	<2	460	<2	<10	<10	10	<10	<10	<10
S12	353145097263801	Feb 24, 2004	—	10	<10	0.3	1.56	<2	520	<2	<10	<10	60	<10	<10	<10
S12	353145097263801	May 11, 2004	—	10	<10	0.2	1.52	2	490	<2	<10	<10	20	<10	<10	<10
S12	353145097263801	MEDIAN	—	10	<10	0.2	1.52	—	—	—	—	—	—	—	—	—
S13	352910097272501	Jun 26, 2003	—	70	70	0.3	5.16	9	100	<2	<10	<10	1,210	120	<10	140
S14	352759097220201	Jun 19, 2003	—	10	20	0.2	5.3	<2	470	<2	<10	<10	20	<10	<10	<10
S14	352759097220201	Aug 18, 2003	—	20	20	0.2	5.56	2	420	<2	<10	<10	<10	<10	<10	<10
S14	352759097220201	Nov 4, 2003	—	10	20	0.2	5.51	2	380	<2	<10	<10	10	<10	<10	<10
S14	352759097220201	Jan 28, 2004	—	10	20	0.2	5.74	2	440	<2	<10	<10	<10	<10	<10	<10
S14	352759097220201	Jun 3, 2004	—	10	20	0.3	5.76	<2	460	<2	<10	<10	<10	<10	<10	<10

Appendix 1. Median values, measured water properties, and concentrations of chemical constituents in water from shallow wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degree Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental Laboratory at the Oklahoma Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Hydroxide (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic ($\mu\text{g}/\text{L}$)	Barium ($\mu\text{g}/\text{L}$)	Cadmium ($\mu\text{g}/\text{L}$)	Chromium ($\mu\text{g}/\text{L}$)	Copper ($\mu\text{g}/\text{L}$)	Iron ($\mu\text{g}/\text{L}$)	Manganese ($\mu\text{g}/\text{L}$)	Selenium ($\mu\text{g}/\text{L}$)	Zinc ($\mu\text{g}/\text{L}$)
S19	351823097215701	Aug 20, 2003	—	<10	50	0.1	0.42	<2	760	<2	<10	<10	<10	<10	<10	<10
S19	351823097215701	Nov 3, 2003	—	<10	50	0.1	0.42	<2	760	<2	<10	10	<10	<10	<10	<10
S19	351823097215701	Feb 25, 2004	—	<10	50	0.2	0.45	<2	810	<2	<10	<10	<10	<10	<10	<10
S19	351823097215701	May 24, 2004	—	<10	50	0.1	0.43	<2	780	<2	<10	<10	<10	<10	<10	<10
S19	351823097215701	MEDIAN	—	<10	50	0.1	0.42	—	—	—	—	—	—	—	—	—
S20	351450097114201	Jun 18, 2003	—	10	<10	0.1	1	<2	510	<2	<10	<10	370	<10	<10	<10
S20	351450097114201	Aug 19, 2003	—	10	<10	<0.1	0.99	<2	430	<2	<10	<10	390	<10	<10	<10
S20	351450097114201	Nov 12, 2003	—	20	20	<0.1	0.86	<2	450	<2	<10	10	1,150	10	<10	<10
S20	351450097114201	Feb 23, 2004	—	10	<10	0.1	0.9	<2	450	<2	<10	<10	330	<10	<10	<10
S20	351450097114201	May 24, 2004	—	20	<10	<0.1	0.83	2	420	<2	<10	10	3,180	20	<10	10
S20	351450097114201	MEDIAN	—	10	<10	<0.1	0.9	—	—	—	—	—	—	—	—	—
S21	350603096550801	Jun 25, 2003	—	90	140	0.2	<0.05	<2	120	<2	<10	<10	1,770	80	<10	<10
S21	350603096550801	Aug 21, 2003	—	80	160	<0.1	<0.05	<2	110	<2	<10	<10	330	80	<10	<10
S21	350603096550801	Nov 14, 2003	—	80	150	0.2	<0.05	<2	130	<2	<10	10	4,170	80	<10	<10
S21	350603096550801	Mar 5, 2004	—	80	130	0.2	<0.05	<2	120	<2	<10	<10	4,290	70	<10	<10
S21	350603096550801	Jun 10, 2004	—	90	140	0.2	<0.05	<2	110	<2	<10	<10	2,710	70	<10	<10
S21	350603096550801	MEDIAN	—	80	140	0.2	<0.05	—	—	—	—	—	—	—	—	—
S22	350003097090102	Jun 25, 2003	—	10	<10	0.2	<0.05	<2	200	<2	<10	<10	90	30	<10	<10
S22	350003097090102	Aug 27, 2003	—	10	<10	0.2	<0.05	<2	200	<2	<10	<10	120	20	<10	<10
S22	350003097090102	Nov 13, 2003	—	<10	<10	0.1	<0.05	<2	190	<2	<10	<10	140	10	<10	<10
S22	350003097090102	Feb 26, 2004	—	<10	<10	0.1	<0.05	<2	190	<2	<10	<10	180	<10	<10	<10
S22	350003097090102	Jun 14, 2004	—	10	<10	0.2	<0.05	<2	190	<2	<10	<10	690	<10	<10	<10
S22	350003097090102	MEDIAN	—	10	<10	0.2	<0.05	—	—	—	—	—	—	—	—	—
S23	345908096593101	Jun 25, 2003	—	90	<10	0.3	0.59	<2	960	<2	<10	60	1,740	650	<10	10
S23	345908096593101	Aug 27, 2003	—	20	<10	0.3	0.51	<2	170	<2	<10	10	80	50	<10	<10
S23	345908096593101	Nov 13, 2003	—	50	<10	0.3	0.53	<2	360	<2	<10	20	190	60	<10	<10

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003-2005

[USGS, U.S. Geological Survey; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligram per liter; $\mu\text{g/L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S/cm}$)	pH	Water temperature. $^{\circ}\text{C}$	Dis-solved oxygen (mg/L)	Acid neutral-izing capacity	Dis-solved solids, total (mg/L)	Calcium (mg/L)	Magne-sium (mg/L)	Sodium (mg/L)	Potas-sium (mg/L)	Bicar-bonate (mg/L)	Carbonate (mg/L)
D1	355446096583601	Jun 19, 2003	279	7.7	17.4	9.2	146	160	23	14	15	1	178	<0.1
D1	355446096583601	Aug 21, 2003	265	7.7	18.0	8.4	E126	150	20	13	14	1	E153	M
D1	355446096583601	Nov 5, 2003	274	7.8	16.5	8.4	139	130	20	14	15	1	169	M
D1	355446096583601	Feb 27, 2004	286	7.7	16.2	8.8	124	140	20	13	15	1	151	M
D1	355446096583601	Jun 3, 2004	346	7.6	17.3	8.9	121	140	21	13	15	1	147	<0.1
D1	355446096583601	MEDIAN	279	7.7	17.3	8.8	126	140	20	13	15	1	153	—
D2	354538097280901	Jun 2, 2004	—	—	—	—	—	330	65	26	18	<1	—	—
D2	354538097280901	Jun 8, 2004	—	—	—	—	—	320	64	25	18	<1	—	—
D2	354538097280901	Jan 6, 2005	—	—	—	—	—	320	61	26	17	<1	—	—
D2	354538097280901	MEDIAN	—	—	—	—	—	320	64	26	18	<1	—	—
D3	353939097301901	Jun 1, 2004	—	—	—	—	—	280	43	20	33	1	—	—
D3	353939097301901	Jun 9, 2004	—	—	—	—	—	260	46	21	31	1	—	—
D3	353939097301901	Dec 27, 2004	—	—	—	—	—	260	48	21	27	1	—	—
D3	353939097301901	MEDIAN	—	—	—	—	—	260	46	21	31	1	—	—
D4	353959097294301	Jun 1, 2004	—	—	—	—	—	260	45	20	22	1	—	—
D4	353959097294301	Jun 9, 2004	—	—	—	—	—	250	45	19	23	1	—	—
D4	353959097294301	Dec 27, 2004	—	—	—	—	—	240	47	20	21	1	—	—
D4	353959097294301	MEDIAN	—	—	—	—	—	250	45	20	22	1	—	—
D5	353948097283501	Jun 1, 2004	—	—	—	—	—	260	43	21	25	1	—	—
D5	353948097283501	Jun 9, 2004	—	—	—	—	—	250	46	21	25	1	—	—
D5	353948097283501	Dec 27, 2004	—	—	—	—	—	250	50	22	17	1	—	—
D5	353948097283501	MEDIAN	—	—	—	—	—	250	46	21	25	1	—	—
D6	353900097284001	Jun 1, 2004	—	—	—	—	—	270	47	24	21	1	—	—
D6	353900097284001	Jun 9, 2004	—	—	—	—	—	270	49	23	24	1	—	—
D6	353900097284001	Dec 27, 2004	—	—	—	—	—	270	49	24	20	1	—	—

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature, $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
D6	353900097284001	MEDIAN	—	—	—	—	—	270	49	24	24	1	—	—
D7	353850097290001	Jun 1, 2004	—	—	—	—	—	260	41	24	23	2	—	—
D7	353850097290001	Jun 9, 2004	—	—	—	—	—	260	48	25	19	2	—	—
D7	353850097290001	Dec 27, 2004	—	—	—	—	—	260	43	24	19	2	—	—
D7	353850097290001	MEDIAN	—	—	—	—	—	260	43	24	19	2	—	—
D8	354008097190901	Jun 17, 2003	3,080	7.7	18.8	3.1	269	1,580	24	17	666	2	326	M
D8	354008097190901	Aug 18, 2003	3,230	7.8	19.1	—	262	1,900	26	17	741	2	319	M
D8	354008097190901	Nov 4, 2003	2,840	7.7	18.4	4.0	260	1,550	22	15	629	2	315	1
D8	354008097190901	Feb 25, 2004	6,120	7.7	17.2	1.7	247	3,400	45	29	1,360	4	300	M
D8	354008097190901	May 11, 2004	5,770	7.6	18.4	2.7	223	3,400	45	26	1,310	3	271	M
D8	354008097190901	MEDIAN	3,230	7.6	18.4	2.9	260	1,900	26	17	741	2	315	—
D9	353925097113101	Feb 3, 2005	—	—	—	—	—	340	52	25	40	1	—	—
D9	353925097113101	Feb 4, 2005	—	—	—	—	—	340	50	24	40	1	—	—
D9	353925097113101	Mar 18, 2005	—	—	—	—	—	540	51	24	38	1	—	—
D9	353925097113101	Apr 25, 2005	—	—	—	—	—	330	51	24	38	1	—	—
D9	353925097113101	MEDIAN	—	—	—	—	—	340	51	24	39	1	—	—
D10	353218097321801	Jun 29, 2004	—	—	—	—	—	970	103	82	120	4	—	—
D11	353224097320401	Mar 22, 2005	—	—	—	—	—	1,210	82	72	132	4	—	—
D11	353224097320401	Mar 30, 2005	—	—	—	—	—	1,120	95	71	96	4	—	—
D11	353224097320401	AVERAGE	—	—	—	—	—	1,165	89	71	114	4	—	—
D12	353229097304301	Jan 11, 2005	—	—	—	—	—	380	17	15	125	2	—	—
D12	353229097304301	Mar 24, 2005	—	—	—	—	—	580	28	24	90	2	—	—
D12	353229097304301	May 3, 2005	—	—	—	—	—	640	60	53	79	3	—	—
D12	353229097304301	MEDIAN	—	—	—	—	—	580	28	24	90	2	—	—
D13	353032097110701	Jun 16, 2004	—	—	—	—	—	630	67	33	138	4	—	—

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003-2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature, $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
D13	353032097110701	Jan 3, 2005	—	—	—	—	—	690	65	36	143	4	—	—
D13	353032097110701	Mar 4, 2005	—	—	—	—	—	980	61	34	140	4	—	—
D13	353032097110701	Mar 14, 2005	—	—	—	—	—	1,140	82	44	149	4	—	—
D13	353032097110701	MEDIAN	—	—	—	—	—	840	66	35	142	4	—	—
D14	353028097161901	Jun 21, 2004	—	—	—	—	—	220	46	19	11	1	—	—
D14	353028097161901	Jan 4, 2005	—	—	—	—	—	210	41	18	9	1	—	—
D14	353028097161901	Feb 3, 2005	—	—	—	—	—	190	39	18	9	1	—	—
D14	353028097161901	MEDIAN	—	—	—	—	—	210	41	18	9	1	—	—
D15	352819097232501	Jun 9, 2004	—	—	—	—	—	220	41	21	11	1	—	—
D15	352819097232501	Dec 21, 2004	—	—	—	—	—	240	48	23	15	1	—	—
D15	352819097232501	Feb 1, 2005	—	—	—	—	—	240	46	22	14	1	—	—
D15	352819097232501	MEDIAN	—	—	—	—	—	240	46	22	14	1	—	—
D16	352717097261601	Jun 1, 2004	—	—	—	—	—	230	43	26	8	1	—	—
D16	352717097261601	Jun 8, 2004	—	—	—	—	—	230	45	26	8	2	—	—
D16	352717097261601	Dec 21, 2004	—	—	—	—	—	210	43	25	9	2	—	—
D16	352717097261601	MEDIAN	—	—	—	—	—	230	43	26	8	2	—	—
D17	352232097190201	Jun 19, 2003	350	6.7	17.1	2.5	165	390	40	20	6	<1	201	<0.1
D17	352232097190201	Aug 19, 2003	341	6.7	16.8	2.5	174	200	36	18	5	<1	212	<0.1
D17	352232097190201	Nov 13, 2003	357	6.8	15.8	2.9	165	180	34	18	6	<1	201	<0.1
D17	352232097190201	Feb 11, 2004	345	6.8	14.8	3.1	169	170	36	19	6	<1	206	<0.1
D17	352232097190201	Jun 3, 2004	342	6.8	16.2	3.4	165	190	36	18	6	<1	201	M
D17	352232097190201	MEDIAN	345	6.8	16.2	2.9	165	190	36	18	6	<1	201	—
D18	352001097273601	Jun 11, 2004	—	—	—	—	—	250	29	23	38	2	—	—
D18	352001097273601	Jan 31, 2005	—	—	—	—	—	330	7	5	119	<1	—	—
D18	352001097273601	Feb 24, 2005	—	—	—	—	—	540	7	5	121	<1	—	—

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003–2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature, $^{\circ}\text{C}$	Dissolved oxygen (mg/L)	Acid neutralizing capacity	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
D18	352001097273601	MEDIAN	—	—	—	—	—	330	7	5	119	<1	—	—
D19	351918097304001	Jun 11, 2004	—	—	—	—	—	270	23	20	58	2	—	—
D19	351918097304001	Jan 31, 2005	—	—	—	—	—	270	25	18	54	3	—	—
D19	351918097304001	Feb 24, 2005	—	—	—	—	—	440	25	19	48	2	—	—
D19	351918097304001	MEDIAN	—	—	—	—	—	270	25	19	54	2	—	—
D20	351904097294201	Aug 28, 2003	575	7.8	18.0	8.7	282	360	19	14	99	2	342	M
D20	351904097294201	Nov 3, 2003	572	7.8	17.7	6.7	274	360	20	15	97	2	332	M
D20	351904097294201	Feb 11, 2004	564	7.8	17.1	6.6	280	330	19	15	96	3	339	1
D20	351904097294201	May 17, 2004	607	7.7	17.7	6.3	274	330	19	14	102	2	331	1
D20	351904097294201	MEDIAN	574	7.8	17.7	6.7	277	343	19	15	98	2	336	—
D21	351853097284701	Jun 11, 2004	—	—	—	—	—	330	8	6	126	1	—	—
D21	351853097284701	Jan 31, 2005	—	—	—	—	—	320	8	7	121	1	—	—
D21	351853097284701	Feb 24, 2005	—	—	—	—	—	450	11	9	85	1	—	—
D21	351853097284701	MEDIAN	—	—	—	—	—	330	8	7	121	1	—	—
D22	351637097291301	Jun 17, 2003	701	9.2	19.5	3.9	342	420	<1	<1	199	<1	387	15
D22	351637097291301	Aug 18, 2003	730	9.2	19.9	4.4	355	460	<1	<1	189	<1	417	8
D22	351637097291301	Nov 4, 2003	748	9.2	18.8	4.5	332	420	<1	<1	192	<1	347	28
D22	351637097291301	Feb 21, 2004	749	9.2	19.0	4.0	340	420	<1	<1	193	<1	328	42
D22	351637097291301	May 17, 2004	747	9.1	19.4	4.1	336	430	<1	<1	189	<1	332	38
D22	351637097291301	MEDIAN	748	9.2	19.4	4.1	340	420	<1	<1	192	<1	347	28
D23	351437097273101	Jun 2, 2004	—	—	—	—	—	360	1	<1	153	<1	—	—
D23	351437097273101	Jun 21, 2004	—	—	—	—	—	360	3	1	150	<1	—	—
D23	351437097273101	Dec 27, 2004	—	—	—	—	—	340	3	<1	143	<1	—	—
D23	351437097273101	MEDIAN	—	—	—	—	—	360	3	<1	150	<1	—	—
D24	351357097242001	Jun 7, 2004	—	—	—	—	—	450	8	5	176	1	—	—

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003-2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature. $^{\circ}\text{C}$	Dis-solved oxygen (mg/L)	Acid neutral-izing capacity	Dis-solved solids, total (mg/L)	Calcium (mg/L)	Magne-sium (mg/L)	Sodium (mg/L)	Potas-sium (mg/L)	Bicar-bonate (mg/L)	Carbonate (mg/L)
D24	351357097242001	Jul 9, 2004	—	—	—	—	—	440	9	5	175	1	—	—
D24	351357097242001	Jan 12, 2005	—	—	—	—	—	350	6	4	138	1	—	—
D24	351357097242001	MEDIAN	—	—	—	—	—	440	8	5	176	1	—	—
D25	351359097145401	Jun 2, 2004	—	—	—	—	—	220	32	22	23	3	—	—
D25	351359097145401	Jan 31, 2005	—	—	—	—	—	210	32	22	15	3	—	—
D25	351359097145401	Mar 22, 2005	—	—	—	—	—	350	29	21	27	3	—	—
D25	351359097145401	MEDIAN	—	—	—	—	—	220	32	22	23	3	—	—
D26	351344097102801	May 31, 2004	—	—	—	—	—	210	35	18	16	2	—	—
D26	351344097102801	Jun 7, 2004	—	—	—	—	—	230	34	18	18	3	—	—
D26	351344097102801	Dec 22, 2004	—	—	—	—	—	210	35	18	18	3	—	—
D26	351344097102801	MEDIAN	—	—	—	—	—	210	35	18	18	3	—	—
D27	351212097045601	Jun 17, 2003	378	6.6	17.2	3.2	108	230	11	8	63	3	131	<0.1
D27	351212097045601	Aug 21, 2003	375	6.5	17.6	3.6	106	220	10	7	59	3	129	<0.1
D27	351212097045601	Nov 12, 2003	378	6.5	17.4	3.3	113	210	9	7	61	3	138	<0.1
D27	351212097045601	Feb 25, 2004	382	6.7	17.4	3.5	112	220	10	7	65	3	136	<0.1
D27	351212097045601	Jun 14, 2004	384	6.5	17.6	4.2	116	240	10	7	60	3	142	<0.1
D27	351212097045601	MEDIAN	378	6.5	17.4	3.5	112	220	10	7	61	3	136	—
D28	350202096585901	Jun 30, 2003	795	8.3	19.8	2.6	344	490	8	4	190	1	417	1
D28	350202096585901	Aug 27, 2003	813	8.3	19.1	3.9	432	500	8	4	198	1	511	8
D28	350202096585901	Nov 14, 2003	841	8.4	17.0	2.1	369	480	6	3	212	1	444	3
D28	350202096585901	Mar 5, 2004	820	8.5	18.2	4.8	355	500	8	4	208	1	411	11
D28	350202096585901	Jun 14, 2004	831	8.3	18.5	4.4	353	490	6	3	197	1	415	7
D28	350202096585901	MEDIAN	820	8.3	18.2	3.9	355	490	8	4	198	1	417	—

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003-2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligrams per liter; $\mu\text{g/L}$, micrograms per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Hydroxide (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic ($\mu\text{g/L}$)	Barium ($\mu\text{g/L}$)	Cadmium ($\mu\text{g/L}$)	Chromium ($\mu\text{g/L}$)	Copper ($\mu\text{g/L}$)	Iron ($\mu\text{g/L}$)	Manganese ($\mu\text{g/L}$)	Selenium ($\mu\text{g/L}$)	Zinc ($\mu\text{g/L}$)
D7	353850097290001	Jun 1, 2004	—	<10	<10	0.2	0.25	<10	280	<5	<5	<5	<20	<5	<10	<5
D7	353850097290001	Jun 9, 2004	—	<10	<10	0.2	0.25	<10	290	<5	<5	<5	50	<5	<10	<5
D7	353850097290001	Dec 27, 2004	—	<10	<10	0.2	0.23	<10	280	<5	<5	<5	<20	<5	<10	<5
D7	353850097290001	MEDIAN	—	<10	<10	0.2	0.25	—	—	—	—	—	—	—	—	—
D8	354008097190901	Jun 17, 2003	—	180	690	<0.1	1.79	2	50	<2	30	<10	10	<10	70	<10
D8	354008097190901	Aug 18, 2003	—	210	810	<0.1	1.58	3	60	<2	30	<10	<10	<10	70	<10
D8	354008097190901	Nov 4, 2003	—	170	580	<0.1	1.82	3	50	<2	40	<10	<10	<10	60	<10
D8	354008097190901	Feb 25, 2004	—	390	1,450	0.2	0.87	6	100	<2	20	<10	<10	<10	130	<10
D8	354008097190901	May 11, 2004	—	400	1,570	0.7	0.82	7	100	<2	20	<10	<10	<10	110	<10
D8	354008097190901	MEDIAN	—	210	810	<0.1	1.58	—	—	—	—	—	—	—	—	—
D9	353925097113101	Feb 3, 2005	—	20	20	0.2	1.64	<10	270	<5	10	<5	<20	<5	10	<5
D9	353925097113101	Feb 4, 2005	—	20	20	0.2	1.64	<10	260	<5	10	<5	<20	<5	<10	8
D9	353925097113101	Mar 18, 2005	—	10	20	0.2	1.67	15	270	<5	10	<5	<20	<5	20	6
D9	353925097113101	Apr 25, 2005	—	10	20	0.2	1.66	18	270	<5	10	<5	<20	<5	10	<5
D9	353925097113101	MEDIAN	—	15	20	0.2	1.65	—	—	—	—	—	—	—	—	—
D10	353218097321801	Jun 29, 2004	—	180	300	0.1	0.15	<10	50	<5	<5	10	50	<5	<10	20
D11	353224097320401	Mar 22, 2005	—	160	280	0.2	0.16	<10	90	<5	9	10	250	<5	<10	<5
D11	353224097320401	Mar 30, 2005	—	170	240	0.2	0.24	<10	40	<5	<5	7	470	60	<10	8
D11	353224097320401	AVERAGE	—	165	265	0.2	0.20	—	—	—	—	—	—	—	—	—
D12	353229097304301	Jan 11, 2005	—	30	100	0.3	0.28	<10	60	<5	30	70	<20	<5	10	30
D12	353229097304301	Mar 24, 2005	—	40	100	0.2	0.27	<10	40	<5	20	<5	150	<5	<10	<5
D12	353229097304301	May 3, 2005	—	90	210	0.2	0.34	13	60	<5	7	<5	150	<5	10	10
D12	353229097304301	MEDIAN	—	40	100	0.2	0.28	—	—	—	—	—	—	—	—	—
D13	353032097110701	Jun 16, 2004	—	90	150	0.2	0.05	<10	50	<5	<5	7	1,930	150	<10	8
D13	353032097110701	Jan 3, 2005	—	100	150	0.2	0.06	<10	40	<5	7	<5	60	40	<10	<5
D13	353032097110701	Mar 4, 2005	—	100	150	0.2	<0.10	19	40	<5	<5	<5	1,780	520	20	<5

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003-2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligrams per liter; $\mu\text{g/L}$, micrograms per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Hydroxide (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic ($\mu\text{g/L}$)	Barium ($\mu\text{g/L}$)	Cadmium ($\mu\text{g/L}$)	Chromium ($\mu\text{g/L}$)	Copper ($\mu\text{g/L}$)	Iron ($\mu\text{g/L}$)	Manganese ($\mu\text{g/L}$)	Selenium ($\mu\text{g/L}$)	Zinc ($\mu\text{g/L}$)
D13	353032097110701	Mar 14, 2005	—	130	170	0.1	<0.10	16	50	<5	<5	<5	1,020	140	10	<5
D13	353032097110701	MEDIAN	—	100	150	0.2	0.08	—	—	—	—	—	—	—	—	—
D14	353028097161901	Jun 21, 2004	—	<10	10	0.1	1.00	<10	310	<5	<5	<5	<20	<5	<10	<5
D14	353028097161901	Jan 4, 2005	—	<10	<10	0.2	0.31	<10	290	<5	<5	<5	<20	<5	<10	10
D14	353028097161901	Feb 3, 2005	—	<10	<10	0.1	0.18	<10	280	<5	<5	<5	<20	<5	<10	<5
D14	353028097161901	MEDIAN	—	<10	<10	0.1	0.31	—	—	—	—	—	—	—	—	—
D15	352819097232501	Jun 9, 2004	—	<10	<10	0.1	0.47	<10	400	<5	<5	<5	20	<5	<10	<5
D15	352819097232501	Dec 21, 2004	—	<10	<10	0.1	1.25	<10	460	<5	<5	<5	<20	<5	<10	<5
D15	352819097232501	Feb 1, 2005	—	<10	<10	0.1	1.20	<10	430	<5	<5	<5	<20	<5	<10	<5
D15	352819097232501	MEDIAN	—	<10	<10	0.1	1.20	—	—	—	—	—	—	—	—	—
D16	352717097261601	Jun 1, 2004	—	<10	<10	0.2	0.54	<10	400	<5	6	<5	110	<5	<10	6
D16	352717097261601	Jun 8, 2004	—	<10	<10	0.2	0.59	<10	410	<5	7	<5	150	<5	<10	<5
D16	352717097261601	Dec 21, 2004	—	<10	<10	0.2	0.57	<10	410	<5	7	<5	<20	<5	<10	<5
D16	352717097261601	MEDIAN	—	<10	<10	0.2	0.57	—	—	—	—	—	—	—	—	—
D17	352232097190201	Jun 19, 2003	—	<10	<10	0.1	0.40	<2	490	<2	<10	<10	<10	50	<10	<10
D17	352232097190201	Aug 19, 2003	—	<10	<10	0.1	0.44	<2	430	<2	<10	<10	60	30	<10	<10
D17	352232097190201	Nov 13, 2003	—	<10	<10	0.1	0.42	<2	440	<2	<10	<10	<10	30	<10	<10
D17	352232097190201	Feb 11, 2004	—	<10	<10	0.1	0.48	<2	450	<2	<10	<10	60	20	<10	<10
D17	352232097190201	Jun 3, 2004	—	<10	<10	0.1	0.49	<2	440	<2	<10	<10	<10	40	<10	<10
D17	352232097190201	MEDIAN	—	<10	<10	0.1	0.44	—	—	—	—	—	—	—	—	—
D18	352001097273601	Jun 11, 2004	—	<10	<10	0.3	0.54	<10	310	<5	40	7	<20	<5	<10	5
D18	352001097273601	Jan 31, 2005	—	10	<10	0.4	0.36	22	100	<5	60	<5	<20	<5	30	<5
D18	352001097273601	Feb 24, 2005	—	10	<10	0.4	0.39	34	110	<5	60	<5	<20	<5	40	<5
D18	352001097273601	MEDIAN	—	10	<10	0.4	0.39	—	—	—	—	—	—	—	—	—
D19	351918097304001	Jun 11, 2004	—	<10	<10	0.3	0.67	<10	310	<5	40	<5	<20	<5	<10	<5
D19	351918097304001	Jan 31, 2005	—	10	<10	0.1	0.60	<10	1,020	<5	20	6	1,230	10	<10	<5

Appendix 2. Median values and measured water properties and concentrations of chemical constituents measured in water from deep wells in the Central Oklahoma aquifer, 2003-2005—Continued

[USGS, U.S. Geological Survey; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; E, estimated; M, present but not quantified; <, less than; —, not measured or calculated; Analyses were performed at the State Environmental laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier	USGS identification number	Sample date	Hydroxide (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic ($\mu\text{g}/\text{L}$)	Barium ($\mu\text{g}/\text{L}$)	Cadmium ($\mu\text{g}/\text{L}$)	Chromium ($\mu\text{g}/\text{L}$)	Copper ($\mu\text{g}/\text{L}$)	Iron ($\mu\text{g}/\text{L}$)	Manganese ($\mu\text{g}/\text{L}$)	Selenium ($\mu\text{g}/\text{L}$)	Zinc ($\mu\text{g}/\text{L}$)
D19	351918097304001	Feb 24, 2005	—	<10	<10	0.2	<0.10	11	780	<5	20	<5	<20	<5	10	<5
D19	351918097304001	MEDIAN	—	<10	<10	0.2	0.67	—	—	—	—	—	—	—	—	—
D20	351904097294201	Aug 28, 2003	—	20	10	0.2	0.63	<2	240	<2	20	<10	60	20	<10	60
D20	351904097294201	Nov 3, 2003	—	10	10	0.2	0.64	<2	160	<2	20	<10	<10	<10	<10	80
D20	351904097294201	Feb 11, 2004	—	10	<10	0.2	0.71	<2	180	<2	20	<10	<10	<10	<10	80
D20	351904097294201	May 17, 2004	—	20	10	0.2	0.67	<2	170	<2	20	<10	140	<10	<10	60
D20	351904097294201	MEDIAN	—	16	10	0.2	0.66	—	—	—	—	—	—	—	—	—
D21	351853097284701	Jun 11, 2004	—	10	<10	0.6	0.51	38	140	<5	70	5	<20	<5	30	<5
D21	351853097284701	Jan 31, 2005	—	10	<10	0.6	0.49	37	150	<5	70	<5	<20	<5	30	<5
D21	351853097284701	Feb 24, 2005	—	10	<10	0.4	0.61	30	200	<5	60	<5	<20	<5	30	<5
D21	351853097284701	MEDIAN	—	10	<10	0.6	0.51	—	—	—	—	—	—	—	—	—
D22	351637097291301	Jun 17, 2003	M	20	10	0.1	0.62	47	80	<2	30	<10	<10	<10	20	<10
D22	351637097291301	Aug 18, 2003	M	20	10	0.2	0.64	44	80	<2	30	<10	<10	<10	30	<10
D22	351637097291301	Nov 4, 2003	M	20	10	0.2	0.65	44	70	<2	30	<10	30	<10	20	<10
D22	351637097291301	Feb 21, 2004	M	20	10	0.2	0.71	47	80	<2	30	<10	<10	<10	20	<10
D22	351637097291301	May 17, 2004	M	20	10	0.2	0.69	51	90	<2	30	<10	<10	<10	20	<10
D22	351637097291301	MEDIAN	M	20	10	0.2	0.65	—	—	—	—	—	—	—	—	—
D23	351437097273101	Jun 2, 2004	—	20	<10	0.2	0.33	41	130	<5	40	30	<20	<5	10	<5
D23	351437097273101	Jun 21, 2004	—	20	<10	0.2	0.33	51	150	<5	40	180	<20	<5	10	<5
D23	351437097273101	Dec 27, 2004	—	10	<10	0.2	0.33	42	160	<5	40	40	<20	<5	20	<5
D23	351437097273101	MEDIAN	—	20	<10	0.2	0.33	—	—	—	—	—	—	—	—	—
D24	351357097242001	Jun 7, 2004	—	20	10	0.1	0.14	18	590	<5	20	<5	<20	<5	10	<5
D24	351357097242001	Jul 9, 2004	—	20	10	0.1	0.14	16	590	<5	20	<5	30	<5	10	<5
D24	351357097242001	Jan 12, 2005	—	20	10	0.3	0.24	13	330	<5	40	<5	<20	<5	<10	<5
D24	351357097242001	MEDIAN	—	20	10	0.1	0.14	—	—	—	—	—	—	—	—	—
D25	351359097145401	Jun 2, 2004	—	<10	<10	0.1	0.11	<10	430	<5	10	6	<20	<5	<10	70

Appendix 3. Concentrations for equipment blank samples for water-quality samples from wells sampled in the Central Oklahoma aquifer, 2003–2005

[Nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; mg/L, milligram per liter; µg/L, microgram per liter; <, less than; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Sample date	Dis-solved solids, total (mg/L)	Cal-cium (mg/L)	Magne-sium (mg/L)	So-dium (mg/L)	Potas-sium (mg/L)	Sul-fate (mg/L)	Chlo-ride (mg/L)	Fluo-ride (mg/L)	Nitrate nitrogen (mg/L)	Arse-nic (µg/L)	Bari-um (µg/L)	Cad-mium (µg/L)	Chro-mium (µg/L)	Cop-per (µg/L)	Iron (µg/L)	Manga-nese (µg/L)	Sele-nium (µg/L)	Zinc (µg/L)
06/10/2003	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 2	< 10	< 2	< 10	< 10	< 10	< 10	< 10	< 10
08/01/2003	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 2	< 10	< 2	< 10	< 10	< 10	< 10	< 10	< 10
11/01/2003	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 2	< 10	< 2	< 10	< 10	< 10	< 10	< 10	< 10
02/01/2004	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 2	< 10	< 2	< 10	< 10	< 10	< 10	< 10	< 10
05/03/2004	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 2	< 10	< 2	< 10	< 10	< 10	< 10	< 10	< 10
06/08/2004	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 10	< 5	< 5	< 5	< 5	< 20	< 5	< 10	< 5
06/16/2004	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 10	< 5	< 5	< 5	< 5	< 20	< 5	< 10	< 5
06/23/2004	< 10	< 1	< 1	< 1	< 1	< 10	< 10	< 0.1	< 0.05	< 10	< 5	< 5	< 5	< 5	< 20	< 5	< 10	< 5

Appendix 4. Analytical relative percent difference for chemical constituents analyzed in water-quality samples from wells sampled in the Central Oklahoma aquifer, 2003–2005

[RPD, relative percent difference; well type, H is domestic well, P is high-capacity well; mg/L, milligram per liter; µg/L, microgram per liter; <, less than; —, not calculated; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier/ well type	Date	Sample type	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magne- sium (mg/L)	Sodium (mg/L)	Potas- sium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic (µg/L)	Barium (µg/L)
S1 / H	08/21/03	Duplicate	380	50	29	56	1	20	30	0.40	0.46	3	250
S1 / H	08/21/03	Sample	370	49	29	56	1	20	30	0.40	0.47	3	250
RPD			2.7	2.0	0	0	0	0	0	0	2.2	0	0
S6 / H	06/02/03	Duplicate	430	77	32	32	<1	20	50	0.20	2.59	<2	560
S6 / H	06/02/03	Sample	440	76	32	32	<1	20	60	0.20	2.59	<2	570
RPD			2.3	1.3	0	0	0	0	18.2	0	0	—	1.8
S9 / H	06/18/03	Duplicate	380	57	39	49	2	<10	<10	0.20	0.95	<2	850
S9 / H	06/18/03	Sample	370	57	39	49	2	<10	<10	0.20	0.96	<2	830
RPD			2.7	0	0	0	0	—	—	0	1.0	—	2.4
S11 / H	02/26/04	Duplicate	420	70	44	34	4	20	90	0.30	0.90	<2	110
S11 / H	02/26/04	Sample	430	69	44	33	4	20	90	0.30	0.90	<2	110
RPD			2.4	1.4	0	3.0	0	0	0	0	0	—	0
S21 / H	11/14/03	Duplicate	750	115	54	101	<1	80	140	0.20	<.05	<2	120
S21 / H	11/14/03	Sample	760	114	54	101	<1	80	150	0.20	<.05	<2	130
RPD			1.3	0.9	0	0	—	0	6.9	0	—	—	8.0
S22 / H	06/14/04	Duplicate	130	18	9	11	<1	10	<10	0.20	<0.05	<2	190
S22 / H	06/14/04	Sample	130	19	9	11	<1	10	<10	0.20	<0.05	<2	190
RPD			0	5.4	0	0	—	0	—	0	—	—	0
S23 / H	06/14/04	Duplicate	190	18	8	41	<1	20	<10	0.30	0.48	<2	140
S23 / H	06/14/04	Sample	190	18	8	42	<1	20	<10	0.30	0.50	<2	130
RPD			0	0	0	2.4	—	0	—	0	4.1	—	7.4
D1 / H	11/05/03	Duplicate	140	21	14	14	1	<10	<10	0.20	0.54	<2	200

Appendix 4. Analytical relative percent difference for chemical constituents analyzed in water-quality samples from wells sampled in the Central Oklahoma aquifer, 2003–2005—Continued

[RPD, relative percent difference; well type, H is domestic well, P is high-capacity well; mg/L, milligram per liter; µg/L, microgram per liter; <, less than; —, not calculated; nitrate nitrogen is equivalent to nitrite plus nitrate nitrogen; Analyses were performed at the State Environmental Laboratory at the Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma]

Well identifier/ well type	Date	Sample type	Dissolved solids, total (mg/L)	Calcium (mg/L)	Magne- sium (mg/L)	Sodium (mg/L)	Potas- sium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate nitrogen (mg/L)	Arsenic (µg/L)	Barium (µg/L)
D1 / H	11/05/03	Sample	130	20	14	15	1	<10	<10	0.20	0.41	<2	200
RPD			7.4	4.9	0	6.9	0	—	—	0	27.4	—	0
D9 / P	02/03/05	Duplicate	330	50	24	40	1	20	20	0.24	1.66	<10	260
D9 / P	02/03/05	Sample	340	52	25	40	1	20	20	0.24	1.64	<10	270
RPD			3	3.9	4.1	0	0	0	0	0	1.2	—	3.8
D13 / P	06/16/04	Duplicate	642	66	32	136	4	94.6	150	0.18	< 0.05	< 10	50
D13 / P	06/16/04	Sample	630	67	33	138	4	93.3	150	0.17	0.05	< 10	50
RPD			1.9	1.5	3.1	1.5	0	1.4	0	5.7	—	—	—
D20 / H	08/28/03	Duplicate	370	19	14	100	2	20	10	0.20	0.63	<2	220
D20 / H	08/28/03	Sample	360	19	14	99	2	20	10	0.20	0.63	<2	240
RPD			2.7	0	0	1.0	0	0	0	0	0	—	8.7
D22 / H	02/21/04	Duplicate	420	<1	<1	194	<1	20	10	0.20	0.71	48	80
D22 / H	02/21/04	Sample	420	<1	<1	193	<1	20	10	0.20	0.71	47	80
RPD			0	—	—	0.5	—	0	0	0	0	2.1	0
D25 / P	01/31/05	Duplicate	210	29	20	14	3	<10	<10	0.17	0.10	<10	370
D25 / P	01/31/05	Sample	210	32	22	15	3	<10	<10	0.17	0.11	<10	420
RPD			0	9.8	9.5	6.9	0	—	—	0	9.5	—	12.7