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Ground-Water Flow, 2004–07, and Water Quality, 1992–2007, in McBaine Bottoms, Columbia, Missouri

Scientific Investigations Report 2008–5182

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

Cover photographs. Eagle Bluffs Conservation Area—looking south across a wetland pool, May 2002 (Left, photograph courtesy of Brenda J. Smith, U.S. Geological Survey) and looking north across pool 8, August 2000 (Right, photograph courtesy of Joseph M. Richards, U.S. Geological Survey).

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°F=(1.8\times°C)+32$$

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

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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

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

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

Ground-Water Flow, 2004–07, and Water Quality, 1992–2007, in McBaine Bottoms, Columbia, Missouri

By Brenda J. Smith and Joseph M. Richards

Abstract

The U.S. Geological Survey, in cooperation with the city of Columbia, Missouri, and the Missouri Department of Conservation, collected ground-water quality data, surface-water quality data, and water-level data in McBaine Bottoms, southwest of Columbia. McBaine Bottoms, adjacent to the Missouri River, is the location of the municipal-supply well field for the city of Columbia, the city of Columbia wastewater-treatment wetlands, and the Missouri Department of Conservation Eagle Bluffs Conservation Area. This report describes the ground-water flow and water quality of McBaine Bottoms and provides information to better understand the interaction between treated effluent from the wetlands used on the Eagle Bluffs Conservation Area and the water in the alluvial aquifer that is pumped from the city of Columbia municipal-supply well field.

Changes in major chemical constituent concentrations have been detected at several sampling sites between pre- and post-effluent application data. Analysis of post-effluent data indicates substantial changes in calcium, potassium, sodium, chloride, and sulfate concentrations in ground water. These changes became apparent shortly after the beginning of the operation of the wastewater-treatment wetland in 1994 and the formation of the Eagle Bluffs Conservation Area, which uses the treated effluent as a water source for the management of migratory water fowl. The changes have continued throughout the 15 years of sample collection. The concentrations of these major chemical constituents are on the mixing continuum between pre-effluent ground water as one end member and the treated wastewater effluent as the other end member. For monitoring wells that had changes in major chemical constituent concentrations, the relative percentage of treated effluent in the ground water, assuming chloride is conservative, ranged from 6 to 88 percent.

Twenty-two monitoring wells throughout McBaine Bottoms have been affected by effluent based on chloride concentrations larger than 40 milligrams per liter. The chloride concentration of ground water in the alluvial aquifer reflects several sources, including precipitation, water from the Missouri River, water in the aquifer, and the treated effluent. Chloride concentrations from precipitation, the Missouri River, and water in the alluvial aquifer were less than 40 milligrams per liter. These monitoring wells affected by effluent are located in two general areas—adjacent to treatment wetland unit 1 and near the ground-water high on and north of the Eagle Bluffs Conservation Area. The probable source of the large chloride concentrations in well samples adjacent to treatment wetland unit 1 is leakage from the unit. The source for the large chloride concentrations in the other monitoring well samples is the effluent mixed with ground water and Missouri River water that is used to fill pools on the Eagle Bluffs Conservation Area. One monitoring well had a single sample with a chloride concentration larger than 40 milligrams per liter. That sample may have been affected by the use of road salt because of the presence of ice and snow immediately before the sample was collected.

Lateral ground-water flow was dominated by the presence of a persistent ground-water high beneath the Eagle Bluffs Conservation Area and the presence of a cone of depression centered around the city of Columbia well field in the northern part of the study area. Ground-water flow was radially away from the apex of the ground-water high; west and south of the high, flow was toward the Missouri River, east of the high, flow was toward Perche Creek, and north of the high, flow was to the north toward the cone of depression around the city of Columbia well field. Another permanent feature on the water-level maps was a ground-water high beneath treatment wetland unit 1.

Although the ground-water high was present throughout the study period, the subsurface expression of the high changed depending on hydrologic conditions. The cone of depression in the northern part of the study area generally extended from the base of the ground-water high in the northern part of the Eagle Bluffs Conservation Area throughout the rest of the study area. The depth of the cone of depression primarily was dependent on the altitude of the Missouri River and the quantity of water being pumped from the alluvial aquifer by the city of Columbia well field.

Introduction

The city of Columbia, Missouri [estimated population on July 1, 2007, of 99,174 (U.S. Census Bureau, 2008)], uses the Missouri River alluvial aquifer in McBaine Bottoms for its municipal water supply and currently (2008) pumps water from 15 wells, including 7 well pairs. Each well pair consists of two, 4-foot (ft) diameter wells about 100 ft deep with pumps rated at about 2,000 gallons per minute (gal/min). From October 2006 through September 2007, the average daily pumpage from 14 wells from the city of Columbia municipal well field was 14.28 million gallons (Mgal) (City of Columbia, 2008b).

When the city of Columbia wastewater treatment facility was expanded, a wastewater-treatment wetland, hereafter referred to as the treatment wetland, was constructed in McBaine Bottoms (fig. 1) as an alternative to expanding the existing activated sludge facilities. The Missouri Department of Conservation uses the treated effluent from the treatment wetland as a water source for the 1,300-acre managed wetland on the 4,200-acre Eagle Bluffs Conservation Area (fig. 1). The city of Columbia municipal-supply well field, also in McBaine Bottoms, is north of the Eagle Bluffs Conservation Area and west of the treatment wetland.

The treatment wetland consists of four units with a total surface area of about 130 acres. Wastewater entering the treatment wetland consists of blended primary and secondary treated effluent from the wastewater treatment facility. The design capacity of the treatment wetland is 20 million gallons per day (Mgal/d), with an average treated effluent of about 16 Mgal/d (City of Columbia, 2008a). When the treatment wetland began receiving treated wastewater, the city of Columbia stopped discharging treated effluent into Perche Creek (Richards, 2002).

Before operations began at the treatment wetland, monitoring wells were drilled from 1991 through 1993 by the city of Columbia and the U.S. Geological Survey (USGS), and samples were collected from the wells for water-quality analyses beginning in August 1992 (Richards, 1995, 1999). The Eagle Bluffs Conservation Area began accepting treated effluent in 1994, and full wetland management began in late 1995. After effluent discharge began in 1994, samples from a shallow monitoring well, (MW1-2A, fig. 2) about 30 ft deep near treatment wetland unit 1 (fig. 1), had steady and gradual concentration increases in various water-quality constituents (Richards, 1999). Soon after, samples from other monitoring wells on the Eagle Bluffs Conservation Area had similar increases. The water-quality constituents with the most substantial changes were calcium, potassium, sodium, chloride, and sulfate (all constituents were dissolved; Richards, 1999, 2002). Water-quality samples have been collected from monitoring wells and surface-water sites from August 1992 through December 2007.

When the treatment wetland and the Eagle Bluffs Conservation Area were constructed, sparse data were available concerning the ground-water flow in McBaine Bottoms. When water-quality sampling began in the area, water levels were measured in the monitoring wells before the collection of the water sample, and maps showing the water levels in the monitoring wells were compiled (Richards, 2002); however, several of the monitoring wells were clustered near the treatment wetland units, and the existing network of monitoring wells was not sufficient to provide adequate water-level coverage for McBaine Bottoms. To further understand ground-water flow and ground- and surface-water interaction at McBaine Bottoms, 55 additional shallow monitoring wells were installed by the USGS in cooperation with the city of Columbia and the Missouri Department of Conservation in 2000. Water levels in the entire monitoring network of more than 85 wells (fig. 3) were measured monthly during 2001 and 2002 (Smith, 2003).

Water samples from the city of Columbia production wells have been analyzed for selected constituents (Richards, 1995, 1999, 2003; Smith and Richards, 2006) after treatment wetland operations began, including those constituents that have shown the most substantial changes. For example, chloride concentrations in the southernmost city of Columbia well pair in January 1999 were 21 and 24 milligrams per liter (mg/L); in January 2002, 57 and 52 mg/L; in January 2003, 89 and 71 mg/L; in January 2005, 78 and 64 mg/L; in December 2006, 129 and 71 mg/L; and in January 2007, 103 and 69 mg/L (B.W. Kirchhoff, City of Columbia, written commun., 2007).

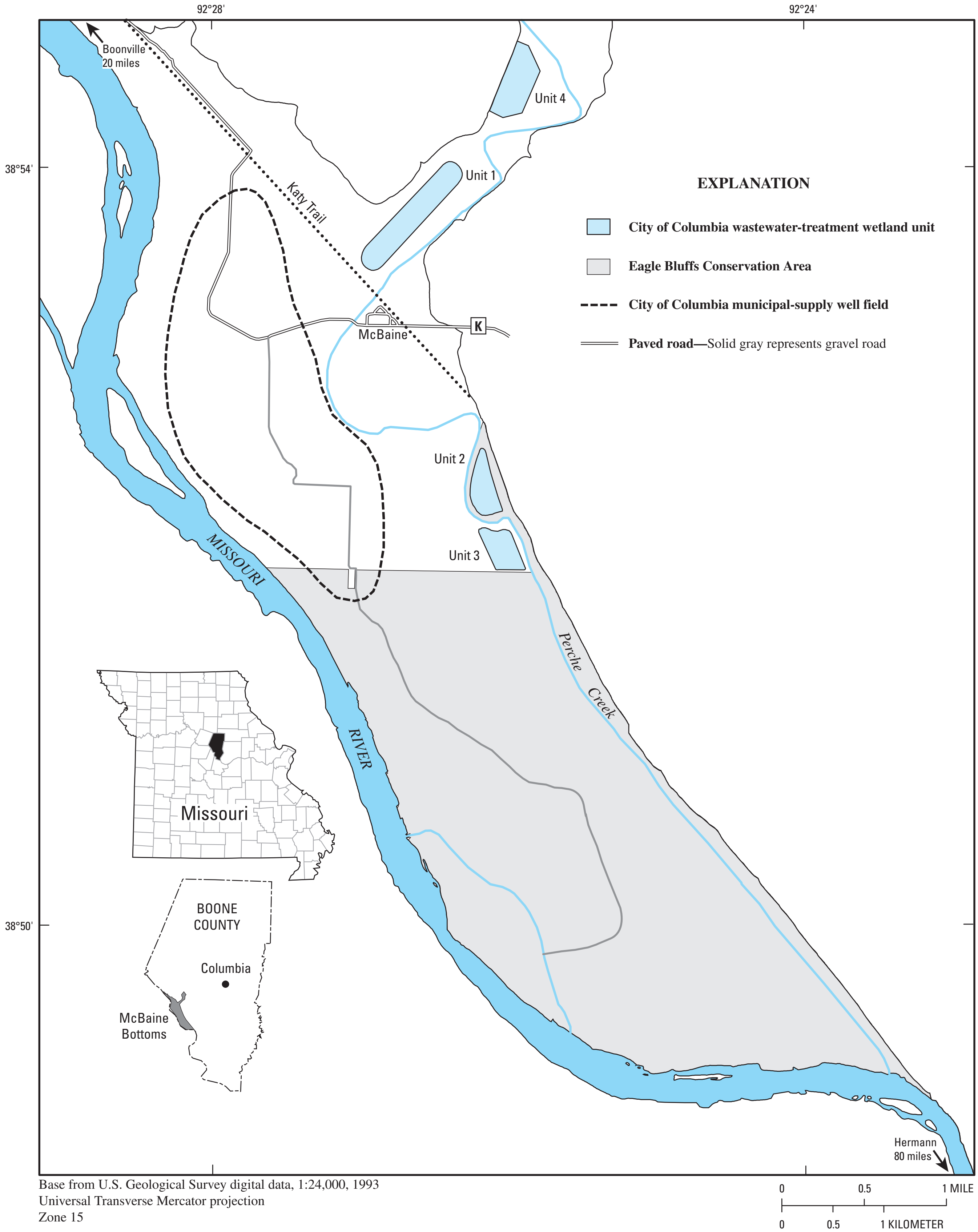
To better understand the interactions between the water in the alluvial aquifer and the treated effluent from the city of Columbia treatment wetland units, information about ground-water flow and water quality needed to be evaluated. Ground-water levels were measured and water samples were collected in cooperation with the city of Columbia and the Missouri Department of Conservation.

Purpose and Scope

The purpose of this report is to describe the ground-water flow and the water quality in McBaine Bottoms. Ground-water levels for the ground-water level monitoring network shown in figure 3 were measured from 2000 through 2002 (described in Smith, 2003) and from 2004 through 2007, which will be the focus of this report. Water-quality samples were collected in McBaine Bottoms from August 1992 through December 2007. Physical properties, inorganic constituent concentrations (including iron), and nutrient concentrations were determined at all sampling sites. Concentrations of trace elements, wastewater organic compounds, and pesticides were measured for selected samples. Water-quality data and analysis have been described in previous reports, including Richards (1995, 1999, 2002) and Smith and Richards (2006). This report provides data that can assist water managers in evaluating the interaction of ground water and surface water in the study area.

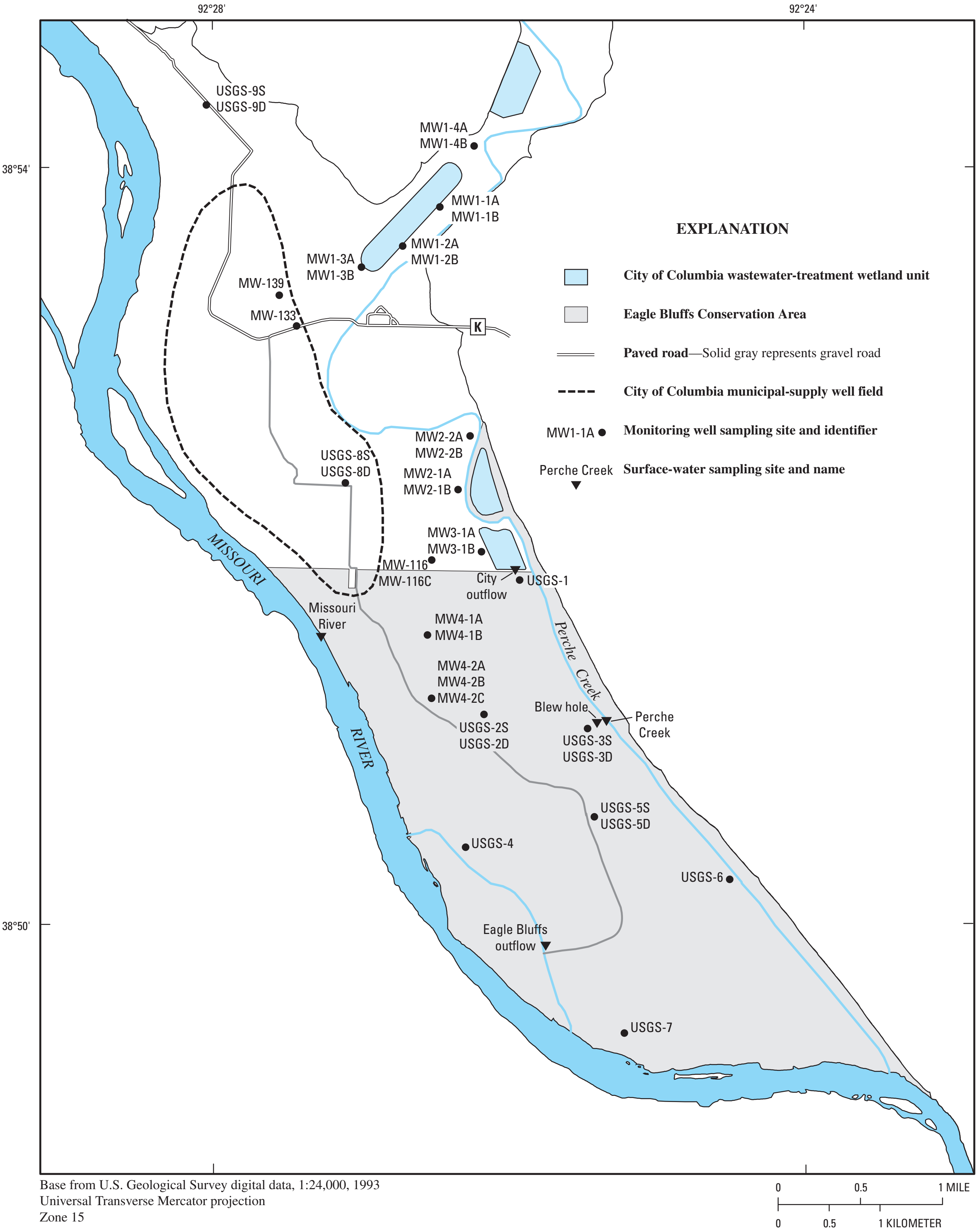
Study Area

McBaine Bottoms is part of the Missouri River alluvial valley about 7 miles (mi) southwest of Columbia, Missouri.



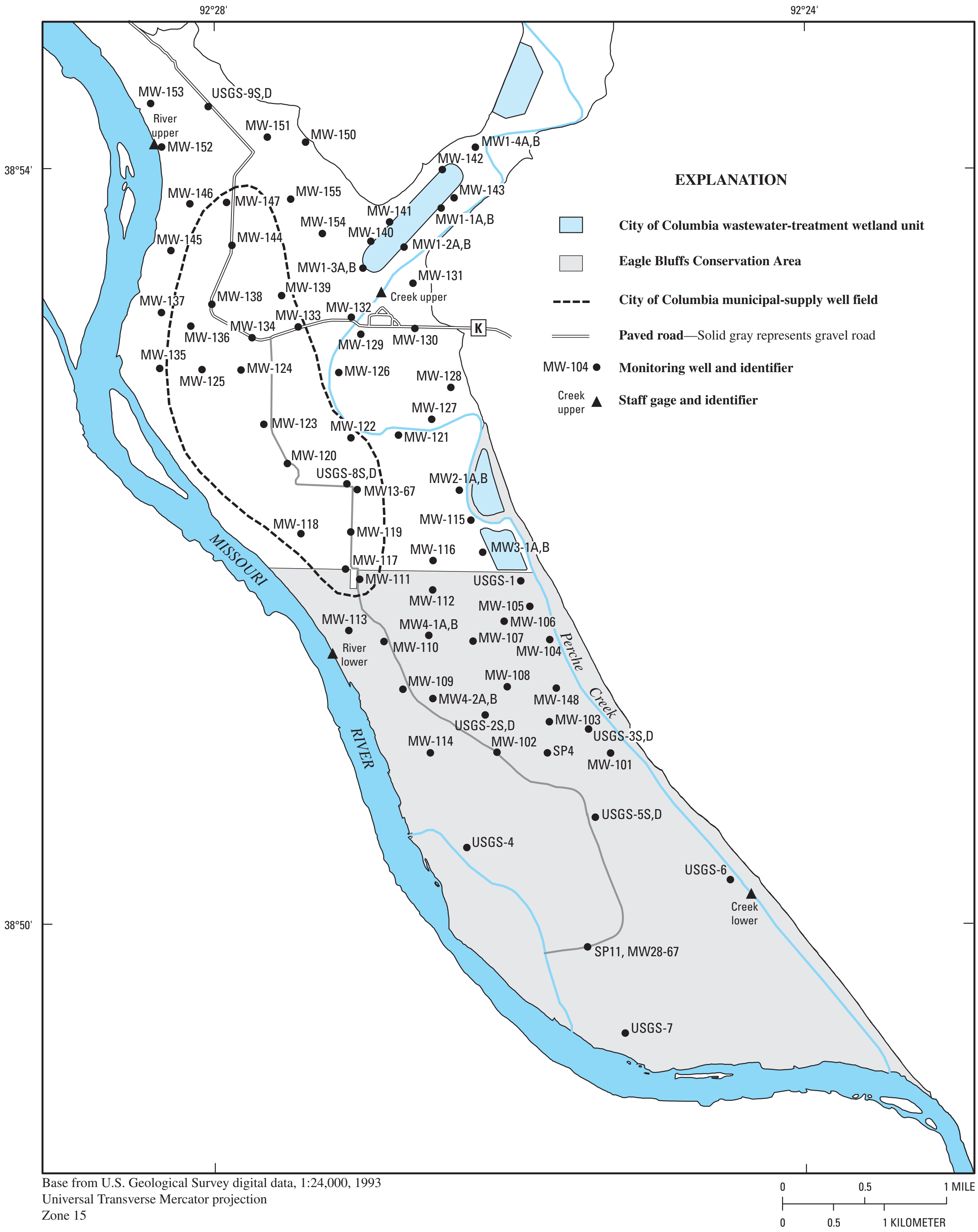
Base from U.S. Geological Survey digital data, 1:24,000, 1993
Universal Transverse Mercator projection
Zone 15

Figure 1. Location of McBaine Bottoms, Columbia, Missouri.



Base from U.S. Geological Survey digital data, 1:24,000, 1993
Universal Transverse Mercator projection
Zone 15

Figure 2. Location of water-quality sampling sites.



Base from U.S. Geological Survey digital data, 1:24,000, 1993
Universal Transverse Mercator projection
Zone 15

Figure 3. Location of ground-water level monitoring network and staff gages.

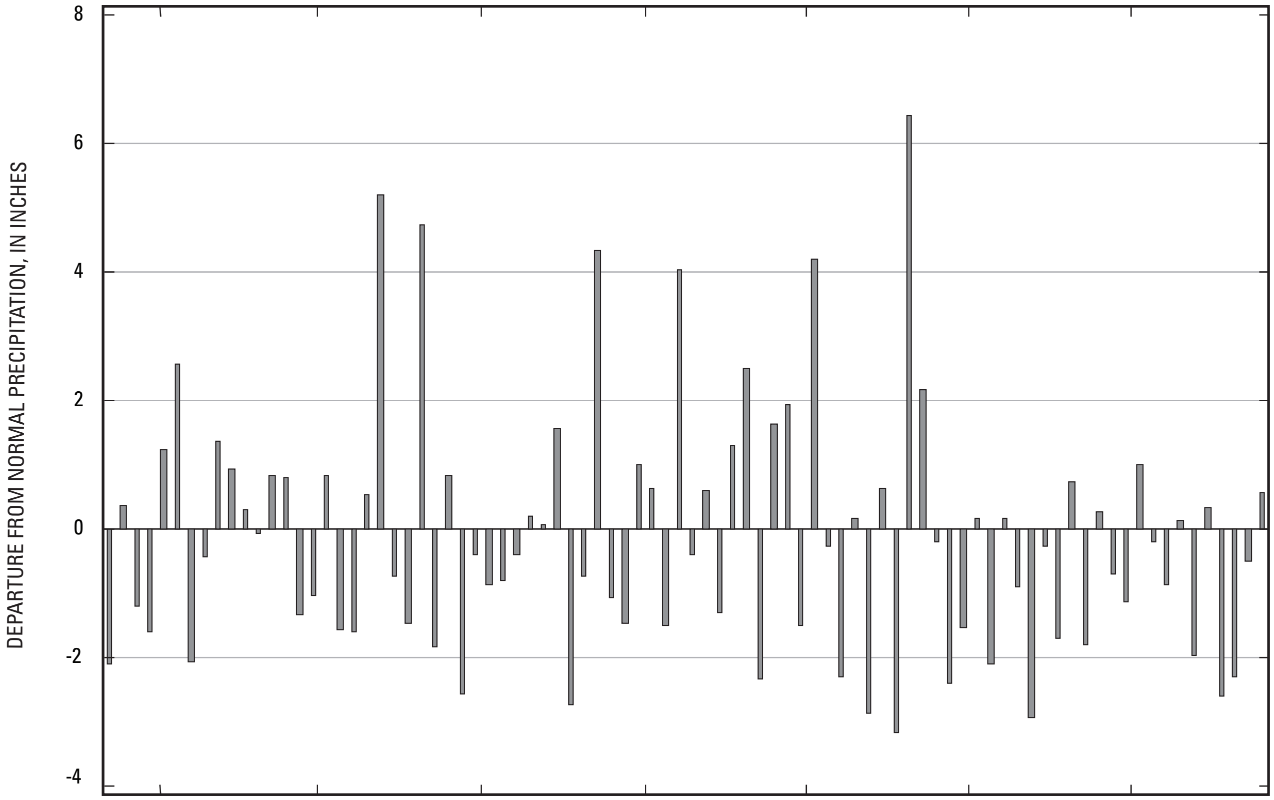
It is an 8.7-square mile (mi^2) area bounded to the south and west by the Missouri River and to the north and east by the bluffs along the Missouri River. Perche Creek flows southward along the bluffs above the flood plain of the Missouri River and discharges to the Missouri River in the southeast part of the study area (fig. 1). Before the treatment wetland was fully operational, the city of Columbia used Perche Creek as the discharge point for treated sewage effluent (Richards, 2002). Several "blew holes" (scour holes) caused by levee failures during past flooding have formed along the levees surrounding the study area. Many of these blew holes contain water year-round and provide habitat for fish and other forms of aquatic life. McBaine Bottoms, including parts of the Eagle Bluffs Conservation Area, is flat-lying agricultural land primarily used for the cultivation of row crops, such as corn and soybeans.

McBaine Bottoms has a temperate climate, with average annual precipitation of about 39 inches (in.) from 2000 through 2007 (National Oceanic and Atmospheric Administration, 2008). From 2004 through 2007, when water levels were measured for this study, the average annual precipitation for each year was 45.95 in. (2004), 41.22 in. (2005), 30.12 in. (2006), and 32.92 in. (2007) (National Oceanic and Atmospheric Administration, 2008). Monthly departure from normal precipitation from January 2000 through October 2007 at the Columbia Regional Airport (National Oceanic and Atmospheric Administration, 2006–07) is shown in figure 4. The airport is about 10 mi east of the study area.

Land-surface altitudes range from 580 ft above the National Geodetic Vertical Datum of 1929 (NGVD 29) in the northwestern part of the study area to 550 ft in the extreme southeastern part of McBaine Bottoms. The altitude of a bluff west of McBaine Bottoms that overlooks the Missouri River and the Missouri River alluvial plain is as much as 800 ft above the NGVD 29 (Smith, 2003). The altitude of the Missouri River at the U.S. Geological Survey streamflow-gaging station at Boonville from January 2000 through October 2007 is shown in figure 5. The streamflow-gaging station at Boonville is about 20 river miles upstream from the study area.

The alluvium underlying McBaine Bottoms is composed of silt, clay, coarse-grained sand, and gravel. The maximum thickness of the alluvium is about 95 ft; the average saturated thickness is about 60 ft (Emmett and Jeffrey, 1969).

Ground water generally flows from north and northwest to south and southeast down the river valley (Foreman and Sharp, 1981). Local differences in the general flow direction result from pumping in the city of Columbia public-supply



Data from National Oceanic and Atmospheric Administration (2000–07)

Figure 4. Monthly departure from normal precipitation at the Columbia Regional Airport, September 2000 through October 2007.

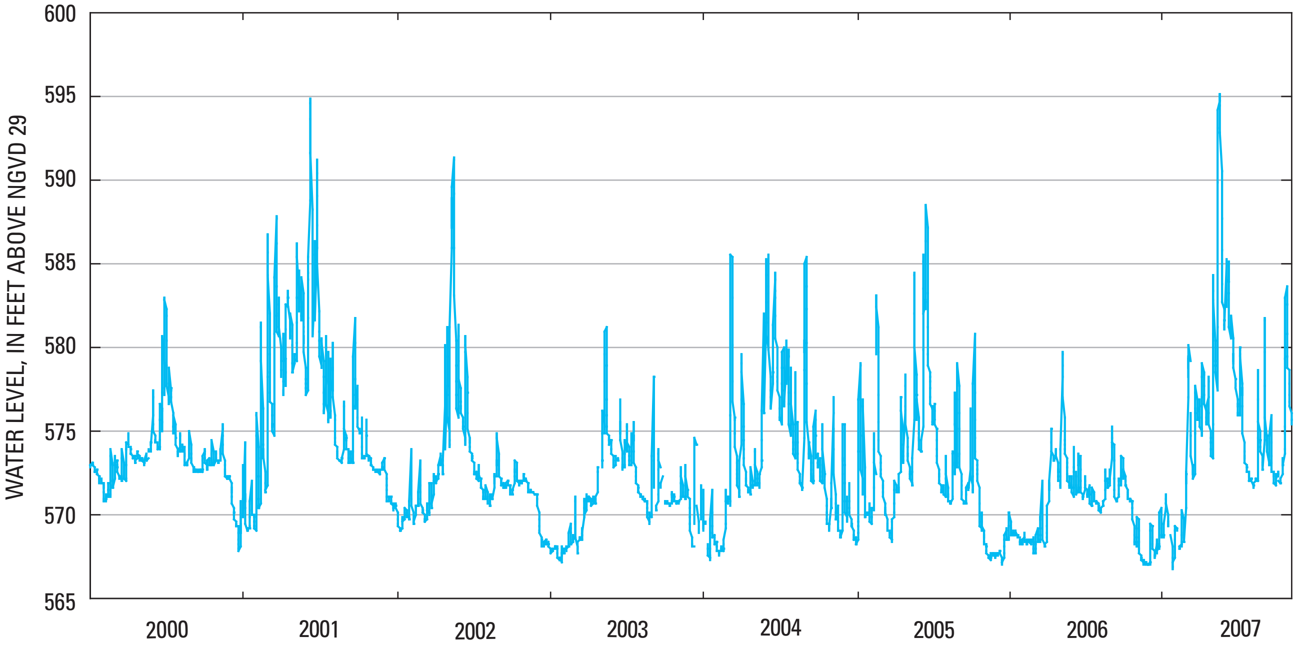


Figure 5. Altitude of the Missouri River at the U.S. Geological Survey gaging station at Boonville, January 2000 through October 2007.

well field, discharge from the treatment wetland, and changes in river stage.

The Missouri Department of Natural Resources has designated specific uses for water bodies in the State. Uses for the Missouri River within the study area include irrigation, livestock and wildlife watering, protection of warm-water aquatic life and human health-fish consumption, whole-body-contact recreation, secondary contact recreation, drinking-water supply, and industrial. Beneficial uses of Perche Creek within the study area include livestock and wildlife watering, protection of warm-water aquatic life and human health-fish consumption, whole-body-contact recreation, and secondary contact recreation (Missouri Department of Natural Resources, 2005). State maximum contaminant level (MCL) standards for selected inorganic constituents for ground water, drinking-water supply, and surface water (protection of warm-water aquatic life and human health-fish consumption) are listed in table 1.

Previous Investigations

The city of Columbia installed 24 observation wells in the area from the northern part of McBaine Bottoms south to the Missouri River. These wells, drilled during the summer of 1967, completely penetrated the alluvium and generally were about 100 ft deep.

In 1968, Layne-Western Company, Inc. (Nuzman, 1969) used an electric analog model to analyze ground-water flow in McBaine Bottoms. Wells drilled in 1967 were used in the simulation. From an aquifer test, the transmissivity was about 58,000 feet squared per day (ft^2/d), and the hydraulic conductivity was computed to be about 1,000 feet per day (ft/d), with an average value of 700 ft/d based on normal saturated thickness. Ground-water flow generally was north to south within McBaine Bottoms and nearly parallel to the flow of the Missouri River.

Foreman and Sharp (1981) used river altitude and water-level data, aquifer test analyses, and three-dimensional simulations to investigate the hydrologic properties of the alluvial

Table 1. Missouri maximum contaminant level standards for selected inorganic constituents for ground water, drinking-water supply, and surface water (protection of warm-water aquatic life and human health-fish consumption) (Missouri Department of Natural Resources, 2005).

[--, no standard; SCL, secondary contaminant level; MCL, maximum contaminant level]

Constituent	Ground water	Drinking-water supply	Protection of warm-water aquatic life and human health-fish consumption
Chloride (milligrams per liter)	--	250 (SCL)	230 (Chronic toxicity) 860 (Acute toxicity)
Sulfate (milligrams per liter)	--	250 (SCL)	--
Fluoride (milligrams per liter)	4	4 (SCL)	--
Nitrate (milligrams per liter)	10	10 (MCL)	--
Iron (micrograms per liter)	300	--	1,000

aquifer in McBaine Bottoms. Ground-water levels primarily were controlled by the altitude of the Missouri River and quantity of water pumped from the aquifer. Other factors affecting ground-water levels were recharge from precipitation, seepage into and out of streams, and recharge from the underlying bedrock. Average transmissivity values were about 54,400 and 63,300 ft^2/d, and hydraulic conductivity values were 679 and 791 ft/d. These values were obtained from an aquifer test from a well and six piezometers that were completed in bedrock.

Metcalf & Eddy (1990) prepared a report on the hydrogeologic evaluation of future water supplies from the alluvium in McBaine Bottoms. The report recommended that city wells be spaced 2,600 ft apart and at least 1,600 ft from the Missouri River or the treatment wetlands to ensure no direct influence of surface water. Estimated travel times for treated effluent to reach simulated city wells (two scenarios—four well sets in the northern part of McBaine Bottoms, three well sets in the northern part of McBaine Bottoms, and one set adjacent to the treatment wetlands) were 17.6 and 15.4 years. Estimated infiltration rates based on soil types and borehole data ranged from 0.000833 to 0.00166 ft/d.

CH2M Hill (1996) evaluated future water-supply sources for the city of Columbia. Several alternative water-supply sources were discussed, including the expansion of the existing well field in McBaine Bottoms, obtaining water from the Eagle Bluffs Conservation Area, and using surface water from the Missouri River.

The USGS has operated several continuous streamflow-gaging stations on the Missouri River. Upstream from McBaine Bottoms, the streamflow-gaging station at Boonville (station number 06909000) has been in operation since 1925, downstream at Jefferson City (stage only) since about 1940, and at Hermann (station number 06934500), about 80 river miles downstream, since 1897. In 2004, the annual mean discharge at Boonville was 53,030 cubic feet per second (ft^3/s); in 2005, 48,720 ft^3/s; in 2006, 35,940 ft^3/s; and in 2007, 62,030 ft^3/s and at Hermann in 2004 was 68,450 ft^3/s; in 2005, 73,420 ft^3/s; in 2006, 41,690 ft^3/s; and in 2007, 79,080 ft^3/s (U.S. Geological Survey, 2008).

A report by Petty and others (2004) describes the bioavailability of selected elements, organochlorine pesticides, polycyclic aromatic hydrocarbons, and pharmaceutical compounds at five sites throughout McBaine Bottoms. A variety of passive integrative sampling devices were used in the collection of the samples. Some compounds that were identified included atrazine and atrazine metabolites and caffeine; tentatively indentified compounds included ibuprofen. The results of the study "provide evidence that the constructed wetlands and the natural wetlands of the Eagle Bluffs Conservation Area function as designed, to remove hydrophobic contaminants from the wastewater stream."

Methods of Study

Ground-Water Level Data

The USGS installed 55 shallow monitoring wells about 30 ft deep during 2000 and 2 wells (MW-116C and MW4-2C, fig. 2) completed near the top of bedrock in December 2007 [installed similar to monitoring wells that were drilled in 1992 and 1993 and described in Richards (1995)]. Because monitoring wells already existed in parts of the study area, the monitoring network was designed to incorporate these existing wells (table 2). Construction data for monitoring wells installed in 2000 are given in Smith (2003); construction data for existing monitoring wells that were incorporated into the network are included in Richards (1995).

Ground-water levels were measured in monitoring wells during February and August 2004, March and August 2005, and February and August 2006 and 2007. This period included conditions of low and high Missouri River stage, flooding and draining of pools at the Eagle Bluffs Conservation Area, and varying quantities of local precipitation. The water-level measurements were made from a reference point [described in Smith (2003)] using an electric tape that was read to the nearest 0.01 ft. Water-level measurements generally were made during 1 day. However, in August 2006, water levels in some monitoring wells were measured when a water sample was collected (August 29) instead on August 28, when most of the water levels were measured. Incorporated into the ground-water level measuring network were four staff gages (fig. 3; data on file at the U.S. Geological Survey, Missouri Water Science Center, Rolla, Missouri). These are described in detail in Smith (2003). Water-table maps were constructed for each set of water-level measurements.

Water-level measurements used for the water-table maps did not include water levels from the wells completed in or near bedrock (SP4, MW13-67, MW28-67, MW-116C, and MW4-2C). For most well pairs (discussed in the Water-Quality Data section), the water level for the shallow well (depth of about 30 ft) was used to construct the water-table maps. The depth of the shallow wells was similar to the depth of the 55 wells that were drilled in 2000 by the USGS.

Water-Quality Data

The water-quality monitoring network was designed to monitor the water quality at various depths (from about 30 to 95 ft deep) in the alluvial aquifer and at selected surface-water sites. The range of sample collection dates for each sampling site is shown in table 2.

Water-quality data have been collected from monitoring wells and surface-water sites since August 1992. Several publications have discussed the results of the data—data from 1992 through June 1993 are available in Richards (1995); data from December 1993 through August 1996 are available in

Table 2. Monitoring well depth, screened interval, and sample collection dates for sites in McBaine Bottoms.

[ft, feet; --, no data; N/A, not applicable]

Site (figs. 2, 3)	Total depth (ft)	Depth to bottom of screen (ft)	Depth to top of screen (ft)	Date sampled	Number of samples collected
MW1-1A	31.0	31.0	21.0	June 1993–August 2006	39
MW1-1B	60.0	60.0	50.0	June 1993–August 2006	37
MW1-2A	31.0	31.0	21.0	June 1993–August 2007	40
MW1-2B	61.0	61.0	51.0	June 1993–August 2007	38
MW1-3A	31.0	31.0	21.0	June 1993–August 2007	38
MW1-3B	61.0	61.0	51.0	June 1993–August 2007	38
MW1-4A	29.5	29.3	19.8	August 1992–August 2007	44
MW1-4B	60.0	59.8	50.3	August 1992–August 2007	42
MW2-1A	29.8	29.6	20.1	August 1992–August 2006	41
MW2-1B	59.9	59.7	50.2	August 1992–August 2006	40
MW2-2A[a]	30.0	30.0	20.0	December 1994–August 1998	16
MW2-2B[a]	60.0	60.0	50.0	December 1994–August 1998	15
MW3-1A	30.0	30.0	20.0	December 1994–August 2007	35
MW3-1B	60.0	60.0	50.0	December 1994–August 2007	33
MW4-1A	29.9	29.7	20.2	August 1992–August 2006	41
MW4-1B	59.4	59.2	49.7	August 1992–August 2006	40
MW4-2A	29.5	29.3	19.8	August 1992–August 2007	43
MW4-2B	59.9	59.7	50.2	August 1992–August 2007	41
MW4-2C	95.0	95.0	85.0	December 2007	1
USGS-1	33.0	27.5	17.5	August 1992–August 2002	30
USGS-2S	32.4	27.4	17.4	August 1992–February 2002	27
USGS-2D	62.0	57.0	47.0	August 1992–February 2002	27
USGS-3S	32.0	27.0	17.0	August 1992–April 2003	32
USGS-3D	63.0	58.0	48.0	August 1992–February 2002	30
USGS-4	62.6	57.6	47.6	August 1992–February 2002	30
USGS-5S	29.5	24.5	14.5	August 1992–April 2003	31
USGS-5D	51.1	51.5	41.4	August 1992–August 2002	30
USGS-6	33.5	28.5	18.5	August 1992–April 2003	32
USGS-7	60.8	60.8	50.8	August 1992–February 2002	29
USGS-8S	32.8	27.8	17.8	August 1992–August 2002	34
USGS-8D	62.8	57.8	47.8	August 1992–August 2002	34
USGS-9S	38.0	33.0	23.0	August 1992–August 2002	34
USGS-9D	68.0	63.0	53.0	August 1992–April 2003	35
MW-116	30.0	30.0	20.0	August 2007	1
MW-116C	92.0	90.0	80.0	December 2007	1
MW-133	40.0	40.0	30.0	August 2007	1
MW-139	35.0	35.0	25.0	August 2007	1
MW13-67	105.0	105.0	85.0	August 1992–June 1993	4
City of Columbia #5	--	--	--	April and August 2003	2
Blew hole	N/A	N/A	N/A	August 1992–March 2002	27
Perche Creek	N/A	N/A	N/A	August 1992–March 2002	30
City outflow	N/A	N/A	N/A	December 1996–August 2003, August 2007	17
Eagle Bluffs outflow	N/A	N/A	N/A	December 1996–March 2002	13
Missouri River	N/A	N/A	N/A	April and August 2003	2

[a] Well abandoned.

Richards (1999); data from December 1996 through March 1999, along with a discussion of the water quality and groundwater hydrology, are available in Richards (2002). Water-quality data from June 1999 through August 2005 are available in Smith and Richards (2006). Water samples were collected from wells (fig. 2) from June 1999 through December 2007. Twenty-eight of the monitoring wells that were sampled were well pairs. Well pairs are identified with the suffix A, B, S, or D. For the well pairs, the shallow well (identified by A or S) is about 30 ft deep and the intermediate well (identified by B or D) is about 60 ft deep. One well pair consisted of a well about 30 ft deep (MW-116) and a well completed near the top of bedrock (MW-116C, about 90 ft deep). Monitoring wells 4-2A, B, and C are about 30, 60, and 95 ft deep. Monitoring well MW4-2C also was completed near the top of bedrock. The rest of the wells are single monitoring wells: USGS-1 and USGS-6 are about 30 ft deep and USGS-4 and USGS-7 are about 60 ft deep. Samples were collected at monitoring wells designated by the prefix MW1- through MW4- from June 1999 through December 2007. Samples were collected from five surface-water sites, including the city outflow, from August 1999 through August 2003. One additional sample from the city outflow was collected in August 2007. Water-quality data from 2006 and 2007 are listed in table 3.

Sample Collection and Analysis Methods

The water level, specific conductance, pH, and temperature were determined onsite at the time of sampling, after properties had stabilized (usually after pumping about two well volumes) according to procedures described in Wilde and Radtke (1998). Samples for nutrient analyses were collected according to standard USGS sample collection and processing protocols described by Edwards and Glysson (1998) and Wilde and others (1999a, 1999b). All major chemical, nutrient, and iron analyses were determined by the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, according to procedures described in Fishman and Friedman (1989) or Fishman (1993). Samples were analyzed for dissolved constituents, unless otherwise noted in the tables.

The depths to water listed in table 3 were measured immediately before the water in the well was pumped. Specific conductance values were measured using a portable conductivity meter with temperature compensation designed to express readings in microsiemens per centimeter at 25 degrees Celsius (°C). The pH value was measured at the time of sample collection with an electronic meter calibrated with buffers bracketing the expected pH values of the samples. The water temperature was determined using the thermistor on the same meter that determined the pH value.

Wastewater indicator compounds were determined from filtered samples by continuous liquid-liquid extraction with methylene chloride and by capillary-column gas chromatography/mass spectrometry using selected-ion monitoring (Brown and others, 1999; Kolpin and others, 2002) at the NWQL. Zaugg and others (2001) provides details about specific wastewater indicator compounds and their uses. Pharmaceutical compounds were determined from filtered samples by high-performance liquid chromatography/electrospray ionization-mass spectrometry analysis (Furlong and others, 2000; Kolpin and others, 2002) at the NWQL.

In several water-quality tables in this report, the terms “estimated” and “presence verified, but not quantified” are used. The term “estimated” indicates a concentration that is between the long-term method detection level (LT-MDL) and the laboratory report level (LRL) or lowest calibration standard, whichever is greater (Childress and others, 1999). The LT-MDL is derived by determining the standard deviation of a minimum of 24 spike-sample measurements near the LT-MDL over an extended period (at least 6 months) and the LRL generally is equal to twice the annually determined LT-MDL. The LT-MDL controls false positive error or the chance of falsely reporting a concentration at or greater than the LT-MDL for a sample that did not contain the analyte is predicted to be no more than 1 percent. The LRL controls false negative error. The probability of falsely reporting a nondetection for a sample that contained an analyte is predicted to be no more than 1 percent. The term “presence verified, but not quantified” indicated that an analyte was detected, but in insufficient quantity to actually determine the concentration.

Quality-assurance (QA) samples were collected and analyzed to ensure the integrity of the water-quality data presented in this report. About 10 percent of all samples collected were blank or replicate QA samples.

The adequacy of the field cleaning and sample processing protocols were evaluated through field and equipment blank samples. Purified water (blank water) was passed through the same equipment used to collect and process water-quality samples and then stored, shipped, and analyzed by the NWQL using the identical methods that were used for environmental samples. Laboratory blank samples were prepared at the laboratory by the NWQL and analyzed with environmental samples to ensure that laboratory contamination was not a concern during analyses. Measurable concentrations in blank water can result from trace quantities of constituents in the water, as well as residual material in sample processing or analytical equipment. Most compounds were not detected in any blank samples; if detected, the reported concentrations were near the detection limit for these compounds (data on file at the U.S. Geological Survey, Missouri Water Science Center, Rolla, Missouri, and data from the National Water Information System at *http://waterdata.usgs.gov*). The blank sample data support the conclusion that equipment cleaning, sample collection, and processing procedures provided an inconsequential source of bias to environmental samples.

Replicate samples were collected to determine the variability in sample collection and processing procedures and to examine the effect these variations may have on concentrations determined from environmental samples. Generally, a replicate sample was collected immediately after an environmental sample using the same equipment and sampling techniques. The environmental and replicate samples were

Table 3. Values of physical properties and major chemical, nutrient, and iron concentrations in samples from monitoring wells and the city outflow, McBaine Bottoms, 2006–07.

[ft, feet; MP, measuring point; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; constituent concentrations are dissolved, unless otherwise indicated; mg/L, milligrams per liter; --, no data; *, replicate sample; <, less than; N, nitrogen; P, phosphorus; E, estimated; µg/L, micrograms per liter; N/A, not applicable]

Date	Time	Depth to water (ft below MP)	Specific conductance (µS/cm)	pH	Water temperature (°C)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)
						MW1-1A						
2/22/2006	1145	9.68	1,150	6.7	14.5	173	30.5	3.36	26.3	32.7	0.28	218
8/30/2006	1150	14.27	1,180	6.6	15.1	163	29.8	3.13	25.7	42.5	.3	204
						MW1-1B						
2/22/2006	1235	17.55	1,250	7.0	14.5	198	37	6.92	20.9	13.6	.2	241
8/30/2006	1200	37.43	1,240	6.8	15.5	182	35.3	6.74	20.5	15.4	.2	220
						MW1-2A						
2/22/2006	1000	21.18	1,050	7.1	14.6	145	40.3	4.65	24.9	93.0	.4	37.4
8/30/2006	1030	26.48	1,150	7.0	15.2	152	41.6	4.64	18.8	106	.3	45.5
8/21/2007	1100	17.51	1,010	6.9	14.9	158	36.8	5.47	15.7	35.5	.2	115
						MW1-2B						
2/22/2006	1045	21.25	1,440	7.2	14.1	149	37.2	6.87	95.0	184	.3	31.3
8/30/2006	1040	26.63	1,590	7.1	15.1	150	39.0	6.83	119	207	.2	46.4
8/21/2007	1105	17.54	1,130	7.2	15.7	121	30.8	5.78	69.0	89	.2	22.8
						MW1-3A						
2/22/2006	1500	23.54	1,220	7.1	15.0	146	45.3	6.40	43.3	147	.3	68.7
8/30/2006[a]	1330	29.99	--	--	--	--	--	--	--	--	--	--
8/21/2007	1355	19.32	1,320	7.0	15.6	166	51.9	7.11	58.4	189	.2	87.8
						MW1-3B						
2/22/2006	1530	23.57	1,380	7.2	14.9	178	44.0	5.25	52.2	189	.4	41.6
8/30/2006	1430	30.25	1,497	7.2	15.1	173	44.2	5.22	64.4	188	.4	42.1
*	1435	30.25	1,497	7.2	15.1	177	45.0	5.39	66.5	188	.4	42.3
8/21/2007	1400	19.38	1,120	7.1	15.4	151	35.6	4.61	24	82	.3	32.5
						MW1-4A						
2/22/2006	1325	12.01	742	7.0	15.0	114	25.6	1.79	16.6	5.59	.4	44.9
8/30/2006	1300	13.13	792	6.9	15.1	117	27.1	1.77	17.3	9.48	.4	54.3
8/21/2007	1245	14.16	944	6.9	15.2	138	30.7	1.94	19.9	32.6	.4	56.3
						MW1-4B						
2/22/2006	1405	23.76	594	7.3	14.4	84.7	17.8	4.00	14.2	2.94	.2	<.20
8/30/2006	1310	48.21	610	7.1	15.8	81.6	18.0	3.83	14.1	3.06	.2	.30
8/21/2007	1250	24.78	585	7.2	15.7	85.4	17.9	4.00	15.2	2.59	.2	<.18
						MW2-1A						
2/23/2006	0935	26.09	701	7.0	14.7	116	26.1	2.54	4.06	2.11	.4	7.5
8/29/2006	1115	25.16	763	7.0	14.5	118	27.0	2.97	5.41	3.16	.3	12.2

Table 3. Values of physical properties and major ion, nutrient, and iron concentrations in samples from monitoring wells and the city outflow, McBaine Bottoms, 2006–07.—Continued

[ft, feet; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; constituent concentrations are dissolved, unless otherwise indicated; mg/L, milligrams per liter; --, no data; *, replicate sample; <, less than; N, nitrogen; P, phosphorus; E, estimated; µg/L, micrograms per liter; N/A, not applicable]

Date	Time	Depth to water (ft)	Specific conductance (µS/cm)	pH	Water temperature °C	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)
MW2-1B												
2/23/2006	1015	24.55	900	7.0	14.4	139	32.2	5.76	11.5	5.90	0.3	E.2
8/29/2006	1130	23.59	908	7.1	15.0	128	30.3	5.32	11.8	5.81	.3	<.2
MW3-1A												
2/23/2006	1125	19.51	980	6.9	14.9	172	26.9	4.86	9.94	9.71	.3	54.6
8/29/2006	1300	19.00	941	6.9	14.8	157	25.5	4.79	8.90	12.3	.3	42.1
8/22/2007	1035	16.74	916	7.0	15.1	160	24.6	4.93	8.96	8.36	.3	42.1
MW3-1B												
2/23/2006	1205	19.57	1,140	7.0	14.2	167	34.3	5.27	11.0	112	.3	58.1
8/29/2006	1310	19.04	1,179	7.1	15.1	163	35.1	5.25	11.2	117	.2	60.5
8/22/2007	1040	16.74	1,240	7.1	15.0	167	34.2	6.01	29.0	165	.2	70.3
MW4-1A												
2/23/2006	1430	15.65	909	7.1	14.6	129	27.2	5.91	25.0	26.6	.2	70.8
8/29/2006	1435	17.08	1,019	7.1	14.9	144	31.5	6.26	23.1	17.9	.2	63.3
MW4-1B												
2/23/2006	1510	15.61	1,220	7.1	14.3	113	27.5	5.90	102	127	.2	72.8
*	1520	15.61	1,220	7.1	14.3	112	27.6	5.89	98.3	122	.2	71.5
8/29/2006	1445	16.90	1,305	7.2	15.1	110	27.9	5.93	104	163	.2	65.1
MW4-2A												
2/23/2006	1310	13.79	1,220	7.0	17.3	116	24.3	9.23	101	146	.4	52.5
8/29/2006	1550	14.45	1,400	7.1	16.5	115	24.2	9.55	124	182	.4	68.2
8/21/2007	1515	13.13	1,380	7.0	16.0	122	25	9.3	121	169	.4	56.7
MW4-2B												
2/23/2006	1345	13.80	1,280	7.1	16.7	104	19.6	9.24	136	167	.5	79.9
8/29/2006	1600	14.43	1,275	7.2	15.7	111	22.6	9.26	102	149	.4	78.1
8/21/2007	1520	13.16	1,380	7.2	15.8	109	20.2	11.9	154	230	.5	85.5
MW4-2C												
12/14/2007	1115	8.65	1,340	7.3	13.2	96.8	22.7	6.78	158	205	.4	62.6
MW-116												
8/22/2007	1200	13.13	986	7.0	14.6	150	25.2	5.28	11.1	25.5	.2	15.1
MW-116C												
12/14/2007	1315	12.20	1,350	7.2	13.7	100	23.9	5.79	156	213	.3	87.8
MW-133												
8/22/2007	1320	30.21	1,210	7.0	15.1	176	42.8	16.5	11.6	21.8	.1	95.2
MW-139												
8/22/2007	1415	27.27	826	6.9	15.3	129	30.7	1.36	5.26	.64	.2	42.2
*	1420	27.27	826	6.9	15.3	129	30.1	1.34	5.12	.86	.2	42.8
City outflow												
8/22/2007	0910	N/A	1,610	7.8	--	55.2	23.2	24.6	222	289	.8	109

Table 3. Values of physical properties and major ion, nutrient, and iron concentrations in samples from monitoring wells and the city outflow, McBaine Bottoms, 2006–07.—Continued

[ft, feet; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; constituent concentrations are dissolved, unless otherwise indicated; mg/L, milligrams per liter; --, no data; *, replicate sample; <, less than; N, nitrogen; P, phosphorus; E, estimated; µg/L, micrograms per liter; N/A, not applicable]

Date	Time	Ammonia + organic N as N (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)	Nitrite + nitrate as N (mg/L)	Orthophosphorus as P (mg/L)	Phosphorus dissolved (mg/L)	Total phosphorus (mg/L)	Iron (µg/L)
MW1-1A									
2/22/2006	1145	1.5	1.3	<0.008	<0.06	<0.02	1.28	1.62	32,200
8/30/2006	1150	1.5	E1.24	<.002	<.06	.03	1.63	1.69	30,900
MW1-1B									
2/22/2006	1235	2.5	2.33	<.008	<.06	<.02	.96	1.34	34,500
8/30/2006	1200	2.4	2.13	<.002	<.06	.03	1.25	1.38	33,100
MW1-2A									
2/22/2006	1000	.16	.11	<.008	<.06	.06	.05	.10	3,200
8/30/2006	1030	.20	.11	<.002	<.06	.06	.15	.17	6,730
8/21/2007	1100	.11	.04	E.001	<.06	.01	<.04	E.03	271
MW1-2B									
2/22/2006	1045	.72	.61	<.008	<.06	<.02	.06	.32	9,250
8/30/2006	1040	.84	.68	.002	<.06	.25	.33	.32	10,300
8/21/2007	1105	.62	.56	.002	<.06	.18	.25	.32	8,600
MW1-3A									
2/22/2006	1500	.10	.04	<.008	<.06	E.01	<.04	E.03	175
8/30/2006	1330	--	--	--	--	--	--	--	--
8/21/2007	1355	.30	.23	E.001	<.06	.02	E.02	.05	343
MW1-3B									
2/22/2006	1530	.55	.44	<.008	<.06	.22	.25	.30	7,780
8/30/2006	1430	.59	.47	<.002	<.06	.03	.28	.29	7,410
*	1435	.60	.47	E.001	<.06	.19	.25	.30	7,480
8/21/2007	1400	.44	.41	.002	<.06	.12	.15	.31	6,760
MW1-4A									
2/22/2006	1325	.14	.10	<.008	<.06	.07	.08	.09	128
8/30/2006	1300	.19	.09	<.002	<.06	.08	.07	.09	53
8/21/2007	1245	.15	.11	E.001	<.06	.09	.10	.10	169
MW1-4B									
2/22/2006	1405	4.0	3.65	<.008	<.06	E.01	1.08	1.41	7,160
8/30/2006	1310	4.0	3.65	<.002	<.06	.14	1.40	1.28	6,540
8/21/2007	1250	4.2	3.58	.003	<.06	.49	1.19	1.43	7,090
MW2-1A									
2/23/2006	0935	E.05	<.04	<.008	E.04	E.02	<.04	<.04	E4
8/29/2006	1115	.17	.08	<.002	E.03	.02	<.04	.04	266

Table 3. Values of physical properties and major ion, nutrient, and iron concentrations in samples from monitoring wells and the city outflow, McBaine Bottoms, 2006–07.—Continued

[ft, feet; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; constituent concentrations are dissolved, unless otherwise indicated; mg/L, milligrams per liter; --, no data; *, replicate sample; <, less than; N, nitrogen; P, phosphorus; E, estimated; µg/L, micrograms per liter; N/A, not applicable]

Date	Time	Ammonia + organic N as N (mg/L)	Ammonia as N (mg/L)	Nitrite as N (mg/L)	Nitrite + nitrate as N (mg/L)	Orthophos-phorus as P (mg/L)	Phosphorus dissolved (mg/L)	Total phosphorus (mg/L)	Iron (µg/L)
MW2-1B									
2/23/2006	1015	0.58	0.48	<0.008	<0.06	<0.02	0.55	0.62	13,600
8/29/2006	1130	.63	.48	<.002	<.06	.01	.40	.63	13,000
MW3-1A									
2/23/2006	1125	.11	<.04	<.008	<.06	.03	E.04	E.03	10
8/29/2006	1300	.13	.02	<.002	<.06	.04	E.02	E.03	10
8/22/2007	1035	.20	E.017	E.001	<.06	.04	E.03	.04	11
MW3-1B									
2/23/2006	1205	.51	.43	<.008	<.06	<.02	.38	.46	18,100
8/29/2006	1310	.57	.42	<.002	<.06	.08	.40	.45	18,600
8/22/2007	1040	.61	.47	E.002	<.06	.06	.29	.39	17,400
MW4-1A									
2/23/2006	1430	.85	.66	<.008	<.06	<.02	.61	.80	18,000
8/29/2006	1435	.90	.75	E.002	<.06	.13	.51	.70	20,400
MW4-1B									
2/23/2006	1510	1.2	1.00	<.008	<.06	<.02	.75	.86	16,600
*	1520	1.2	1.02	<.008	<.06	<.02	.69	.86	16,500
8/29/2006	1445	1.2	1.02	<.002	<.06	.01	.85	.79	14,500
MW4-2A									
2/23/2006	1310	1.5	1.37	<.008	<.06	<.02	.33	.40	9,350
8/29/2006	1550	1.7	1.48	<.002	<.06	.07	.18	.35	9,440
8/21/2007	1515	1.4	1.21	E.002	<.06	.08	.39	.43	10,200
MW4-2B									
2/23/2006	1345	.92	.77	<.008	<.06	<.02	.39	.67	12,600
8/29/2006	1600	.92	.76	<.002	<.06	.01	.56	.58	14,600
8/21/2007	1520	1.10	.93	.004	<.06	.36	.48	.56	13,300
MW4-2C									
12/14/2007	1115	1.4	1.08	.002	<.04	.61	.57	.57	9,470
MW-116									
8/22/2007	1200	.25	.15	.004	<.06	.33	.33	.51	17,900
MW-116C									
12/14/2007	1315	.76	.54	E.002	<.04	.54	.54	.55	8,900
MW-133									
8/22/2007	1320	.31	<.02	.080	22.7	.040	.04	.04	7
MW-139									
8/22/2007	1415	E.09	<.02	E.002	3.12	.02	<.04	<.04	E5
*	1420	.14	<.02	E.001	3.17	.02	<.04	<.04	6
City outflow									
8/22/2007	0910	12	8.83	.004	<.06	4.13	4.00	4.35	172

[a] Insufficient water to sample.

analyzed at the NWQL using identical analytical techniques. Analysis of replicate samples indicated that the laboratory analysis and the sampling procedure were producing consistent results. Results of the environmental and replicate sample analyses were within 5 percent of each other (data on file at the U.S. Geological Survey, Missouri Water Science Center, Rolla, Missouri, and data from the National Water Information System at *http://waterdata.usgs.gov*).

Data Analysis Methods

The distribution of selected physical property values or constituent concentrations at sampling sites is shown using side-by-side boxplots (Tukey, 1977; fig. 6). A boxplot is a useful tool for visually examining the central tendency and dispersion of a group of data or for comparing two or more groups of data. To construct a boxplot, the median value is plotted as a horizontal line, and a box is drawn from the 25th percentile to the 75th percentile. The box length equals the interquartile range (IQR). Vertical lines are then drawn from the quartiles to two “adjacent” values. The upper adjacent value is defined as the largest data point less than or equal to the upper quartile plus 1.5 times the IQR (90th percentile). The lower adjacent value is the smallest data point greater than or equal to the lower quartile minus 1.5 times the IQR (10th percentile). Values more extreme in either direction than the adjacent values are plotted individually. Those values equal to 1.5 to 3.0 times the IQR are called “outside values” and generally are represented by an asterisk; those values greater than 3.0 times the IQR are called “far-out values” and generally are represented by a circle (Davis and Schumacher, 1992).

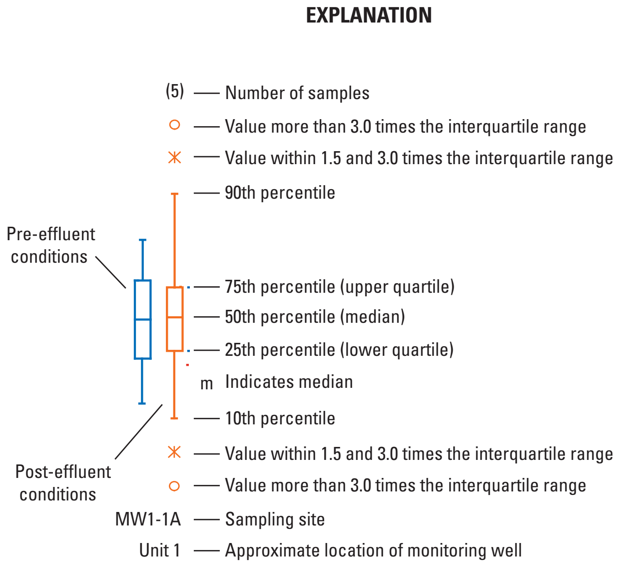


Figure 6. Boxplot example.

Ground-Water Flow

Water-level measurements were made twice each year from 2004 through 2007 (table 4, at the back of this report). Observing the resulting water-table maps in chronological order provides insight about the response of water levels in the alluvial aquifer to changing hydrologic conditions. Also, information about ground-water flow will aid in the understanding of the movement of chemical constituents related to the water quality in the alluvial aquifer.

Lateral Flow Interpreted from Water-Table Maps

Ground-water levels in McBaine Bottoms are affected by several variables. These include the stage of the Missouri River, leakage of surface water from the treatment wetland units and wetland pools on the Eagle Bluffs Conservation Area, rainfall and infiltration to the alluvial aquifer, ground-water withdrawal from the aquifer by the city of Columbia well field, and operations of the Eagle Bluffs Conservation Area. Treated wastewater of acceptable quality that could be discharged to the Missouri River is directed into a distribution channel and then into various pools to manage wetland habitats. The placement of water is largely dictated by the timing of bird migration and requirements of wetland plant growth (Tim James, Missouri Department of Conservation, written commun., 2008). The treated wastewater is supplemented with water from the Missouri River to meet the needs of the Eagle Bluffs Conservation Area. An estimated 7 to 9 Mgal/d of wastewater is delivered to the Eagle Bluffs Conservation Area when the University of Missouri is not in session and 13 to 15 Mgal/d when the university is in session. After waterfowl hunting season ends, pumpage of Missouri River water ceases and the water levels recede in some of the pools (Tim James, written commun., 2008).

The water-table maps display certain similarities. Generally, recharge to the aquifer was from precipitation that infiltrated through the root zone and percolated to the water table. Induced recharge from the Missouri River caused by pumpage from the city of Columbia well field occurred along much of the northern one-half of the study area. In the southern part of the study area, recharge occurred from infiltration of water through the bottom of the Eagle Bluffs Conservation Area wetland pools.

Ground-water flow is perpendicular to the water-table contours shown on the water-table maps (figs. 7–14, at the back of this report). Lateral ground-water flow was dominated by the presence of a ground-water high beneath the Eagle Bluffs Conservation Area and the presence of a cone of depression in the northern part of the study area centered around the city of Columbia well field [for example, February 2006 (fig. 11)]. Flow was radially away from the center of the high north toward the city of Columbia well field, west and south toward the Missouri River, and east toward Perche Creek. Flow toward the well field was from the south in the vicinity of the Eagle Bluffs Conservation Area, west from the Missouri River, from the northeast beneath treatment wetland unit 1, and from the east through the alluvial aquifer in the vicinity of Perche Creek. The ground-water high beneath the Eagle Bluffs Conservation Area has been a persistent feature since the treatment wetlands were constructed (Richards, 2002; Smith, 2003).

Although the ground-water high beneath the Eagle Bluffs Conservation Area generally was present throughout the study period, the configuration of the ground-water high changed depending on hydrologic conditions. Based on previous water-level measurements (Smith, 2003), the height of the ground-water high began to decrease in March of each year; in April the high became shallower and hydraulic gradients around the high became gentler. During the summer months, the ground-water high was the least pronounced. Generally, in the fall beginning in October, the ground-water high became more pronounced and the hydraulic gradients around the high became steeper (Smith, 2003). This coincides with the flooding of the pools on the Eagle Bluffs Conservation Area.

For water levels measured during 2004 through 2007, the ground-water high in March 2005 and February 2006 was pronounced and the hydraulic gradients around the high were steep. The ground-water high in February 2004 and 2007 was present, but not extremely pronounced and with corresponding shallow gradients. The ground-water high in August 2005, 2006, and 2007 was present, but not extremely pronounced, and with corresponding shallow gradients.

Water levels measured at the end of August 2004 (fig. 8) indicated that the ground-water high was not present beneath the Eagle Bluffs Conservation Area. In August 2004, water-table contours indicated inflow to the alluvial aquifer from the Missouri River [measurement of 567.4 ft at the River lower staff gage (table 4)]. During the time of the water-level measurements, the altitude of the river was approaching flood stage at Boonville. Flood stage is 21.0 ft (altitude of 586.4 ft) and the stage for the day of water level measurements was 18.7 ft (altitude of 584.1 ft) at Boonville (U.S. Geological Survey, 2008).

The cone of depression surrounding the city of Columbia public-supply well field was present for all water-level measurements; however, the gradient was shallow in March 2005 (fig. 9), when water levels were measured at the end of a sharp rise in the water level in the Missouri River over 4 weeks in January and February 2005 The cone of depression in August 2006 (fig. 12) had shifted eastward and was not centered around the city of Columbia public-supply well field because of dewatering for a transmission line (Dave Storbick, City of Columbia, oral commun., 2006). Localized cones of depression were apparent around the public-supply wells; the position of these localized cones was dependent on which public-supply well was being used.

Ground-water flow in the extreme northeastern part of the study area was to the southwest away from the city of Columbia treatment wetland unit 1. The water surface was higher beneath the treatment wetland, possibly caused by infiltration of surface water from the wetland unit into the underlying ground-water system.

For all the water-level maps, ground-water flow in the extreme northeastern part of the study area was to the southwest away from wetland treatment units 1 and 4. During 2004 through 2007, some variations appeared in the water table in this area, but the water table generally was similar for all water-level measurements. From 2000 through 2002, the water levels in monitoring well MW-140 were several feet higher than they were in monitoring well MW-141 (Smith, 2003), which is immediately to the northeast of monitoring well MW-140. Water levels measured from 2004 through 2007 followed this trend. The high water-level altitude in monitoring well MW-140 probably reflects perched water that was trapped by lenses of sticky, blue-gray clay encountered in the borehole during drilling. The low permeability of the clay impedes the downward movement of infiltrated precipitation that recharges the alluvial aquifer, causing a small mound of ground water to form (Smith, 2003).

Vertical Ground-Water Gradients

The well pairs included in the monitoring well network provided an opportunity to estimate vertical hydraulic-head differences in the alluvial aquifer. The wells in each well pair are within a few feet of one another and are completed in the alluvial aquifer, except for well MW13-67, which is completed in bedrock.

Four well pairs are around treatment wetland unit 1. These pairs are identified as MW1-1, MW1-2, MW1-3, and MW1-4 (fig. 2). Available data indicated the vertical hydraulic gradients for well pairs MW1-1, MW1-3, and MW1-4 were downward toward the base of the alluvial aquifer; the gradient for well pair MW1-2 was both downward and upward during the study period. Differences in the measured water levels for the MW1-2 well pair were 0.03 ft or less. Water levels in well MW1-1A (31 ft deep) ranged from 5.91 to 23.47 ft higher than the water levels in well MW1-1B (60 ft deep). Water levels in well MW1-4A (29.5 ft deep) ranged from 8.81 to 34.78 ft higher than the water levels in well MW1-4B (60 ft deep). The maximum difference in water levels in these two well pairs was measured in August 2006, when a utility company was dewatering part of the area for the construction of a transmission line. With the exception of these maximum values, the differences in water levels generally were 10 ft or less—differences similar to those discussed in Smith (2003). The overall large differences in the water levels for these two well pairs probably were because low permeability clay at these locations impedes the downward movement of water.

The direction of the vertical hydraulic gradient could not be determined conclusively for the well pairs adjacent to treatment wetland units 2 and 3 and two well pairs in the northern part of the Eagle Bluffs Conservation Area (well pairs MW4-1 and MW4-2). Measured water levels generally varied by less than 0.20 ft.

Three well pairs are located in the central part of the Eagle Bluffs Conservation Area. The vertical hydraulic gradient for well pairs USGS-2 and USGS-5 varied, but the difference in the measured water levels generally was less than 0.10 ft. The gradient for well pair USGS-3 was downward, and the differences in the measured water levels were less than 0.30 ft.

Wells USGS-8S and USGS-8D, both completed in the alluvial aquifer, are near well MW13-67, which was drilled by the city of Columbia in 1967 and was completed in bedrock to a depth of 105 ft. During the study period, the measured water levels were highest in well USGS-8S, lower in well USGS-8D, and lowest in well MW13-67, except for August 2006. These measurements indicated that the potential for ground-water movement was downward toward the base of the alluvial aquifer. In August 2006, the range between the three water-level measurements was 0.08 ft.

Water Quality

Ground- and surface-water samples were collected at sites in McBaine Bottoms from 1992 through 2007. Physical properties and concentrations of major chemical constituents, nutrients, iron, selected wastewater indicator compounds, and pharmaceutical compounds were determined to describe the water quality in ground and surface water. The following discussion will focus on the differences between the pre-effluent conditions considered to represent background conditions (August 1992 to August 1994) and the post-effluent conditions (after August 1994 through December 2007).

In this discussion on water quality and in related figures, the monitoring wells in McBaine Bottoms will be grouped and described according to location (fig. 2). Monitoring wells MW1-1A, MW1-1B, MW1-2A, MW1-2B, MW1-3A, MW1-3B, MW1-4A, and MW1-4B will be referred to as those wells adjacent to treatment wetland unit 1; monitoring wells MW2-1A and MW2-1B are wells adjacent to treatment wetland unit 2; monitoring wells MW3-1A and MW3-1B are wells adjacent to treatment wetland unit 3; and monitoring wells MW4-1A, MW4-1B, MW4-2A, MW4-2B, USGS-1, USGS-2S, USGS-2D, USGS-3S, USGS-3D, USGS-4, USGS-5S, USGS-5D, USGS-6, and USGS-7 are wells in the Eagle Bluffs Conservation Area; monitoring wells USGS-8S and USGS-8D are immediately north of the Eagle Bluffs Conservation Area; and monitoring wells USGS-9S and USGS-9D are in the northern part of McBaine Bottoms.

Physical Properties

Physical properties, including specific conductance, pH, and water temperature, contribute to the overall water quality of ground or surface water. The properties affect the rates of chemical and biological activity.

Specific conductance is a measure of the ability of the water to conduct an electric current. The specific conductance is related to the type and concentrations of dissolved ions in solution. Minimum, median, maximum, and mean values for sampling sites are listed in table 5 (at the back of this report).

Pre-effluent median specific conductance values ranged from 597 to 1,280 microsiemens per centimeter at 25 °C (µS/cm) in samples from monitoring wells adjacent to treatment wetland unit 1, were 710 and 797 µS/cm in samples from monitoring wells adjacent to treatment wetland unit 2, ranged from 722 to 1,420 µS/cm in samples from monitoring wells in the Eagle Bluffs Conservation Area, and were less than 850 µS/cm in samples from monitoring wells north of the Eagle Bluffs Conservation Area and northern McBaine Bottoms. Post-effluent values ranged from 610 to 1,290 µS/cm in samples from monitoring wells adjacent to treatment wetland unit 1, were 758 and 877 µS/cm in samples from monitoring wells adjacent to treatment wetland unit 2, 778 and 805 µS/cm near unit 3, and ranged from 748 to 1,260 µS/cm in samples from monitoring wells in the Eagle Bluffs Conservation Area throughout McBaine Bottoms.

Specific conductance values generally increased in post-effluent samples as opposed to the values in pre-effluent samples from monitoring wells adjacent to treatment wetland units (fig. 15). Specific conductance values increased in samples from several monitoring wells in the Eagle Bluffs Conservation Area, but no overall increase was apparent. Samples from several monitoring wells have a greater variability (indicated by longer boxes) in specific conductance values, but also an increase in magnitude.

Samples from the blew hole indicated an increase in specific conductance values, and samples from Perche Creek indicated an overall decrease. The blew hole is outside of the flood control levee along Perche Creek. Water from the blew hole most likely contains a large component of recharge from the local ground-water system because of water present all year, the small area that diverts precipitation to the blew hole, and the relative infrequency of flooding. The blew hole probably also has large evaporative losses that could concentrate solutes during the summer.

Major Chemical Constituents

Hem (1985) defines major chemical constituents as those substances that commonly occur in concentrations greater than 1.0 mg/L. The cations generally included in this category are calcium, magnesium, potassium, and sodium; the anions generally included are chloride and sulfate.

Calcium

Median calcium concentrations (table 5; fig. 16) in samples from monitoring wells adjacent to treatment wetland unit 1 ranged from 83 to 220 mg/L (pre-effluent conditions) and from 85 to 200 mg/L (post-effluent conditions); adjacent to treatment wetland unit 2 concentrations were 120 and about 130 mg/L (pre- and post-effluent conditions). In the Eagle

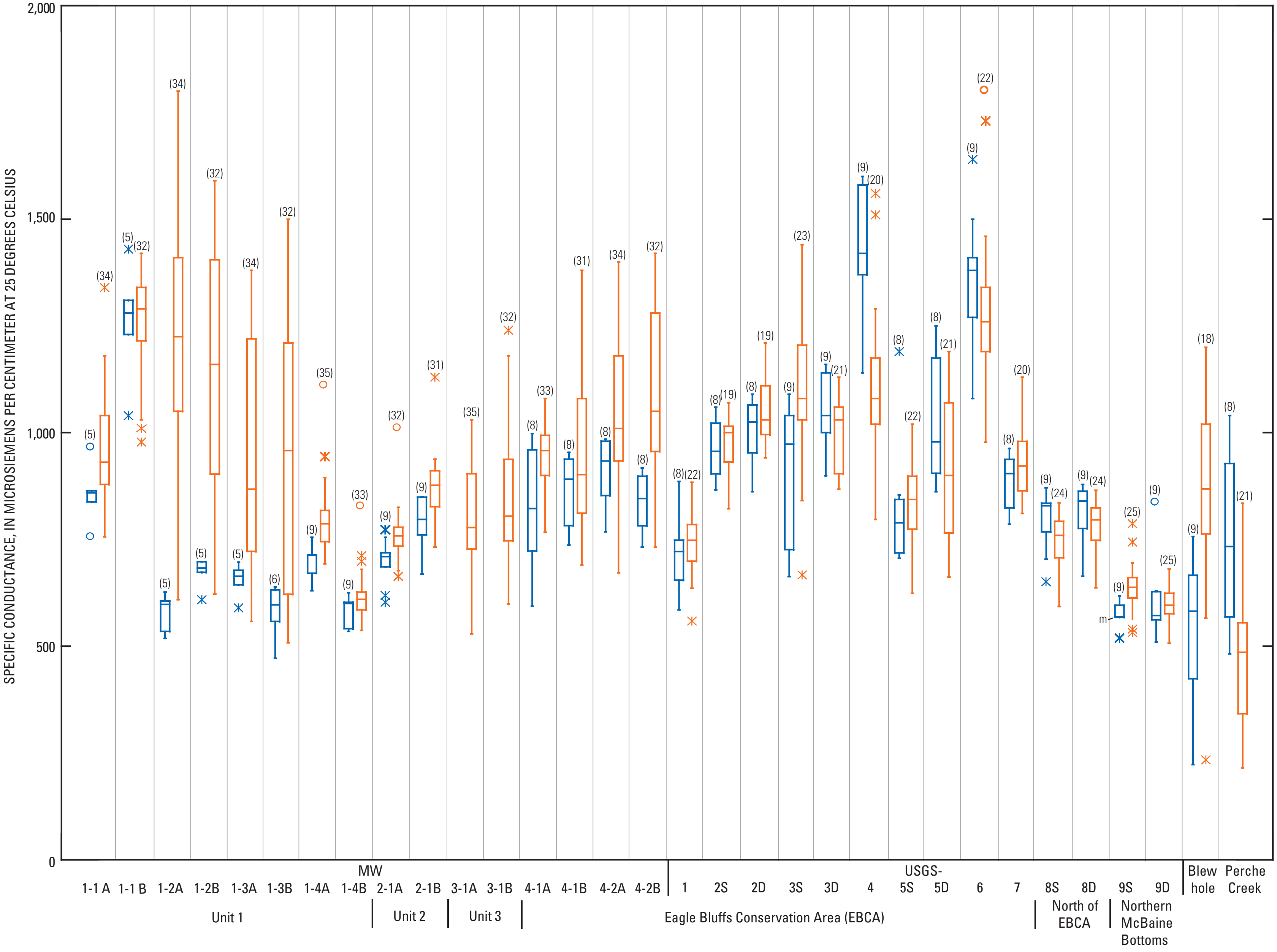


Figure 15. Distribution of specific conductance values in samples from McBaine Bottoms, 1992–2007.

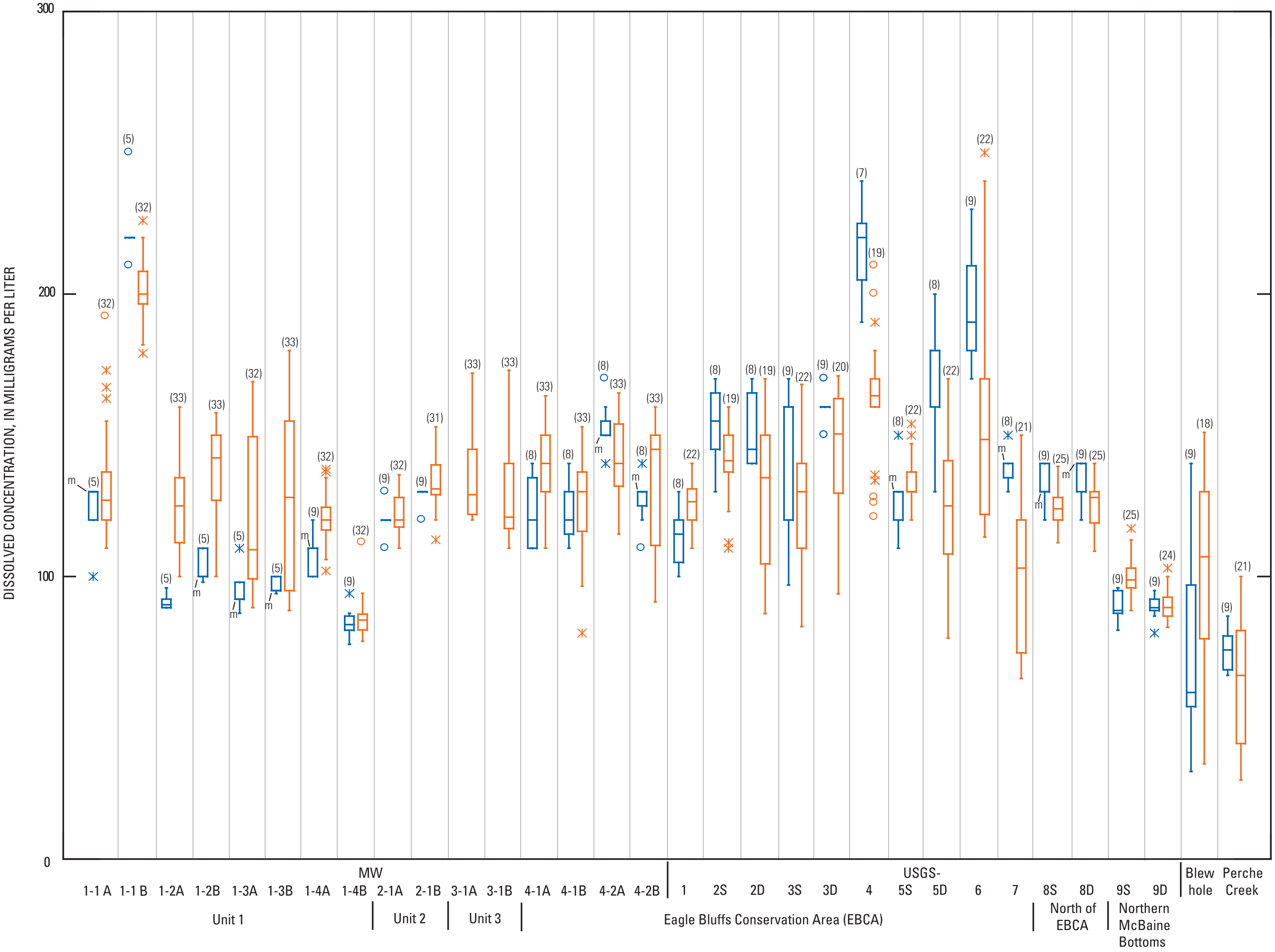


Figure 16. Distribution of calcium concentrations in samples from McBaine Bottoms, 1992–2007.

Bluffs Conservation Area, the median calcium concentrations were 115 to 220 mg/L (pre-effluent conditions) and 125 to 163 mg/L (post-effluent conditions); north of the Eagle Bluffs Conservation Area were 130 and 140 mg/L (pre-effluent conditions) and 124 and 128 mg/L (post-effluent conditions); and in northern McBaine Bottoms were 88 and 89 mg/L (pre-effluent conditions) and 89 and 99 mg/L (post-effluent conditions).

Magnesium

Median magnesium concentrations (table 5; fig. 17) in samples from monitoring wells adjacent to treatment wetland unit 1 ranged from 18 to 40 mg/L (pre-effluent conditions) and from 18 to 37 mg/L (post-effluent conditions); in samples from monitoring wells adjacent to treatment wetland unit 2 concentrations were 26 and 27 mg/L (pre-effluent conditions) and 26 and 30 mg/L (post-effluent conditions); in samples from monitoring wells adjacent to treatment wetland unit 3 concentrations were 22 and 26 mg/L (post-effluent conditions). In samples from monitoring wells on the Eagle Bluffs Conservation Area, the median magnesium concentration ranged from 19 to 56 mg/L (pre-effluent conditions) and from 21 to 41 mg/L (post-effluent conditions); in samples from monitoring wells north of the Eagle Bluffs Conservation Area the concentrations were 26 mg/L (pre-effluent conditions) and 24 and 26 mg/L (post-effluent conditions); and in samples from monitoring wells in northern McBaine Bottoms concentrations were 17 and 20 (pre-effluent conditions) and 19 and 22 mg/L (post-effluent conditions).

Potassium

Median concentrations (table 5; fig. 18) for potassium were less than 10 mg/L in samples from all monitoring wells throughout the study area. Potassium concentrations in post-effluent samples increased substantially in samples from monitoring wells MW1-2A, MW1-2B, and MW4-2B from pre-effluent concentrations. They decreased or remained about the same in the rest of the monitoring wells throughout the study area.

Sodium

Human activities can have a substantial effect on sodium concentrations in ground and surface water (Hem, 1985). Sodium and chloride (discussed in the next section of this report) are indicators of municipal and industrial wastes and urban runoff. Effluent from municipal wastewater treatment plants commonly contains increased concentrations of potassium, sodium, chloride, and sulfate, relative to calcium and magnesium (Schumacher, 2001). Although specific conductance values and calcium and magnesium concentrations increased in several monitoring wells throughout the study area, the increase in sodium concentrations in samples from the same monitoring wells was much larger.

Median sodium concentrations (table 5; fig. 19) in samples from monitoring wells adjacent to treatment wetland unit 1 ranged from 4.9 to 30 mg/L (pre-effluent conditions) and 5.6 to 62 mg/L (post-effluent conditions); in samples from monitoring wells adjacent to treatment wetland unit 2 concentrations were 4.2 and 7.5 mg/L (pre-effluent conditions) and 4.5 and 10 mg/L (post-effluent conditions). In samples from monitoring wells on the Eagle Bluffs Conservation Area the median sodium concentrations ranged from 5.4 to 34 mg/L (pre-effluent conditions) and from 6.4 to 56 mg/L (post-effluent conditions); in samples from monitoring wells north of the Eagle Bluffs Conservation Area concentrations were 6.1 and 6.8 mg/L (pre-effluent conditions) and 5.4 and 7.7 mg/L (post-effluent conditions); and in samples from monitoring wells in northern McBaine Bottoms concentrations were 7.4 mg/L (pre-effluent conditions) and 7.2 and 8.5 mg/L (post-effluent conditions).

Chloride

Median chloride concentrations (table 5; fig. 20) in samples from monitoring wells adjacent to treatment wetland unit 1 ranged from 2.9 to 15 mg/L (pre-effluent conditions) and from 2.6 to 200 mg/L (post-effluent conditions); in samples from monitoring wells adjacent to treatment wetland unit 2 concentrations were 4.6 and 6.0 mg/L (pre-effluent conditions) and 5.6 and 6.2 mg/L (post-effluent conditions). In samples from monitoring wells on the Eagle Bluffs Conservation Area the median chloride concentration ranged from 1.8 to 14 mg/L (pre-effluent conditions) and from 5.2 to 131 mg/L (post-effluent conditions); in samples from monitoring wells north of the Eagle Bluffs Conservation Area concentrations were 5.5 and 10 mg/L (pre-effluent conditions) and 4.8 and 6.5 mg/L (post-effluent conditions); in samples from monitoring wells in northern McBaine Bottoms concentrations were 2.1 and 8.8 mg/L (pre-effluent conditions) and were 3.1 and 9.3 mg/L (post-effluent conditions).

Missouri has a secondary MCL for chloride in drinking water of 250 mg/L. The maximum chloride concentration detected in samples collected from monitoring wells throughout McBaine Bottoms was 259 mg/L. Drinking-water standards, although not strictly applicable to the water from the alluvial aquifer in McBaine Bottoms, offer pertinent information on the quality of the ground water.

Sulfate

Median sulfate concentrations (table 5; fig. 21) in monitoring wells adjacent to treatment wetland unit 1 ranged from 0.2 to 350 mg/L (pre-effluent conditions) and from 0.2 to 279 mg/L (post-effluent conditions); in samples from monitoring wells adjacent to treatment wetland unit 2 concentrations were 16 and 24 mg/L (pre-effluent conditions) and 0.7 and 12 mg/L (post-effluent conditions). In samples from monitoring wells on the Eagle Bluffs Conservation Area, the median sulfate

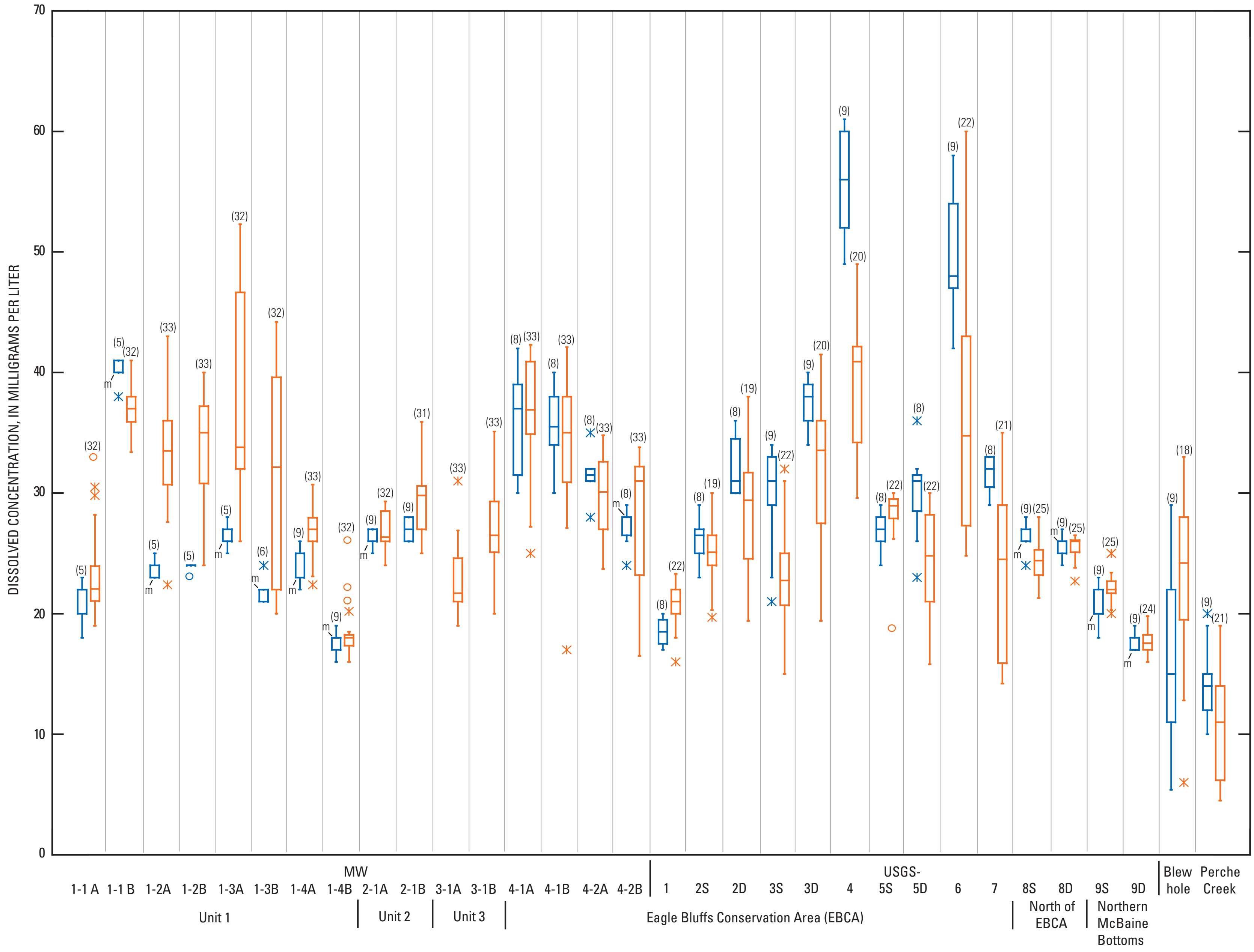


Figure 17. Distribution of magnesium concentrations in samples from McBaine Bottoms, 1992–2007.

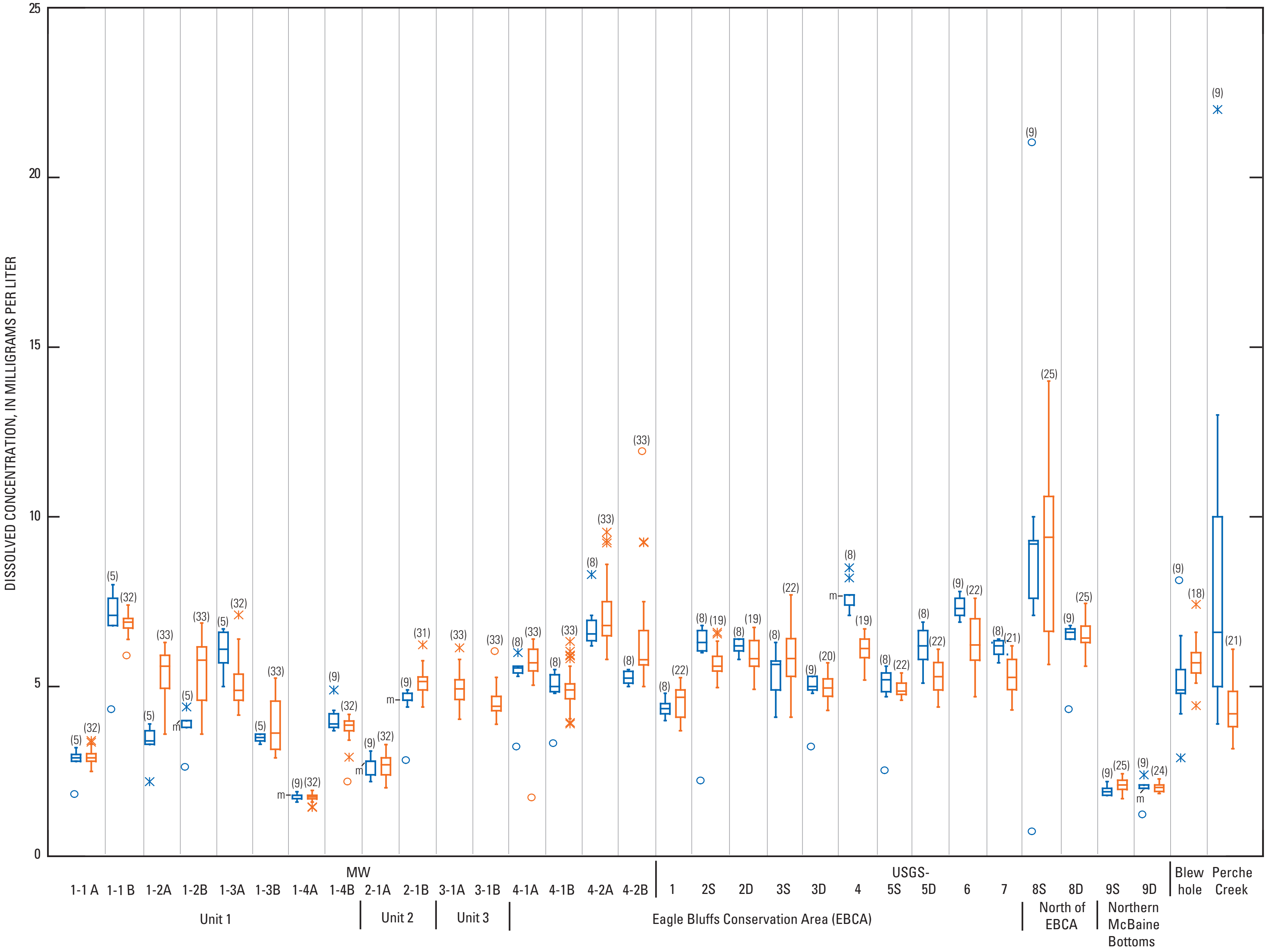


Figure 18. Distribution of potassium concentrations in samples from McBaine Bottoms, 1992–2007.

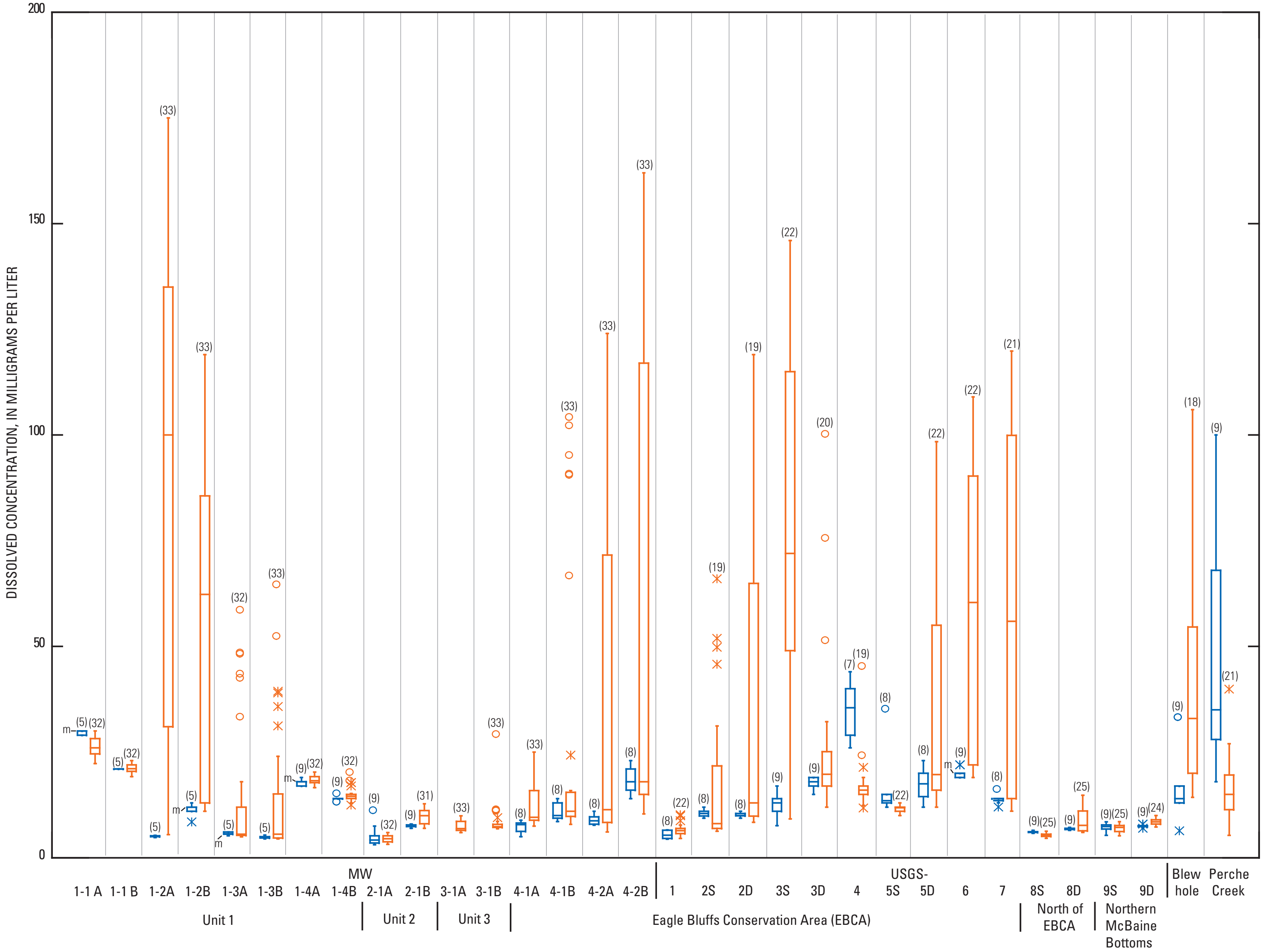


Figure 19. Distribution of sodium concentrations in samples from McBaine Bottoms, 1992–2007.

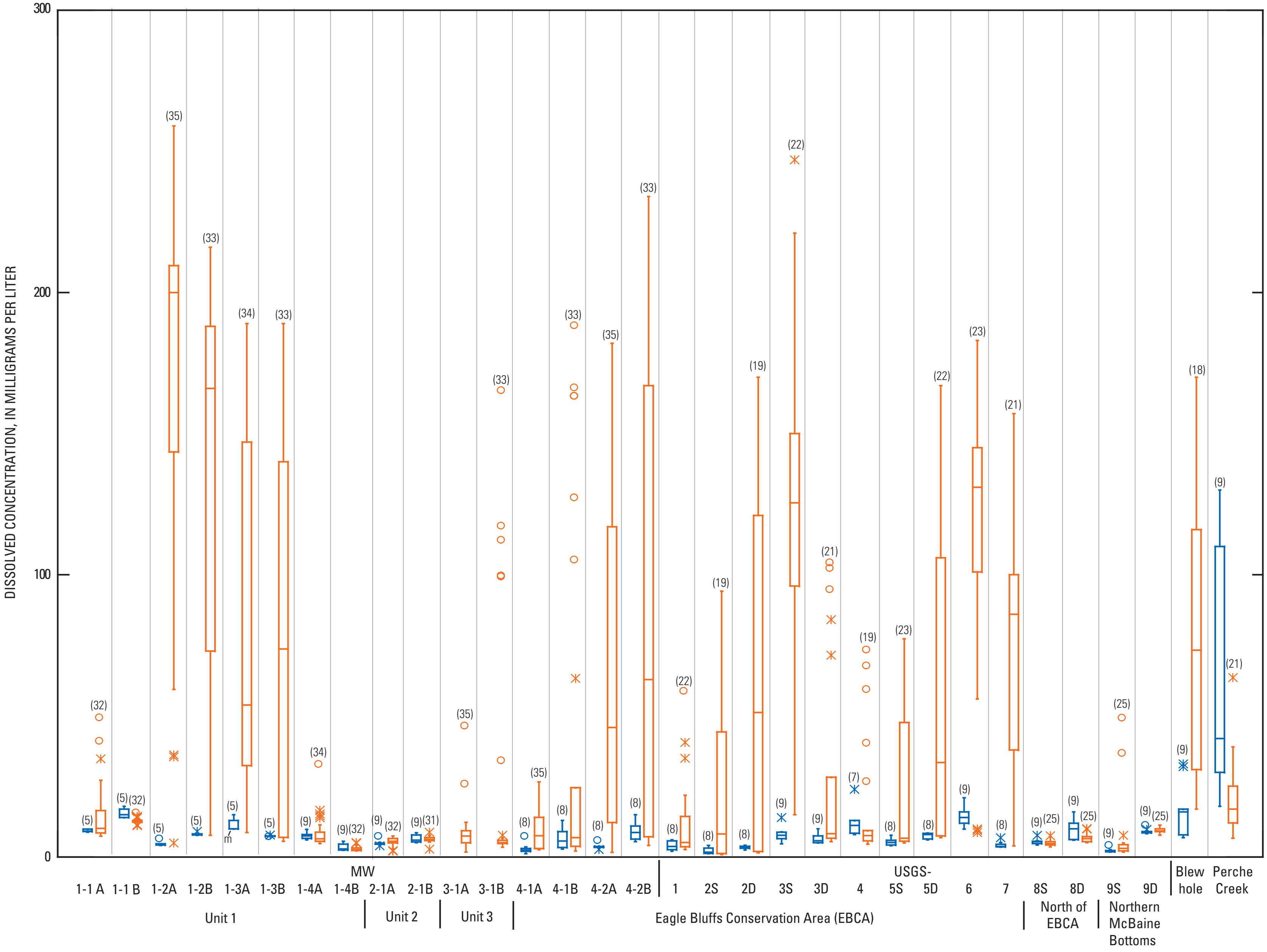


Figure 20. Distribution of chloride concentrations in samples from McBaine Bottoms, 1992–2007.

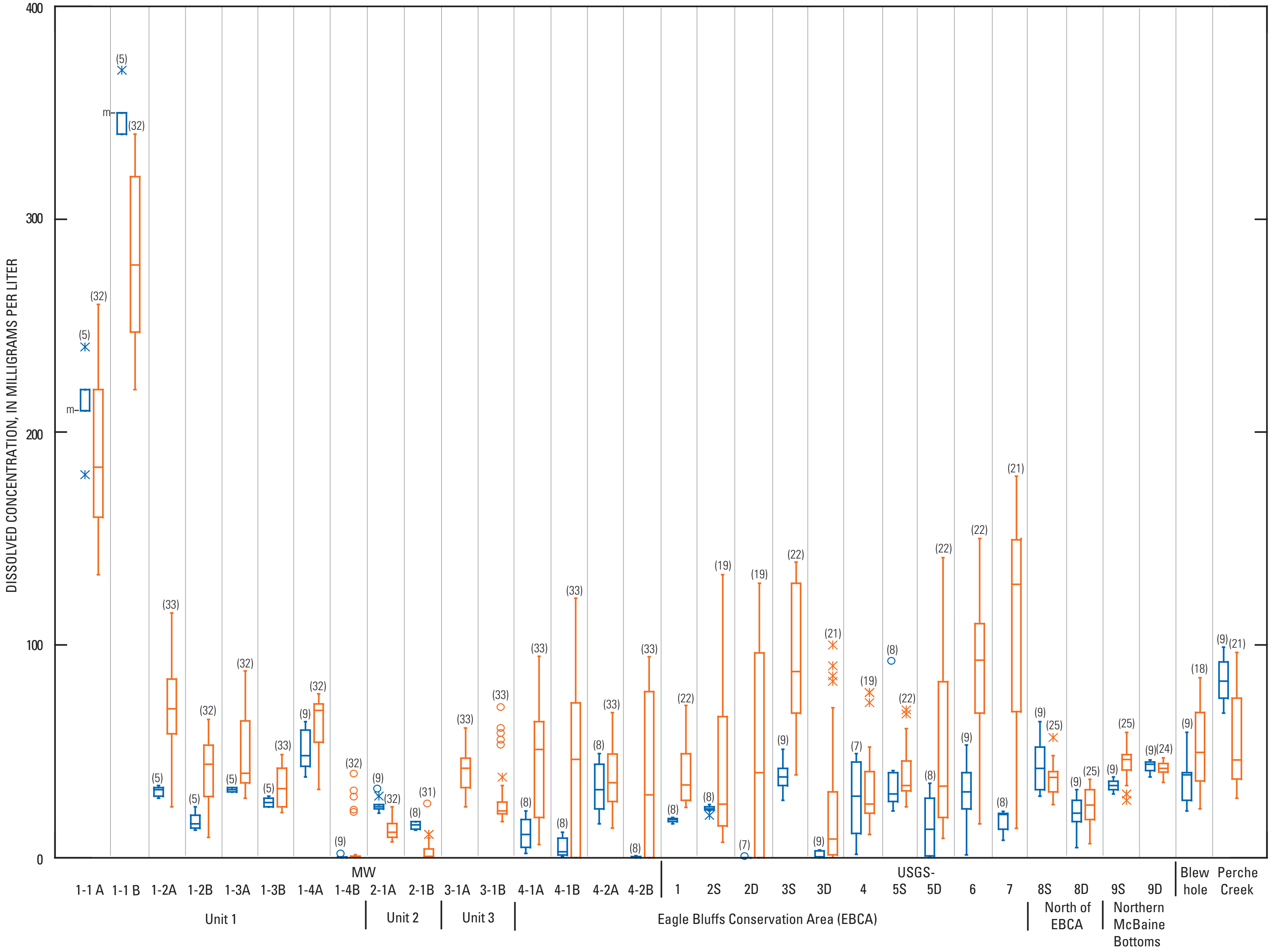


Figure 21. Distribution of sulfate concentrations in samples from McBaine Bottoms, 1992–2007.

concentrations ranged from 0.1 to 40 mg/L (pre-effluent conditions) and from 8.8 to 129 mg/L (post-effluent conditions); in samples from monitoring wells north of the Eagle Bluffs Conservation Area concentrations were 21 and 42 mg/L (pre-effluent conditions) and 25 and 38 mg/L (post-effluent conditions); and in samples from monitoring wells in northern McBaine Bottoms concentrations were 34 and 44 (pre-effluent conditions) and 42 and 46 mg/L (post-effluent conditions).

The sulfate concentrations exceeded the secondary MCL in drinking water of 250 mg/L (table 1) in samples from monitoring wells MW1-1A and MW1-1B during pre- and post-effluent conditions (fig. 21). The measured concentrations from these wells, therefore, were not the result of interaction with treated effluent (Richards, 2002).

Nutrients

Nutrients are constituents that are essential to plant growth. The fate of nutrients is of particular interest in a wastewater-treatment wetland. Aquatic vegetation, such as algae, depends on nitrogen and phosphorus compounds for a nutrient supply, but growth also can be affected by the availability of other required elements. Although nitrogen and phosphorus both are essential for algal growth, phosphorus availability is considered to be the limiting factor in many natural waters (Hem, 1985). Phosphorus-containing rocks are relatively insoluble and the chemistry of the element favors its precipitation in water, thereby limiting the quantity of phosphorus available for plant growth. Nitrogen most commonly occurs in water as nitrite (NO_2^-) and nitrate (NO_3^-) anions or the ammonium (NH_4^+) cation. Generally, the nitrogen species remained largely unchanged between pre- and post-effluent sampling. The Missouri MCL for drinking water was not exceeded in any samples collected in McBaine Bottoms from 1992 through 2007. The distribution of ammonia as nitrogen from sampling sites in McBaine Bottoms is shown in figure 22.

For the most part, phosphorus species concentrations were similar for samples from pre- and post-effluent conditions (fig. 23). Samples from several monitoring wells increased in total phosphorus concentration between pre- and post-effluent samples. The total phosphorus concentration in samples from Perche Creek substantially decreased.

Wastewater Indicator and Pharmaceutical Compounds

Recent studies have shown that a considerable range of human-caused wastewater indicator and pharmaceutical compounds remain after wastewater treatment and are discharged to receiving waters across the United States (Barber and others, 2000; Kolpin and others, 2002; Glassmeyer and others, 2005). Glassmeyer and others (2005) analyzed treated wastewater discharged to a river from 10 wastewater treatment plants for 110 wastewater indicator and pharmaceutical compounds. Between 28 and 50 of these compounds were detected. Commonly detected compounds included antimicrobial disinfectants (triclosan), musk fragrances (tonalide), antibiotics (sulfamethoxazole), antihistamines (diphenhydramine), and antiepileptic drugs (carbamazepine) (Glassmeyer and others, 2005).

Concentrations of wastewater indicator compounds and pesticides were determined in samples from selected monitoring wells in McBaine Bottoms from 1999 through 2003. Most concentrations were estimated or their presence was verified, but not quantified. The exceptions were atrazine concentrations of 0.007 microgram per liter (μg/L; MCL of 3 μg/L) in the water sample from monitoring well MW4-1A and 0.008 μg/L in the sample from monitoring well MW1-3B and 10 phenol concentrations that ranged from 0.5 to 1.8 μg/L. The phenol concentrations were detected in samples from monitoring wells MW1-1A, MW1-3A, MW1-4A, MW3-1A, MW4-1A, MW4-2A, USGS-3S and USGS 9D (Smith and Richards, 2006). Atrazine, a pre- and post-emergence herbicide, is used to control broad-leafed weeds and is used in corn cultivation. Phenol is present in consumer products, including mouthwashes, gargles, and throat lozenges. It also is used to make aspirin, herbicides, and synthetic resins.

Samples for wastewater indicator compounds and pesticides were collected from surface-water sites and the outflow from the city wetland treatment units from 1999 through 2003. More than 35 wastewater indicator compounds and pesticides were detected in samples from the city outflow. Most concentrations of the compounds were estimated or their presence was verified, but not quantified. Atrazine concentrations in samples from the blew hole, Perche Creek, and the city outflow ranged from 0.013 to 0.192 μg/L (Smith and Richards, 2006).

In August and December 2007, samples were collected for analyses of wastewater indicator and pharmaceutical compounds from selected wells throughout McBaine Bottoms (tables 6, 7). Three wastewater indicator compounds were detected in samples from five monitoring wells—MW1-3B, MW1-4B, MW4-2B, MW4-2C, and MW-133; two compounds were detected in the sample from monitoring well MW-139 and one compound was detected in the sample from monitoring wells MW1-2B and MW-116. Most of the wells were more than 30 ft deep. In the sample from the city outflow, 29 wastewater indicator compounds were detected (fig. 24); the presence of 10 of the compounds was verified, but not quantified. The concentration of several more compounds was estimated.

Several wastewater indicator compounds were detected in samples from the monitoring wells throughout McBaine Bottoms during 2007. The most widely detected compound was DEET (N,N-diethyl-meta-toluamide), an insecticide and insect repellent. This compound was present in samples from eight monitoring wells. The presence of this compound can be attributed to widespread use, continual usage throughout the year, and the persistence of the compound in water (Kolpin and others, 2002). Phenol was detected in samples from four

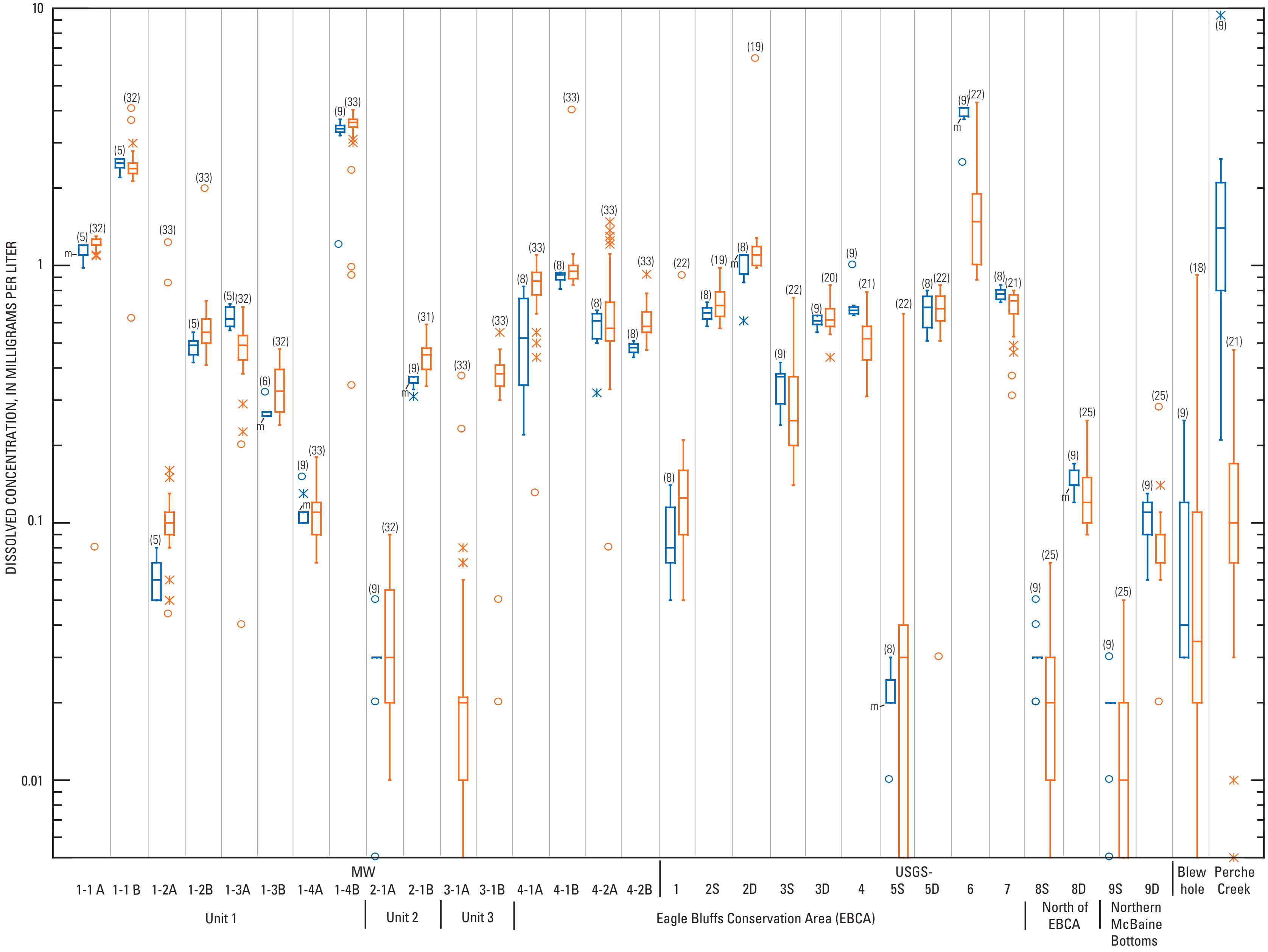


Figure 22. Distribution of ammonia as nitrogen concentrations in samples from McBaine Bottoms, 1992–2007.

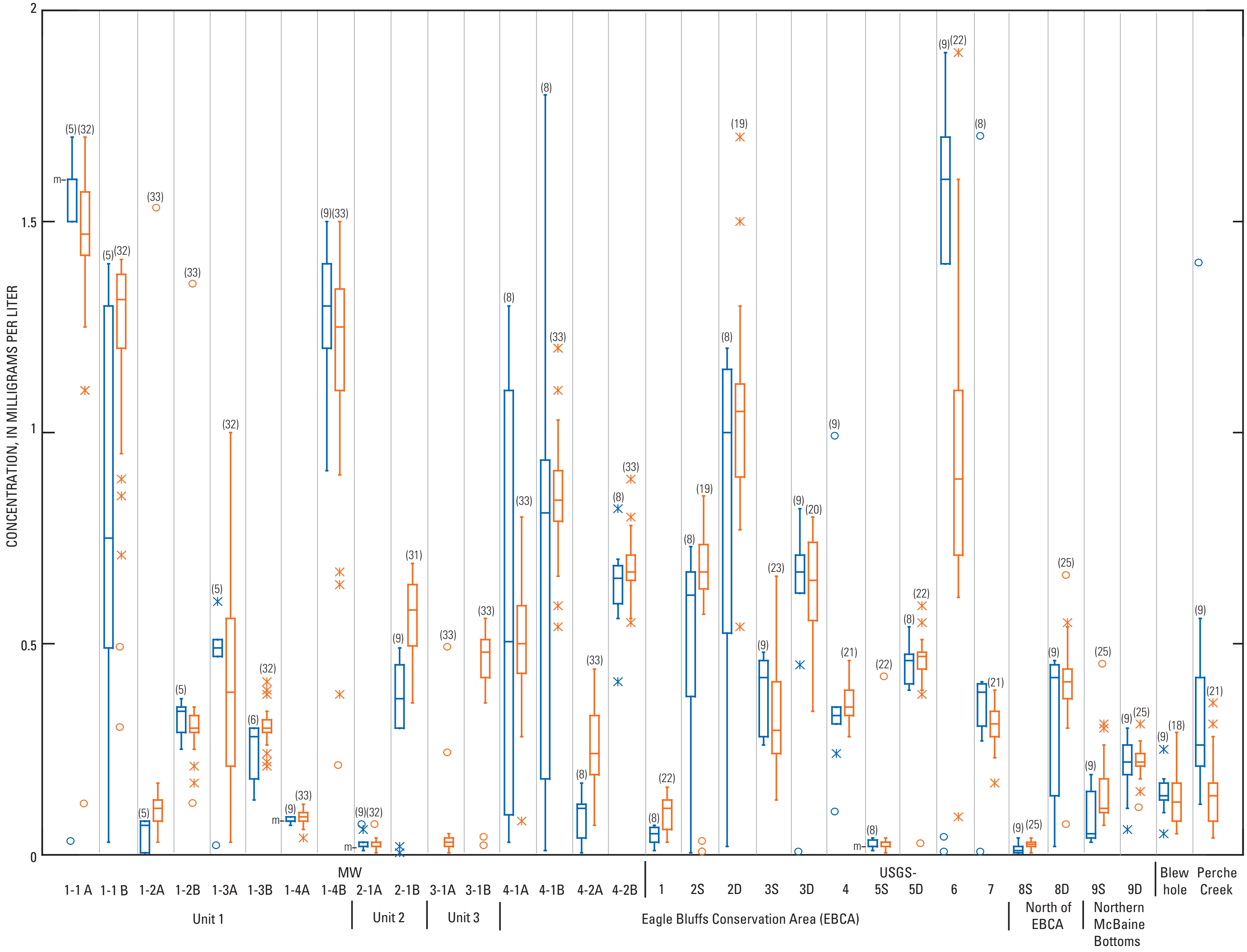


Figure 23. Distribution of total phosphorus concentrations in samples from McBaine Bottoms, 1992–2007.

Table 6. Wastewater indicator compounds analyzed, minimum reporting limit, and concentration in samples from the city outflow and monitoring wells, McBaine Bottoms, 2007.

[µg/L, micrograms per liter; concentrations are in micrograms per liter; E, estimated; --, not detected; M, presence verified, but not quantified; AHTN, acetyl hexamethyl tetrahydronaphthalene; BDE, 2,2',4,4'-tetrabromodiphenyl ether; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethylcyclopentabenzopyran]

Constituent	Minimum reporting limit (µg/L)	Detected in city outflow sample (concentration)	Detected in monitoring well samples (well, concentration)
1,4-Dichlorobenzene	0.5	E0.1	--
1-Methylnaphthalene	.2	--	--
2,6-Dimethylnaphthalene	.2	--	--
2-Methylnaphthalene	.2	--	--
3-beta-Coprostanol	.8	M	--
3-Methyl-1H-indole	.2	--	--
3-tert-Butyl-4-hydroxyanisole (BHA)	.2	--	--
3,4-Dichlorophenyl isocyanate	2	E.08	--
4-Cumylphenol	.2	--	--
4-n-Octylphenol	.2	--	--
4-Nonylphenol	2	--	--
4-tert-Octylphenol	.2	2	--
5-Methyl-1H-benzotriazole	2	E1	--
9,10-Anthraquinone	.2	--	--
Acetophenone	.2	--	--
AHTN	.2	.4	--
Anthracene	.2	--	--
Atrazine	.2	--	--
BDE congener 47	.2	--	--
Benzo[a]pyrene	.2	--	--
Benzophenone	.2	.4	--
beta-Sitosterol	.8	M	--
beta-Stigmastanol	.8	--	--
Bis(2-ethylhexyl) phthalate	2	M	MW1-3B, M
Bisphenol A	.4	M	MW4-2B, M
Bromacil	.2	--	--
Bromoform	.2	--	--
Caffeine	.2	.7	--
Camphor	.2	E.1	--
Carbaryl	.2	--	--
Carbazole	.2	--	--
Chlorpyrifos	.2	--	--
Cholesterol	.8	E1	--
Cotinine	.8	--	--
DEET	.2	.5	MW1-2B, M MW1-3B, M MW1-4B, M MW4-2B, E.2 MW-116, M MW-133, M MW-139, M MW4-2C, E.058

Constituent	Minimum reporting limit (µg/L)	Detected in city outflow sample (concentration)	Detected in monitoring well samples (well, concentration)
Diazinon	0.2	--	--
Dichlorvos	.2	--	--
Diethoxynonylphenol	3	--	--
Diethoxyoctylphenol	.32	M	--
Diethyl phthalate	.2	--	MW-133, E.2 MW4-2C, E.196
d-Limonene	.2	--	--
Flouranthene	.2	--	--
HHCB	.2	0.43	--
Indole	.2	--	MW1-4B, M
Isoborneol	.2	--	--
Isophorone	.2	E.1	--
Isopropylbenzene	.2	--	--
Isoquinoline	.2	--	--
Menthol	.2	--	--
Metalaxyl	.2	--	--
Methyl salicylate	.2	--	--
Metolachlor	.2	--	--
Monoethoxynonylphenol	2	E.64	--
Monoethoxyoctylphenol	1	M	--
Naphthalene	.2	--	--
p-Cresol	.2	--	--
para-nonylphenol	1.6	E4	--
Pentachlorophenol	3	--	--
Phenanthrene	.2	--	--
Phenol	.2	.5	MW1-3B, E.01 MW4-2B, E.02 MW4-2C, .211 MW1-4B, .2
Prometon	.2	--	
Pyrene	.2	--	--
Tetrachloroethene	.4	M	--
Tribromomethane	.2	--	--
Tributyl phosphate	.2	M	MW-133, M
		--	MW-139, M
Triclosan	.2	M	--
Triethyl citrate	.2	.3	--
Triphenyl phosphate	.2	M	--
Tris(2-butoxyethyl) phosphate	.2	E1.9	--
Tris(2-chloroethyl) phosphate	.2	.4	--
Tris(dichloroisopropyl) phosphate	.2	.5	--

Table 7. Pharmaceutical compounds analyzed, minimum reporting limit, and concentration in samples from the city outflow and monitoring wells, McBaine Bottoms, 2007.

[All concentrations are in microgram per liter; E, estimated; --, not detected]

Constituent	Minimum reporting limit	Detected in city outflow sample (concentration)	Detected in monitoring well samples (well, concentration)
1,7-Dimethylxanthine	0.024	0.118	MW-139, E0.0007
Acetaminophen	.015	--	MW-116, E.006 MW-133, E.005 MW-139, E.0009
Caffeine	.018	.143	MW4-2B, E.007
Carbamazepine	.022	E.025	--
Codeine	.028	--	--
Cotinine	.022	--	--
Dehydronifedipine	.023	--	MW-116, E.0005
Diphenhydramine	.018	--	--
Diltiazem	.016	--	--
Fluoxetine	.025	--	--
Ranitidine	.014	--	--
Salbutamol (albuterol)	.024	.105	--
Sulfamethoxazole	.025	--	--
Thiabendazole	.020	--	--
Trimethoprim	.019	--	--
Warfarin	.021	.036	MW-116, E.003

monitoring wells. Bis(2-ethylhexyl) phthalate and bisphenol A were detected in samples from one monitoring well; diethyl phthalate and tributyl phosphate were each detected in samples from two monitoring wells. Indole (fragrance) also was detected in samples from one monitoring well. Diethyl phthalate (used in plastics, cosmetics, insecticides and aspirin) was not detected in the sample from the city outflow, whereas all other compounds detected in samples from the monitoring wells were detected in the sample from the city outflow.

Five pharmaceutical compounds were detected in samples from monitoring wells (table 7). These compounds were 1,7-dimethylxanthine (caffeine metabolite), acetaminophen (pain and fever reducer), caffeine, dehydronifedipine (allergy symptoms), and warfarin (anticoagulant). Concentrations of all compounds were estimated. Three compounds were detected in the sample from monitoring well MW-116, two compounds from monitoring well MW-139, and one compound from monitoring wells MW-133 and MW4-2B. Five pharmaceutical compounds were detected in the city outflow sample [1,7-dimethylxanthine (0.118 µg/L), caffeine (0.143 µg/L), carbamazepine (E0.025 µg/L; treatment of bipolar disorder and epileptic seizures), salbutamol (0.105 µg/L; asthma control), and warfarin (0.036 µg/L)].

Ground-Water Quality Trends

The chloride concentration in water samples was used to assess the possible effects of the use of treated effluent in the Eagle Bluffs Conservation Area on the water quality of the surrounding area. Chloride was selected because of its chemical behavior. “The chemical behavior of chloride in natural water is tame and subdued compared with the other major ions. Chloride ions do not significantly enter into oxidation or reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and play few vital biochemical roles…Chloride is present in all natural water, but mostly the concentrations are low” (Hem, 1985). Chloride was one of the constituents that initially showed the most change when samples were collected after the beginning of effluent application in the Eagle Bluffs Conservation Area (Richards, 1999, 2002).

The chloride concentration of ground water in the alluvial aquifer reflects several sources, including precipitation, water from the Missouri River, water in the aquifer, and the treated effluent. The chloride concentration in rainwater in two sam-

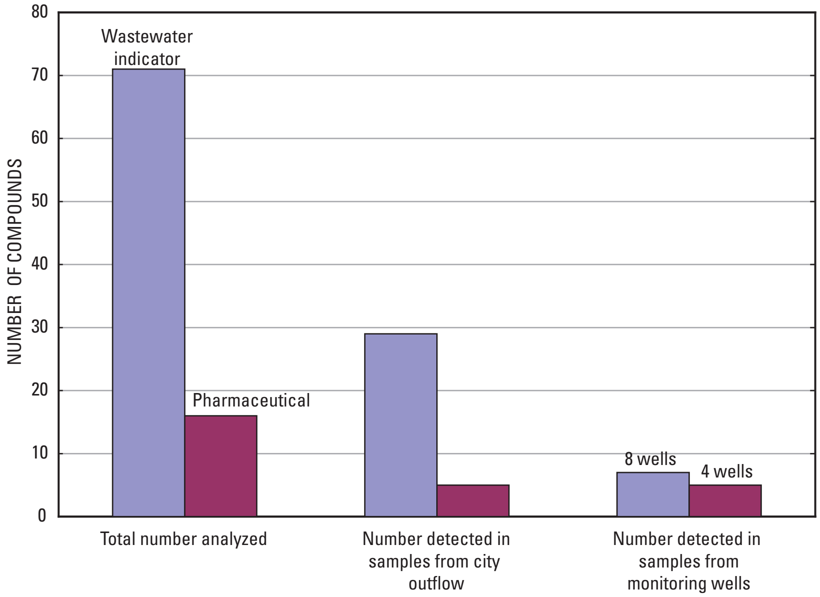


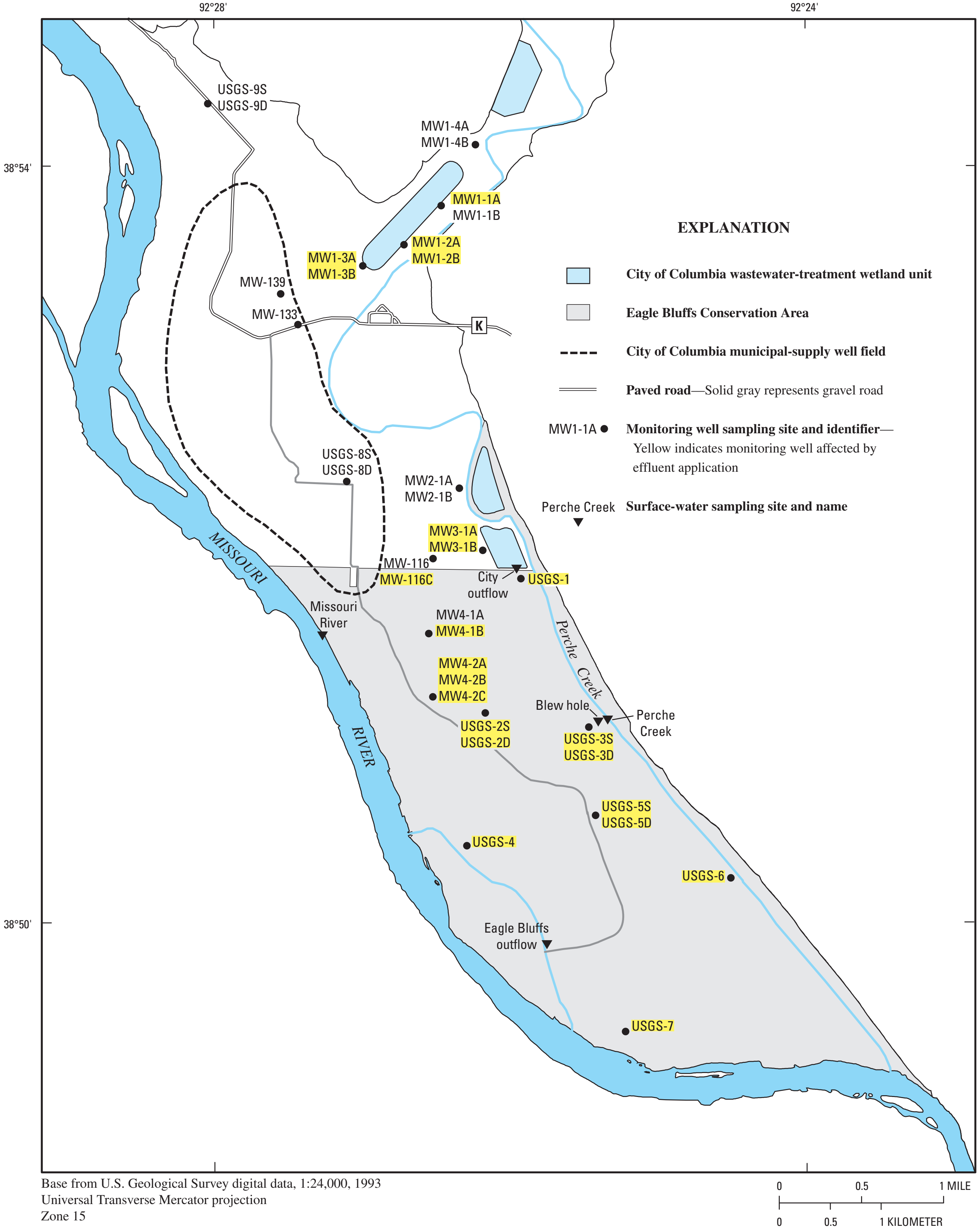
Figure 24. Wastewater indicator and pharmaceutical compounds detected in samples from McBaine Bottoms, 2007.

ples from Missouri was less than 1.1 mg/L (Root and others, 2004). The median chloride concentration in samples collected from August 1993 through August 2007 from the Missouri River at Hermann (the streamflow-gaging station closest to the study area where long-term water samples have been collected) was 19 mg/L (data from the National Water Information System at *http://waterdata.usgs.gov*), and the largest chloride concentration measured during that time was 38 mg/L. From August 1993 through August 2007, 185 chloride concentrations were determined from samples collected in the study area. The largest median chloride concentration in pre-effluent samples from monitoring wells throughout McBaine Bottoms collected from August 1992 through October 1994 was 15 mg/L (table 5), and the largest chloride concentration detected in a single sample from a monitoring well was 21 mg/L. The median chloride concentration in the samples from the city outflow was 240 mg/L from 1996 through 2007; therefore, the maximum background concentration of chloride in the alluvial aquifer was less than 40 mg/L before effluent application. This value was chosen as the baseline concentration to determine if the quality of water at a sampling site has changed since the operation of the treatment wetlands began. Based on the aforementioned criteria, samples from the following monitoring wells have chloride concentrations larger than 40 mg/L: MW1-1A, MW1-2A, MW1-2B, MW1-3A, and MW1-3B (adjacent to treatment wetland unit 1); MW3-1A and MW3-1B (adjacent to treatment wetland unit 3); MW4-1B, MW4-2A, MW4-2B, USGS-1, USGS-2S, USGS-2D, USGS-3S, USGS-3D, USGS-4, USGS-5S, USGS-5D, USGS-6, and USGS-7 on the Eagle Bluffs Conservation Area; and USGS-9S in northern McBaine Bottoms. Samples from monitoring wells MW-116C and MW4-2C also are included in this category because the chloride concentration in the single water sample collected from both wells was larger than 40 mg/L (213 and 205 mg/L, table 3); however, several wells in this category have not been sampled since 2003 (monitoring wells USGS-1, USGS-2S, USGS-2D, USGS-3S, USGS-3D, USGS-4, USGS-5S, USGS-5D, USGS-6, USGS-7, and USGS-9S).

Samples from monitoring well USGS-9S (fig. 2) had chloride concentrations larger than 40 mg/L. Although the chloride concentrations in samples from this well indicated that the quality of the water has changed in this well, this well has not been affected by effluent. This well is located in northern McBaine Bottoms, near the Missouri River, and not in the ground-water flow path from treatment wetland unit 1. The chloride concentrations in samples from this well were less than 10 mg/L until the concentration increased substantially in samples collected during 2002. The chloride concentration of 49 mg/L was detected in the sample collected in March 6, 2002. The concentration probably was affected by the usage of road salt on the paved road a few feet from the monitoring well because there was a maximum depth of about 5 in. of ice or snow on March 3, 2002 (National Oceanic and Atmospheric Administration, 2000–07). The chloride concentration of 49 mg/L was the only concentration to exceed 40 mg/L. The concentration detected in the sample collected in August 2002 was 36 mg/L, which is similar to several chloride concentrations of 35 mg/L or larger in samples from the Missouri River at Hermann from August 1993 through August 2007.

The remaining 22 monitoring wells throughout McBaine Bottoms have been affected by effluent (fig. 25). Monitoring wells MW1-1A, MW1-2A, MW1-2B, MW1-3A, and MW1-3B are adjacent to treatment wetland unit 1. The source for the large chloride concentrations in these wells possibly is leakage from unit 1. The rest of the wells that have been affected by effluent are on the Eagle Bluffs Conservation Area or immediately north of the area. These wells are near the apex of the ground-water high or are along flow paths of ground water from the high. Adjacent to the ground-water high, samples from wells that are shallow (about 30 ft), of intermediate depth (about 60 ft), and completed in or near bedrock have chloride concentrations larger than 40 mg/L. Effluent mixed with ground water and Missouri River water in the Eagle Bluffs Conservation Area has infiltrated into the shallow aquifer and is present in lower depths within the aquifer. All monitoring wells located on the Eagle Bluffs Conservation Area have been affected by effluent. North of the ground-water high and the Eagle Bluffs Conservation area, samples from two of the shallow wells have not been affected by effluent (monitoring wells MW4-1A and MW-116).

Many of the water-quality changes between pre- and post-effluent conditions were most pronounced in the major chemical constituent concentrations (fig. 26). Calcium and



Base from U.S. Geological Survey digital data, 1:24,000, 1993
Universal Transverse Mercator projection
Zone 15

Figure 25. Location of monitoring wells that have been affected by effluent application.

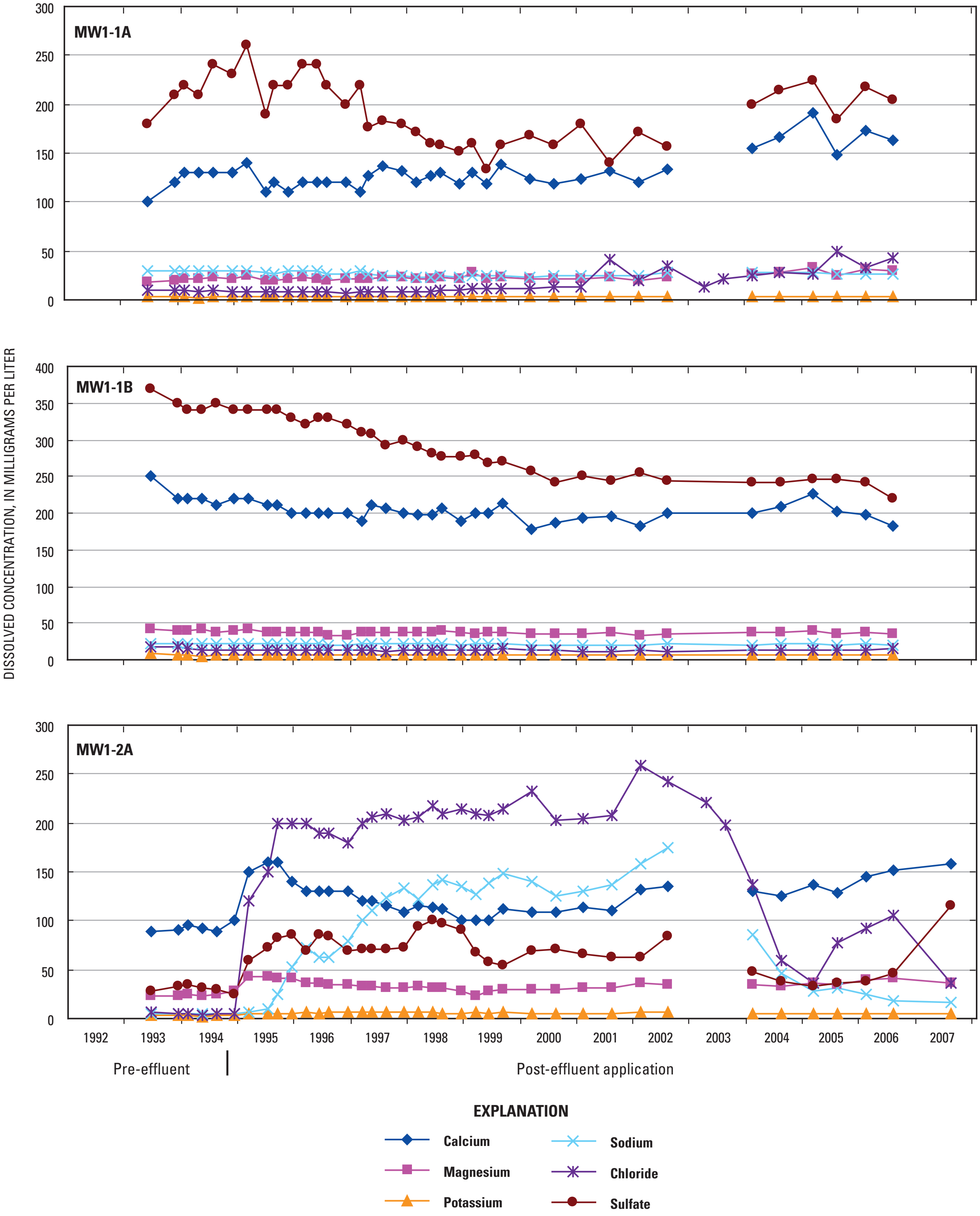


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.

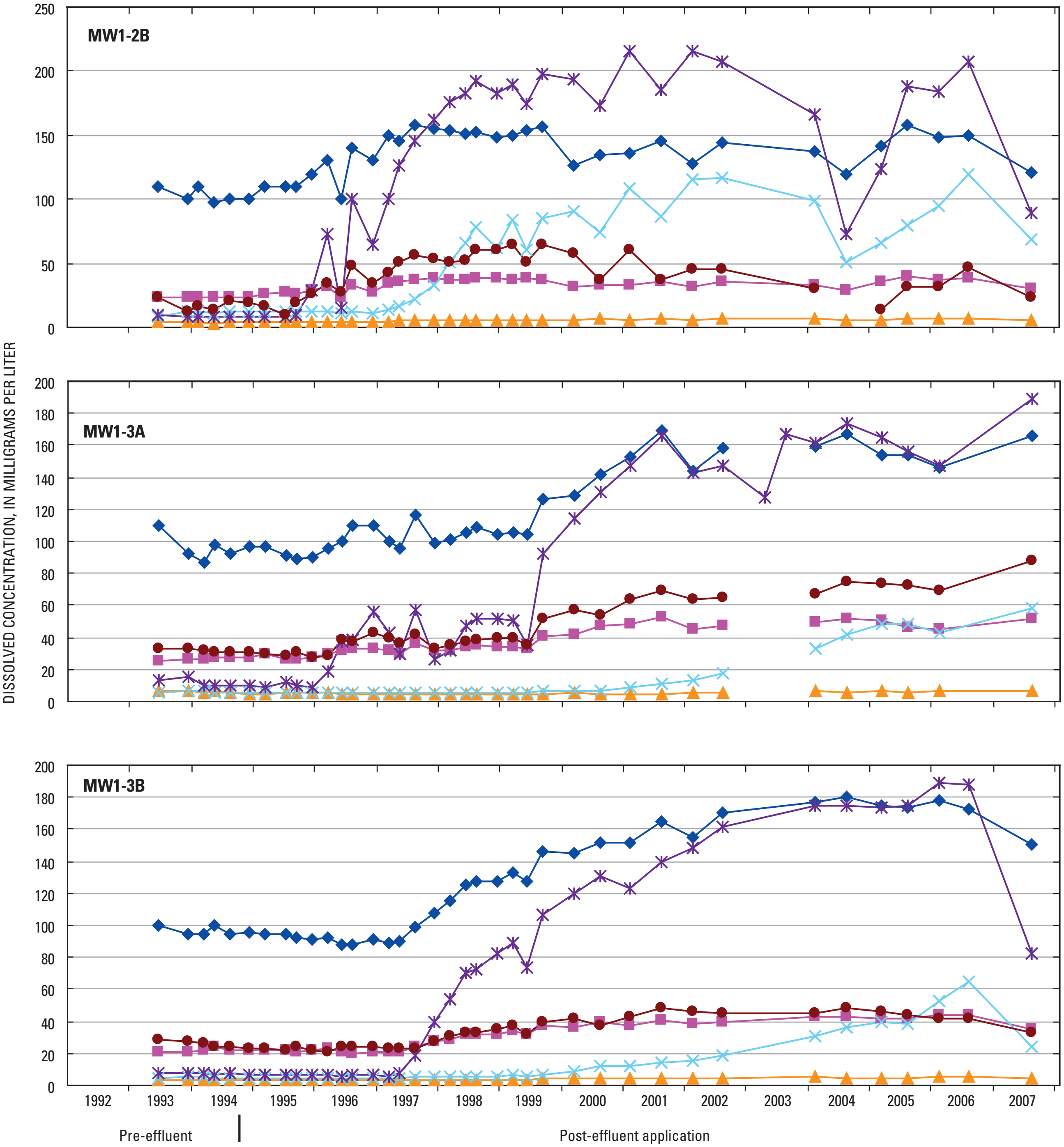


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

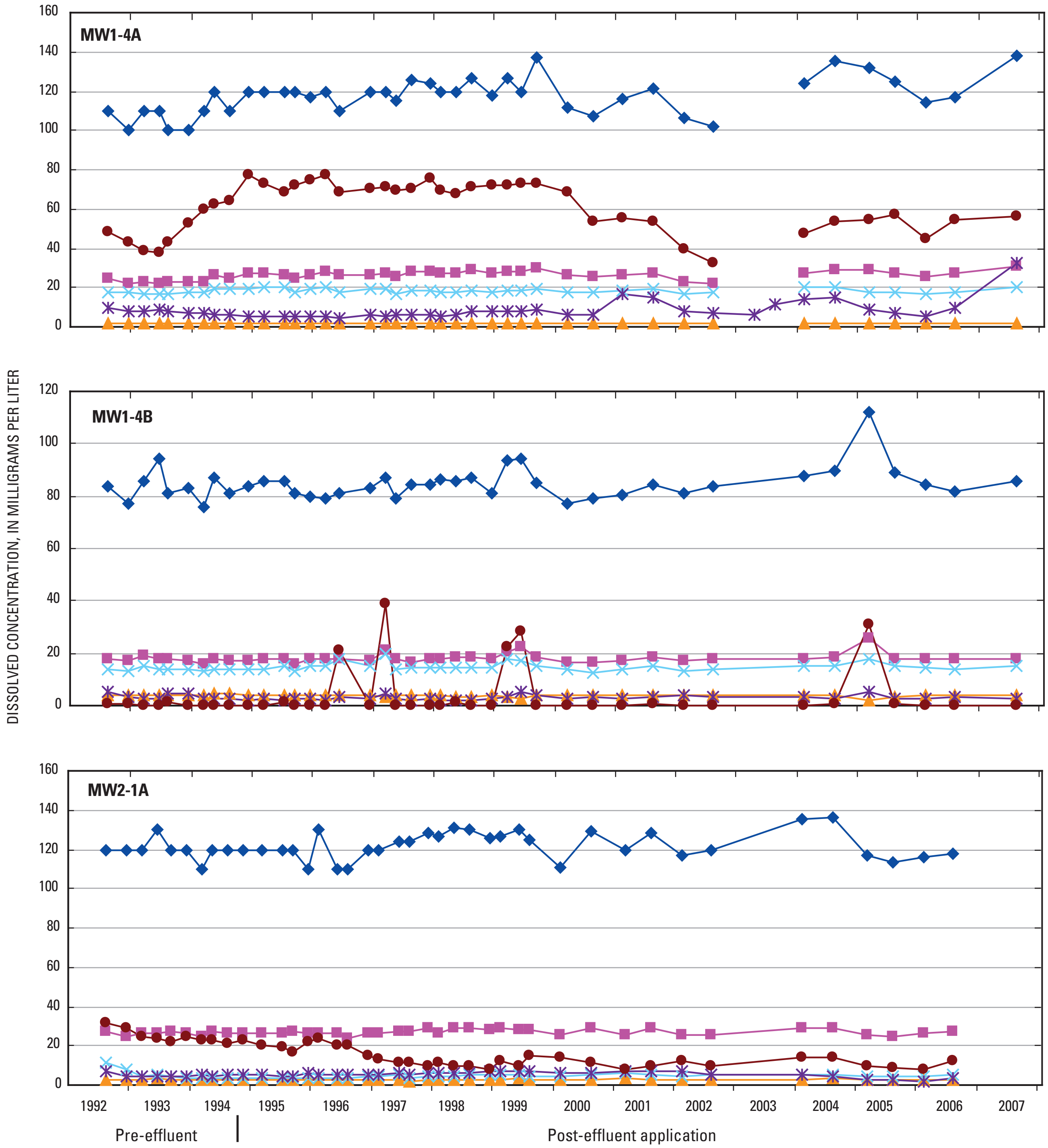


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

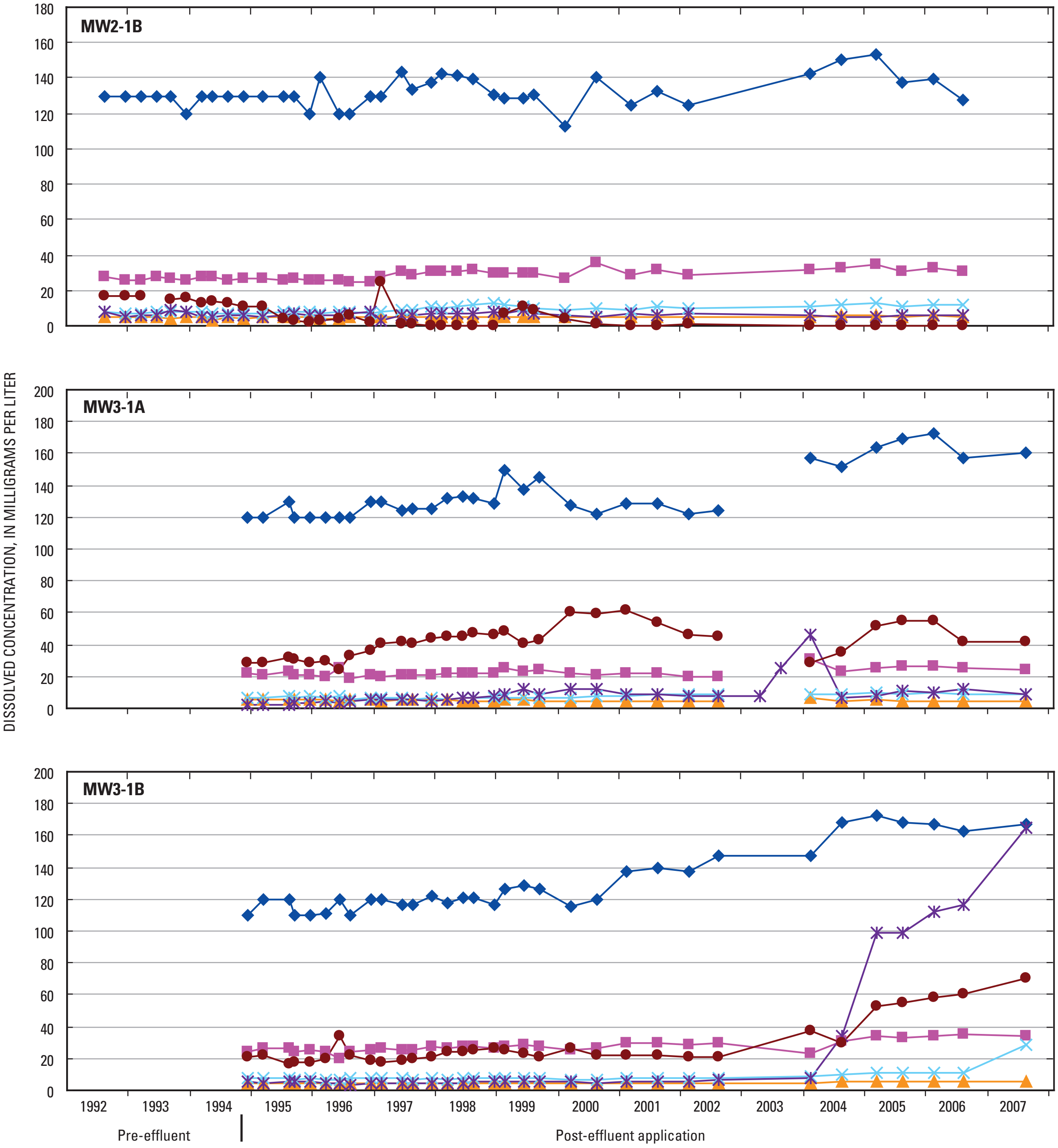


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

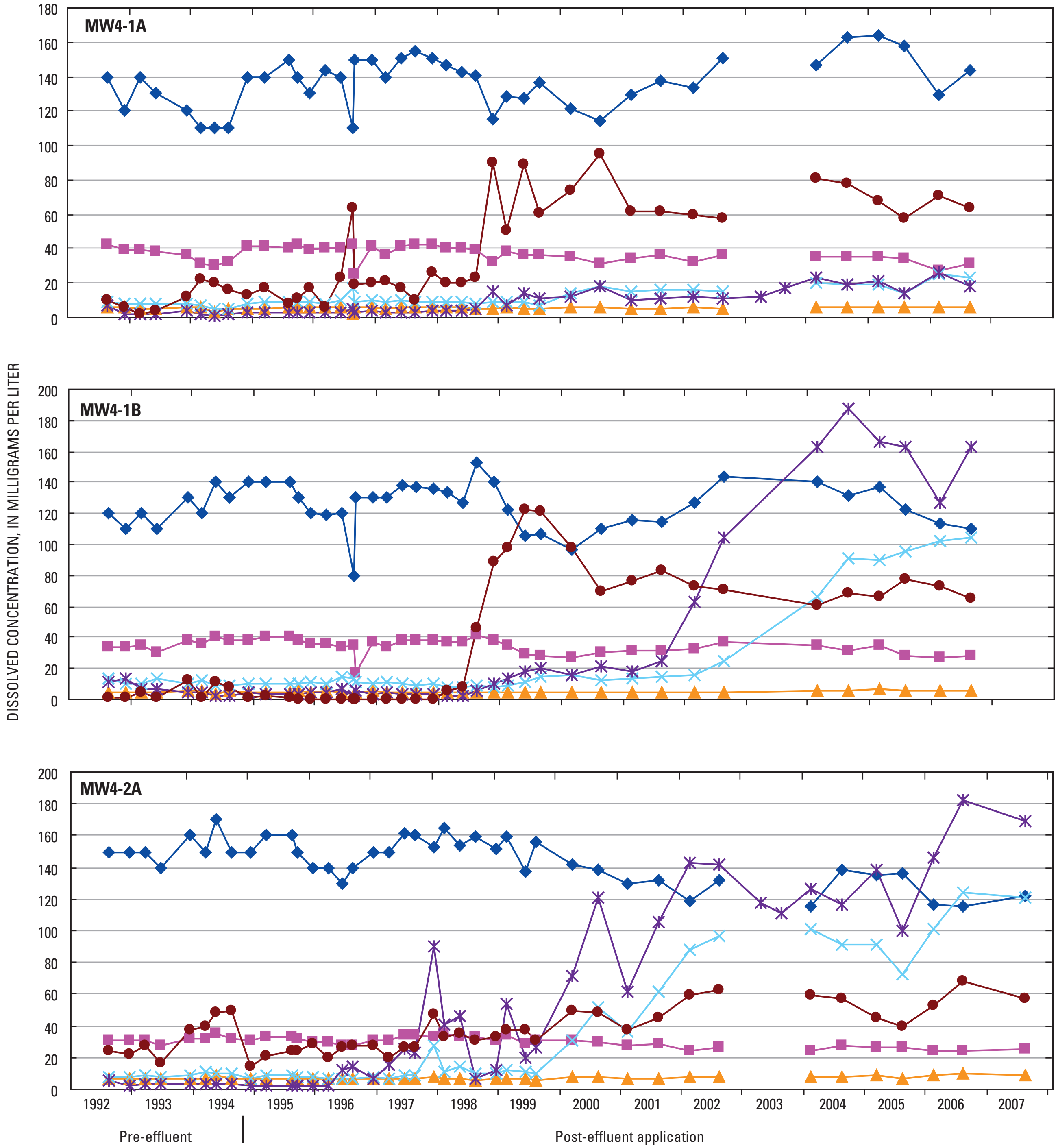


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

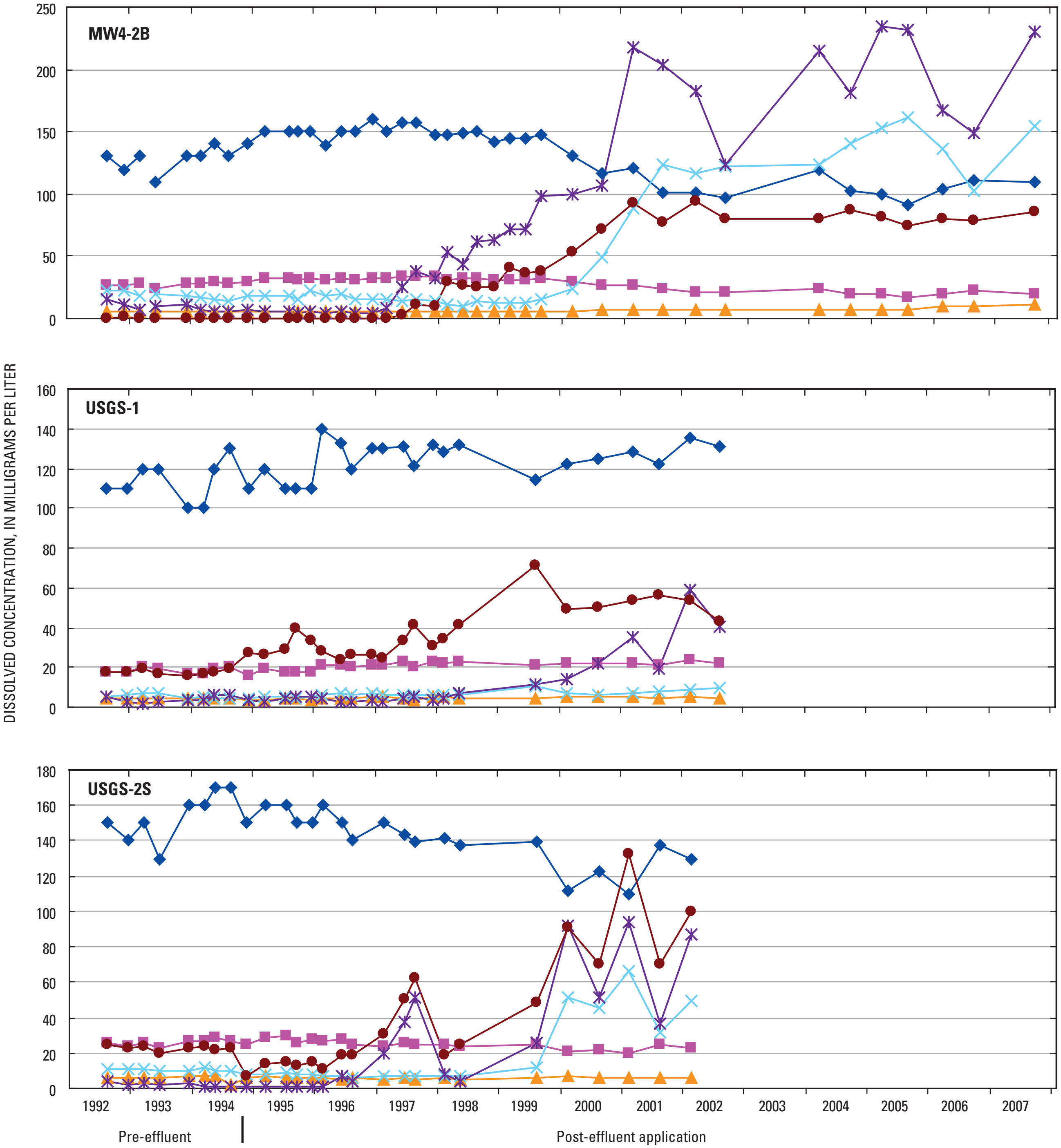


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

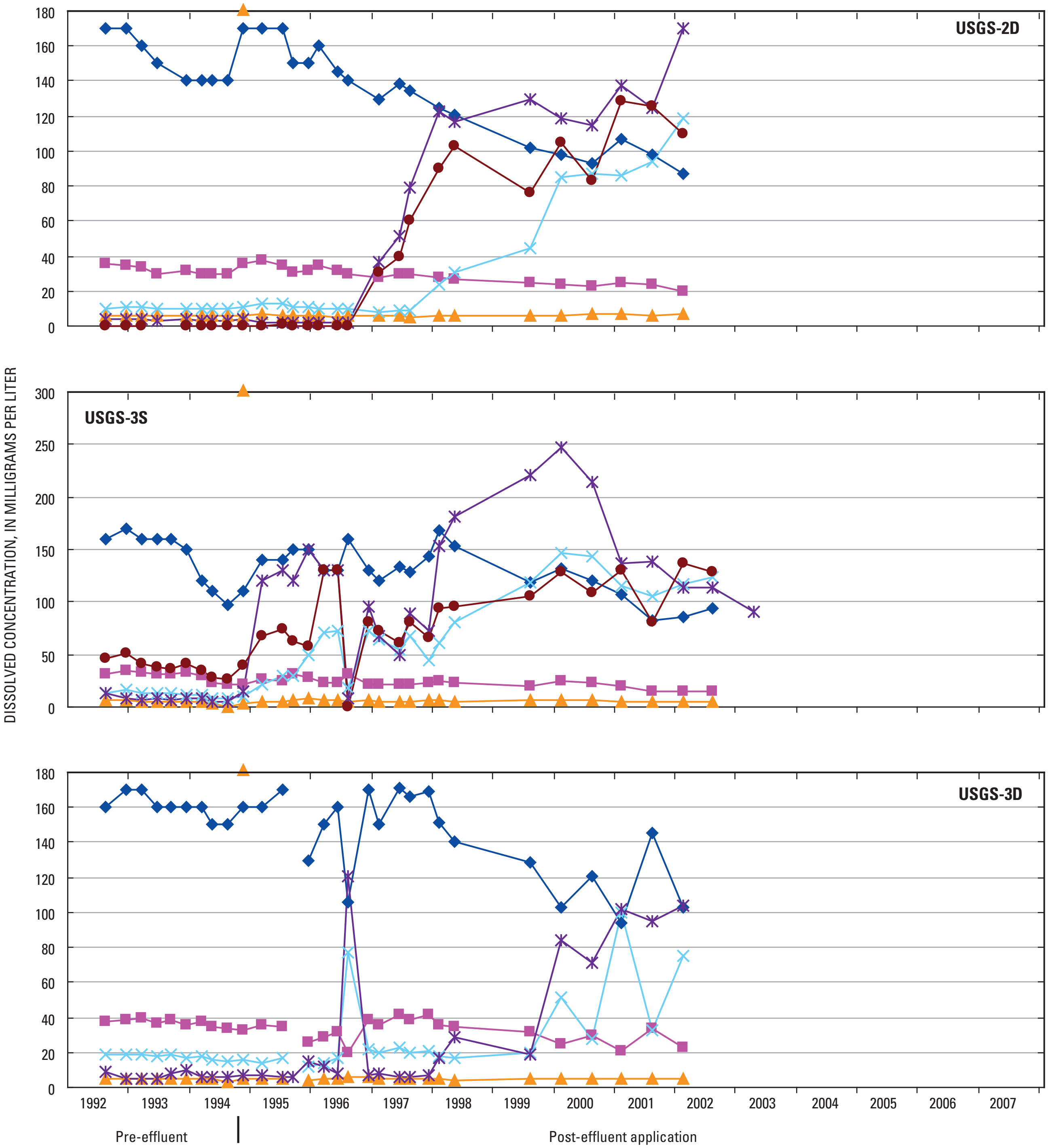


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

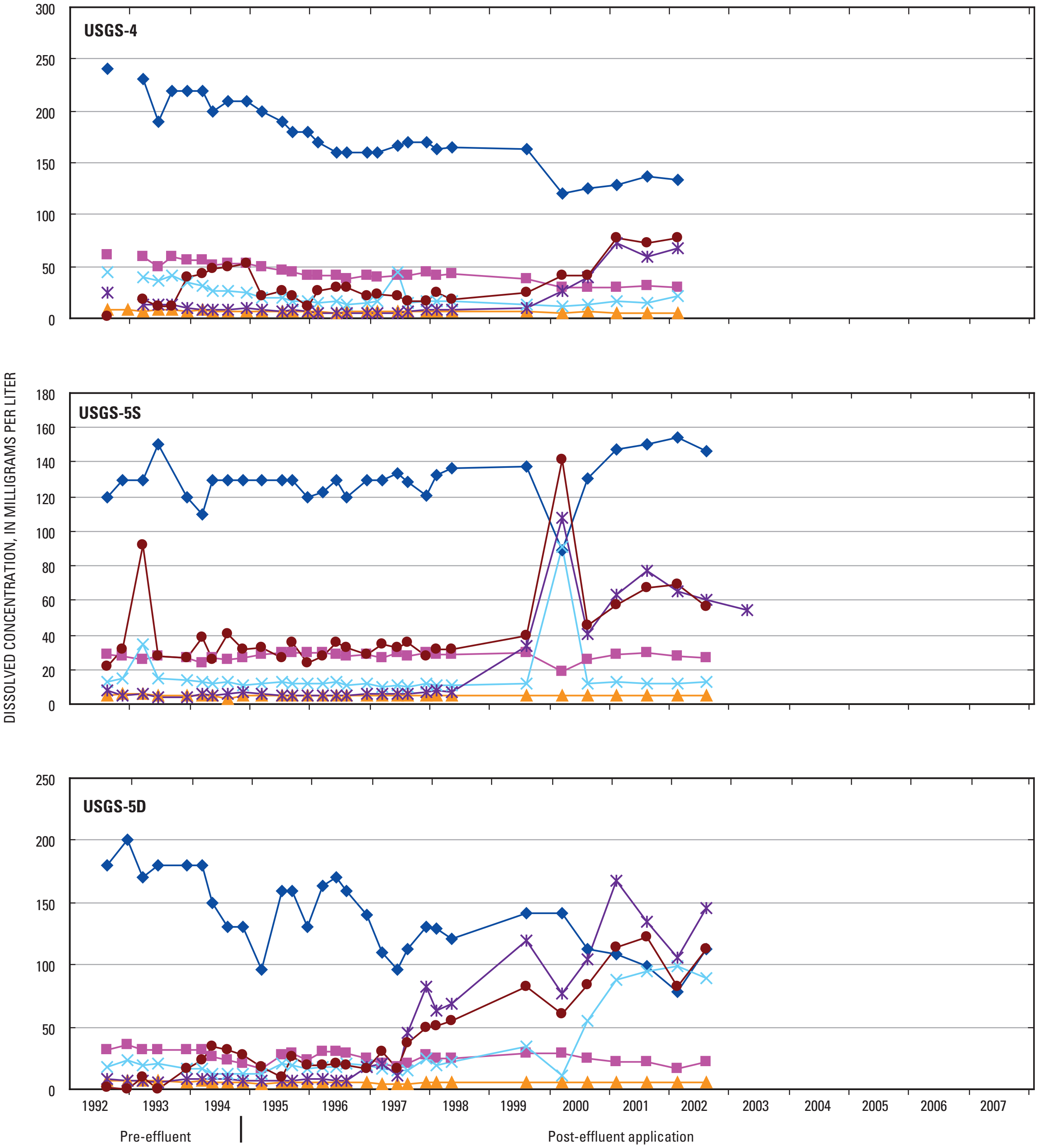


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

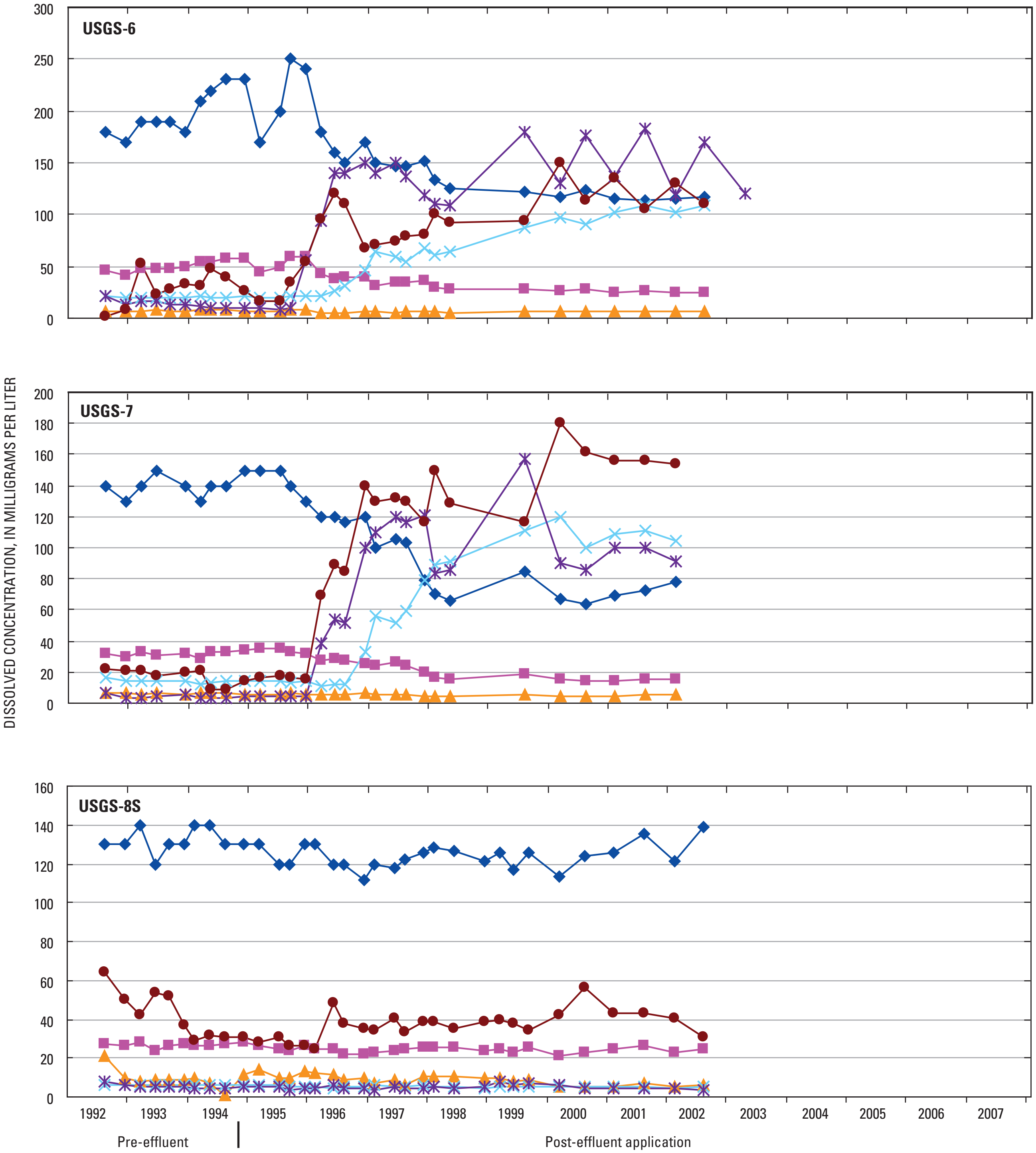


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

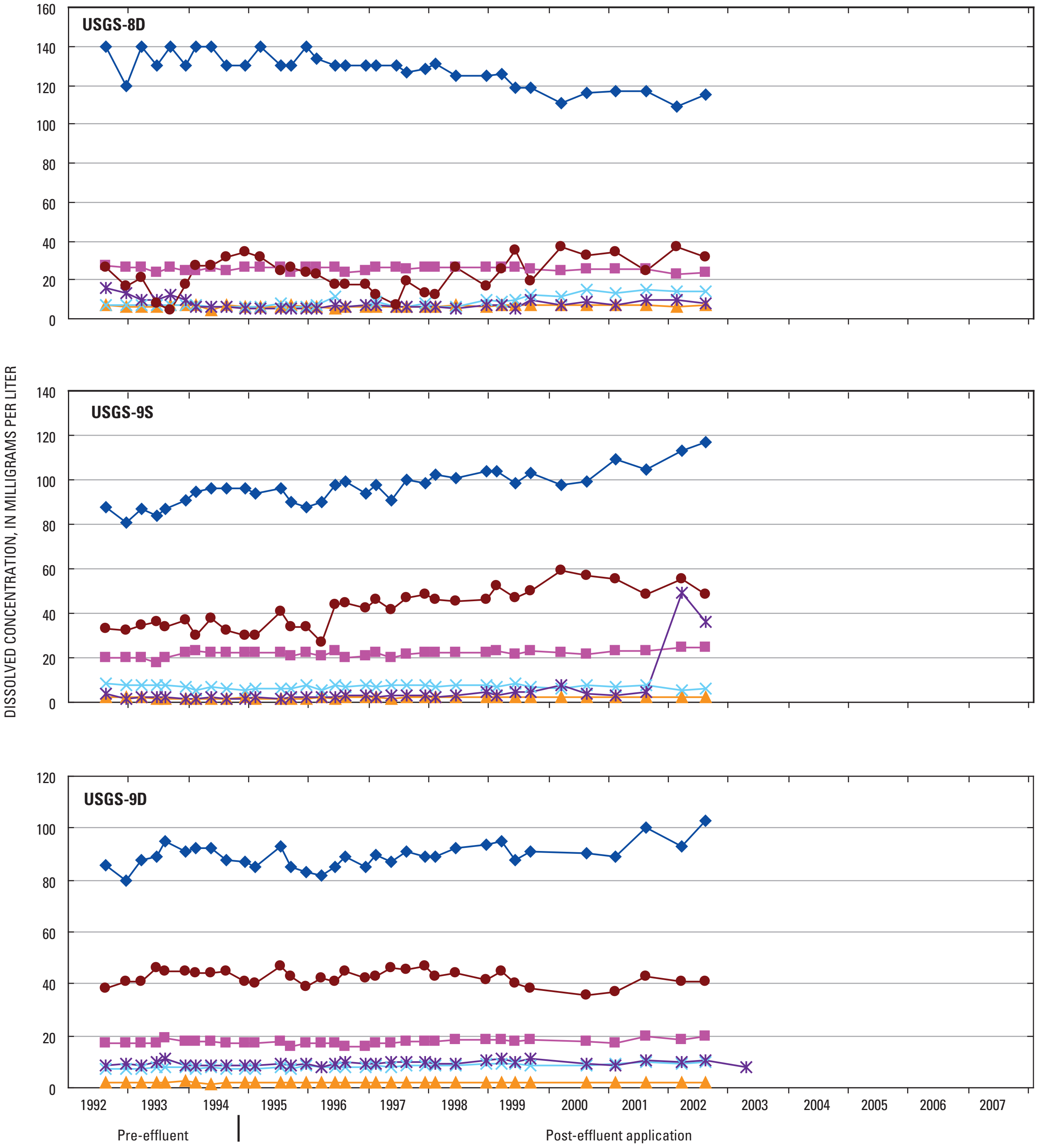


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

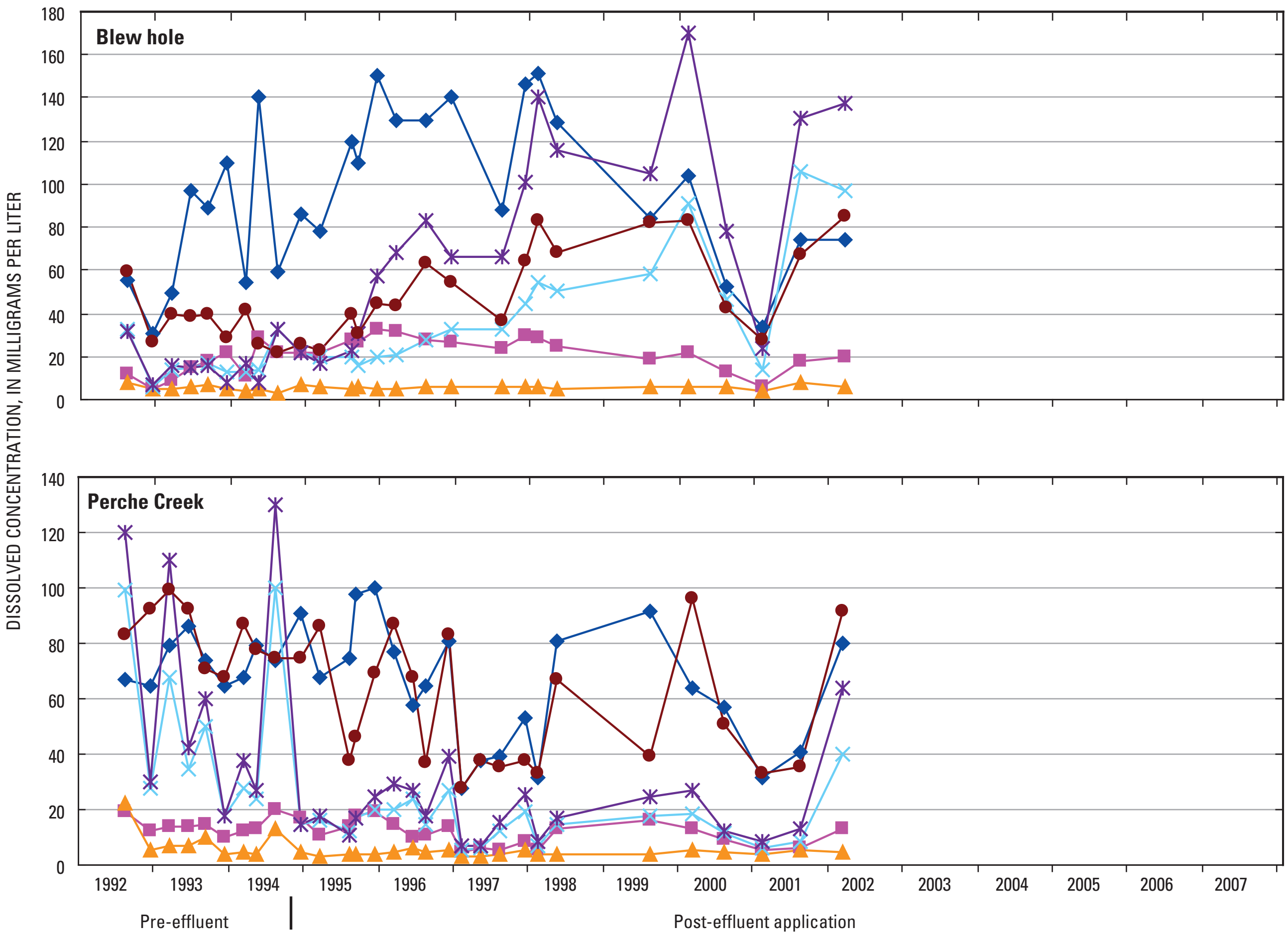


Figure 26. The major chemical constituent concentrations in samples from selected sites in McBaine Bottoms, 1992–2007.—Continued

sodium had the largest changes for cation concentrations. Chloride concentrations had the largest magnitude of change in the ground and surface water throughout McBaine Bottoms. The largest chloride concentrations of 259 and 247 mg/L were detected in samples from monitoring wells MW1-2A and USGS-3S.

The timing of the increase of major ion concentrations in monitoring wells varied throughout McBaine Bottoms. In samples from some wells adjacent to the treatment wetland unit 1 (monitoring wells MW1-2A, MW1-2B, MW1-3A, and MW1-3B), calcium, chloride, and sulfate concentrations increased at the same time followed by sodium concentrations (fig. 26). The increase in sodium concentrations in samples from monitoring well MW1-3A and MW1-3B occurred several years after the initial increase in calcium, chloride, and sulfate concentrations. In samples from monitoring well MW3-1B, the calcium concentration increased slightly before the chloride and sulfate concentrations increased (fig. 26). Sulfate concentrations in samples from monitoring well pair MW4-1 increased before other constituent concentrations increased and chloride and sodium concentrations increased simultaneously. In samples from monitoring wells MW4-2A and MW4-2B, chloride, sodium, and sulfate concentrations increased in the same general time, with those concentrations lagging in samples from monitoring well MW4-2B. Also in samples from these monitoring wells, calcium concentrations decreased by the end of the study period. In samples from the rest of the wells in the Eagle Bluffs Conservation Area, calcium concentrations generally decreased during the period of sample collection or increased only slightly. These wells had much larger initial calcium concentrations than the initial calcium concentrations in samples from monitoring wells adjacent to the treatment wetland units. Sulfate concentrations either increased first or increased with chloride concentrations. Sodium concentrations generally lagged by several months to a few years if they increased. Sodium concentrations in monitoring wells USGS-1 and USGS-4 did not increase substantially.

Chloride concentrations increased in samples from monitoring well MW1-2A (about 30 ft deep) in early 1995, and they increased in samples from monitoring well MW1-2B (about 60 ft deep) in late 1995. Chloride concentrations appeared to have stabilized in monitoring well MW1-2A at about 200 mg/L until 2002 when concentrations peaked at 259 and 242 mg/L.

After those large concentrations, the chloride concentrations began decreasing rapidly, and from August 2004 to August 2007, the concentrations generally were less than 100 mg/L. During the flood of 1993, water was held in treatment wetland unit 1 for about 30 days at a level immediately below the top of the exterior berm and above the clay liner. This undermined the clay liner and weakened the berm. Sloughs appeared along the interior side of the northern berm, and samples from monitoring well MW1-2A began to show increased chloride concentrations. Repair of the sloughs was completed in late 2003 and early 2004 (C.J. Cuvellier, City of Columbia, written commun., 2008). Chloride concentrations in monitoring well MW1-2B tended to follow the trend of the concentrations in monitoring well MW1-2A (fig. 27).

Chloride concentrations in samples from monitoring well MW1-3A increased in June 1996 and remained less than 60 mg/L until September 1999, when the chloride concentration increased to more than 90 mg/L. They remained less than 175 mg/L until August 2007, when the concentration was 189 mg/L. Concentrations in the adjacent monitoring well MW1-3B began increasing in August 1997 and generally continued to increase until August 2007, when the chloride concentration decreased from188 mg/L (August 2006) to 82 mg/L.

The chloride concentration in samples from monitoring well MW1-4A more than doubled in the sample from February 2001 from concentrations in previous samples, and the concentration remained less than 20 mg/L until the sample collected in August 2007 (chloride concentration of 32 mg/L). Chloride concentrations in samples from monitoring well MW1-4B generally were less than 5 mg/L throughout the study period. This well pair is upgradient from treatment wetland unit 1, but is downgradient from wetland treatment unit 4, which was completed in 2001. The increase in the chloride concentration in the August 2007 sample from the shallow monitoring well MW1-4A may possibly indicate the beginnings of effects from wetland treatment unit 4. Chloride concentrations increased before any of the other major constituents increased in samples from monitoring wells that have chloride concentrations larger than 40 mg/L.

Chloride concentrations in monitoring well MW3-1A (fig. 28) increased in August 2003 and February 2004, but concentrations from subsequent samples decreased to generally less than 10 mg/L. However, chloride concentrations in monitoring well MW3-1B began increasing in August 2004 and continued to increase through August 2007 to a concentration of 165 mg/L.

In the well pairs southwest of wetland treatment units 2 and 3, post-effluent chloride concentrations in monitoring wells MW4-1A, MW4-1B, MW4-2A, and MW4-2B have increased from the pre-effluent concentrations (fig. 28). In samples from monitoring well MW4-1A, chloride concentrations have increased from less than 4 to more than 25 mg/L; in samples from monitoring wells MW4-1B and MW4-2A, from less than 15 to more than 175 mg/L; and in samples from monitoring well MW4-2B, from less than 15 to more than 230 mg/L. Chloride concentrations in these four wells began to increase in samples collected during 1997.

Samples collected from wells in the southern part of McBaine Bottoms on the Eagle Bluffs Conservation Area also had increasing chloride concentrations. These wells included monitoring wells USGS-1, USGS-2S, USGS-2D, USGS-3S, USGS-3D, USGS-4, USGS-5S, USGS-5D, USGS-6, and USGS-7. Samples in several of these wells often showed a substantial increase in chloride concentration immediately followed by varying concentrations. Chloride concentrations began increasing in all wells as early as December 1995 (monitoring well USGS-6) and March 1996 (monitoring well USGS-7). Sample collection in monitoring wells USGS-1, USGS-2S, USGS-2D, USGS-3S, USGS-3D, USGS-4, USGS-5S, USGS-5D, USGS-6, and USGS-7 ended in April 2003.

Chloride concentrations in monitoring well USGS-9S increased in samples collected in 2002. This well is in the northern part of McBaine Bottoms, upgradient from the wetland treatment units and the Eagle Bluffs Conservation Area. Chloride concentrations in samples from this well were less than 5 mg/L except in one sample until March 2002 when the chloride concentration increased to 49 mg/L and in August 2002 (36 mg/L).

In samples from some monitoring wells (for example, MW4-2B), increases in other major ion concentrations lagged behind the increase in chloride concentrations by several months. Chloride is a relatively non-reactive constituent and generally is transported at the water velocity (Hem, 1985). As reactive cations and anions move through aquifer material, various physical and chemical processes such as oxidation and reduction, complexation, and surface exchange with, or sorption to, clays or organic materials, or both, tend to retard or slow transport relative to water velocity. The alluvial aquifer in the study area is chemically reducing—small concentrations of dissolved oxygen (Richards, 1995, 1999, 2002; Smith and Richards, 2006) and nitrate, and large ammonia and iron concentrations.

Chloride concentrations in samples from the shallow monitoring well USGS-3S increased almost immediately after the wetland began receiving effluent; however, chloride concentrations in samples from USGS-3D did not increase until about 2 years after the beginning of the wetland. Measured water levels in well pairs differ only slightly, which indicated that the vertical component of the hydraulic gradient is small in the study area (Richards, 2002; Smith, 2003). Although this gradient is small, the permeability of the aquifer is high, and a large volume of surface water can be lost to the ground water. Because flow is predominantly horizontal in the aquifer, flow paths from the surface to a particular well (or depth in the aquifer) could be quite long. This would account for the time lag between the introduction of the treated effluent on the surface and the detected constituent changes in some well samples. The variability in the major chemical constituent changes with respect to the depth and spatial distribution of the wells partly is a reflection of the anisotropy in the aquifer (Richards, 2002).

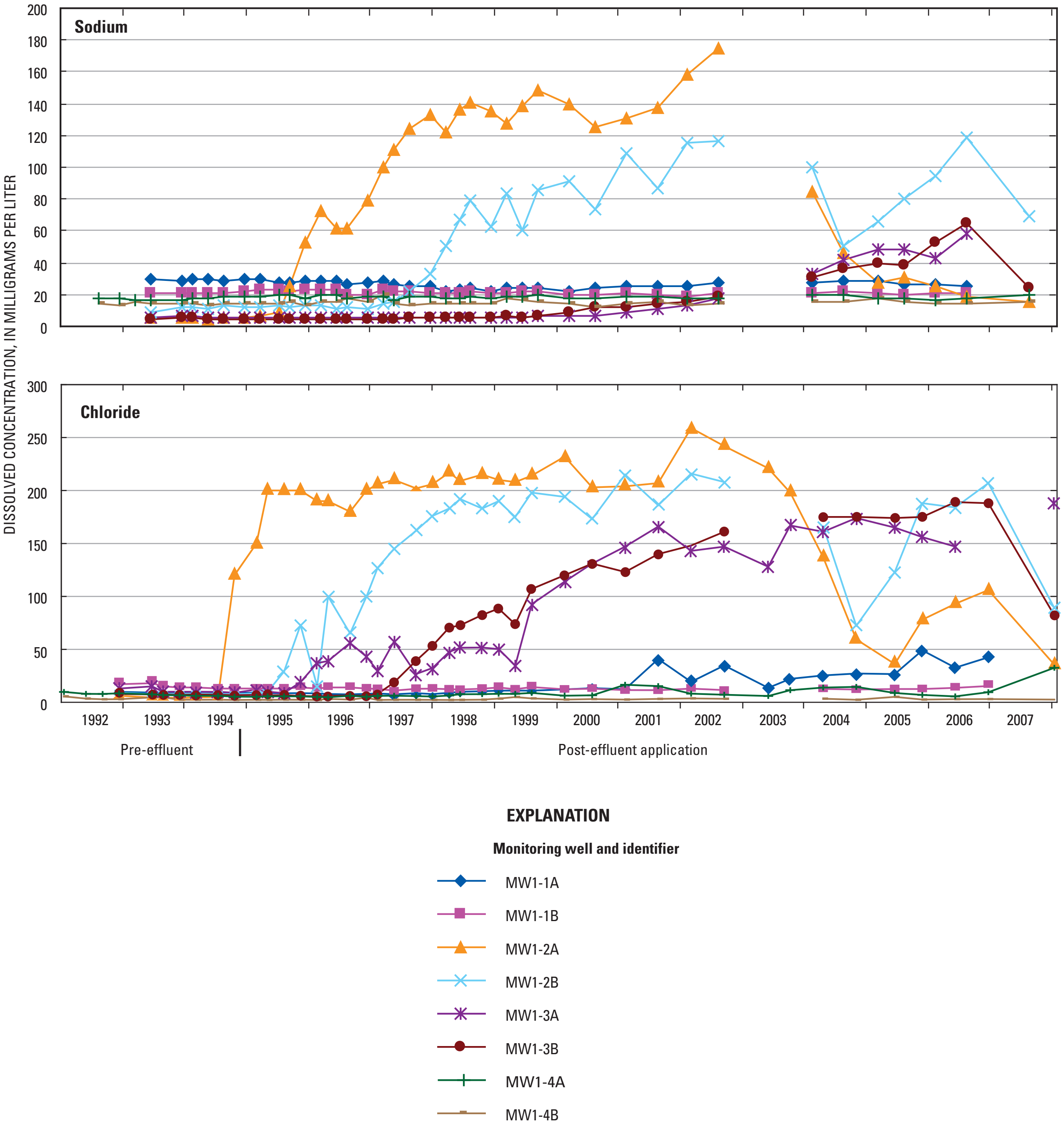


Figure 27. Sodium and chloride concentrations in samples from monitoring wells adjacent to wetland treatment unit 1, 1992–2007.

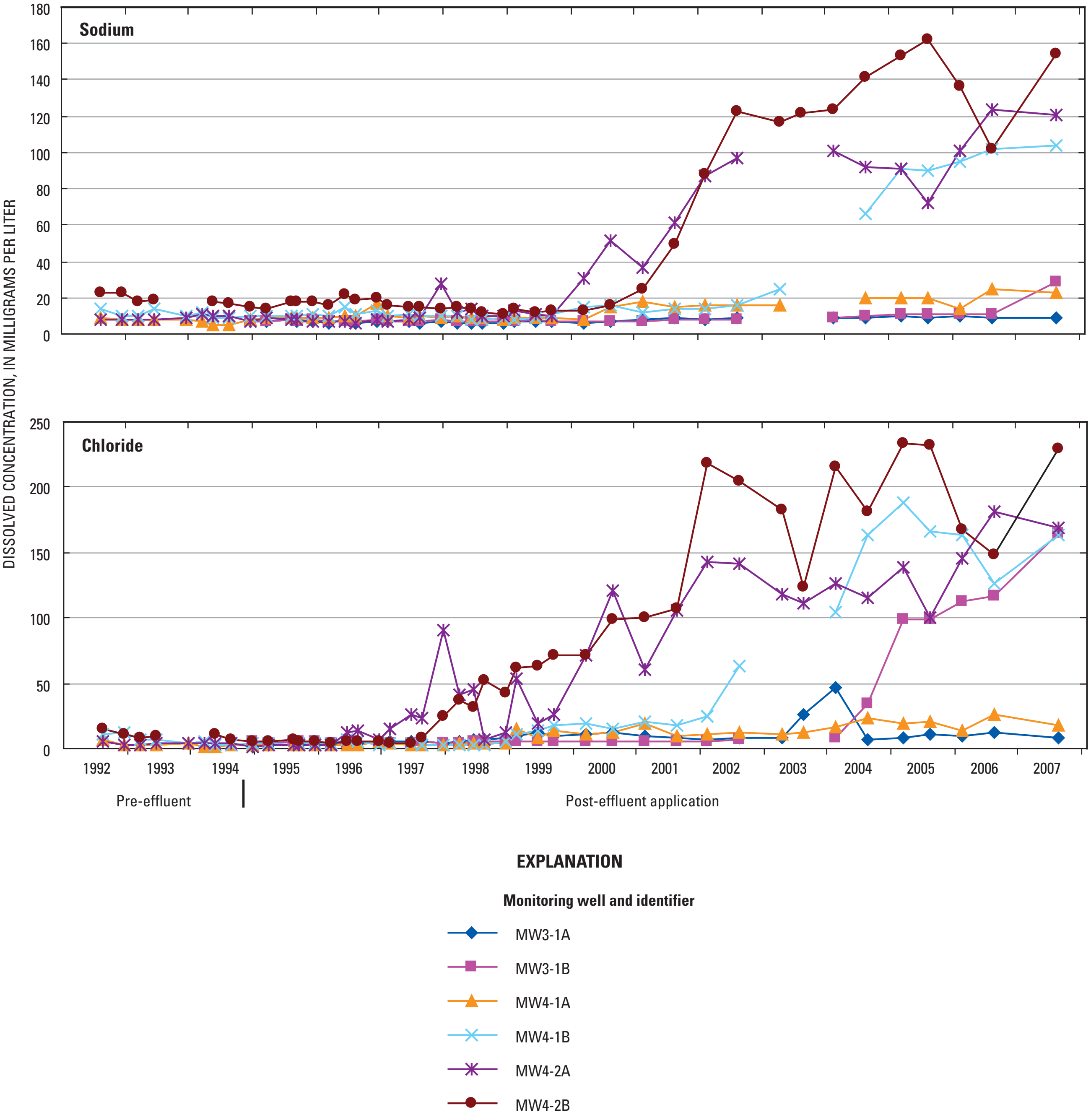


Figure 28. Sodium and chloride concentrations in samples from monitoring wells adjacent to wetland treatment unit 3 and in the northern Eagle Bluffs Conservation Area, 1992–2007.

Concentrations of major constituents in samples from some monitoring wells indicate evidence for surface exchange on clays and organic material. For example, samples from monitoring well MW1-2A had an increased chloride concentration at the same time as the calcium concentration increased (fig. 26); however, the concentrations of calcium in the treated effluent and the pre-effluent ground water both were less than the concentration in post-effluent ground water. Sodium and potassium ions in solution are suspected to have been exchanged with calcium ions that were sorbed to clays and organic material. This process would account for the calcium concentrations being greater than the concentration in the two mixing waters. As time progressed, the geochemical system would begin to approach equilibrium with respect to cation exchange, and the concentration of calcium would begin to decrease, whereas the concentrations of sodium would begin to increase (Richards, 2002).

Major chemical constituent concentrations in pre-effluent samples from monitoring wells indicate that the ground water predominantly was a calcium-magnesium bicarbonate type (fig. 29). Concentrations in post-effluent samples indicated the water type had shifted toward a predominantly sodium-chloride type (fig. 30), which is represented by samples from the city outflow. The concentrations of the major constituents in samples from these wells are on the mixing continuum between the pre-effluent ground water as one end member and the treated effluent as represented by samples from the city outflow as the other end member.

Chloride generally is considered a conservative ion in ground- and surface-water environments because it does not readily exchange with other anions and is fairly unreactive during normal conditions (Hem, 1985). In a natural system, the endpoint concentration of chloride usually can be explained by mixing all of the source concentrations. As a result, calculations can be performed to determine the relative mixture of the source waters using the following equation (Whittemore, 1988):

$$C\ (mix) = C\ (1) \times V + C\ (2) \times (1-V) \qquad (1)$$

and rearranged where

$$V = \frac{C\ (mix) - C\ (2)}{C\ (1) - C\ (2)} \qquad (2)$$

where

C (mix) = concentration of chloride in the sample from the monitoring well;
C (1) = chloride concentration in the city outflow;
C (2) = pre-effluent chloride concentration in the sample from the monitoring well;
V = the relative percentage in the sample from the monitoring well; and multiplying V by 100 converts to a percentage.

Based on this assumption and using a simple mixture of treated effluent and typical ground water [treated effluent concentration of 260 mg/L (median chloride concentration in samples from the city outflow from 1996 through 2007)], the relative percentage of treated effluent in ground water ranged from 6 percent in samples from monitoring well MW4-1A to 88 percent in samples from monitoring well MW4-2B (table 8). However, Missouri River water is used to supplement the treated effluent for management of the Eagle Bluffs Conservation Area, so mixing of the river water with the treated effluent and ground water occurs.

Summary

The U.S. Geological Survey, in cooperation with the city of Columbia, Missouri, and the Missouri Department of Conservation, collected ground-water quality data from June 1999 through December 2007, surface-water quality data from August 1999 through August 2003, and water-level data from February 2004 through August 2007 in McBaine Bottoms, southwest of Columbia. McBaine Bottoms, adjacent to the Missouri River, is the location of the municipal-supply well field for the city of Columbia, the city of Columbia wastewater-treatment wetlands, and the Missouri Department of Conservation Eagle Bluffs Conservation Area.

The Missouri Department of Conservation uses the treated effluent from the city of Columbia wastewater-treatment wetlands as a primary water source for managing the Eagle Bluffs Conservation Area. The treatment wetlands are designed to treat an average flow of about 16 million gallons per day of effluent. The area is bounded to the south and west by the Missouri River and to the north and east by Missouri River bluffs.

Lateral ground-water flow was dominated by the presence of a ground-water high beneath the Eagle Bluffs Conservation Area and the presence of a cone of depression in the northern part of the study area. The ground-water high was present most times when water levels were measured during this study. Ground-water flow was radially away from the apex of the ground-water high; west and south of the ground-water high, flow was toward the Missouri River, east of the ground-water high, flow was toward Perche Creek, and north of the ground-water high, flow was to the north toward the city of Columbia well field. The cone of depression was centered around the city of Columbia well field. Flow toward the well field was from the south in the vicinity of the Eagle Bluffs Conservation Area, from the west from the Missouri River, from the north downgradient through the alluvial aquifer, from the northeast beneath treatment wetland unit 1, and from the east through the alluvial aquifer in the vicinity of Perche Creek.

Another permanent feature on the water-table maps was a ground-water high beneath treatment wetland unit 1. Ground-water flow was downgradient through the alluvial valley that contains unit 1 and unit 4 completed in 2001. Around unit 1, perched water was present because ground-water flow was impeded by low permeability clay that traps the ground water.

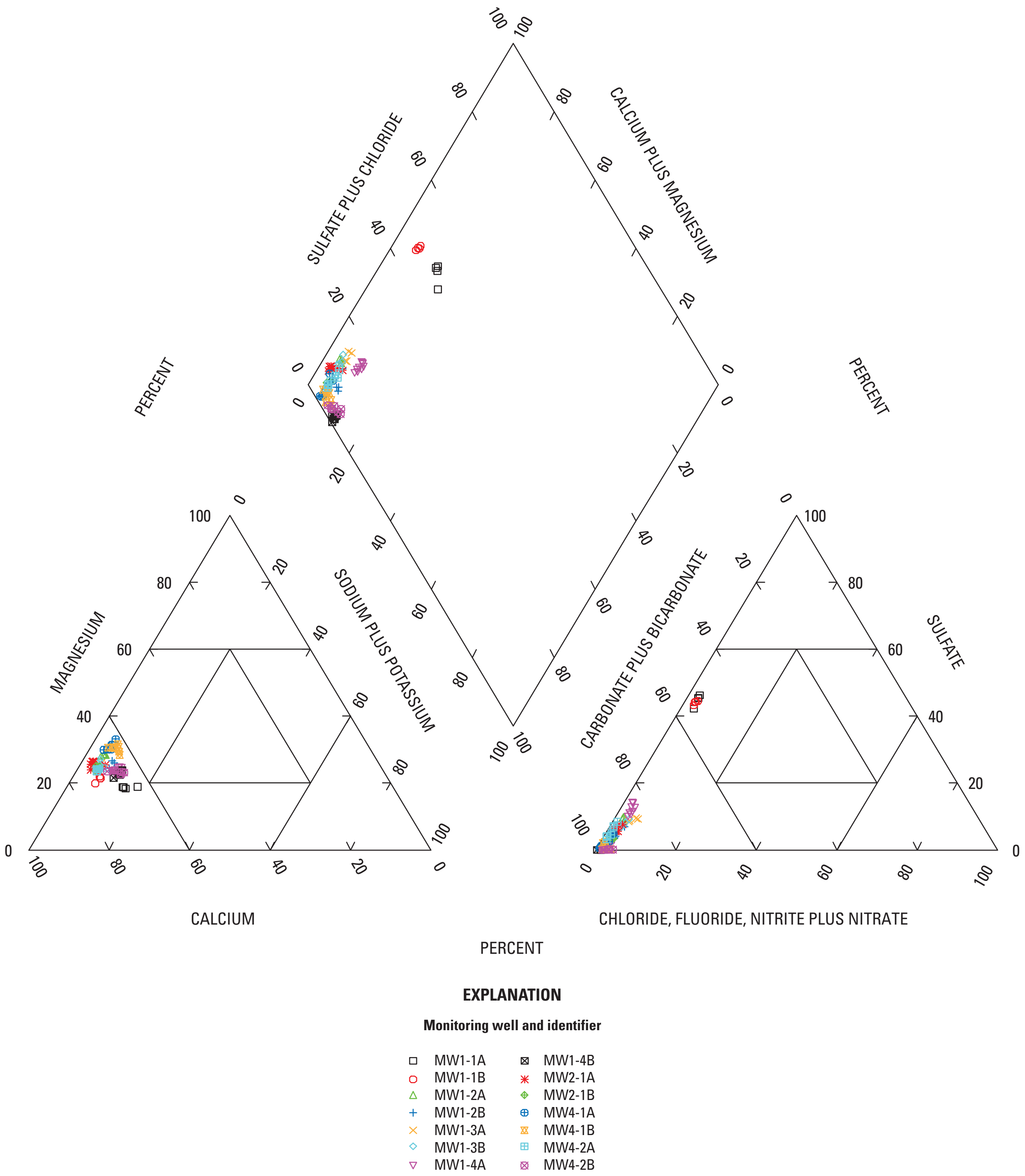


Figure 29. Pre-effluent samples from monitoring wells adjacent to treatment wetland units and in the northern Eagle Bluffs Conservation Area in McBaine Bottoms, 1992–2007.

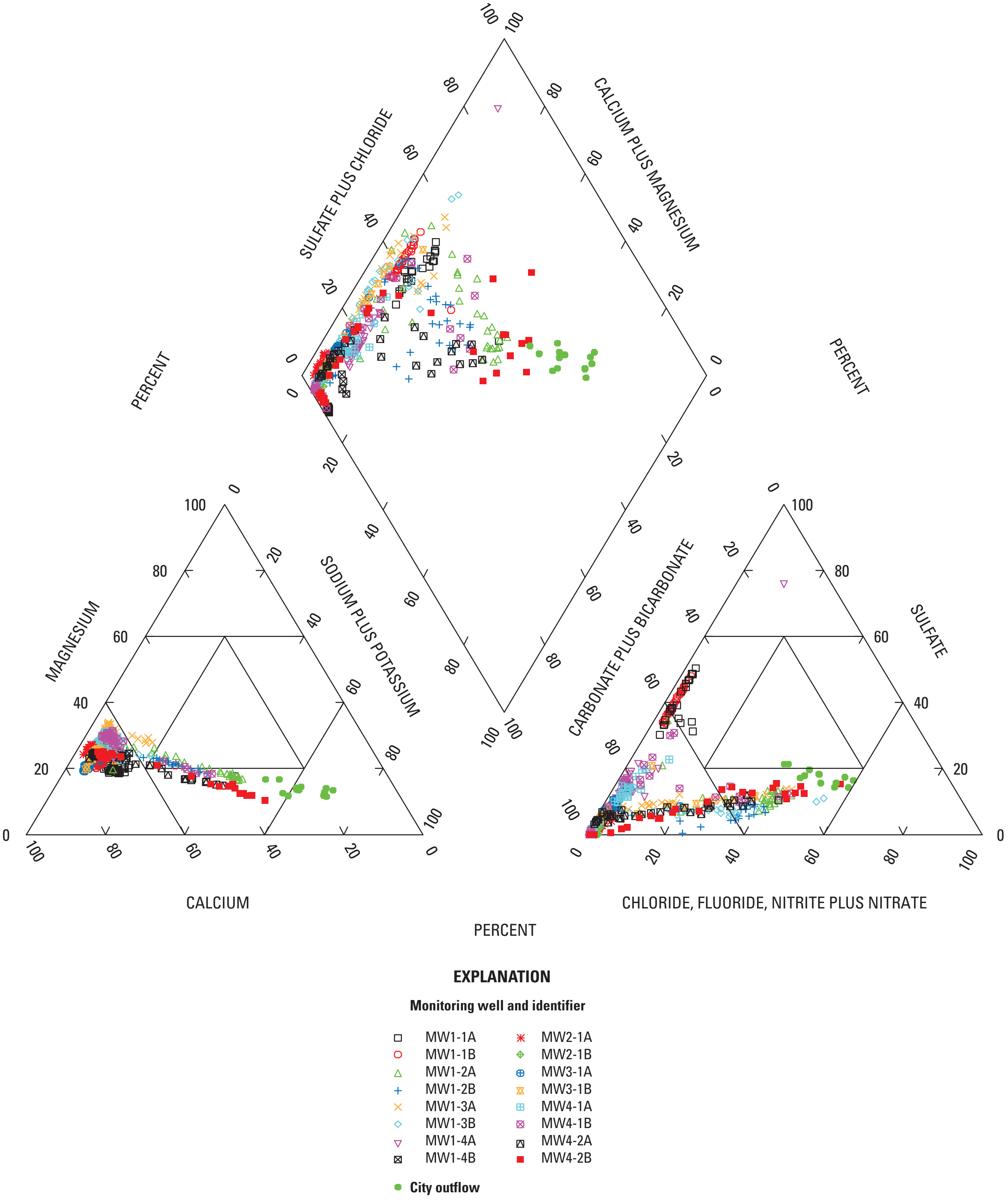


Figure 30. Post-effluent samples from monitoring wells adjacent to treatment wetland units and in the northern Eagle Bluffs Conservation Area in McBaine Bottoms, 1992–2007.

Table 8. Estimated relative percentage of treated effluent in ground water at selected sites in McBaine Bottoms.

[mg/L, milligrams per liter; based on equation from Whittemore (1988)]

Site (fig. 3)	Pre-effluent median chloride concentration (mg/L)	Most recent chloride concentration (mg/L)	Date of most recent chloride concentration	Relative percentage
MW1-2A	4.5	36	8/21/2007	12
MW1-2B	7.9	89	8/21/2007	32
MW1-3A	10	189	8/21/2007	72
MW1-3B	7.4	82	8/21/2007	30
MW4-1A	2.4	18	8/29/2006	6
MW4-1B	5.7	163	8/29/2006	62
MW4-2A	3.6	169	8/21/2007	65
MW4-2B	8.7	230	8/21/2007	88
USGS-1	3.8	41	8/22/2002	15
USGS-2S	1.8	87	2/26/2002	33
USGS-2D	3.4	170	2/26/2002	65
USGS-3S	7.7	91	4/01/2003	33
USGS-3D	5.8	104	2/26/2002	39
USGS-4	9.4	68	2/25/2002	23
USGS-5S	5.2	55	4/01/2003	20
USGS-5D	8.0	145	8/19/2002	54
USGS-6	14	121	4/01/2003	43
USGS-7	3.8	92	2/25/2002	34

The cone of depression in the northern part of the study area generally extended from the base of the ground-water high in the northern part of the Eagle Bluffs Conservation Area throughout the rest of the study area. During times of higher Missouri River flow, the gradient from the river toward the city of Columbia well field became steeper, but the measured water levels near the central part of the study area tended to increase, probably from induced surface-water flow into this area. Localized cones of depression were apparent around the public-supply wells; the position of these localized cones was dependent on which public-supply well was being used.

Changes in major chemical constituent concentrations have been detected at several sampling sites when analyzing pre- and post-effluent data. Water-quality data indicate that there was an increase in chloride concentration in several monitoring wells. The constituents calcium, potassium, sodium, and sulfate also had changes at many of these sites that appear to be correlated to the flooding of the wetland complex with treated effluent. Concentrations of major chemical constituents also are affected by factors such as oxidation and reduction, sorption to clays and organic materials, cation exchange, and chemical changes associated with water-level fluctuation. The variability in the major chemical constituent concentration changes with respect to the depth and spatial distribution of the wells also is partly a reflection of the anisotropy in the aquifer material.

Twenty-two monitoring wells throughout McBaine Bottoms have been affected by effluent based on chloride concentrations larger than 40 milligrams per liter. The chloride concentration of ground water in the alluvial aquifer reflects several sources, including precipitation, water from the Missouri River, water in the aquifer, and the treated effluent. Chloride concentrations from precipitation, the Missouri River, and water in the alluvial aquifer were less than 40 milligrams per liter. These monitoring wells affected by effluent are located in two general areas—adjacent to treatment wetland unit 1 and near the ground-water high on and north of the Eagle Bluffs Conservation Area. The probable source of the large chloride concentrations in well samples adjacent to treatment wetland unit 1 is leakage from the unit. The source for the large chloride concentrations in the other monitoring well samples is the effluent mixed with ground water and Missouri River water that is used to fill pools on the Eagle Bluffs Conservation Area. One monitoring well had a single sample with the chloride concentration larger than 40 milligrams per liter. That sample may have been affected by the use of road salt because of the presence of ice and snow immediately before the sample was collected.

The concentrations of major chemical constituents are on the mixing continuum between pre-effluent ground water as one end member and the treated effluent as the other end member. The relative percentage of treated effluent in the ground water at sites that had major chemical constituent changes, assuming chloride is conservative, ranged from 6 to 88.

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Tables and Figures

Table 4. Altitude of water levels in monitoring wells (2006–07) and staff gages (2004–07), McBaine Bottoms.

[Altitudes are in feet above National Geodetic Vertical Datum of 1929 (NGVD 29); ft, feet; --, no data]

Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)
MW-101	02-21-2006	559.37	MW-109	02-21-2006	556.73	MW-117	02-21-2006	550.76	MW-125	02-21-2006	549.05
	08-28-2006	555.45		08-28-2006	556.32		08-28-2006	551.99		08-28-2006	548.78
	02-27-2007	560.21		02-27-2007	558.56		02-27-2007	552.00		02-27-2007	548.68
	08-20-2007	557.61		08-20-2007	557.97		08-20-2007	555.12		08-20-2007	553.30
MW-102	02-21-2006	560.31	MW-110	02-21-2006	555.88	MW-118	02-21-2006	550.78	MW-126	02-21-2006	549.04
	08-28-2006	558.49		08-28-2006	554.93		08-28-2006	552.85		08-28-2006	547.78
	02-27-2007	560.70		02-27-2007	556.41		02-27-2007	553.60		02-27-2007	547.80
	08-20-2007	559.80		08-20-2007	557.05		08-20-2007	555.64		08-20-2007	553.42
MW-103	02-21-2006	559.62	MW-111	02-21-2006	551.46	MW-119	02-21-2006	550.17	MW-127	02-21-2006	550.26
	08-28-2006	557.15		08-28-2006	552.07		08-28-2006	551.36		08-28-2006	550.22
	02-27-2007	559.41		02-27-2007	552.03		02-27-2007	550.82		02-27-2007	549.88
	08-20-2007	558.67		08-20-2007	555.22		08-20-2007	554.67		08-20-2007	554.14
MW-104	02-21-2006	557.68	MW-112	02-21-2006	554.42	MW-120	02-21-2006	547.11	MW-128	02-21-2006	550.67
	08-28-2006	559.74		08-28-2006	553.98		08-28-2006	548.72		08-28-2006	550.37
	02-27-2007	557.19		02-27-2007	553.15		02-27-2007	547.92		02-27-2007	550.08
	08-20-2007	557.80		08-20-2007	556.67		08-20-2007	554.02		08-20-2007	554.53
MW-105	02-21-2006	555.22	MW-113	02-21-2006	553.48	MW-121	02-21-2006	549.85	MW-129	02-21-2006	549.94
	08-28-2006	557.59		08-28-2006	554.70		08-28-2006	550.01		08-28-2006	546.97
	02-27-2007	557.21		02-27-2007	557.26		02-27-2007	549.80		02-27-2007	548.88
	08-20-2007	556.99		08-20-2007	556.53		08-20-2007	553.77		08-20-2007	554.46
MW-106	02-21-2006	556.97	MW-114	02-21-2006	557.23	MW-122	02-21-2006	548.63	MW-130	02-21-2006	551.27
	08-28-2006	557.17		08-28-2006	557.74		08-28-2006	548.98		08-28-2006	546.62
	02-27-2007	555.10		02-27-2007	560.00		02-27-2007	548.46		02-27-2007	549.48
	08-20-2007	--		08-20-2007	558.66		08-20-2007	553.05		08-20-2007	555.26
MW-107	02-21-2006	558.13	MW-115	02-21-2006	550.95	MW-123	02-21-2006	546.55	MW-131	02-21-2006	552.99
	08-28-2006	556.89		08-29-2006	552.51		08-28-2006	547.44		08-28-2006	--
	02-27-2007	555.68		02-27-2007	553.02		02-27-2007	546.96		02-27-2007	550.21
	08-20-2007	558.67		08-20-2007	554.87		08-20-2007	553.10		08-20-2007	556.32
MW-108	02-21-2006	559.40	MW-116	02-21-2006	553.02	MW-124	02-21-2006	548.62	MW-132	02-21-2006	550.01
	08-28-2006	559.28		08-29-2006	553.05		08-28-2006	547.61		08-28-2006	545.87
	02-27-2007	557.50		02-27-2007	552.45		02-27-2007	547.23		02-27-2007	548.85
	08-20-2007	560.30		08-20-2007	555.90		08-20-2007	553.07		08-20-2007	554.60

Table 4. Altitude of water levels in monitoring wells (2006–07) and staff gages (2004–07), McBaine Bottoms.—Continued

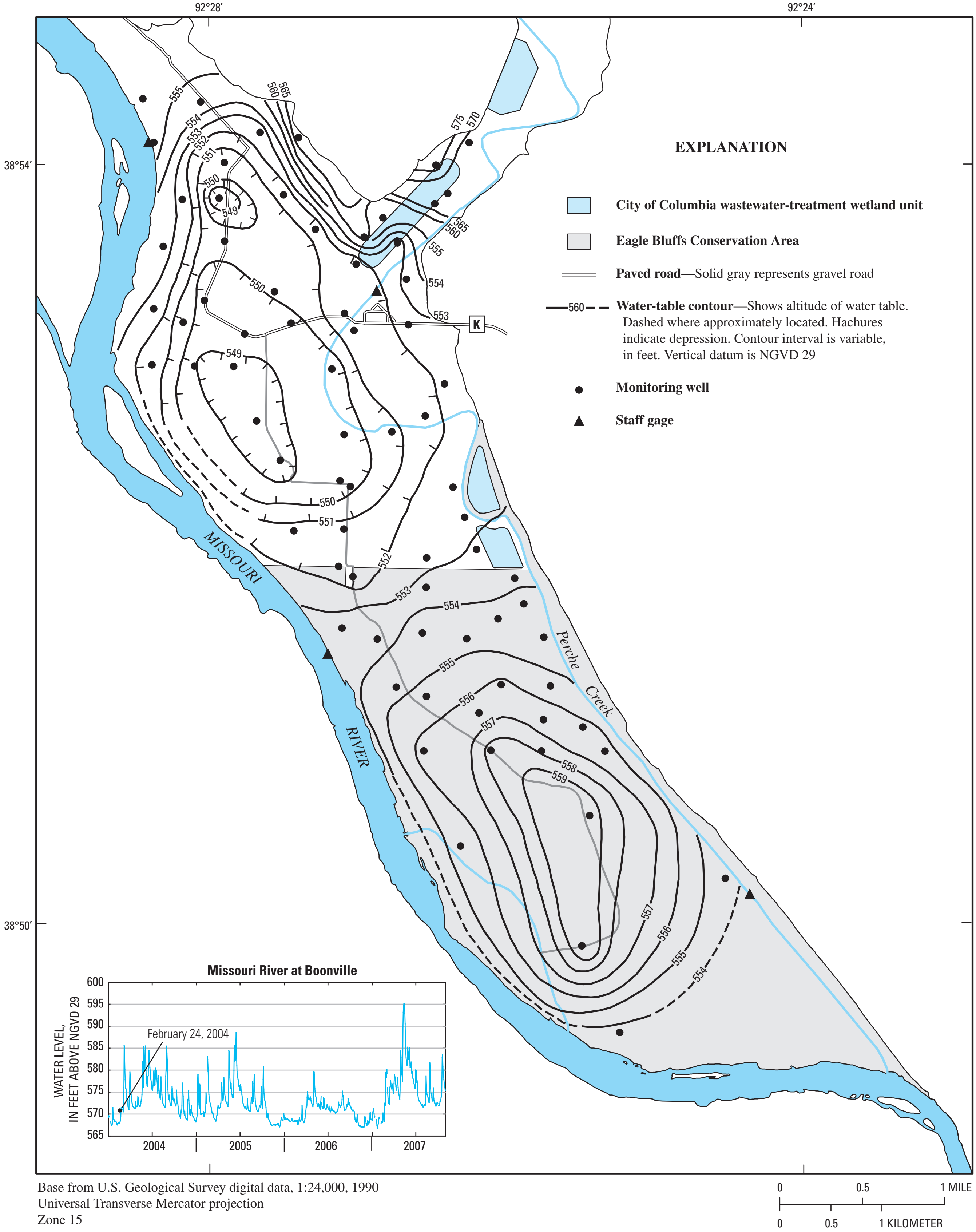
[Altitudes are in feet above National Geodetic Vertical Datum of 1929 (NGVD 29); ft, feet; --, no data]

Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)
MW-133	02-21-2006	548.70	MW-141	02-21-2006	551.82	MW-151	02-21-2006	552.71	MW1-2B	02-21-2006	551.83
	08-28-2006	546.18		08-28-2006	548.41		08-28-2006	552.76		08-28-2006	547.06
	02-27-2007	547.08		02-27-2007	548.83		02-27-2007	551.06		02-27-2007	549.28
	08-20-2007	552.49		08-20-2007	556.14		08-20-2007	558.82		08-20-2007	556.07
MW-134	02-21-2006	548.76	MW-142	02-21-2006	574.73	MW-152	02-21-2006	554.25	MW1-3A	02-21-2006	551.11
	08-28-2006	547.64		08-28-2006	573.93		08-28-2006	557.90		08-28-2006	545.19
	02-27-2007	547.50		02-27-2007	575.20		02-27-2007	560.73		02-27-2007	548.83
	08-20-2007	553.44		08-20-2007	573.51		08-20-2007	560.13		08-20-2007	555.78
MW-135	02-21-2006	550.95	MW-143	02-21-2006	567.50	MW-153	02-21-2006	554.56	MW1-3B	02-21-2006	550.98
	08-28-2006	552.95		08-28-2006	562.18		08-28-2006	558.07		08-28-2006	544.84
	02-27-2007	554.09		02-27-2007	567.63		02-27-2007	559.77		02-27-2007	548.75
	08-20-2007	555.96		08-20-2007	567.00		08-20-2007	560.60		08-20-2007	555.67
MW-136	02-21-2006	550.74	MW-144	02-21-2006	550.35	MW-154	02-21-2006	550.85	MW1-4A	02-21-2006	571.07
	08-28-2006	550.52		08-28-2006	549.87		08-28-2006	549.03		08-28-2006	570.38
	02-27-2007	549.70		02-27-2007	549.32		02-27-2007	548.47		02-27-2007	570.75
	08-20-2007	554.76		08-20-2007	555.90		08-20-2007	556.13		08-21-2007	569.30
MW-137	02-21-2006	552.00	MW-145	02-21-2006	552.74	MW-155	02-21-2006	551.66	MW1-4B	02-21-2006	559.34
	08-28-2006	553.68		08-28-2006	554.64		08-28-2006	550.74		08-28-2006	535.60
	02-27-2007	554.89		02-27-2007	555.96		02-27-2007	548.97		02-27-2007	559.29
	08-20-2007	556.78		08-20-2007	558.00		08-20-2007	556.82		08-21-2007	558.75
MW-138	02-21-2006	550.25	MW-146	02-21-2006	552.42	MW1-1A	02-21-2006	568.40	MW2-1A	02-21-2006	550.72
	08-28-2006	549.11		08-28-2006	553.68		08-28-2006	564.64		08-29-2006	551.73
	02-27-2007	547.98		02-27-2007	554.42		02-27-2007	567.75		02-27-2007	551.83
	08-20-2007	553.49		08-20-2007	558.01		08-21-2007	567.71		08-20-2007	554.56
MW-139	02-21-2006	549.95	MW-147	02-21-2006	--	MW1-1B	02-21-2006	560.31	MW2-1B	02-21-2006	--
	08-28-2006	547.74		08-28-2006	549.49		08-28-2006	541.17		08-29-2006	--
	02-27-2007	547.71		02-27-2007	549.37		02-27-2007	559.93		02-27-2007	--
	08-20-2007	554.44		08-20-2007	555.34		08-21-2007	559.93		08-20-2007	--
MW-140	02-21-2006	557.05	MW-150	02-21-2006	565.72	MW1-2A	02-21-2006	551.83	MW3-1A	02-21-2006	552.98
	08-28-2006	553.64		08-28-2006	--		08-28-2006	547.04		08-28-2006	553.53
	02-27-2007	565.57		02-27-2007	565.92		02-27-2007	549.29		02-27-2007	553.01
	08-20-2007	559.01		08-20-2007	564.63		08-20-2007	556.04		08-21-2007	555.79

Table 4. Altitude of water levels in monitoring wells (2006–07) and staff gages (2004–07), McBaine Bottoms.—Continued

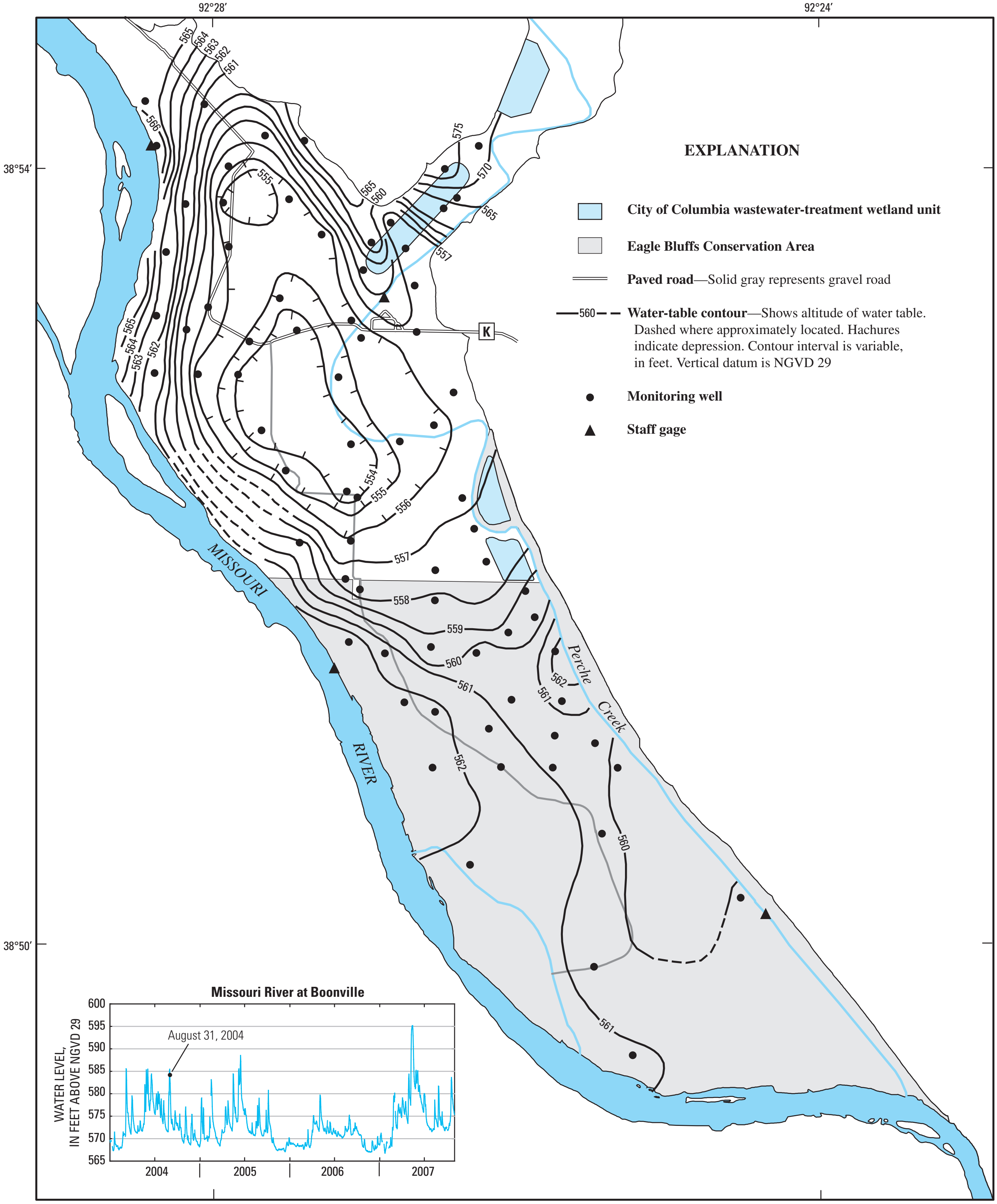
[Altitudes are in feet above National Geodetic Vertical Datum of 1929 (NGVD 29); ft, feet; --, no data]

Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)	Site (fig. 3)	Date	Altitude (ft)
MW3-1B	02-21-2006	552.91	USGS-3S	02-21-2006	558.58	USGS-8D	02-21-2006	547.05	River upper	02-21-2006	559.4
	08-29-2006	553.47		08-28-2006	555.62		08-28-2006	549.18		08-28-2006	--
	02-27-2007	553.01		02-27-2007	559.72		02-27-2007	548.51		02-27-2007	568.9
	08-21-2007	555.77		08-20-2007	557.39		08-20-2007	551.96		08-20-2007	--
MW4-1A	02-21-2006	556.86	USGS-3D	02-21-2006	558.29	USGS-9S	02-21-2006	553.70	River lower	02-24-2004	547.5
	08-29-2006	555.58		08-28-2006	555.44		08-28-2006	555.68		08-31-2004	567.4
	02-27-2007	555.08		02-27-2007	559.49		02-27-2007	553.94		03-08-2005	--
	08-20-2007	557.75		08-20-2007	557.20		08-20-2007	560.13		08-02-2005	--
MW4-1B	02-21-2006	556.70	USGS-4	02-21-2006	556.84	USGS-9D	02-21-2006	--		02-21-2006	551.7
	08-29-2006	555.58		08-28-2006	555.73		08-28-2006	--		08-28-2006	--
	02-27-2007	555.26		02-27-2007	559.30		02-27-2007	554.02		02-27-2007	--
	08-20-2007	557.68		08-20-2007	557.51		08-20-2007	560.16		08-20-2007	--
MW4-2A	02-21-2006	558.17	USGS-5S	02-21-2006	561.75	SP11	02-21-2006	560.05	Creek upper	02-24-2004	552.8
	08-29-2006	557.67		08-28-2006	556.13		08-28-2006	--		08-31-2004	547.3
	02-27-2007	558.29		02-27-2007	561.85		02-27-2007	559.05		03-08-2005	552.3
	08-20-2007	559.04		08-20-2007	558.39		08-20-2007	560.69		08-02-2005	551.4
MW4-2B	02-21-2006	558.18	USGS-5D	02-21-2006	561.77	SP4	02-21-2006	562.70		02-21-2006	550.7
	08-29-2006	557.71		08-28-2006	556.17		08-28-2006	--		08-28-2006	--
	02-27-2007	558.38		02-27-2007	561.91		02-27-2007	561.39		02-27-2007	--
	08-20-2007	559.05		08-20-2007	558.42		08-20-2007	--		08-20-2007	--
USGS-1	02-21-2006	553.98	USGS-6	02-21-2006	554.31	MW13-67	02-21-2006	546.27	Creek lower	02-24-2004	549.9
	08-28-2006	554.68		08-28-2006	553.68		08-28-2006	549.13		08-31-2004	544.5
	02-27-2007	554.08		02-27-2007	558.16		02-27-2007	548.49		03-08-2005	549.4
	08-20-2007	556.50		08-20-2007	555.96		08-20-2007	551.00		08-02-2005	551.1
USGS-2S	02-21-2006	559.82	USGS-7	02-21-2006	552.53	MW28-67	02-21-2006	558.35		02-21-2006	547.5
	08-28-2006	--		08-28-2006	553.65		08-28-2006	555.21		08-28-2006	--
	02-27-2007	--		02-27-2007	558.24		02-27-2007	560.24		02-27-2007	--
	08-20-2007	560.17		08-20-2007	555.74		08-20-2007	558.10		08-20-2007	--
USGS-2D	02-21-2006	559.83	USGS-8S	02-21-2006	548.02	River upper	02-24-2004	556.9			
	08-28-2006	--		08-28-2006	549.10		08-31-2004	--			
	02-27-2007	--		02-27-2007	548.55		03-08-2005	557.3			
	08-20-2007	560.20		08-20-2007	552.65		08-02-2005	561.7			



Base from U.S. Geological Survey digital data, 1:24,000, 1990
Universal Transverse Mercator projection
Zone 15

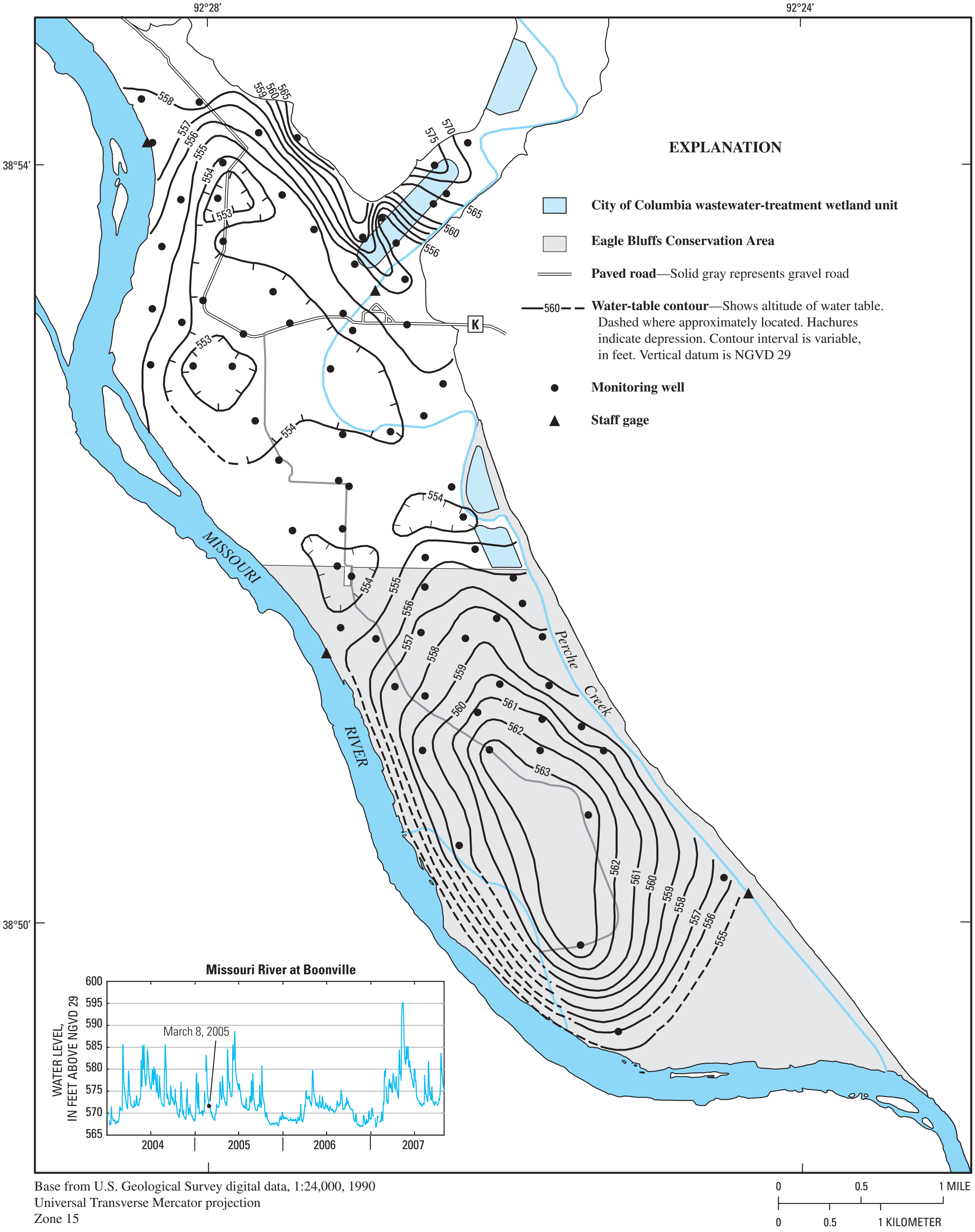
Figure 7. Altitude of the water table in the alluvial aquifer, February 24, 2004.



Base from U.S. Geological Survey digital data, 1:24,000, 1993
Universal Transverse Mercator projection
Zone 15

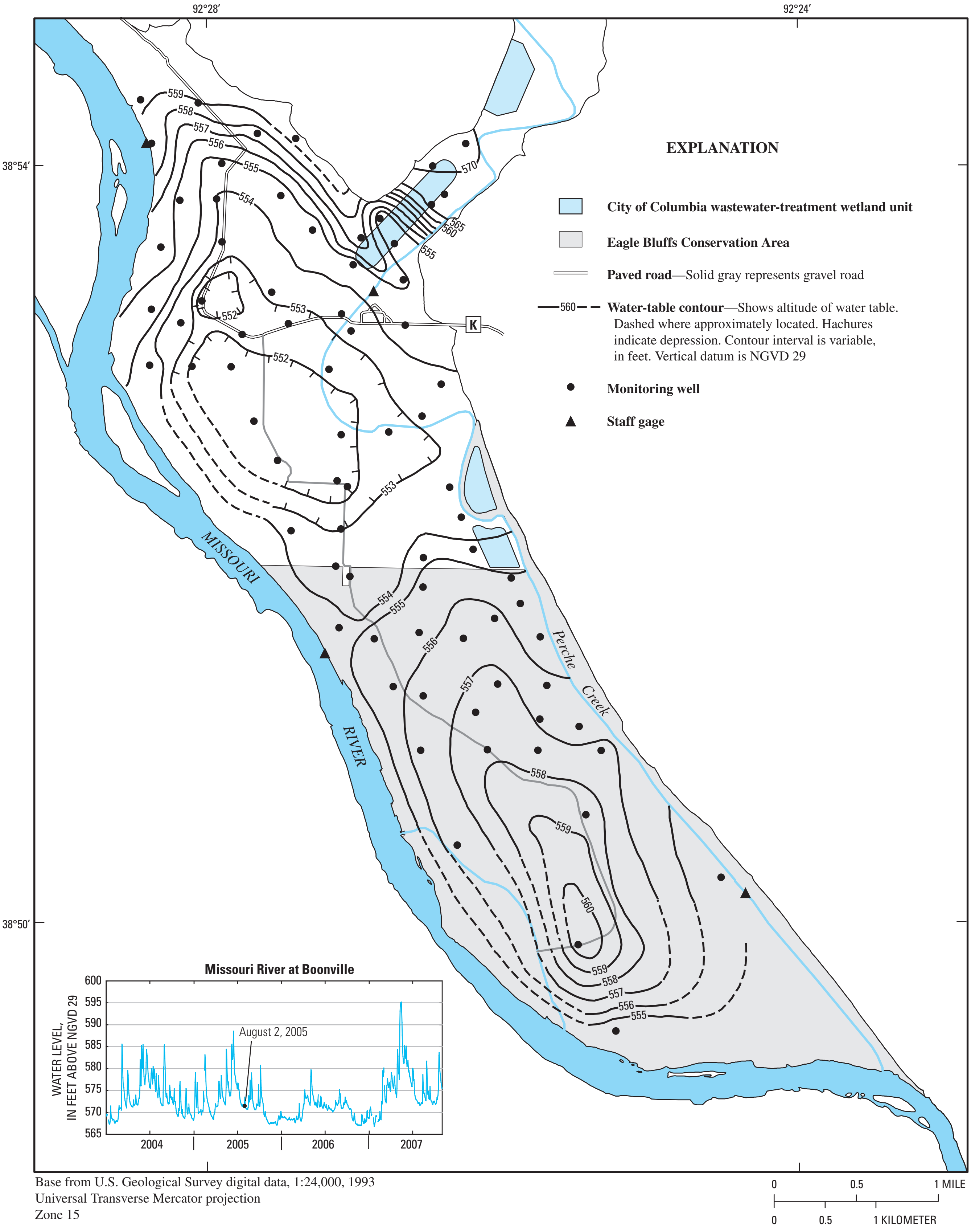
0 0.5 1 MILE
0 0.5 1 KILOMETER

Figure 8. Altitude of the water table in the alluvial aquifer, August 31, 2004.



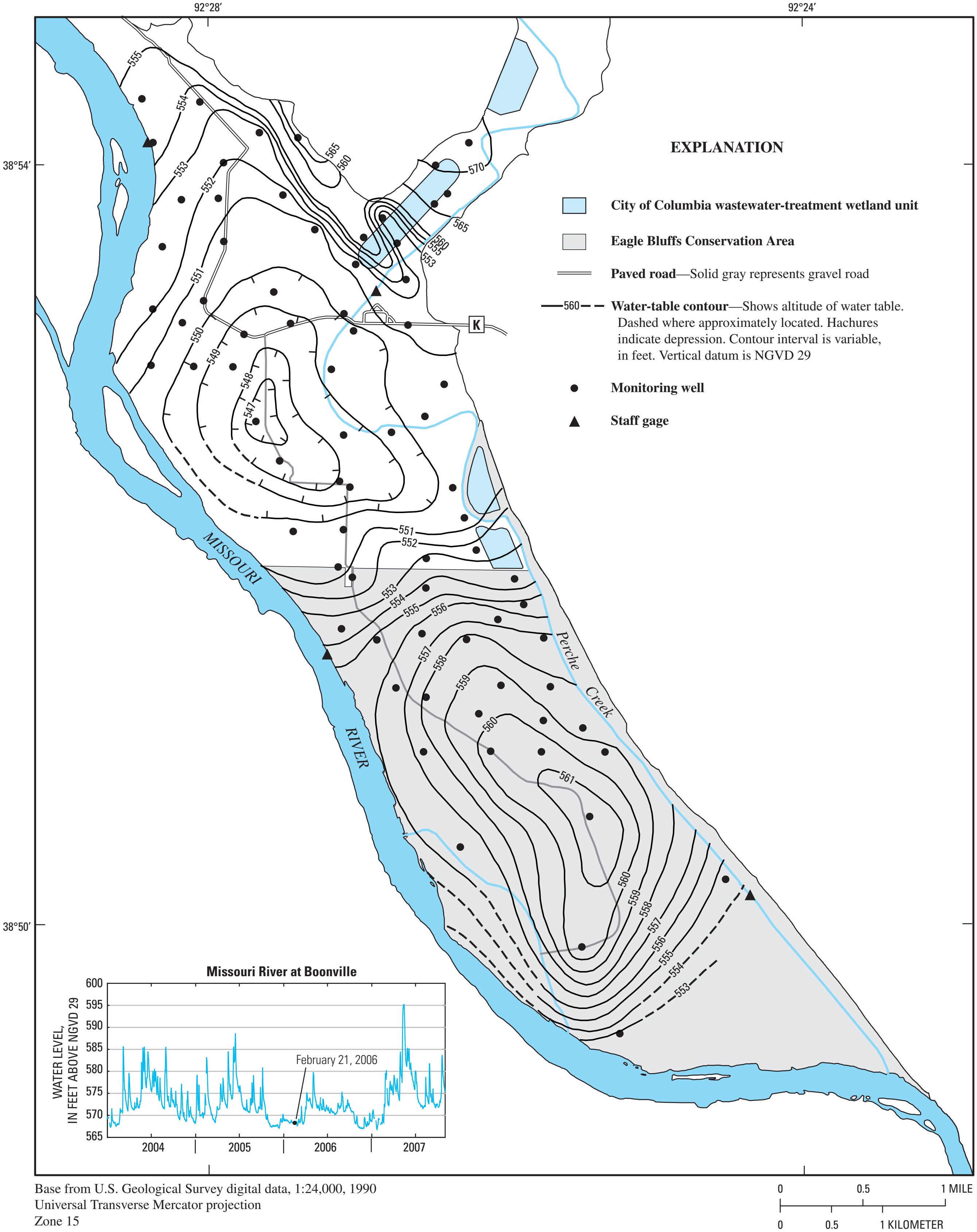
Base from U.S. Geological Survey digital data, 1:24,000, 1990
Universal Transverse Mercator projection
Zone 15

Figure 9. Altitude of the water table in the alluvial aquifer, March 8, 2005.



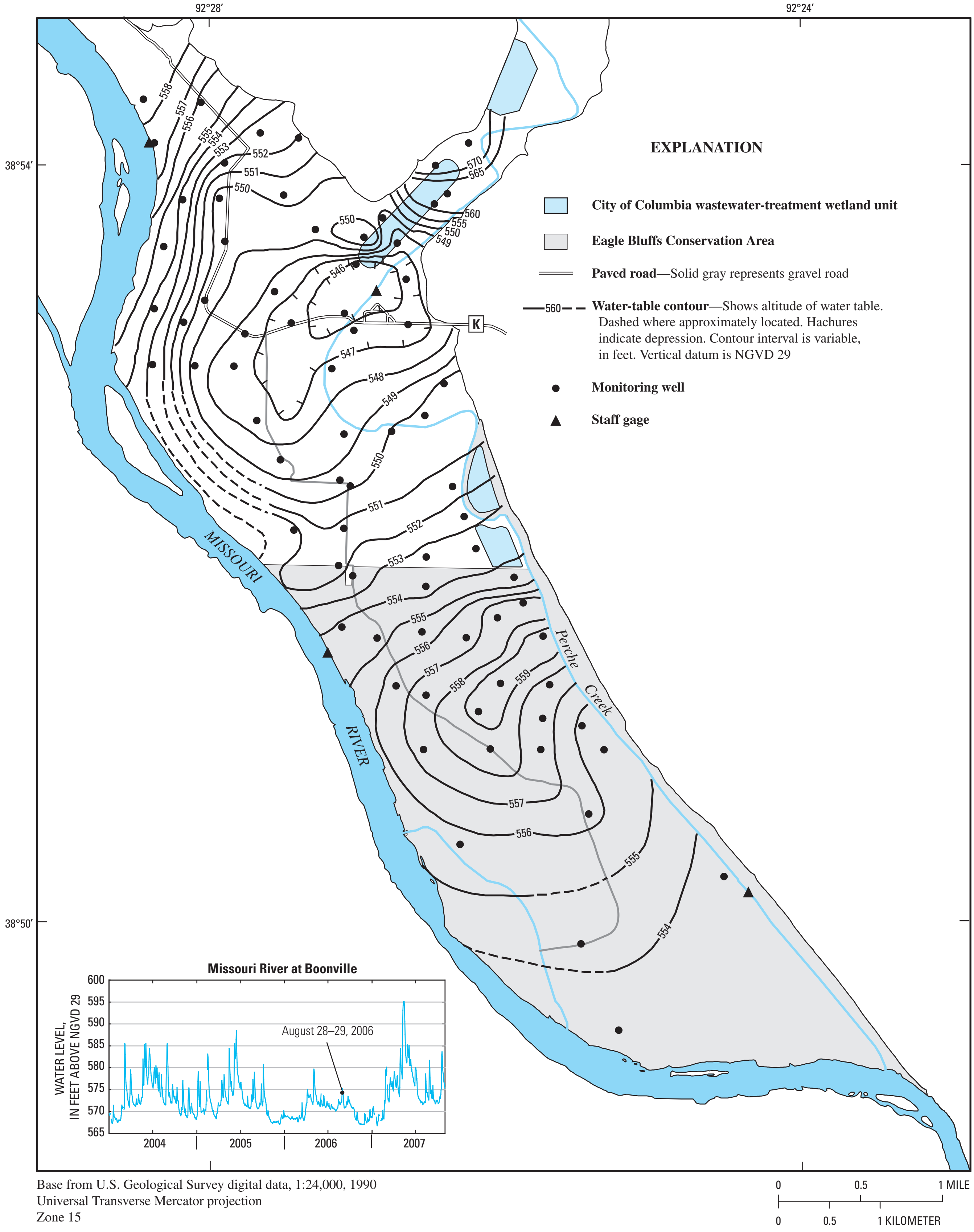
Base from U.S. Geological Survey digital data, 1:24,000, 1993
Universal Transverse Mercator projection
Zone 15

Figure 10. Altitude of the water table in the alluvial aquifer, August 2, 2005.



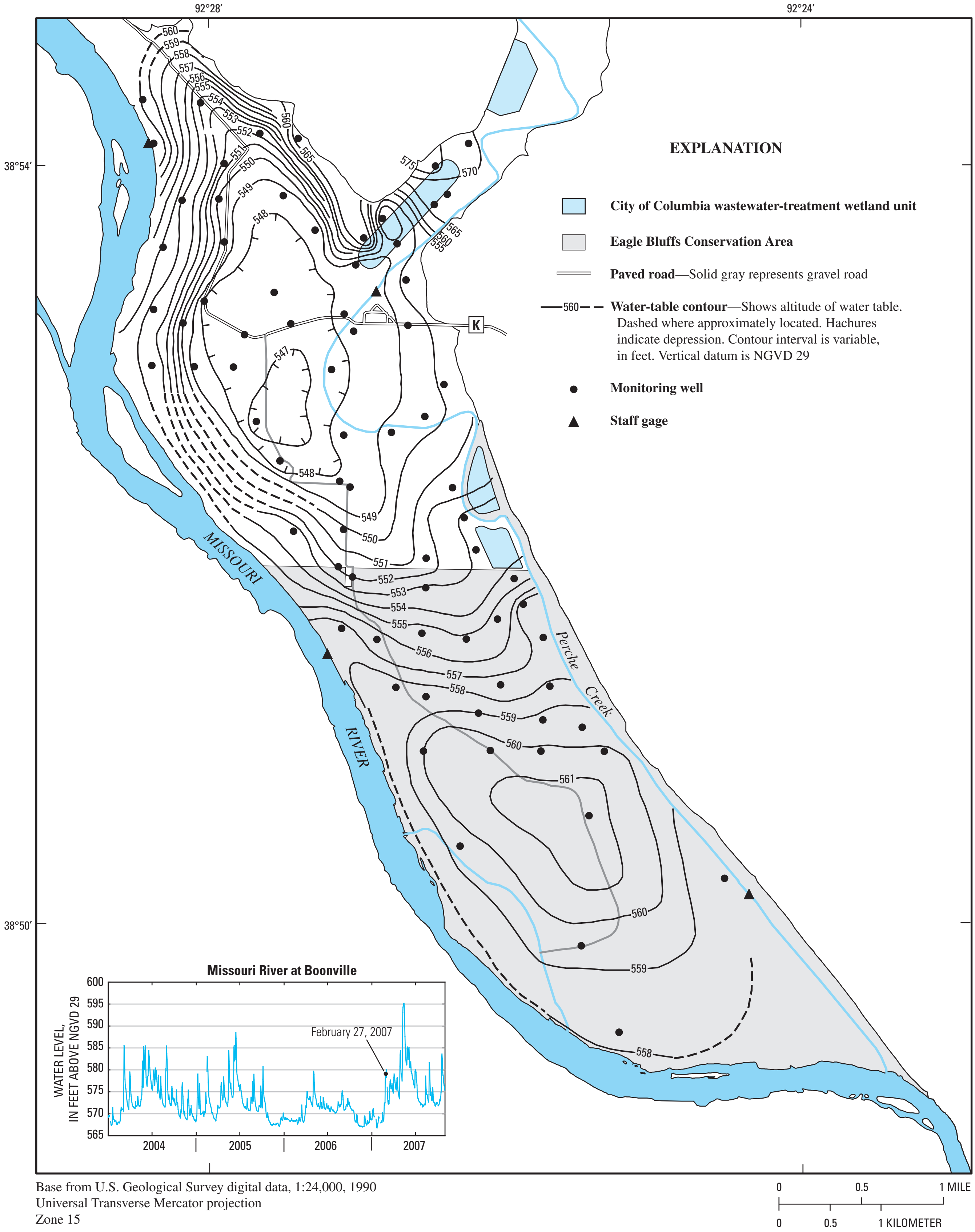
Base from U.S. Geological Survey digital data, 1:24,000, 1990
Universal Transverse Mercator projection
Zone 15

Figure 11. Altitude of the water table in the alluvial aquifer, February 21, 2006.



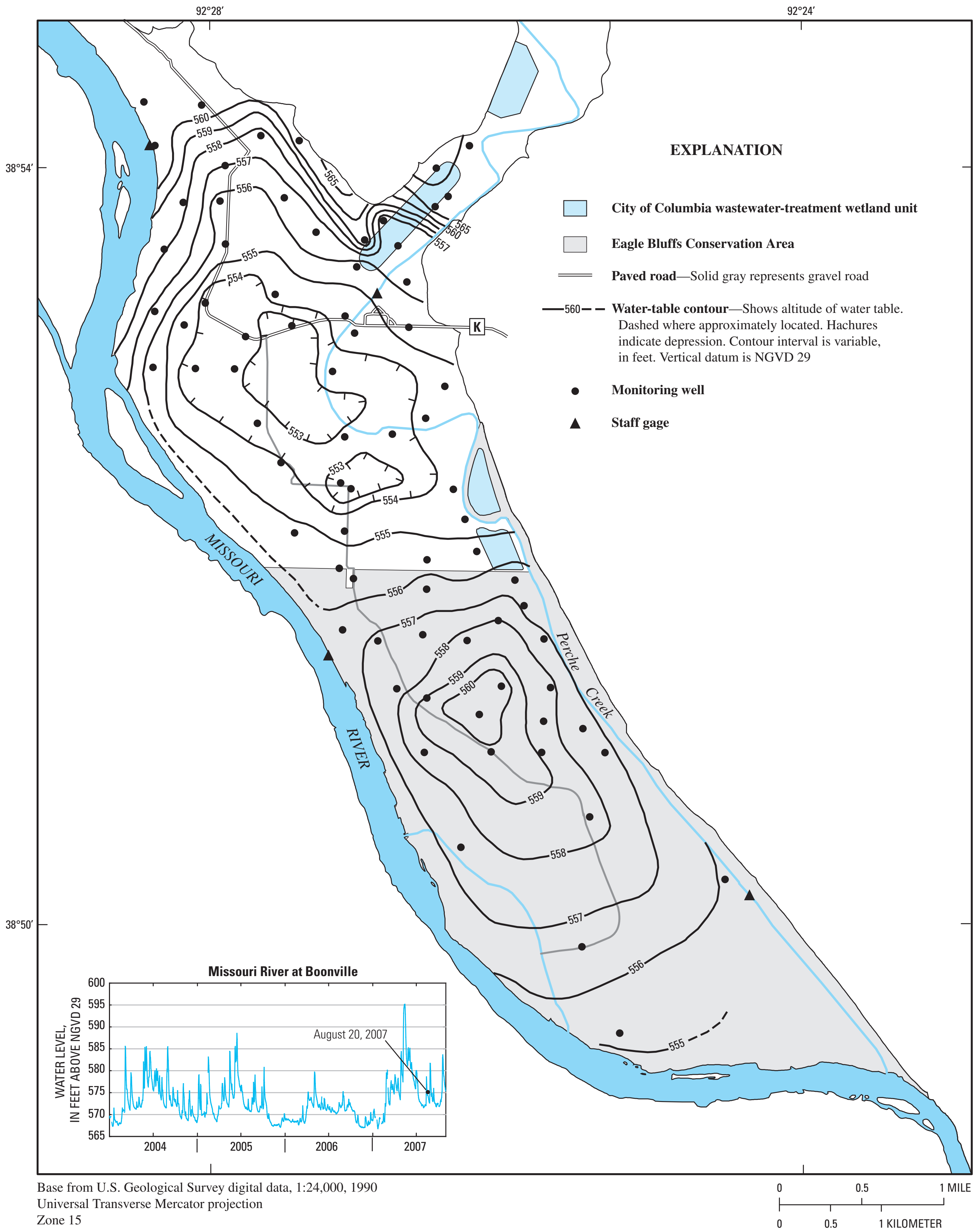
Base from U.S. Geological Survey digital data, 1:24,000, 1990
Universal Transverse Mercator projection
Zone 15

Figure 12. Altitude of the water table in the alluvial aquifer, August 28–29, 2006.



Base from U.S. Geological Survey digital data, 1:24,000, 1990
Universal Transverse Mercator projection
Zone 15

Figure 13. Altitude of the water table in the alluvial aquifer, February 27, 2007.



Base from U.S. Geological Survey digital data, 1:24,000, 1990
Universal Transverse Mercator projection
Zone 15

Figure 14. Altitude of the water table in the alluvial aquifer, August 20, 2007.

Table 5. Summary statistics for selected constituents in samples from McBaine Bottoms, 1992–2007.

[Pre-, indicates pre-effluent sample; post-, indicates post-effluent sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; concentrations dissolved unless otherwise indicated; --, no data]

	Specific conductance		Calcium		Magnesium		Potassium		Sodium		Chloride		Sulfate		Ammonia		Total phosphorus	
	Pre- (µS/cm)	Post- (µS/cm)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)
MW1-1A																		
Number of samples	5	34	5	32	5	32	5	32	5	32	5	32	5	32	5	32	5	32
Minimum	755	756	100	110	18	19	1.8	2.5	29	22	8.8	7.4	180	133	.98	.08	.03	.12
Median	859	931	130	127	22	22	2.9	2.9	30	26	9.2	10	210	184	1.1	1.2	1.6	1.5
Maximum	965	1,340	130	192	23	33	3.2	3.4	30	30	9.9	49	240	260	1.2	1.3	1.7	1.7
Mean	856	961	122	132	21	23	2.7	2.9	30	26	9.4	16	212	190	1.1	1.2	1.3	1.4
Standard deviation	75	129	13	19	2.0	3.3	.55	.22	.55	2.2	.50	12	22	33	.09	.21	.71	.28
MW1-1B																		
Number of samples	5	32	5	32	5	32	5	32	5	32	5	32	5	32	5	32	5	32
Minimum	1,040	978	210	179	38	33	4.3	5.9	21	19	14	11	340	220	2.2	.62	.03	.30
Median	1,280	1,290	220	200	40	37	7.1	6.9	21	21	15	13	350	279	2.5	2.4	.75	1.3
Maximum	1,430	1,420	250	226	41	41	8.0	7.4	21	23	18	15	370	340	2.6	4.1	1.4	1.4
Mean	1,258	1,262	224	201	40	37	6.8	6.8	21	21	16	13	350	284	2.5	2.4	.79	1.2
Standard deviation	142	111	15	11	1.2	1.8	1.45	.30	0	1.1	1.8	.92	12	37	.17	.52	.57	.28
MW1-2A																		
Number of samples	5	34	5	33	5	33	5	33	5	33	5	35	5	33	5	33	5	33
Minimum	518	609	89	100	23	22	2.2	3.6	4.8	5.5	4.1	5	28	24	.05	.04	.01	.03
Median	598	1,225	90	125	23	34	3.4	5.6	5.1	100	4.5	200	32	70	.06	.10	.07	.11
Maximum	627	1,800	96	160	25	43	3.9	6.3	5.3	175	6.2	259	34	115	.08	1.2	.08	1.5
Mean	577	1,254	91	125	24	34	3.3	5.4	5.1	88	4.8	173	31	68	.06	.15	.05	.14
Standard deviation	48	252	3.0	18	.89	4.9	.66	.68	.19	53	.84	65	2.6	21	.01	.23	.04	.25
MW1-2B																		
Number of samples	5	32	5	33	5	33	5	33	5	33	5	33	5	32	5	33	5	33
Minimum	609	622	98	100	23	24	2.6	3.6	8.5	11	7.7	7.7	13	9.6	.42	.41	.25	.12
Median	683	1,160	100	142	24	35	4.0	5.8	12	62	7.9	166	16	44	.49	.55	.34	.30
Maximum	698	1,590	110	158	24	40	4.4	6.9	13	119	9.1	216	24	65	.55	2.0	.37	1.4
Mean	672	1,147	104	137	24	33	3.8	5.5	11	56	8.2	132	17	41	.48	.60	.32	.33
Standard deviation	37	280	5.9	17	.45	4.6	.68	.90	1.7	38	.56	71	4.6	16	.05	.26	.05	.19
MW1-3A																		
Number of samples	5	34	5	32	5	32	5	32	5	32	5	34	5	32	5	32	5	32
Minimum	590	558	87	89	25	26	5	4.2	5.2	5.0	10	8.7	31	28	.56	.04	.02	.03
Median	664	868	92	110	26	34	6.1	4.9	5.7	5.6	10	54	32	40	.62	.49	.49	.39
Maximum	697	1,380	110	169	28	52	6.7	7.1	6.1	58	15	189	33	88	.71	.69	.60	1.0
Mean	655	949	96	121	26	38	6.0	5.1	5.7	14	12	84	32	48	.63	.46	.42	.37
Standard deviation	41	258	8.8	27	1.1	8.6	.70	.70	.38	16	2.3	62	1.0	17	.07	.13	.23	.21
MW1-3B																		
Number of samples	6	32	5	33	6	32	5	33	5	33	5	33	5	33	6	32	6	32
Minimum	472	508	94	88	21	20	3.3	2.9	4.5	4.5	7.0	5.6	24	21	.26	.24	.13	.21
Median	597	958	95	128	22	32	3.5	3.6	4.9	5.6	7.4	74	26	33	.26	.33	.28	.30
Maximum	639	1,500	100	180	24	44	3.6	5.3	5.4	64	7.8	189	29	49	.32	.47	.30	.41
Mean	583	933	97	129	22	32	3.5	3.8	4.9	14	7.4	81	26	34	.27	.33	.25	.30
Standard deviation	65	308	3.0	34	1.1	8.5	.13	.75	.34	16	.29	68	2.3	9.4	.02	.07	.07	.04

Table 5. Summary statistics for selected constituents in samples from McBaine Bottoms, 1992–2007.—Continued

[Pre-, indicates pre-effluent sample; post-, indicates post-effluent sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; concentrations dissolved unless otherwise indicated; --, no data]

	Specific conductance		Calcium		Magnesium		Potassium		Sodium		Chloride		Sulfate		Ammonia		Total phosphorus	
	Pre- (µS/cm)	Post- (µS/cm)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)
MW1-4A																		
Number of samples	9	35	9	32	9	33	9	32	9	32	9	34	9	32	9	33	9	33
Minimum	630	693	100	102	22	0	1.6	1.4	17	17	6.1	4.8	38	32	.10	.07	.07	.04
Median	713	787	110	120	23	27	1.8	1.8	18	18	7.5	6.5	48	69	.11	.11	.08	.09
Maximum	755	1,110	120	138	26	31	1.9	1.9	19	20	9.8	33	64	77	.15	.18	.09	.12
Mean	699	795	108	120	24	26	1.8	1.7	18	18	7.5	8.5	50	64	.11	.11	.08	.09
Standard deviation	37	77	6.7	8.3	1.4	5.0	.10	.12	.78	1.0	1.2	5.3	10	12	.02	.03	.01	.02
MW1-4B																		
Number of samples	9	33	9	32	9	32	9	32	9	32	9	32	9	32	9	33	9	33
Minimum	535	537	76	77	16	16	3.7	2.2	13	13	2.4	2.2	.10	.09	1.2	.34	.91	.21
Median	600	610	83	85	18	18	3.9	3.9	14	15	2.9	2.6	.20	.20	3.4	3.6	1.3	1.3
Maximum	625	827	94	112	19	26	4.9	4.2	15	20	5.6	5.1	1.5	39	3.7	4.0	1.5	1.5
Mean	584	617	83	85	18	18	4.0	3.8	14	15	3.5	2.9	.37	4.7	3.2	3.3	1.2	1.2
Standard deviation	36	55	5.5	6.3	0.88	1.9	.39	.38	.60	1.6	1.2	.77	.44	11	.77	.88	.20	.30
MW2-1A																		
Number of samples	9	32	9	32	9	32	9	32	9	32	9	32	9	32	9	32	9	32
Minimum	603	663	110	110	25	24	2.2	2.0	3.1	3.2	4.0	2.1	21	7.5	.01	.01	.01	.01
Median	710	758.5	120	120	26	26	2.8	2.7	4.2	4.5	4.6	5.6	24	12	.03	.03	.02	.02
Maximum	773	1,010	130	136	27	29	3.1	3.3	11	6.0	7.1	7.4	32	24	.05	.09	.07	.07
Mean	697	759	120	122	26	27	2.7	2.7	5.1	4.5	4.9	5.5	25	14	.03	.04	.03	.02
Standard deviation	56	62	5	7.2	.78	1.5	.29	.31	2.6	.80	.89	1.4	3.5	4.8	.01	.02	.02	.01
MW2-1B																		
Number of samples	9	31	9	31	9	31	9	31	9	31	9	31	8	31	9	31	9	31
Minimum	669	732	120	113	26	25	2.8	4.4	7.0	7.0	5.1	2.8	13	.10	.31	.34	.01	.36
Median	797	877	130	131	27	30	4.6	5.2	7.5	10	6.0	6.3	16	.70	.35	.45	.37	.58
Maximum	850	1,130	130	153	28	36	4.9	6.2	8.0	13	8.6	8.8	17	25	.37	.59	.49	.69
Mean	786	868	129	133	27	29	4.5	5.1	7.5	9.8	6.5	6.3	15	3.5	.35	.44	.32	.56
Standard deviation	69	76	3.3	8.9	1.0	2.7	.65	.40	.33	1.8	1.4	1.0	1.8	5.4	.02	.06	.18	.09
MW3-1A																		
Number of samples	--	35	--	33	--	33	--	33	--	33	--	35	--	33	--	33	--	33
Minimum	--	0	--	120	--	19	--	4.0	--	6.0	--	1.8	--	24	--	<.01	--	.01
Median	--	778	--	129	--	22	--	4.9	--	6.9	--	7.4	--	42	--	.02	--	.03
Maximum	--	1,030	--	172	--	31	--	6.1	--	9.9	--	46	--	61	--	.37	--	.49
Mean	--	784	--	135	--	23	--	4.9	--	7.4	--	8.6	--	42	--	.04	--	.05
Standard deviation	--	185	--	16	--	2.6	--	.45	--	1.2	--	7.8	--	10	--	.07	--	.09
MW3-1B																		
Number of samples	--	32	--	33	--	33	--	33	--	33	--	33	--	33	--	33	--	33
Minimum	--	599	--	110	--	20	--	3.9	--	6.9	--	3.5	--	17	--	.02	--	.02
Median	--	805	--	121	--	27	--	4.4	--	7.4	--	5.1	--	22	--	.38	--	.48
Maximum	--	1,240	--	173	--	35	--	6.0	--	29	--	165	--	70	--	.55	--	.56
Mean	--	845	--	131	--	27	--	4.6	--	8.5	--	23	--	28	--	.36	--	.44
Standard deviation	--	168	--	20	--	3.5	--	.44	--	3.9	--	42	--	14	--	.10	--	.12

Table 5. Summary statistics for selected constituents in samples from McBaine Bottoms, 1992–2007.—Continued

[Pre-, indicates pre-effluent sample; post-, indicates post-effluent sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; concentrations dissolved unless otherwise indicated; --, no data]

	Specific conductance		Calcium		Magnesium		Potassium		Sodium		Chloride		Sulfate		Ammonia		Total phosphorus	
	Pre- (µS/cm)	Post- (µS/cm)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)
MW4-1A																		
Number of samples	8	33	8	33	8	33	8	33	8	33	8	35	8	33	8	33	8	33
Minimum	594	767	110	110	30	25	3.2	1.7	5	7.5	1.2	2.6	2.1	6.3	.22	.13	.03	.08
Median	822.5	958	120	140	37	37	5.6	5.7	7.9	9.6	2.5	7.6	11	51	.55	.87	.51	.50
Maximum	998	1,080	140	164	42	42	6.0	6.4	8.9	25	7.1	27	22	95	.83	1.1	1.3	.80
Mean	825	945	123	140	36	37	5.3	5.6	7.3	12	2.9	9.5	12	44	.54	.82	.59	.49
Standard deviation	143	78	13	13	4.4	4.4	.87	.80	1.4	4.9	1.8	7.1	7.4	28	.24	.20	.54	.14
MW4-1B																		
Number of samples	8	31	8	33	8	33	8	33	8	33	8	33	8	33	8	33	8	33
Minimum	737	690	110	80	30	17	3.3	3.9	8.6	7.9	2.8	2.1	.60	.10	.81	.84	.01	.54
Median	891	902	120	130	36	35	5.0	4.9	10	11	5.7	6.9	2.8	46	.92	.95	.81	.84
Maximum	954	1,380	140	153	40	42	5.5	6.3	14	104	13	188	12	122	.94	4.0	1.8	1.2
Mean	864	978	123	126	36	34	4.9	4.9	11	26	6.5	41	4.9	42	.90	1.0	.71	.86
Standard deviation	85	198	10	15	3.1	5.1	.69	.59	2.149	32	3.8	62	4.6	42	.05	.54	.58	.14
MW4-2A																		
Number of samples	8	34	8	33	8	33	8	33	8	33	8	35	8	33	8	33	8	33
Minimum	768	672	140	115	28	24	6.2	5.8	7.7	6.1	2.7	1.7	16	14	.32	.08	.01	.07
Median	934	1,010	150	140	32	30	6.6	6.8	8.8	11	3.6	46	32	35	.61	.57	.11	.24
Maximum	985	1,400	170	165	35	35	8.3	9.6	11	124	5.6	182	49	68	.67	1.5	.17	.44
Mean	911	1,037	153	142	32	30	6.8	7.1	8.9	38	3.7	65	33	38	.57	.69	.09	.25
Standard deviation	83	174	8.9	15	1.9	3.3	.68	.96	1.2	40	.83	58	12	14	.12	.33	.06	.11
MW4-2B																		
Number of samples	8	32	8	33	8	33	8	33	8	33	8	33	8	33	8	33	8	33
Minimum	732	732	110	91	24	17	5	5	14	10	5.5	4.1	.10	.10	.44	.47	.41	.55
Median	846	1,050	130	145	28	31	5.3	5.8	18	18	8.7	63	.20	30	.48	.58	.66	.67
Maximum	917	1,420	140	160	29	34	5.5	12	23	162	15	234	1.0	95	.51	.93	.82	.89
Mean	838	1,089	128	133	27	28	5.3	6.4	18	55	9.1	90	.36	39	.48	.62	.64	.68
Standard deviation	71	202	8.9	22	1.6	5.4	.20	1.4	3.3	55	3.2	83	.34	36	.02	.11	.12	.07
USGS-1																		
Number of samples	8	22	8	22	8	22	8	22	8	22	8	22	8	22	8	22	8	22
Minimum	585	559	100	110	17	16	4	3.7	4.4	4.6	2.1	2.6	16	24	.05	.05	.01	.03
Median	721.5	748	115	126	19	21	4.4	4.7	5.4	6.4	3.8	5.2	18	34	.08	.13	.05	.11
Maximum	886	884	130	140	20	23	4.8	5.3	6.6	10	6.1	59	19	72	.14	.91	.07	.16
Mean	715	744	114	124	19	21	4.4	4.6	5.5	6.6	4.1	12	18	38	.09	.15	.05	.10
Standard deviation	90	75	11	9.1	1.2	1.9	.26	.46	.97	1.5	1.6	15	1.0	13	.03	.18	.02	.04
USGS-2S																		
Number of samples	8	19	8	19	8	19	8	19	8	19	8	19	8	19	8	19	8	19
Minimum	866	822	130	110	23	20	2.2	5.0	9.4	6.3	1.2	0.9	20	7.3	.58	.57	.01	.01
Median	956.5	1,000	155	141	27	25	6.3	5.6	11	8.1	1.8	8.2	23	25	.66	.70	.62	.67
Maximum	1,060	1,070	170	160	29	30	6.8	6.6	12	66	4.1	94	25	133	.72	.98	.73	.85
Mean	961	969	154	141	26	25	5.9	5.7	11	19	2.2	28	23	43	.65	.72	.51	.63
Standard deviation	71	66	14	14	1.9	2.7	1.5	.46	.86	20	1.1	33	1.5	36	.05	.13	.26	.23

Table 5. Summary statistics for selected constituents in samples from McBaine Bottoms, 1992–2007.—Continued

[Pre-, indicates pre-effluent sample; post-, indicates post-effluent sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; concentrations dissolved unless otherwise indicated; --, no data]

	Specific conductance		Calcium		Magnesium		Potassium		Sodium		Chloride		Sulfate		Ammonia		Total phosphorus	
	Pre- (µS/cm)	Post- (µS/cm)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)
USGS-2D																		
Number of samples	8	19	8	19	8	19	8	19	8	19	8	19	7	19	8	19	8	19
Minimum	862	941	140	87	30	19	5.8	4.9	9.4	8.4	2.5	1.5	.10	.10	.61	.98	.02	.54
Median	1,025	1,030	145	135	31	29	6.2	5.8	10	13	3.5	51	.10	40	1.1	1.1	1.0	1.1
Maximum	1,090	1,210	170	170	36	38	6.4	6.7	11	119	4.2	170	.30	129	1.1	6.3	1.2	1.7
Mean	1,005	1,055	151	131	32	29	6.2	5.9	10	36	3.4	64	.13	50	1.0	1.4	.82	1.0
Standard deviation	79	82	14	27	2.5	5.1	.22	.49	.56	38	.54	62	.08	50	.18	1.2	.43	.26
USGS-3S																		
Number of samples	9	23	9	22	9	22	8	22	9	22	9	22	9	22	9	22	9	22
Minimum	663	667	97	82	21	15	4.1	4.1	7.6	9.2	4.7	15	27	39	.24	.14	.26	.13
Median	973	1,080	160	130	31	23	5.7	5.8	13	72	7.7	126	38	88	.37	.25	.42	.30
Maximum	1,090	1,440	170	168	34	32	6.3	7.7	17	146	14	247	51	139	.42	.75	.48	.66
Mean	905	1,108	143	126	30	23	5.4	5.8	12	76	7.9	128	38	94	.34	.29	.38	.32
Standard deviation	173	182	27	22	4.6	4.5	.73	.84	2.9	39	2.7	55	7.9	31	.07	.14	.10	.12
USGS-3D																		
Number of samples	9	21	9	20	9	20	9	20	9	20	9	21	9	21	9	20	9	20
Minimum	899	868	150	94	34	19	3.2	4.3	15	12	5	5.5	.10	.01	.55	.44	.01	.34
Median	1,040	1,030	160	151	38	34	5.0	5.0	18	20	5.8	8.3	.50	8.8	.61	.62	.67	.65
Maximum	1,160	1,130	170	171	40	42	5.3	5.7	19	100	10	104	3.7	100	.64	.84	.82	.80
Mean	1,048	1,006	160	145	37	32	4.9	5.0	18	28	6.5	30	1.7	28	.61	.63	.60	.64
Standard deviation	100	85	7.1	24	2.0	6.5	.65	.36	1.5	23	1.9	36	1.7	35	.03	.09	.25	.13
USGS-4																		
Number of samples	9	20	7	19	9	20	8	19	7	19	7	19	7	19	9	21	9	21
Minimum	1,140	797	190	121	49	30	7.1	5.2	26	12	8	4.6	11	11	.64	.31	.10	.28
Median	1,420	1,080	220	163	56	41	7.6	6.1	34	16	9.4	7.5	40	25	.67	.52	.33	.35
Maximum	1,600	1,560	230	200	61	49	8.2	6.6	41	45	13	73	49	78	1.0	.79	.99	.46
Mean	1,432	1,104	213	160	55	39	7.6	6.1	34	17	10	19	31	32	.70	.51	.37	.36
Standard deviation	167	188	14	22	4.4	5.8	.35	.37	6.0	7.1	2.4	23	17	21	.11	.12	.25	.05
USGS-5S																		
Number of samples	8	22	8	22	8	22	8	22	8	22	8	23	8	22	8	22	8	22
Minimum	706	624	110	120	24	19	2.5	4.6	12	10	4	5	22	24	.01	<.01	.01	.01
Median	789	843.5	130	130	27	29	5.2	4.9	14	12	5.2	6.7	30	34	.02	.03	.02	.03
Maximum	1,190	1,020	150	154	29	30	5.6	5.4	35	13	7.7	77	92	70	.03	.65	.04	.42
Mean	825	841	128	133	27	28	4.9	4.9	16	12	5.3	24	38	39	.02	.06	.03	.04
Standard deviation	158	100	12	9.4	1.6	2.4	1.0	.22	7.6	.89	1.2	27	23	14	.01	.13	.01	.09
USGS-5D																		
Number of samples	8	21	8	22	8	22	8	22	8	22	8	22	8	22	8	22	8	22
Minimum	862	662	130	78	23	16	5.1	4.4	12	12	6.1	6.9	.10	9.2	.51	.03	.39	.03
Median	978.5	900	180	125	31	25	6.2	5.3	18	20	8.0	34	13	34	.69	.68	.46	.47
Maximum	1,250	1,190	200	170	36	30	6.9	6.1	23	98	8.5	167	35	141	.80	.84	.54	.59
Mean	1,029	915	171	125	30	24	6.2	5.3	17	37	7.5	57	15	52	.67	.65	.45	.45
Standard deviation	151	166	22	26	3.9	4.3	.59	.51	3.7	32	1.0	54	14	41	.11	.17	.05	.11

Table 5. Summary statistics for selected constituents in samples from McBaine Bottoms, 1992–2007.—Continued

[Pre-, indicates pre-effluent sample; post-, indicates post-effluent sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; concentrations dissolved unless otherwise indicated; --, no data]

	Specific conductance		Calcium		Magnesium		Potassium		Sodium		Chloride		Sulfate		Ammonia		Total phosphorus	
	Pre- (µS/cm)	Post- (µS/cm)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)
USGS-6																		
Number of samples	9	22	9	22	9	22	9	22	9	22	9	23	9	22	9	22	9	22
Minimum	1,080	978	170	114	42	25	6.9	4.7	19	19	9.9	8.7	1.4	16	2.5	.88	.01	.09
Median	1,380	1,260	190	149	48	35	7.3	6.2	20	60	14	131	31	93	3.8	1.5	1.6	.89
Maximum	1,640	1,800	230	250	58	60	7.8	7.6	22	109	21	183	53	150	4.1	4.3	1.9	1.9
Mean	1,354	1,289	196	156	49	37	7.3	6.3	20	59	14	113	29	85	3.8	1.8	1.3	.96
Standard deviation	163	189	20	42	5.0	11	.32	.76	1.2	33	3.4	56	17	38	.50	1.037	.74	.41
USGS-7																		
Number of samples	8	20	8	21	8	21	8	21	8	21	8	21	8	21	8	21	8	21
Minimum	786	811	130	64	29	14	5.7	4.3	12	11	3.6	4.0	8.4	14	.72	.31	.01	.17
Median	904.5	922	140	103	32	25	6.2	5.3	14	56	3.8	86	20	129	.78	.73	.39	.31
Maximum	963	1,130	150	150	33	35	6.4	6.2	16	120	6.9	157	22	180	.84	.80	1.7	.39
Mean	885	928	139	103	32	24	6.1	5.3	14	58	4.3	73	18	104	.78	.67	.49	.31
Standard deviation	66	77	6.4	31	1.5	7.5	.26	.60	1.1	42	1.2	47	5.5	56	.04	.15	.51	.05
USGS-8S																		
Number of samples	9	24	9	25	9	25	9	25	9	25	9	25	9	25	9	25	9	25
Minimum	651	593	120	112	24	21	0.7	5.7	5.8	4.6	4.3	3.6	29	25	.02	.01	.01	.01
Median	829	759.5	130	124	26	24	9.2	9.4	6.1	5.4	5.5	4.8	42	38	.03	.02	.01	.03
Maximum	871	836	140	139	28	28	21	14	6.5	6.3	7.7	7.6	64	57	.05	.07	.04	.04
Mean	795	749	132	124	26	24	9.2	9.0	6.1	5.4	5.5	5.0	43	37	.03	.02	.01	.02
Standard deviation	73	62	6.7	6.4	1.1	1.5	5.2	2.4	.22	.44	.97	1.0	12	7.2	.01	.02	.01	.01
USGS-8D																		
Number of samples	9	24	9	25	9	25	9	25	9	25	9	25	9	25	9	25	9	25
Minimum	664	637	120	109	24	23	4.3	5.6	6.5	6.0	6.0	5.1	4.8	6.7	.12	.09	.02	.07
Median	840	796	140	128	26	26	6.6	6.4	6.8	7.7	10	6.5	21	25	.14	.12	.42	.41
Maximum	879	865	140	140	27	27	6.8	7.5	7.2	15	16	10	32	37	.17	.25	.46	.66
Mean	814	781	134	126	26	25	6.3	6.5	6.8	9.1	9.9	6.8	20	24	.15	.13	.32	.41
Standard deviation	73	61	7.3	8.2	.88	.99	.78	.40	.25	3.1	3.4	1.5	9.1	8.7	.02	.04	.17	.10
USGS-9S																		
Number of samples	9	25	9	25	9	25	9	25	9	25	9	25	9	25	9	25	9	25
Minimum	518	532	81	88	18	20	1.8	1.7	5.3	5.2	1.8	1.8	30	27	<.01	<.01	.03	.07
Median	569	638	88	99	20	22	1.9	2.1	7.4	7.2	2.1	3.1	34	46	.02	.01	.05	.11
Maximum	618	787	96	117	23	25	2.2	2.4	8.5	8.5	3.9	49	38	59	.03	.05	.19	.45
Mean	572	635	89	99	21	22	1.9	2.1	7.2	7.0	2.3	6.4	34	45	.02	.02	.09	.15
Standard deviation	34	59	5.4	6.9	1.6	1.2	.14	.19	.96	.89	.66	11	2.6	8.5	.01	.01	.07	.10
USGS-9D																		
Number of samples	9	25	9	24	9	24	9	24	9	24	9	25	9	24	9	25	9	25
Minimum	510	507	80	82	17	16	1.2	1.9	7.0	7.3	8.3	7.8	38	35	.06	.02	.06	.11
Median	572	596	89	89	17	18	2.0	2.0	7.4	8.5	8.8	9.3	44	42	.11	.07	.22	.22
Maximum	836	681	95	103	19	20	2.4	2.3	8.0	10	11	11	46	47	.13	.28	.30	.31
Mean	602	596	89	90	18	18	2.0	2.0	7.5	8.5	9.1	9.5	43	42	.10	.09	.21	.22
Standard deviation	98	45	4.3	5.0	.73	.99	.32	.12	.35	.75	.84	.85	2.6	3.0	.02	.05	.08	.04

Table 5. Summary statistics for selected constituents in samples from McBaine Bottoms, 1992–2007.—Continued

[Pre-, indicates pre-effluent sample; post-, indicates post-effluent sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; concentrations dissolved unless otherwise indicated; --, no data]

	Specific conductance		Calcium		Magnesium		Potassium		Sodium		Chloride		Sulfate		Ammonia		Total phosphorus	
	Pre- (µS/cm)	Post- (µS/cm)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)	Pre- (mg/L)	Post- (mg/L)
Blew hole																		
Number of samples	9	18	9	18	9	18	9	18	9	18	9	18	9	18	9	18	9	18
Minimum	223	234	31	34	5.4	6	2.9	4.4	6.4	14	6.9	17	22	23	.03	<.01	.05	.05
Median	582	868.5	59	107	15	24	4.9	5.7	14	33	16	73	39	50	.04	.04	.14	.13
Maximum	757	1,200	140	151	29	33	8.1	7.4	33	106	33	170	59	85	.25	.92	.25	.29
Mean	516	836	76	104	16	23	5.2	5.8	18	43	17	80	36	54	.09	.15	.15	.13
Standard deviation	196	229	35	35	7.5	6.8	1.5	.62	9.2	29	9.8	47	11	21	.09	.27	.06	.07
Perche Creek																		
Number of samples	8	21	9	21	9	21	9	21	9	21	9	21	9	21	9	21	9	21
Minimum	482	215	65	28	10	4.5	3.9	3.17	18	5.3	18	6.7	68	28	.21	<.01	.12	.04
Median	733.5	486	74	65	14	11	6.6	4.2	35	15	42	17	83	46	1.4	.10	.26	.14
Maximum	1,040	835	86	100	20	19	22	6.1	100	40	130	64	99	97	9.4	.47	1.4	.36
Mean	748	463	73	64	14	11	8.5	4.3	50	16	64	20	83	56	2.2	.14	.42	.15
Standard deviation	204	170	7.3	23	3.3	4.6	5.9	.78	32	8.1	44	13	11	23	2.8	.11	.39	.09

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