

Water-Quality and Ground-Water Hydrology of the Columbia/Eagle Bluffs Wetland Complex, Columbia, Missouri—1992–99

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Abstract

In an effort to restore riverine wetlands along the Missouri River, the Missouri Department of Conservation constructed the 2,700-acre Eagle Bluffs Conservation Area. The primary water source for managing 1,200 wetland acres on the Eagle Bluffs Conservation Area is treated effluent received from a 91-acre constructed wastewater-treatment wetland operated by the city of Columbia, Missouri. The combined areas of the Eagle Bluffs Conservation Area and the wastewater-treatment wetland are termed the Columbia/Eagle Bluffs Wetland Complex. The U.S. Geological Survey, in cooperation with the Missouri Department of Conservation and the city of Columbia, Missouri, collected samples quarterly from August 1992 to March 1999 from a monitoring network that included 33 ground-water sites and 4 surface-water sites to establish a baseline pre-effluent data set and to provide post-effluent data for trend analysis.

Changes in major chemical constituent concentrations have been observed at several sampling locations between pre- and post-effluent data. Analysis of post-effluent time-series water-quality data indicates changes occurred in sodium, potassium, calcium, sulfate, and chloride concentrations at 13 sites. These changes can be correlated to the beginning of the operation of the wastewater-treatment wetland. The concentrations of these major chemical constituents plot on the mixing continuum between pre-effluent ground

water as one end member and the treated effluent as the other end member. At ground-water sites that had changes in concentrations, the relative percentage of treated effluent in the ground water, assuming chloride is conservative, ranged from 11 to more than 100 percent.

At ground-water sites, few changes were noted in fecal indicator bacteria, nutrients, trace constituents, total and dissolved organic carbon, and organic constituents. Other than changes in boron concentrations at one ground-water site, these changes could not be directly correlated to the operation of the treatment wetland or the management of the Eagle Bluffs Conservation Area. After the treatment wetland began operation, improvement in the water quality in Perche Creek was observed. With respect to fecal indicator bacteria and nutrient concentrations, the water quality of water discharging from the Eagle Bluffs Conservation Area was improved relative to the water entering the area.

Persistent ground-water highs have been observed beneath the Eagle Bluffs Conservation Area and wastewater-treatment unit 1 following the flooding of the wetland areas. These ground-water highs occur during the fall and winter months when ground- and surface-water levels are high and during the spring and summer months when the water levels are lower. The Missouri River stage had a strong effect on the water levels in the aquifer during pre-effluent conditions, but the effect has been lessened by the ground-water high.

INTRODUCTION

The Missouri Department of Conservation (MDC) and the city of Columbia, Missouri (fig. 1), initiated a project to utilize constructed wetlands to treat municipal sewage. Because expansion of the Columbia wastewater-treatment facility became necessary, constructing a wastewater-treatment wetland, hereafter referred to as treatment wetland, was selected as an alternative to expanding the existing activated sludge facilities. The MDC uses the treated effluent from the treatment wetland as a water source for managing 1,200 wetland acres on the 2,700-acre MDC Eagle Bluffs Conservation Area, a restored riverine wetland on the Missouri River alluvium (Baskett, 1991). The combined areas of the treatment wetland and the Eagle Bluffs Conservation Area are termed the Columbia/Eagle Bluffs Wetland Complex.

The treatment wetland consists of three wetland units with a total surface area of 91 acres and is designed to treat an average flow of 17.68 Mgal/d (million gallons per day). Unit 1 is the largest and northernmost of the three units (fig. 1). Flow distribution and control structures have been designed for peak flows of as much as 60 Mgal/d. Wastewater entering the treatment wetland consists of blended primary and secondary treated effluent from the existing city wastewater-treatment facility. The treatment wetland has been designed to consistently meet U.S. Environmental Protection Agency National Point Discharge Elimination System permit limitations and treated effluent is pumped to the Eagle Bluffs Conservation Area. Treatment wetland vegetation primarily consists of cattails (*Typha*).

The city of Columbia pumps water for its municipal supply from a well field containing seven pairs of wells located north of the Eagle Bluffs Conservation Area and adjacent to the treatment wetland (fig. 1). During 1992, the U.S. Geological Survey (USGS) began a study in cooperation with the MDC and the city of Columbia to collect hydrologic data in the Columbia/Eagle Bluffs Wetland Complex. The objective of the study was to evaluate effects on water quality and ground-water hydrology that result from the construction and use of the treatment wetland and the use of the treated effluent on the Eagle Bluffs Conservation Area. Because wetland areas are sensitive to both physical and chemical changes in the hydrologic environment, a hydrologic monitoring network of ground-water and surface-water sites was developed to provide data that

can be used to evaluate changes and to analyze trends. The ability to evaluate changes is important because treated sewage effluent is used as a major source of water for wetland management on the Eagle Bluffs Conservation Area. Trend analysis is an invaluable tool for identifying concerns so that management options can be considered. The first task of the study was to collect background data before the area was inundated and wetland management processes began so that a baseline for the hydrologic environment could be established.

Before October 1994, Perche Creek was the receiving water for the discharge from the Columbia wastewater-treatment facility, and this discharge affected the water quality of the creek for approximately 11 mi (miles) between the plant discharge point and the confluence of the creek with the Missouri River. When the treatment wetland began treating wastewater, the city of Columbia stopped using Perche Creek as the receiving water for the treated effluent. The city of Columbia was scheduled to begin using the treatment wetland in the fall of 1993, but because of the damage caused by the 1993 Missouri River flood, operation of the treatment wetland began in October 1994. Management of the wetland areas on the Eagle Bluffs Conservation Area for recreation, hunting, and wildlife habitat was to begin in the fall of 1993, but as a result of the damage caused by the 1993 and 1995 Missouri River floods, full management of the wetland areas began in late 1995. The Eagle Bluffs Conservation Area began accepting treated effluent from the treatment wetland in October 1994. While repairing the damage from the Missouri River floods, the treated effluent that was discharged to the Eagle Bluffs Conservation Area from the treatment wetland was confined mainly to the distribution canal and the areas designated as semi-permanent marsh (fig. 1). The distribution canal is used to control the various wetland pool water levels by diverting water either out of, or into, the canal from the wetland pools on the Eagle Bluffs Conservation Area. After the damage caused by the 1993 and 1995 Missouri River floods to the internal levee system of the Eagle Bluffs Conservation Area was repaired in late 1995, the area was flooded with a blend of Missouri River water and treated effluent from the treatment wetland. This was the beginning of the MDC management cycle of annually flooding and draining parts of the Eagle Bluffs wetland. The MDC floods the wetland in the late summer to attract migrating waterfowl and keeps the wetland flooded through

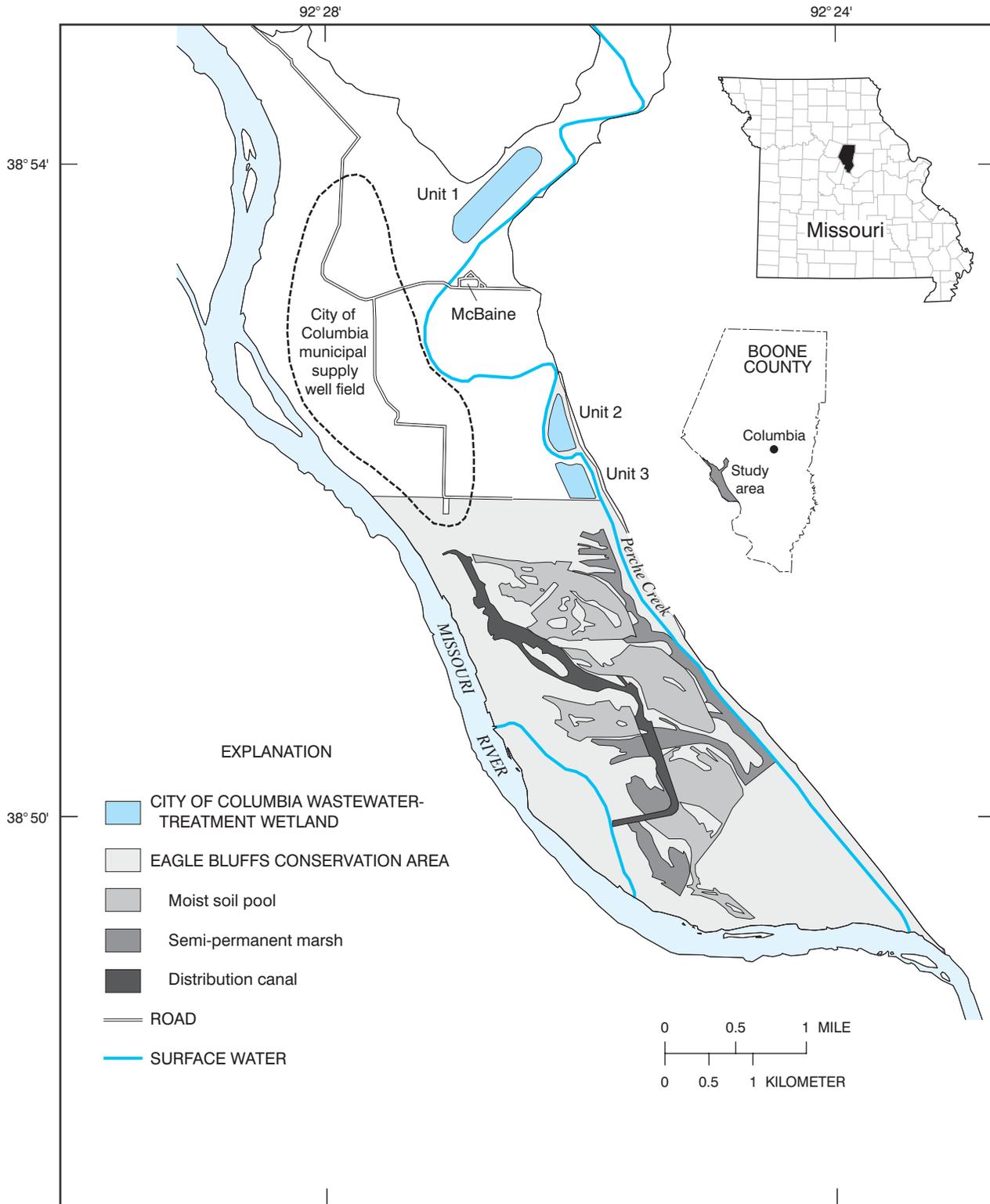


Figure 1. Location of the Columbia/Eagle Bluffs Wetland Complex near McBaine, Missouri.

the fall and winter months. In the spring, the wetland is slowly drained so that the seasonal wetland can be farmed to provide forage for waterfowl in the next year. While the wetland is being farmed in the spring and summer, the treated effluent again is confined to the distribution canal and the semi-permanent marsh areas. The Eagle Bluffs Conservation Area was officially dedicated by the MDC on October 12, 1996.

The purpose of this report is to: (1) present the water-quality data from samples collected from August 1996 through March 1999 from 33 monitoring wells [data collected before August 1996 can be obtained from Richards (1995, 1999)]; (2) present water-level data collected from the monitoring wells and from two continuous water-level recorders; and (3) discuss the changes and trends in ground- and surface-water quality and the changes in ground-water hydrology as a result of the operation of the treatment wetland and the wetland management at the Eagle Bluffs Conservation Area.

STUDY AREA

The Columbia/Eagle Bluffs Wetland Complex is located 7 mi southwest of Columbia, Missouri, near the town of McBaine, along the north bank of the Missouri River (fig. 1). The 8.7-mi² (square mile) area is bounded to the south and west by the Missouri River and to the north and east by the Missouri River bluffs. Perche Creek flows southward along the base of the Missouri River bluffs and discharges into the Missouri River in the southeast part of the study area. Before the construction and operation of the treatment wetland, Perche Creek was used by the city of Columbia as the discharge point for their treated sewage effluent. Several “blew holes” (scour holes) caused by levee failures during past flooding events 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. The area outside of the wetland complex is flat lying agricultural land that primarily is used for raising row crops such as corn, wheat, and soybeans. The area receives an average of 38 in. (inches) of precipitation annually (Missouri Department of Natural Resources, 1986).

The surficial material underlying the Columbia/Eagle Bluffs Wetland Complex primarily consists of Missouri River alluvium that is composed of fine sand, silt, or clay near the surface and sand and gravel at depth. The sand and gravel in the lower part of the

alluvium form the alluvial aquifer. The average saturated thickness of the alluvial aquifer is approximately 60 ft (feet; Emmett and Jeffery, 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 Columbia municipal well field, discharge from the treatment wetland, and changes in river stage.

METHODS OF STUDY

Water-quality samples were collected at 37 sites from August 1992 through March 1999. The samples were analyzed for several constituents at the USGS National Water Quality Laboratory (NWQL). Quality-assurance/quality-control (QA/QC) samples were collected and analyzed to evaluate accuracy of analytical results. Ground-water levels were measured at 35 sites from August 1992 through March 1999. Statistical methods were used to analyze the water-quality data for changes and trends.

Water-quality samples were collected quarterly from as many as 33 ground-water and 4 surface-water sites beginning in August 1992 (fig. 2). Sample collection dates for the ground-water and surface-water sites are shown in table 1. The sampling sites include 19 monitoring wells installed by the city of Columbia, 14 monitoring wells installed by the USGS, and 4 surface-water sites. Well-construction data are given in Richards (1995). The four surface-water sites include one blew hole, the outflow from the treatment wetland (city outflow), the outflow from the Eagle Bluffs Conservation Area (Eagle Bluffs outflow), and Perche Creek. Samples from the city outflow and the Eagle Bluffs outflow were collected to better understand the changes observed in the ground- and surface-water quality.

Water-Quality Sampling

Ground-water samples and the blew hole and Perche Creek surface-water samples were collected and processed as described in Richards (1995, 1999). Samples collected at the city outflow and the Eagle Bluffs outflow were collected in a 1-gallon basket sampler as close as practical to the outflow point. Samples were analyzed for specific conductance, pH, temperature, dissolved oxygen, fecal bacteria, alkalinity, major

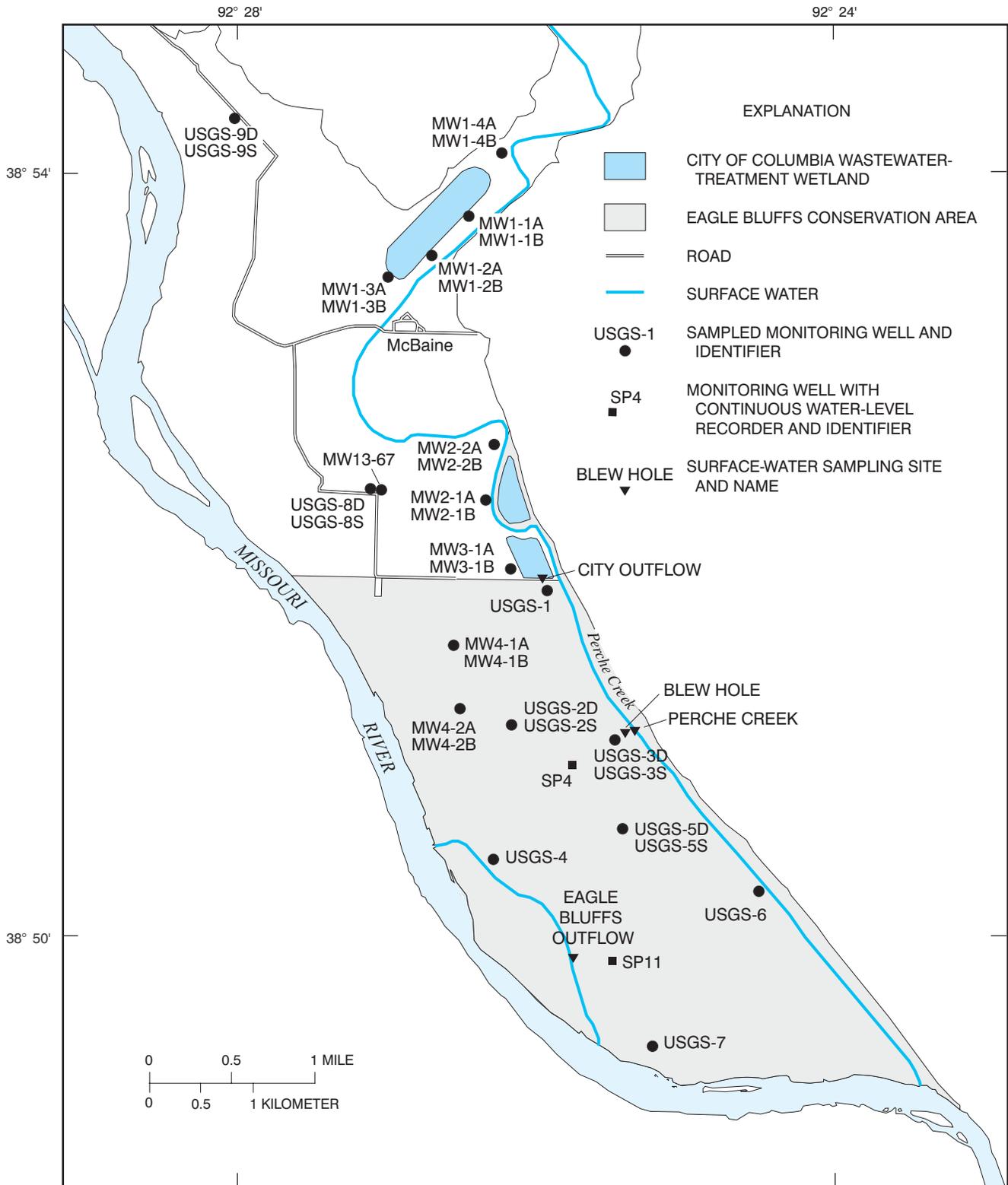


Figure 2. Location of sampling sites and water-level measuring points.

Table 1. Monitoring well depth and screened intervals, and sample collection dates for sites at the Columbia/Eagle Bluffs Wetland Complex

[N/A, not applicable; EB, Eagle Bluffs]

Site identifier or name (fig. 2)	Total depth (feet)	Depth to bottom of screen (feet)	Depth to top of screen (feet)	Period sampled
MW1-1A	31	31	21	June 1993, December 1993 - March 1999
MW1-1B	60	60	50	June 1993, December 1993 - March 1999
MW1-2A	31	31	21	June 1993, December 1993 - March 1999
MW1-2B	61	61	51	June 1993, December 1993 - March 1999
MW1-3A	31	31	21	June 1993, December 1993 - March 1999
MW1-3B	61	61	51	June 1993, December 1993 - March 1999
MW1-4A	29.5	29.3	19.8	August 1992 - March 1999
MW1-4B	60.0	59.8	50.3	August 1992 - March 1999
MW2-1A	29.8	29.6	20.1	August 1992 - March 1999
MW2-1B	59.9	59.7	50.2	August 1992 - March 1999
MW2-2A	30	30	20	December 1994 - August 1998
MW2-2B	60	60	50	December 1994 - August 1998
MW3-1A	30	30	20	December 1994 - March 1999
MW3-1B	60	60	50	December 1994 - March 1999
MW4-1A	29.9	29.7	20.2	August 1992 - March 1999
MW4-1B	59.4	59.2	49.7	August 1992 - March 1999
MW4-2A	29.5	29.3	19.8	August 1992 - March 1999
MW4-2B	59.9	59.7	50.2	August 1992 - March 1999
MW13-67	105	105	85	August 1992 - June 1993
USGS-1	33.0	27.5	17.5	August 1992 - June 1998
USGS-2D	62.0	57.0	47.0	August 1992 - June 1998
USGS-2S	32.4	27.4	17.4	August 1992 - June 1998
USGS-3D	63.0	58.0	48.0	August 1992 - June 1998
USGS-3S	32.0	27.0	17.0	August 1992 - June 1998
USGS-4	62.6	57.6	47.6	August 1992 - June 1998
USGS-5D	51.1	51.1	41.1	August 1992 - June 1998
USGS-5S	29.5	24.5	14.5	August 1992 - June 1998
USGS-6	33.5	28.5	18.5	August 1992 - June 1998
USGS-7	60.8	60.8	50.8	August 1992 - June 1998
USGS-8D	62.8	57.8	47.8	August 1992 - March 1999
USGS-8S	32.8	27.8	17.8	August 1992 - March 1999
USGS-9D	68.0	63.0	53.0	August 1992 - March 1999
USGS-9S	38.0	33.0	23.0	August 1992 - March 1999
Perche Creek	N/A	N/A	N/A	August 1992 - August 1998
Blew Hole	N/A	N/A	N/A	August 1992 - August 1998
City Outflow	N/A	N/A	N/A	December 1996 - June 1998
EB Outflow	N/A	N/A	N/A	December 1996 - June 1998

chemical constituents, nutrients, trace constituents, total and dissolved organic carbon, and selected organic compounds. The USGS NWQL analyzed all samples for inorganic (major chemical constituents, nutrients, and trace constituents) and organic constituents according to methods described by Wershaw and others (1983), Fishman and Friedman (1989), Patton and Truitt (1992), and Fishman (1993).

Specific conductance, pH, temperature, dissolved oxygen, fecal coliform, and fecal streptococci were determined onsite using procedures described by Wilde and Radtke (1998). Occasionally, equipment problems occurred onsite and the onsite specific conductance values were considered unreliable. On such occasions, the reported values in table 2 (at the back of this report) were determined in the laboratory. Specific conductance and temperature values were measured using a portable conductivity meter with temperature compensation designed to express readings in microsiemens per centimeter ($\mu\text{S}/\text{cm}$) at 25 °C (degrees Celsius). The pH value of the water was measured at the time of collection with an electronic meter calibrated with buffers bracketing the expected pH values of the samples. Dissolved-oxygen concentrations were determined using a low-range, colorimetric method for ground-water sites and a portable temperature compensated meter for surface-water sites.

Based on spatial distribution, 8 of the 33 wells were selected to receive detailed sampling for organic compounds. Samples from these eight wells and four surface-water sites were analyzed for base/neutral/acid (BNA) semi-volatile organic compounds, selected pesticides (and metabolites), and selected organochlorine compounds. In addition, samples from the eight wells were analyzed for purgeable volatile organic compounds. Most of the organic compounds were not detected in the samples from the wells or the surface-water sites (table 3, at the back of this report). Data for the samples collected from the wells and the surface-water sites that had organic compounds detected are listed in table 4, at the back of this report. The method detection limits (MDL; less than values) in table 4 vary from constituent to constituent and with time, for the same constituent. An explanation for the variation in the MDL is given in Richards (1999).

Quality Assurance/Quality Control

The components of analytical variability (uncertainty) in water-quality results can be estimated when

QA/QC samples of the correct types and quantities are incorporated into measurement procedures. The USGS NWQL incorporates numerous QA/QC samples in the laboratory to ensure that the measurement system is functioning properly. In addition to the laboratory QA/QC procedures, QA/QC samples were collected onsite at the Columbia/Eagle Bluffs Wetland Complex.

The most common error attributable to onsite procedures is contamination of the sample matrix. Two general forms of contamination occur: systematic and erratic. The goal of the field QA program is to decrease the systematic component and provide evidence of the erratic component by collecting replicate samples and filtration, equipment, field, and trip blanks. The onsite QA/QC samples made up approximately 10 percent of all water-quality samples collected for the project.

Replicate Samples

Replicate samples are collected and analyzed to determine the precision of sampling, processing, and field analysis. Generally a replicate sample is collected immediately after a regular sample using the same equipment and sampling techniques. Both the regular and replicate samples are analyzed at the NWQL using identical analytical techniques. A relative percent difference greater than 20 percent between the regular sample and replicate usually indicates that the sampling process is not representative.

Replicate samples were collected throughout the project and most of the analyses were less than the relative percent difference threshold of 20 percent. The nutrient analyses (nitrogen and phosphorus constituents) and the organic carbon analyses had the highest relative percent differences and were sometimes greater than the 20 percent threshold. Occasionally, some trace constituents also had high relative percent differences. However, the concentrations of nutrient and the trace constituents usually were close to the detection limits, and small errors in measurement precision at the laboratory translate to large relative percent differences for these constituents. Based on the results of the blank analyses (discussed in the next section), the samples were unlikely to have been contaminated with nutrients or trace constituents onsite while sampling. A small amount of dissolved organic carbon contamination may have been present in the organic free water used to clean the sampling apparatus. However, following the cleaning of the dissolved organic carbon apparatus, almost none of the cleaning water remains in or on the apparatus. The device is rinsed

with native water before the collection of a regular sample is attempted, and the contamination from cleaning water is considered to be minimal. Organic carbon analyses probably were most affected by interference of a large amount of iron precipitate present in most of the ground-water samples.

Blanks

Filtration blanks are defined as samples obtained by pumping analyte-free water through the sampling pump mechanism and through the capsule filter used for preparing dissolved nutrient, major ion, and trace constituent samples for shipment to the laboratory. The filtration blank is processed according to the same procedures used for a regular sample and is submitted to the NWQL for analysis. These samples are used to determine the cleanliness of the pump and filter.

Equipment blanks are defined as samples obtained by processing analyte-free water through sampling and/or sample-processing equipment. The equipment blank sample is processed according to the same procedures used for a regular sample and is submitted to the NWQL for analysis. These samples are used to determine the effectiveness of cleaning procedures, both onsite and in the laboratory.

Field blanks are defined as the onsite collection (the transfer of analyte-free water into the appropriate sample collection containers) of analyte-free water. These blanks are submitted to the NWQL and analyzed for the same constituents as a regular sample. These samples are used to determine if any contaminants are present in the sample collection area that may affect sample results. Field blanks are randomly collected throughout the sampling year.

The purpose of the trip blank is to assess the effect that transporting a sample has on representativeness. The trip blank is prepared by completely processing a particular laboratory schedule with analyte-free water, then transporting this package to and from the site. The sample is then sent to the laboratory for analysis as if it were a regular sample.

The blanks collected throughout the study showed few instances of contamination. Calcium and silica were detected in the blanks at or near detection limits in most of the blank samples. The reason for the presence of these two constituents in the blank samples is uncertain. Analytical uncertainty at the detection limit could account for these concentrations. The frequency and consistency of the detections indicate that the purity of the "analyte-free" water used for the

blanks could be suspect. The calcium and silica concentrations in the natural water are approximately four orders of magnitude higher than the concentrations detected in the blank water. Even if contamination of the samples did occur, the small mean concentrations in the blank samples of 0.02 mg/L (milligram per liter) for calcium and 0.03 mg/L for silica will not affect the analytical results or interpretation for the natural-water samples collected.

Dissolved ammonia, total phosphorus, dissolved phosphorus, and orthophosphorus were detected at or near detection limits in about one-third of the blanks. The analytical variability near the detection limit for these constituents could explain the measured concentrations in the blanks.

Total and dissolved organic carbon were detected in several of the blanks. The average concentration for both the total and dissolved organic carbon in the blank samples was 0.3 mg/L. Because of the consistency of the organic carbon detections in the blank samples, the purity of the "organic free" blank water used for the blank samples and for onsite cleaning of the sampling apparatus could be suspect.

Ground-Water Levels

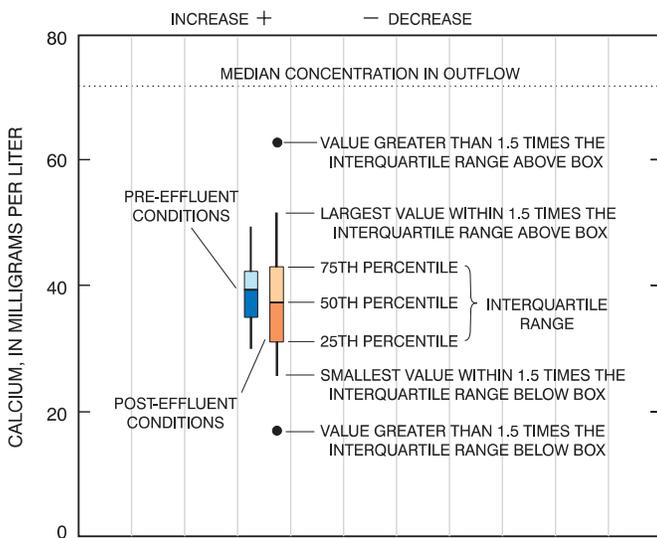
Ground-water levels were measured at the 33 wells in the water-quality monitoring network and at 2 wells with water-level recorders (SP 4 and SP 11; fig. 2). The altitude of well measuring points (usually the top of the riser pipe) was surveyed so that accurate water levels referenced to a common datum (mean sea level) could be measured and potentiometric-surface maps could be made. Water-level measurements at all sites were made synoptically so that Missouri River stage fluctuations or temporal ground-water fluctuations would have a minimal effect on the measurements. Water-level measurements were made quarterly for the period indicated on table 1. An electric tape was lowered into the well, and the depth to the ground water from the measuring point was read to the nearest 0.01 ft. The wells with water-level recorders (SP 4 and SP 11) collected water-level data at hourly intervals using a float from July 1992 to July 1997 and using a submerged pressure transducer from July 1997 to June 1998.

The 35 wells for ground-water-level measurement are distributed throughout the study area. Two of the wells (USGS-9D and USGS-9S) are in the north part of the study area and two wells (USGS-8D and

USGS-8S) are located in the southern part of the Columbia municipal-supply well field. Several wells located near the treatment wetland with eight wells surrounding unit 1, four wells near unit 2, and two wells near unit 3. The other wells are spatially distributed on Eagle Bluffs to provide a reasonable representation of the potentiometric surface in that area. The monitoring network was not designed to allow a detailed potentiometric surface to be interpreted for the entire study area.

Statistical Analysis

A boxplot is useful for visually examining the central tendency and dispersion of a group of data or for comparing two or more groups of data. An example boxplot is shown in figure 3. Only sites having an adequate number of samples to evaluate pre- and post-effluent conditions using boxplots are shown on figures 4 to 24.



NOTE: Statistically significant increase (+) or decrease (-) from pre-effluent to post-effluent conditions using the Mann-Whitney test with the p-value less than 0,05

Figure 3. Boxplot example.

Nonparametric statistical methods were used to analyze the water-quality data collected. These methods were appropriate because the data were not normally distributed, and a large percentage of the data were censored; that is, many of the concentrations were less than the reporting limit. The nonparametric statistical method used was the Mann-Whitney test (Helsel and Hirsch, 1992). Because this study was undertaken

to determine if the operation of the wetland increased or decreased concentrations of constituents in the ground and surface water, a two-tailed Mann-Whitney test was used. For statistical analysis, censored data were changed to one-half the laboratory reporting limit.

A significance level of 0.05 was applied for all statistical tests in this study. Results of the Mann-Whitney test with a p-value less than 0.05 indicated that a statistical difference exists. Indication of a statistical difference does not always indicate a practical or chemically significant difference. This acceptable probability of error (alpha = 0.05) means that the chance is 1 in 20 that results of the statistical test indicated a significant difference when one did not exist.

WATER-QUALITY CHARACTERISTICS

During the study, samples were collected at ground-water and surface-water sites to establish a baseline and to identify changes and trends in the ground- and surface-water quality. Characteristics in physical properties, major chemical constituents, nutrients, trace constituents, organic carbon, and certain organic compounds are used to evaluate the interaction of treated sewage effluent with the ground and surface water in the Columbia/Eagle Bluffs Wetland Complex. In most cases, the discussion will focus on the differences between the pre-effluent background conditions (August 1992 to August 1994) and the post-effluent conditions (December 1994 to March 1999) that exist in the study area. To better understand the changes observed in the ground and surface water, samples from the city outflow and the Eagle Bluffs outflow were collected. Data collected prior to December 1996 are listed in Richards (1995, 1999) and data collected from December 1996 to March 1999 are listed in table 2.

Physical Properties

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

Specific Conductance

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 ions in solution and can be used for approximating the dissolved-solids concentration of the water. Boxplots of the pre- and post-effluent specific conductance values for sites sampled throughout the study are shown in figure 4.

Pre-effluent minimum, mean, median, and maximum specific conductance values from all ground-water samples collectively were 458, 839, 803, and 1,630 $\mu\text{S}/\text{cm}$ (microsiemens per centimeter at 25 °C), respectively. Pre-effluent median specific conductance in the ground-water samples ranged from 458 $\mu\text{S}/\text{cm}$ at MW2-2A to 1,420 $\mu\text{S}/\text{cm}$ at USGS-4. Post-effluent minimum, mean, median, and maximum specific conductance values from allground-water samples collectively were 421, 863, 838, and 1,800 $\mu\text{S}/\text{cm}$, respectively. Post-effluent median specific conductance in ground-water samples ranged from 452 at MW2-2A to 1,300 at MW1-1B.

In most cases, at sites with well clusters (wells with A and B or D and S in their site designations), samples from the deeper wells (B and D designations) have a higher median specific conductance value. The exception to this is when the water in one or both wells in the cluster have been substantially affected by surface water. The ground-water sites with a larger range of values (longer boxes) generally are those that have been affected by effluent-enriched surface water.

Samples from wells MW1-2A, MW1-2B, MW1-3A, MW1-4A, MW2-1A, MW2-1B, MW4-2B, and USGS-9S had a statistically significant increase in specific conductance values between pre- and post-effluent samples. Samples from USGS-4, USGS-5D, and USGS-8S had a statistically significant decrease in specific conductance values.

Pre-effluent minimum, mean, median, and maximum specific conductance values from the blew hole and Perche Creek surface-water samples collectively were 223, 621, 600, and 1,040 $\mu\text{S}/\text{cm}$, respectively. The pre-effluent median specific conductance values for the blew hole and Perche Creek were 582 and 691 $\mu\text{S}/\text{cm}$, respectively. Post-effluent minimum, mean, median, and maximum specific conductance values from blew hole and Perche Creek surface-water samples collectively were 215, 641, 624, and 1,200 $\mu\text{S}/\text{cm}$, respec-

tively. The post-effluent median specific conductance values for the blew hole and Perche Creek were 866 and 461 $\mu\text{S}/\text{cm}$, respectively.

Samples from the blew hole indicate a gradual increase in specific conductance values with time, and samples from Perche Creek indicate an overall decrease. The blew hole is located outside of the flood control levee along Perche Creek; however, when flood conditions exist, water from Perche Creek or the Missouri River, or both, interacts with the water in the blew hole. The maximum depth of the blew hole is approximately 12 ft, and it has a soft mud bottom. Because of the relative infrequency of flooding, the small basin (approximately 1 acre) diverting precipitation to the blew hole, and water remaining in the blew hole all year, water from the blew hole most likely contains a large component of recharge from the local ground-water system. The blew hole also probably has large evaporative losses that could concentrate solutes in the summer.

Median specific conductance values for the outflow from the treatment wetland and the outflow from Eagle Bluffs were 1,200 and 984 $\mu\text{S}/\text{cm}$, respectively. In nearly all samples, the specific conductance values at the outflow from the treatment wetland exceeded the values at the outflow from Eagle Bluffs. Based on the specific conductance values of the outflow from the treatment wetland, the specific conductance in wells with median pre-effluent values less than 1,200 $\mu\text{S}/\text{cm}$ would be expected to increase and those with median pre-effluent values larger than 1,200 $\mu\text{S}/\text{cm}$ to decrease. Post-effluent specific conductance values in samples from 15 of 25 wells with median pre-effluent specific conductivity values greater than 1,200 $\mu\text{S}/\text{cm}$ increased and in samples from 2 of the 3 wells with median pre-effluent specific conductivity values less than 1,200 $\mu\text{S}/\text{cm}$ decreased.

pH

The pH value is a measure of the hydrogen ion activity in water and is an important factor regulating the rates of chemical and biological activity. In the Columbia/Eagle Bluffs Wetland Complex, as with most natural waters, the principal factors regulating the pH are carbonate reactions. The degree of dissociation of weak acids or bases, some of which are toxic, is affected by changes in pH. For example, the dissociation of ammonia is increasingly inhibited by increasing pH, and the water becomes more toxic as a result. The

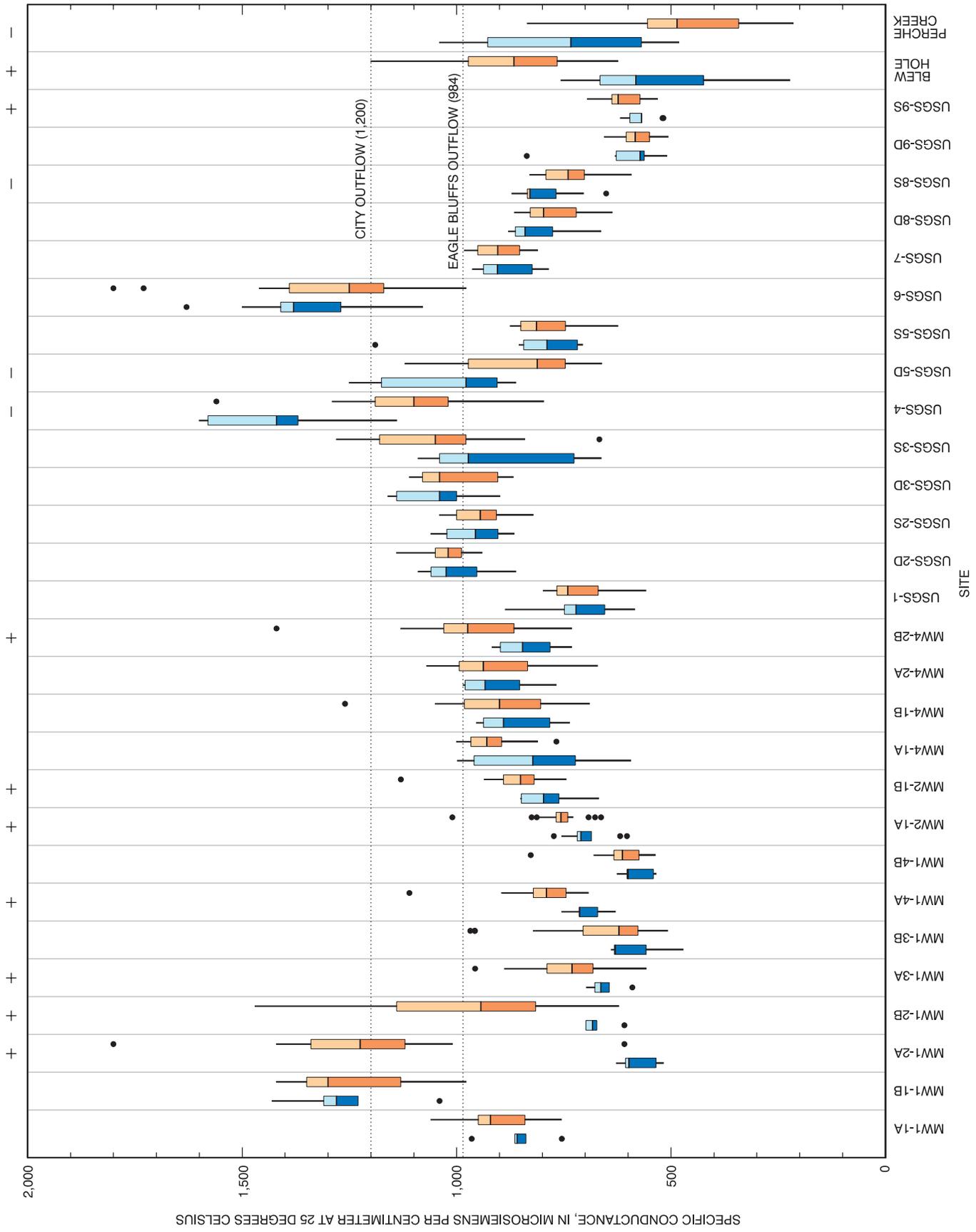


Figure 4. Distribution of specific conductance values at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

solubility of trace constituents contained in the aquifer material and the bottom or suspended sediments associated with surface water also generally increases with decreasing pH. Boxplots of the pH values for ground-water sites sampled throughout the study are shown in figure 5.

Sample pH values did not change substantially between pre- and post-effluent sampling, and as a result, the summary statistics are not split into pre- and post-effluent categories. Minimum, mean, median, and maximum pH values from all ground-water samples collectively were 6.2, 7.0, 7.0, and 7.4, respectively. Median pH values in the ground-water samples ranged from 6.6 at MW1-1A to 7.2 at MW1-2B, MW1-3B, and USGS-3D. Minimum, mean, median, and maximum pH values from all surface-water samples collectively were 6.3, 7.7, 7.6, and 9.0, respectively. Median pH values in the surface-water samples ranged from 7.4 at the city outflow and Perche Creek to 8.4 at the Eagle Bluffs outflow.

Temperature

The rates of most chemical reactions and biological processes generally increase with increasing temperature. Increased temperature accelerates the biodegradation of organic material in water and bottom sediments. Boxplots of the temperature values for sites sampled throughout the study are shown in figure 6.

Temperature values did not vary significantly between pre- and post-effluent sampling, and as a result, the summary statistics were not split into pre- and post-effluent categories. Minimum, mean, median, and maximum temperature values from all ground-water samples collectively were 6.9, 14.4, 14.3, and 18 °C, respectively. Minimum, mean, median, and maximum temperature values from all surface-water samples collectively were 1.5, 13.7, 10.9, and 28 °C, respectively. Because of the seasonal nature of the sampling events and the relatively few number of data points for the surface-water sites, these summary statistics may not adequately represent daily and seasonal variations in surface-water temperature.

Dissolved Oxygen

Dissolved oxygen is required for survival by most forms of aquatic life and also is necessary for chemical oxidation of naturally occurring organic materials, waste loads, and dissolved trace constituents that precipitate as metal oxides. The concentration of

dissolved oxygen in a surface-water body is determined by water temperature, atmospheric pressure, plant photosynthesis, biological activity, chemical reactions, waste loads, and hydraulic properties that affect rates at which atmospheric oxygen can be supplied. The water quality and ability of a surface-water body to support diverse aquatic life are directly related to the dissolved-oxygen concentrations.

The ground water at the Columbia/Eagle Bluffs Wetland Complex generally had little (less than 0.1 mg/L) dissolved oxygen (table 2). Wells MW2-1A and USGS-9S had fairly consistent measurable dissolved-oxygen concentrations. Most other wells had dissolved-oxygen concentrations that were less than 0.1 mg/L. Often when purging the well during sampling, a slight to almost pungent hydrogen sulfide odor was present. Gaseous hydrogen sulfide generally indicates a strong reducing environment and, as a result, the dissolved-oxygen concentration usually is extremely low.

Dissolved-oxygen concentrations did not change substantially between pre- and post-effluent sampling for surface-water sites, and as a result, the summary statistics were not split into pre- and post effluent categories. Minimum, mean, median, and maximum dissolved-oxygen concentrations from all surface-water samples were 2.5, 9.41, 9.10, and 19.7 mg/L, respectively. Median concentrations of dissolved oxygen in surface-water samples ranged from 4.8 mg/L in the city outflow to 12.0 mg/L in the Eagle Bluffs outflow.

Indicator Bacteria

Fecal coliform and fecal streptococci bacteria occur in the intestinal tracts of warm-blooded animals. Although fecal coliform bacteria are not pathogenic, their presence in water indicates fecal contamination and, therefore, the possible presence of other organisms that are pathogenic (Hem, 1992). The sources of fecal coliform and fecal streptococci contamination include municipal wastewater-treatment effluents, septic tanks, animal wastes from feedlots and barnyards, and animal wastes from waterfowl and other warm-blooded animals living in and near the wetland areas.

Few ground-water samples contained indicator bacteria, and the densities did not differ significantly between pre- and post-effluent conditions. Fecal streptococci were the indicator bacteria most often detected. The range of densities of fecal streptococci bacteria in ground-water samples was from less than 1 to 256 (non-ideal count) col/100 mL (colonies per 100

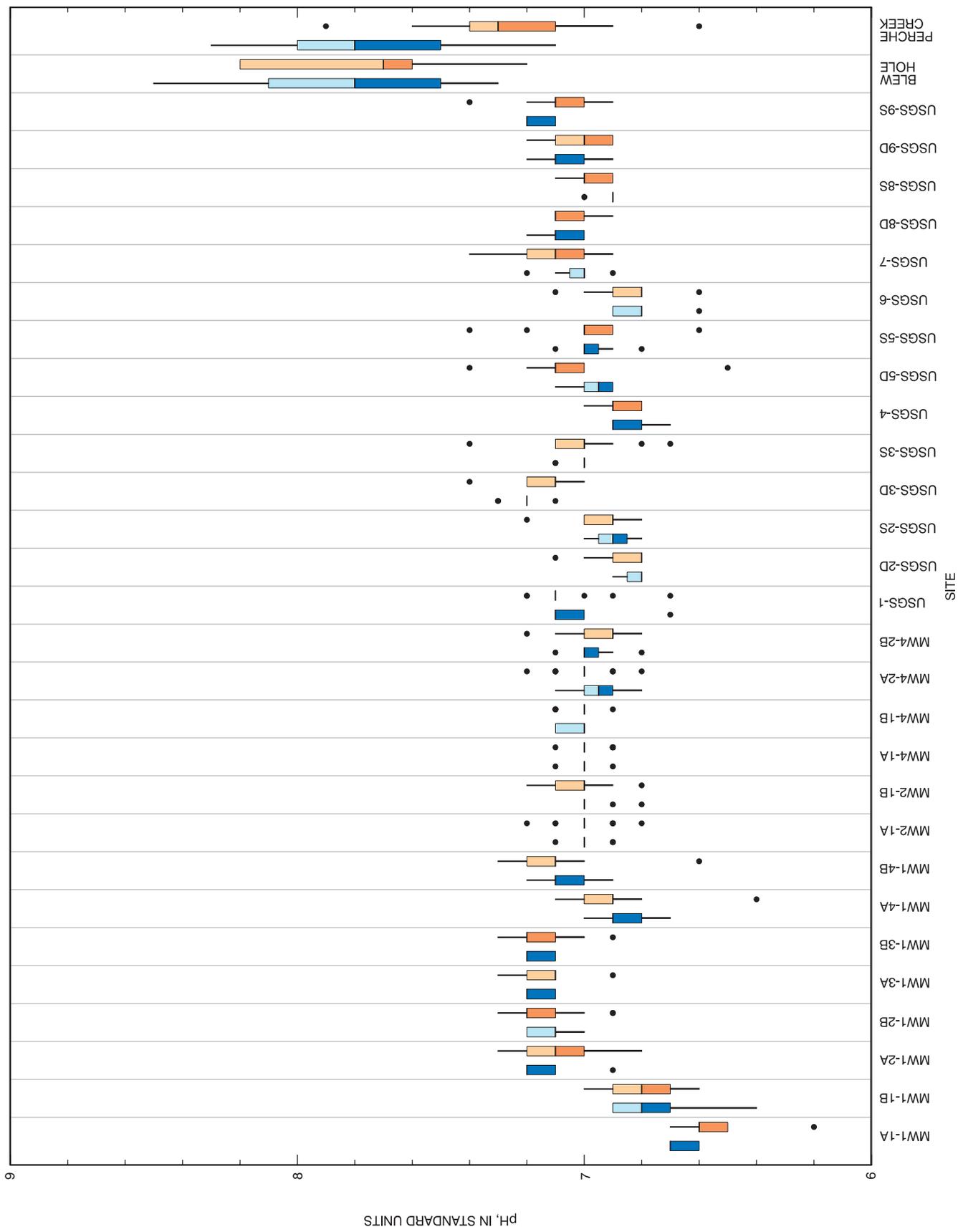


Figure 5. Distribution of pH values at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

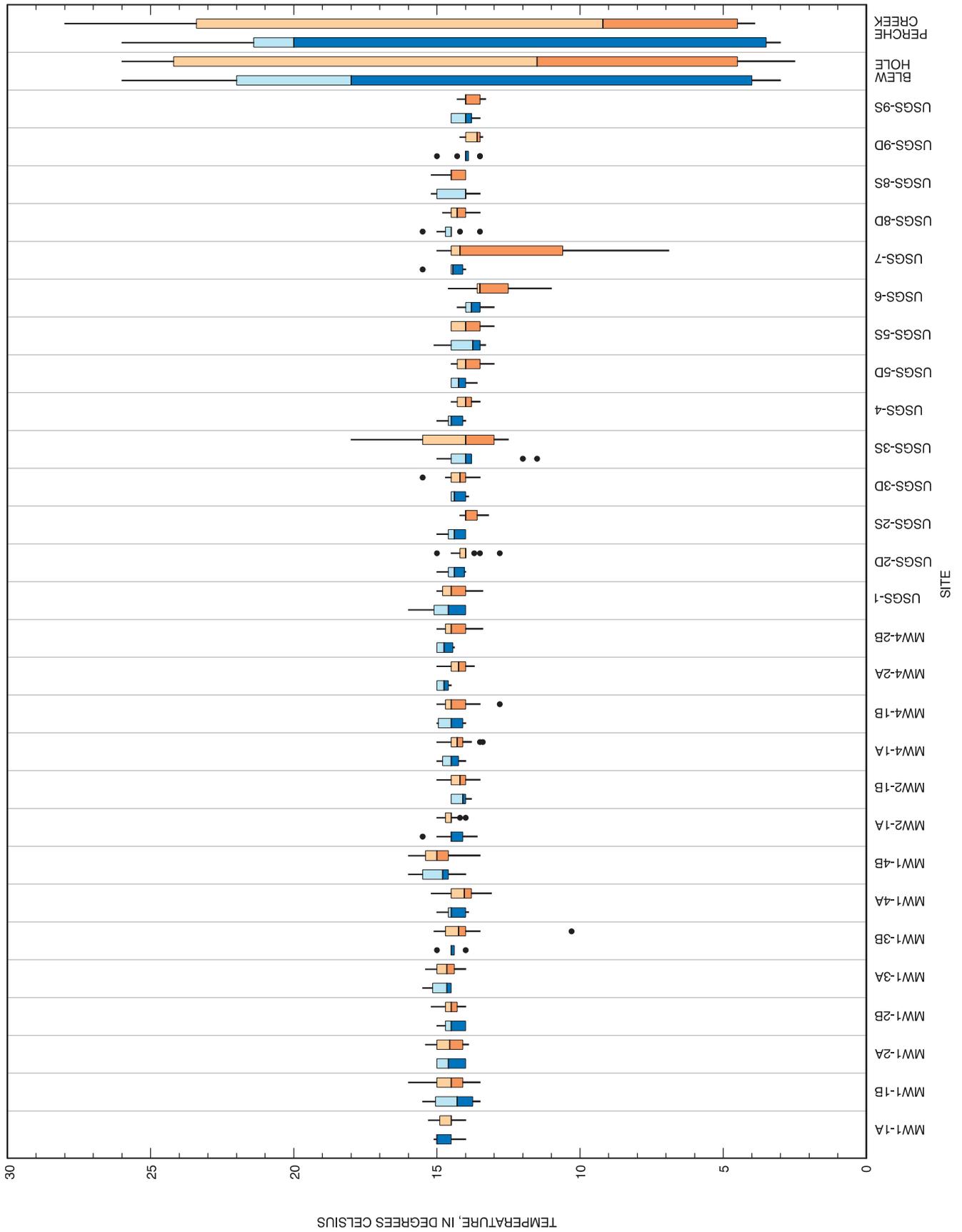


Figure 6. Distribution of temperature values at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

milliliters). The range for fecal coliform in ground-water samples was from less than 1 to 39 col/100 mL. The median concentration for both fecal streptococci and fecal coliform was less than 1 col/100 mL in ground-water samples.

In surface-water samples, the median bacteria density decreased slightly between the pre- and post-effluent conditions. Pre-effluent median fecal coliform densities in the blew hole and Perche Creek were 20 and 135 col/100 mL, respectively. Pre-effluent median fecal streptococci densities in the blew hole and Perche Creek were 100 and 78 col/100 mL, respectively. Post-effluent median fecal coliform densities in the blew hole and Perche Creek were 10 and 92 col/100 mL, respectively. Post-effluent median fecal streptococci densities in the blew hole and Perche Creek were 90 and 65 col/100 mL, respectively.

Alkalinity

The property of alkalinity is an important characteristic of natural and contaminated waters. The alkalinity of a solution can be defined as the capacity of the solution to neutralize an acid. In almost all natural waters, alkalinity is produced by the dissociation of dissolved carbon dioxide and is reported in terms of the equivalent amount of bicarbonate and carbonate (Hem, 1992).

Alkalinity values changed substantially between pre- and post-effluent sampling in many of the ground-water sites and one surface-water site (table 5, at the back of this report; fig. 7). The minimum, mean, median, and maximum pre-effluent alkalinity values for all ground-water sites were 171, 433, 412, and 914 mg/L, respectively. The range of median alkalinity values for pre-effluent ground-water samples was from 250 mg/L at well MW1-1A to 798 mg/L at well USGS-4. The minimum, mean, median, and maximum post-effluent alkalinity values for all ground-water sites were 178, 401, 395, and 953 mg/L, respectively. The range of median alkalinity values for post-effluent ground-water samples was from 205 mg/L at well MW2-2A to 639 mg/L at well USGS-4. The median pre-effluent alkalinity values for the blew hole and Perche Creek were 217 and 185 mg/L, respectively. The median post-effluent alkalinity values for the blew hole and Perche Creek were 369 and 176 mg/L, respectively. The median alkalinity values for the city outflow and Eagle Bluffs outflow were 192 and 167 mg/L, respectively.

Samples from wells MW1-4A, MW2-1A, MW2-1B, MW4-1A, USGS-5S, and USGS-9S had a statistically significant increase in alkalinity values between pre- and post-effluent samples. Samples from USGS-3S, USGS-4, USGS-6, and USGS-7 had a statistically significant decrease in alkalinity values. Alkalinity values significantly increased in samples from the blew hole surface-water site.

Major Chemical Constituents

Hem (1992) 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, sodium, and potassium. The anions generally included in this category are sulfate, chloride, and bicarbonate. Bicarbonate is the primary contributor to alkalinity.

Significant differences in the concentrations of several of the major chemical constituents were measured between pre- and post-effluent sampling. Summary statistics for major chemical constituents for samples collected from ground- and surface-water sites are shown in table 5. Boxplots of the major chemical constituents separated into pre- and post-effluent groups for ground-water sites are presented in figures 8 through 13. Sites where post-effluent changes in water chemistry occurred are generally indicated by a larger data distribution (larger boxplot) and a higher or lower median than the pre-effluent data. The temporal changes in the major chemical constituents are discussed in further detail later in this report.

State maximum contaminant level (MCL) standards for selected inorganic constituents for ground water, drinking-water supply, and surface water (protection of aquatic life) are given in table 6. The following discussion will focus on the constituent concentration distribution, the relation between the concentration and the MCL, and the concentration changes measured during pre- and post-effluent conditions.

Calcium

Calcium concentrations changed substantially at many of the ground-water sites and at two surface-water sites (table 5, fig. 8). No MCL standards exist for calcium. The minimum, mean, median, and maximum pre-effluent calcium concentrations for all ground-water sites were 72, 132, 130, and 250 mg/L,

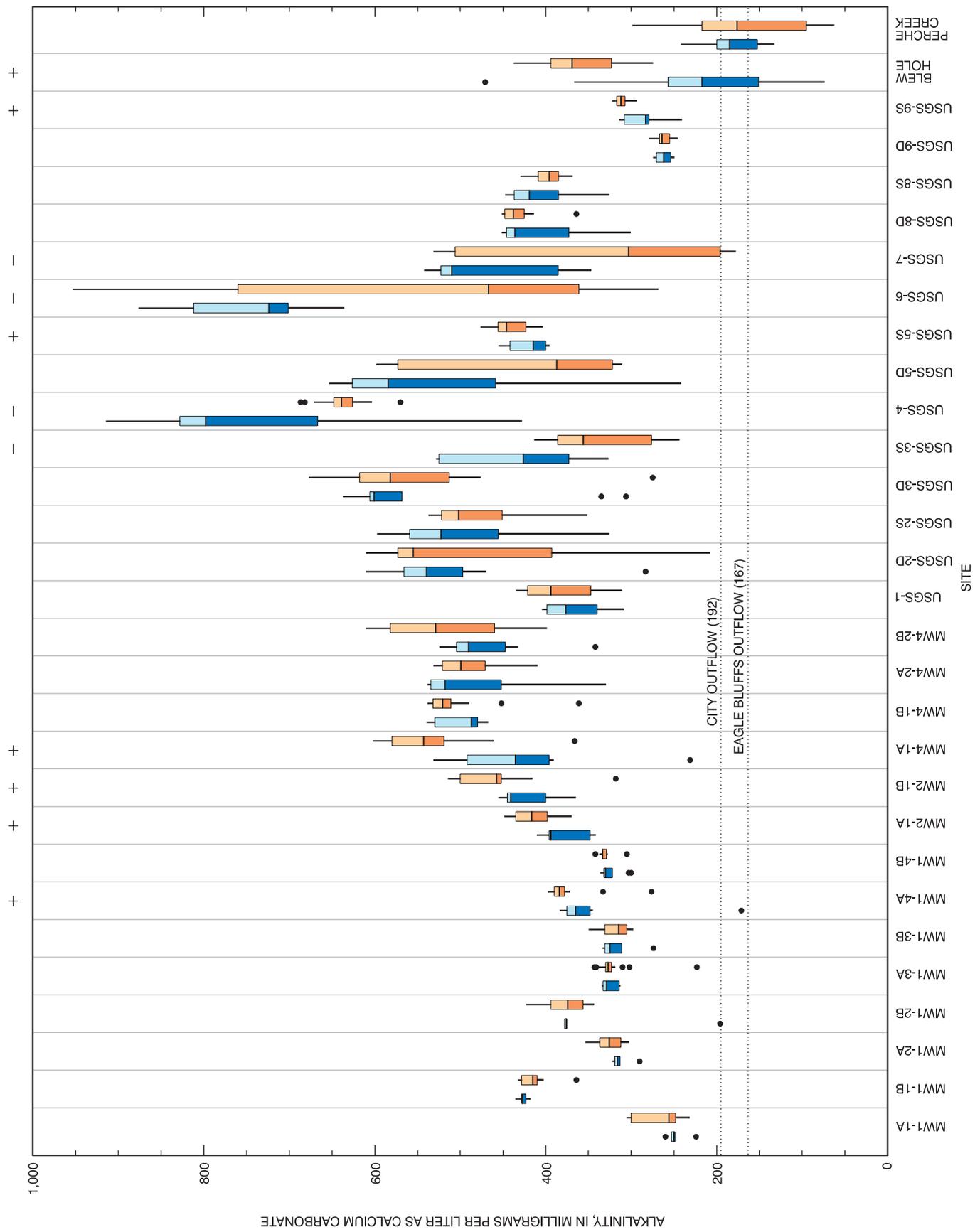


Figure 7. Distribution of alkalinity values at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

Table 6. State maximum contaminant level standards for selected inorganic constituents for ground water, drinking-water supply, and surface water (protection of aquatic life; Missouri Department of Natural Resources, 1996)
[mg/L, milligrams per liter; --, no data available; µg/L, micrograms per liter]

Constituent	Drinking-water supply			Protection of aquatic life
	Ground water			
Dissolved oxygen (mg/L)	--	250	--	5
	--	--	--	6
Sulfate (mg/L)	--	250	--	
Chloride (mg/L)	--	250	Chronic toxicity	230
	--	--	Acute toxicity	860
Fluoride (mg/L)	4	4	--	--
Nitrate (mg/L)	10	10	--	--
Aluminum (µg/L)	--	6	--	750
Arsenic (µg/L)	--	50	--	20
Barium (µg/L)	2,000	2,000	--	--
Beryllium (µg/L)	--	4	--	5
Cadmium (µg/L)	--	--	Chronic toxicity	1.1-20 ^a
	--	--	Acute toxicity	3.7-94 ^a
Chromium (µg/L)	--	--	Chronic toxicity	11-190 ^b
	--	--	Acute toxicity	16-280 ^b
Cobalt (µg/L)	--	--	--	--
Copper (µg/L)	1,300	1,300	Chronic toxicity	19-53 ^a
	--	--	Acute toxicity	29-84 ^a
Iron (µg/L)	300	300	--	1,000
Lead (µg/L)	15	15	Chronic toxicity	9-23 ^c
	--	--	Acute toxicity	63-150 ^c
Manganese (µg/L)	50	50	--	--
Mercury (µg/L)	--	--	Chronic toxicity	.5
	--	--	Acute toxicity	2.4
Nickel (µg/L)	100	100	Chronic toxicity	160-770 ^a
	--	--	Acute toxicity	1,400-6,900 ^a
Selenium (µg/L)	50	50	--	5
Silver (µg/L)	50	50	--	3.5-11 ^c
Zinc (µg/L)	5,000	5,000	Chronic toxicity	103-1,893 ^a
	--	--	Acute toxicity	112-2,073 ^a

^aDepending on the water body and hardness.

^bDepending on the water body.

^cDepending on the hardness.

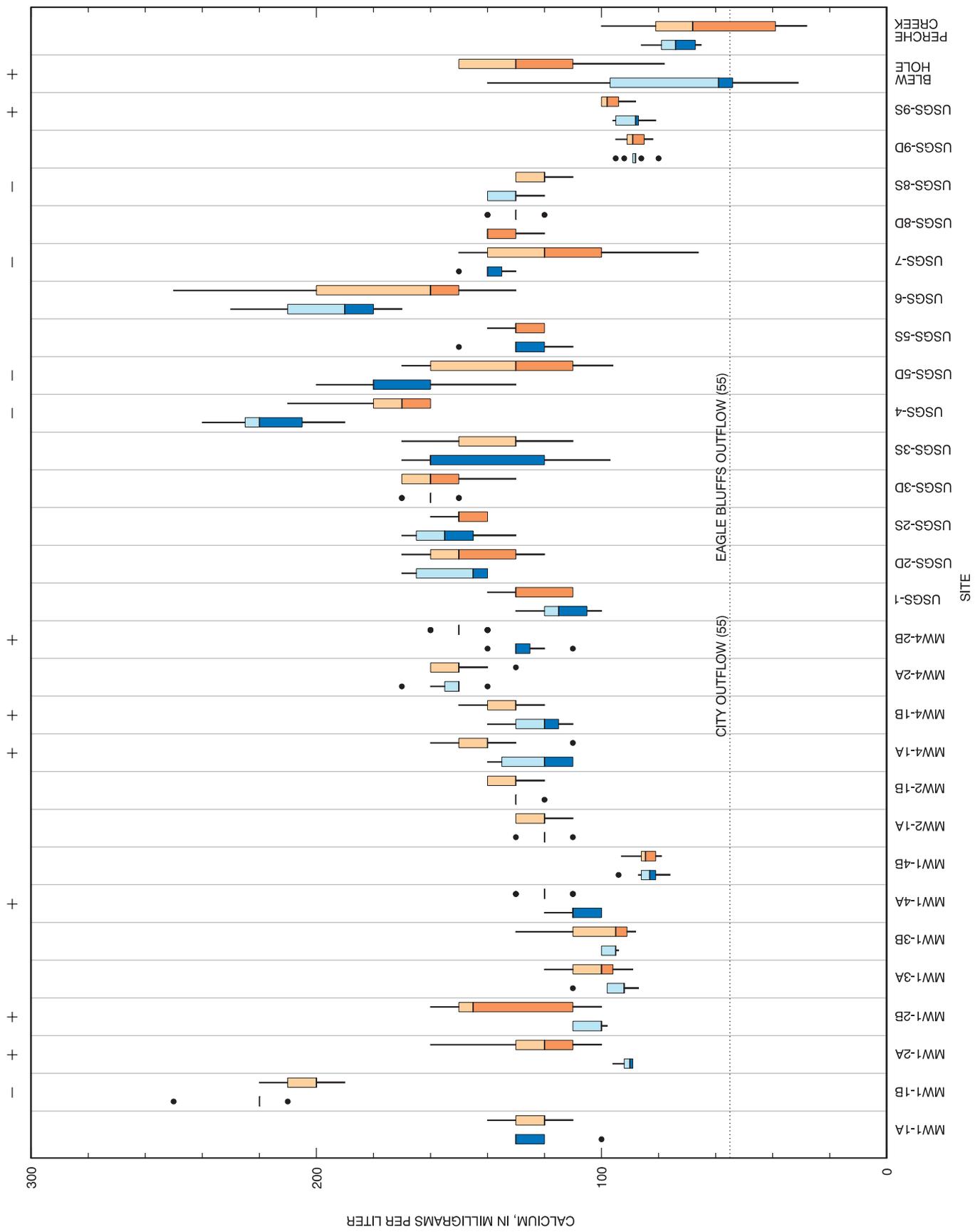


Figure 8. Distribution of calcium concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

respectively. The range of median calcium concentrations for pre-effluent ground-water samples was from 83 mg/L at well MW1-4B to 220 mg/L at wells MW1-1B and USGS-4. The minimum, mean, median, and maximum post-effluent calcium concentrations for all ground-water sites were 49, 126, 130, and 250 mg/L, respectively. The range of median calcium concentrations for post-effluent ground-water samples was from 56 mg/L at well MW2-2A to 200 mg/L at well MW1-1B. The median pre-effluent calcium concentrations for the blew hole and Perche Creek were 59 and 74 mg/L, respectively. The median post-effluent calcium concentrations for the blew hole and Perche Creek were 130 and 68 mg/L, respectively. The median calcium concentration for both the city outflow and Eagle Bluffs outflow was 55 mg/L.

Samples from ground-water sites MW1-2A, MW1-2B, MW1-4A, MW4-1A, MW4-1B, MW4-2B, and USGS-9S had a statistically significant increase in calcium concentration between pre- and post-effluent samples. Samples from MW1-1B, USGS-4, USGS-5D, USGS-7, and USGS-8S had a statistically significant decrease in calcium concentration. Calcium concentration significantly increased in samples from the blew hole surface-water site.

Magnesium

Magnesium concentrations changed in several of the ground-water sites and in one surface-water site (table 5, fig. 9). No MCL standards exist for magnesium. The minimum, mean, median, and maximum pre-effluent magnesium concentrations for all ground-water sites were 16, 29, 27, and 61 mg/L, respectively. The range of median magnesium concentrations for pre-effluent ground-water samples was from 17 mg/L at well USGS-9D to 56 mg/L at well USGS-4. The minimum, mean, median, and maximum post-effluent magnesium concentrations for all ground-water sites were 11, 28, 27, and 60 mg/L, respectively. The range of median magnesium concentrations for post-effluent ground-water samples was from 12 mg/L at well MW2-2A to 41 mg/L at well USGS-4. The median pre-effluent magnesium concentrations for the blew hole and Perche Creek were 15 and 14 mg/L, respectively. The median post-effluent magnesium concentrations for the blew hole and Perche Creek were 28 and 11 mg/L, respectively. The median magnesium concentrations for the city outflow and Eagle Bluffs outflow were 19 and 18 mg/L, respectively.

Samples from ground-water sites MW1-2A, MW1-2B, MW1-3A, MW1-4A, MW4-1A, MW4-2B, USGS-1, and USGS-5S had a statistically significant increase in magnesium concentration between pre- and post-effluent samples. Samples from MW1-1B, USGS-3S, USGS-4, USGS-5D, USGS-6, and USGS-8S had a statistically significant decrease in magnesium concentration. Magnesium concentration significantly increased in samples from the blew hole surface-water site.

Sodium

Sodium concentrations changed substantially in several of the ground-water sites and in two surface-water sites (table 5, fig. 10). No MCL standards exist for sodium. The minimum, mean, median, and maximum pre-effluent sodium concentrations for all ground-water sites were 3.1, 13, 11, and 44 mg/L, respectively. The range of median sodium concentrations for pre-effluent ground-water samples was from 4.2 mg/L at well MW2-1A to 36 mg/L at well USGS-4. The minimum, mean, median, and maximum post-effluent sodium concentrations for all ground-water sites were 3.2, 17, 9.4, and 141 mg/L, respectively. The range of median sodium concentrations for post-effluent ground-water samples was from 3.9 mg/L at well MW2-1A to 90 mg/L at well MW1-2A. The median pre-effluent sodium concentrations for the blew hole and Perche Creek were 14 and 35 mg/L, respectively. The median post-effluent sodium concentrations for the blew hole and Perche Creek were 28 and 15 mg/L, respectively. The median sodium concentrations for the city outflow and Eagle Bluffs outflow were 140 and 114 mg/L, respectively.

Samples from ground-water sites MW1-2A, MW1-2B, MW2-1B, MW4-1A, USGS-3S, USGS-6, and USGS-9D had a statistically significant increase in sodium concentration between pre- and post-effluent samples. Samples from MW1-3A, USGS-2S, USGS-4, USGS-5S, and USGS-8S had a statistically significant decrease in sodium concentration. Sodium concentration in samples from surface-water sites significantly increased in the blew hole and decreased in Perche Creek.

Potassium

Potassium concentrations changed substantially in many of the ground-water sites and two surface-water sites (table 5, fig. 11). No MCL standards

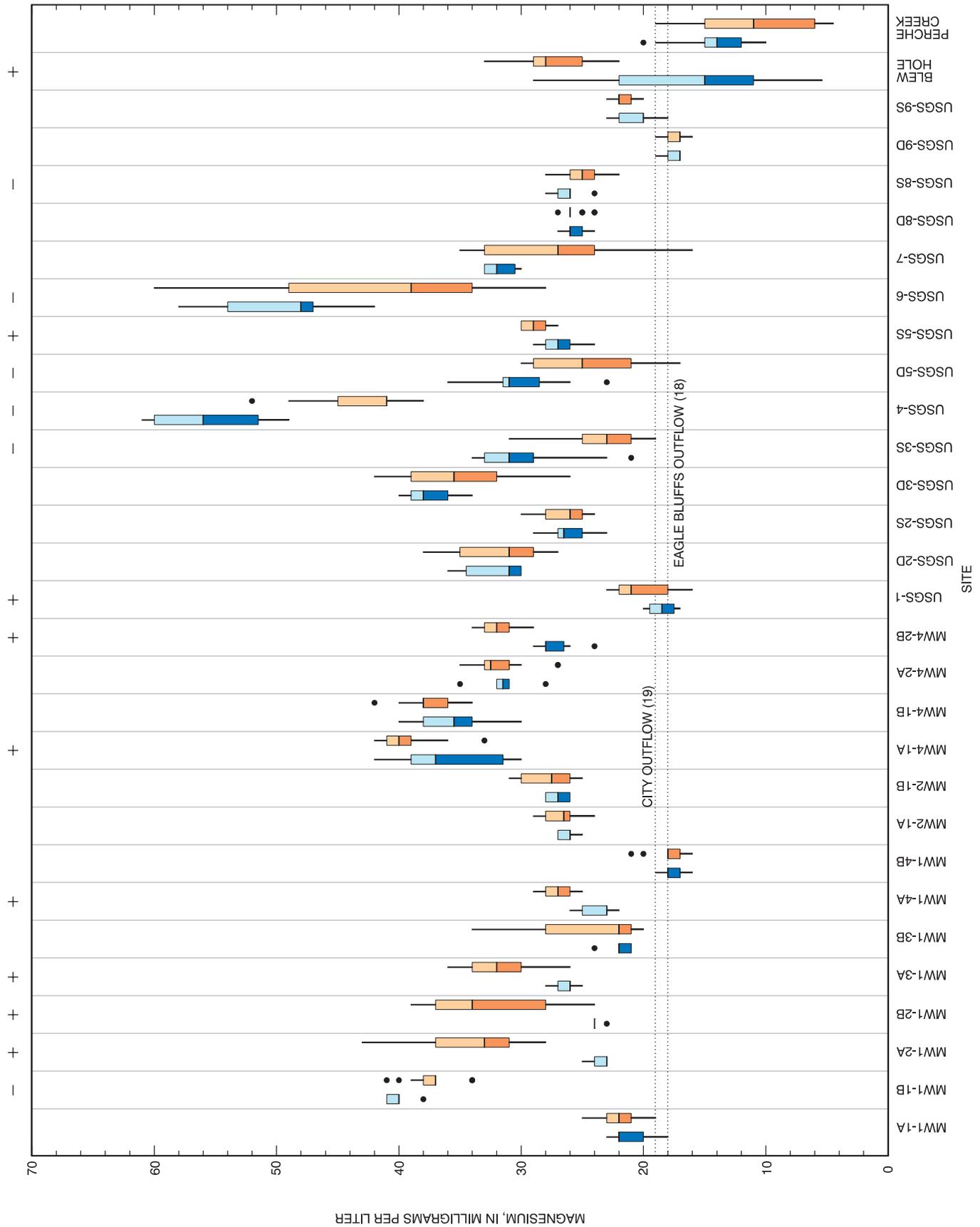


Figure 9. Distribution of magnesium concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

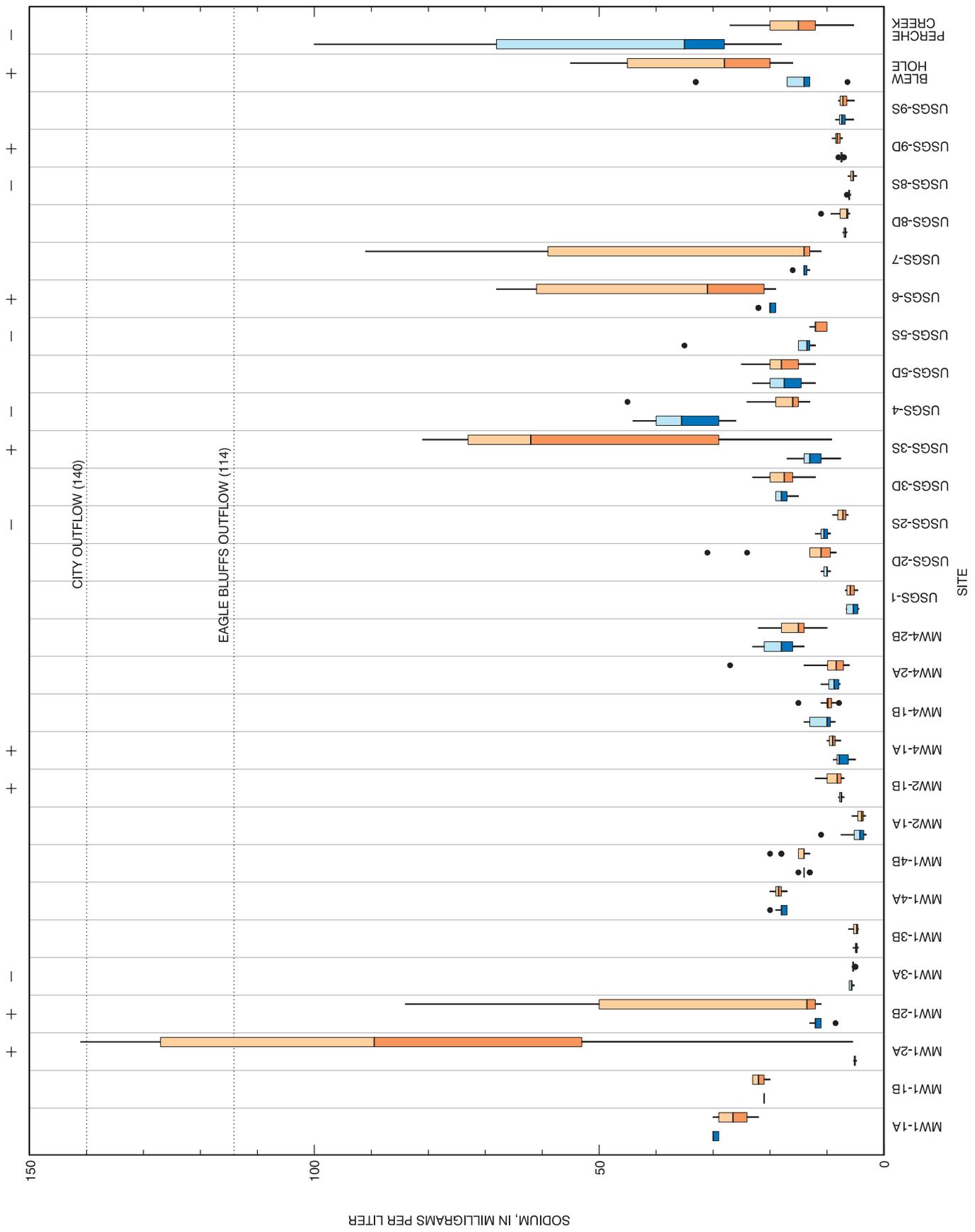


Figure 10. Distribution of sodium concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

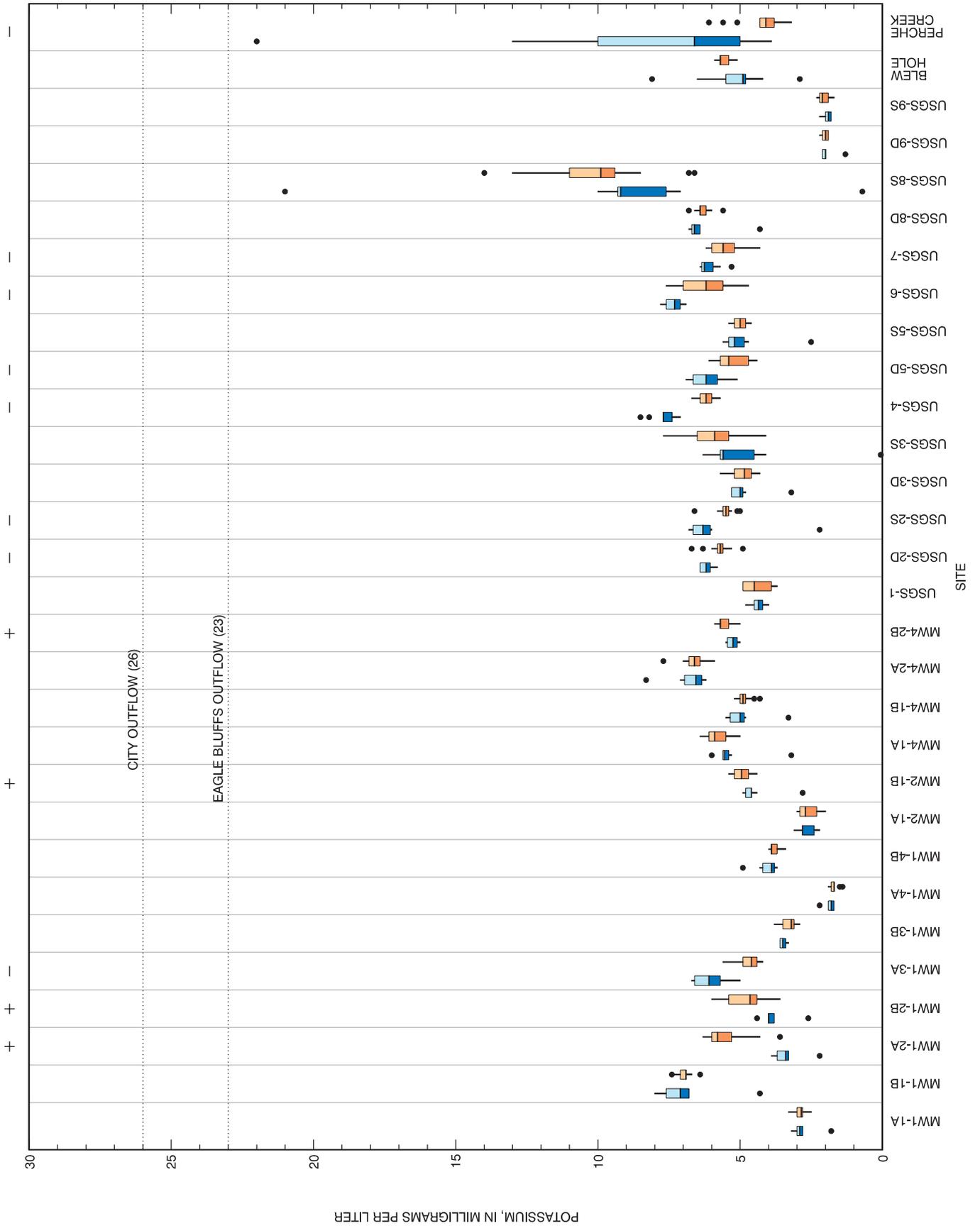


Figure 11. Distribution of potassium concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

exist for potassium. The minimum, mean, median, and maximum pre-effluent potassium concentrations for all ground-water sites were 0.7, 5.0, 5.1, and 21 mg/L, respectively. The range of median potassium concentrations for pre-effluent ground-water samples was from 1.8 mg/L at well MW1-4A to 9.2 mg/L at well USGS-8S. The minimum, mean, median, and maximum post-effluent potassium concentrations for all ground-water sites were 1.4, 4.8, 4.9, and 14 mg/L, respectively. The range of median potassium concentrations for post-effluent ground-water samples was from 1.7 mg/L at well MW1-4A to 9.9 mg/L at well USGS-8S. The median pre-effluent potassium concentrations for the blew hole and Perche Creek were 4.9 and 6.6 mg/L, respectively. The median post-effluent potassium concentrations for the blew hole and Perche Creek were 5.7 and 4.1 mg/L, respectively. The median potassium concentrations for the city outflow and Eagle Bluffs outflow were 26 and 23 mg/L, respectively.

Samples from ground-water sites MW1-2A, MW1-2B, MW2-1B, and MW4-2B had a statistically significant increase in potassium concentration between pre- and post-effluent samples. Samples from MW1-3A, USGS-2D, USGS-2S, USGS-4, USGS-5D, USGS-6, and USGS-7 had a statistically significant decrease in potassium concentration. The potassium concentration in samples from Perche Creek significantly decreased.

Sulfate

Sulfate concentrations changed substantially in many of the ground-water sites and two surface-water sites (table 5, fig. 12). All sulfate concentrations were less than the secondary MCL standard for drinking water of 250 mg/L (Missouri Department of Natural Resources, 1996), except for sites MW1-1A and MW1-1B. Because the sulfate concentrations exceeded the MCL at sites MW1-1A and MW1-1B during both pre- and post-effluent conditions, the observed sulfate concentrations in samples from those wells were not the result of interaction with treated effluent. The minimum, mean, median, and maximum pre-effluent sulfate concentrations for all ground-water sites were 0.1, 39, 26, and 370 mg/L, respectively. The range of median sulfate concentrations for pre-effluent ground-water samples was from 0.2 mg/L at well USGS-2D to 350 mg/L at well MW1-1B. The minimum, mean, median, and maximum post-effluent sulfate concentrations for all ground-water sites were 0.1,

51, 30, and 340 mg/L, respectively. The range of median sulfate concentrations for post-effluent ground-water samples was from 0.2 mg/L at well MW1-4B to 315 mg/L at well MW1-1B. The median pre-effluent sulfate concentrations for the blew hole and Perche Creek were 39 and 83 mg/L, respectively. The median post-effluent sulfate concentrations for the blew hole and Perche Creek were 45 and 46 mg/L, respectively. The median sulfate concentrations for the city outflow and Eagle Bluffs outflow were 100 and 98 mg/L, respectively.

Samples from ground-water sites MW1-2A, MW1-2B, MW1-4A, MW4-1A, USGS-1, USGS-3S, USGS-6, USGS-7, and USGS-9S had a statistically significant increase in sulfate concentration between pre- and post-effluent samples. Samples from MW1-1B, MW2-1A, and MW2-1B had a statistically significant decrease in sulfate concentration. Sulfate concentration in samples from surface-water sites significantly decreased in Perche Creek.

Chloride

Chloride concentrations changed substantially in many of the ground-water sites and in two surface-water sites (table 5, fig. 13). All ground-water chloride concentrations were less than the secondary MCL standard for drinking water of 250 mg/L (Missouri Department of Natural Resources, 1996). Monthly samples collected between January 1999 and December 1999 by the city of Columbia at the 12 municipal-supply wells had a mean concentration of 17 mg/L (B.W. Kirchoff, City of Columbia, written commun., 2000). The minimum, mean, median, and maximum pre-effluent chloride concentrations for all ground-water sites sampled by the USGS were 1.2, 7.0, 6.1, and 24 mg/L, respectively. The range of median chloride concentrations for pre-effluent ground-water samples was from 1.8 mg/L at well USGS-2S to 19 mg/L at well MW13-67. The minimum, mean, median, and maximum post-effluent chloride concentrations for all ground-water sites were 0.9, 26, 6.6, and 220 mg/L, respectively. The range of median chloride concentrations for post-effluent ground-water samples was from 2.1 mg/L at well USGS-2D to 200 mg/L at well MW1-2A.

For the protection of aquatic life, the chronic toxicity concentration for chloride is 230 mg/L (table 6; Missouri Department of Natural Resources, 1996). Chronic toxicity is defined by the Missouri Department of Natural Resources (1996) as "conditions producing

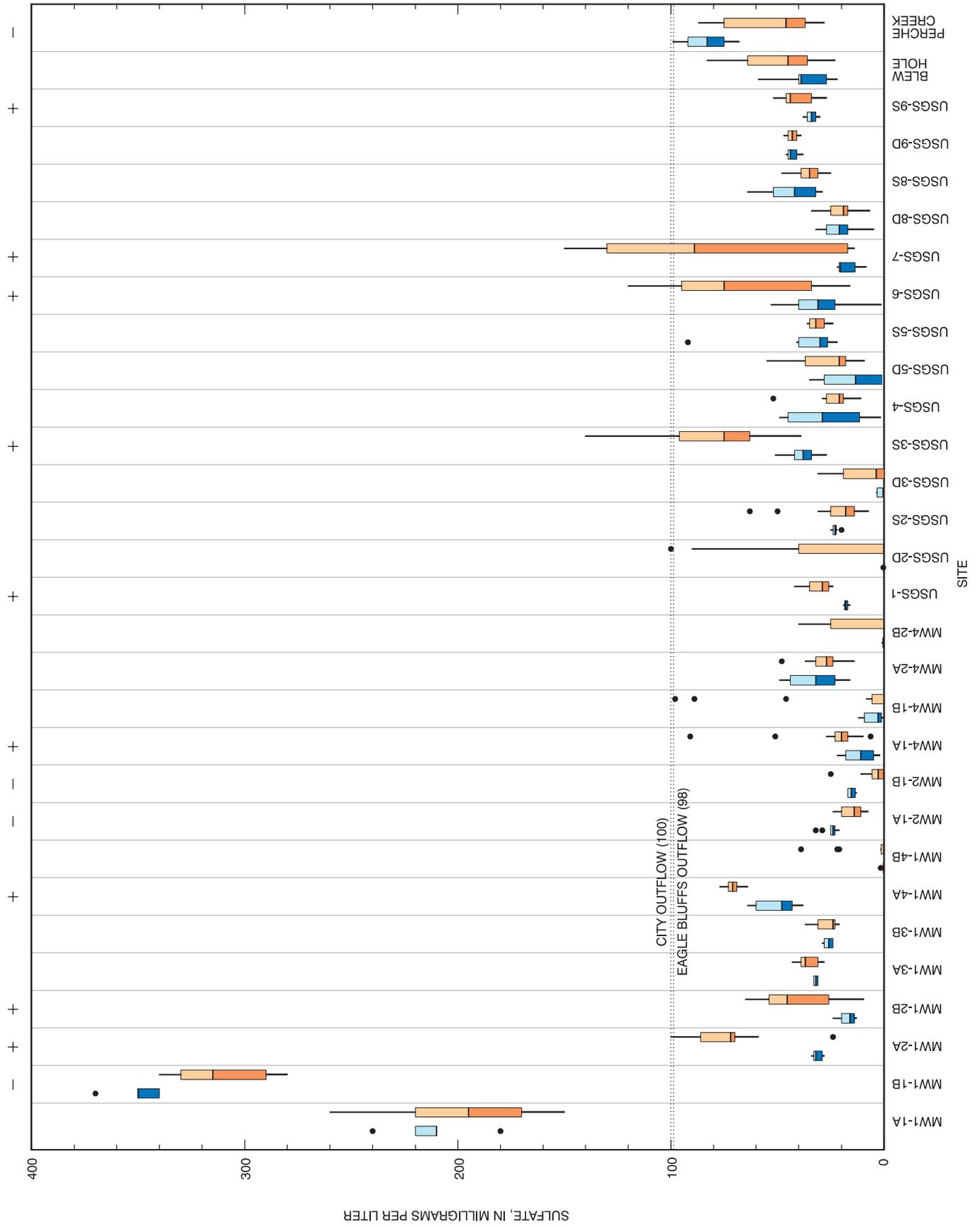


Figure 12. Distribution of sulfate concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

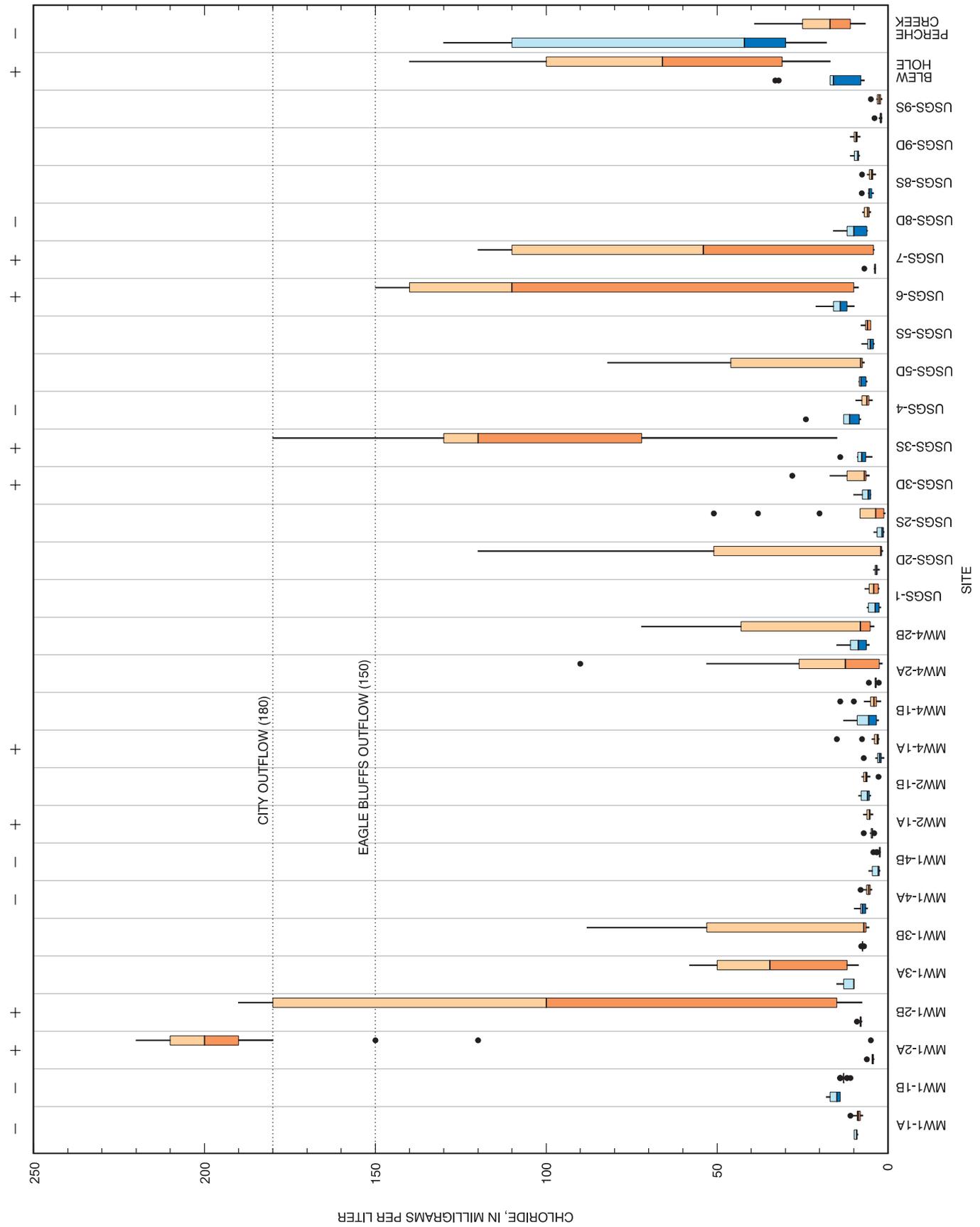


Figure 13. Distribution of chloride concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

adverse effects on aquatic life or wildlife following long-term exposure but having no readily observable effect over a short time." Chloride concentrations in surface water exceeded the chronic toxicity MCL for the protection of aquatic life at the outflow from the treatment wetland and the outflow from Eagle Bluffs. The median pre-effluent chloride concentrations for the blew hole and Perche Creek were 16 and 42 mg/L, respectively. The median post-effluent chloride concentrations for the blew hole and Perche Creek were 66 and 17 mg/L, respectively. The median chloride concentrations for the city outflow and Eagle Bluffs outflow were 180 and 150 mg/L, respectively.

Samples from sites MW1-2A, MW1-2B, MW2-1A, MW4-1A, USGS-3D, USGS-3S, USGS-6, USGS-7, and the blew hole had a statistically significant increase in chloride concentration between pre- and post-effluent samples. Samples from MW1-1A, MW1-1B, MW1-4A, MW1-4B, USGS-4, and USGS-8D had a statistically significant decrease in chloride concentration. The chloride concentration in samples from the Perche Creek surface-water site significantly decreased. Although the Mann-Whitney test did not indicate a statistically significant difference in the chloride concentrations, the boxplots for sites MW1-3A, MW1-3B, MW4-2A, MW4-2B, USGS-2D, and USGS-5D indicate wider data distributions and often substantially different means (table 5, fig. 13) between pre- and post-effluent data. Temporal chloride concentration changes are evident in these wells and are discussed in more detail later in the report.

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 may be affected by the availability of other required elements. Although nitrogen and phosphorus are both essential for algal growth, phosphorus availability is considered to be the limiting factor in many natural waters (Hem, 1992). 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 drinking-water MCL standard for nitrate was exceeded one time in a sample from USGS-5S during pre-effluent conditions, and this nitrate concentration was not the result of interaction with treated effluent.

Samples from ground-water sites MW1-1A, MW1-2A, MW1-4B, MW2-1B, MW4-1A, and MW4-2B had a statistically significant increase in ammonia concentration between pre- and post-effluent samples (table 5, fig. 14). Samples from MW1-3A, USGS-4, USGS-6, USGS-8D, and USGS-9D had a statistically significant decrease in ammonia concentration. The ammonia concentration in samples from the Perche Creek surface-water site significantly decreased.

For the most part, phosphorus species concentrations were similar for samples from pre- and post-effluent conditions (table 5, fig. 15). Samples from ground-water sites MW1-3B, MW2-1B, MW4-2A, USGS-1, and USGS-9S had a statistically significant increase in total phosphorus concentration between pre- and post-effluent conditions. The total phosphorus concentration in samples from the Perche Creek surface-water site significantly decreased. There are no MCL standards for phosphorus.

Trace Constituents

Hem (1992) defines trace constituents as those substances that nearly always occur at concentrations less than 1.0 mg/L. Small quantities of many trace constituents are essential for plant and animal life, but often slightly larger concentrations of these same elements can be toxic to aquatic life. Trace constituents considered in this section are the dissolved metals aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, vanadium, and zinc.

The trace constituents that changed at several sites between the pre- and post-effluent sampling were arsenic, barium, boron, iron, lithium, manganese, and strontium (table 7, at the back of this report). Boxplots of these seven constituents separated into pre- and post-effluent groups for ground-water sites are presented in figures 16 through 22. The concentration of

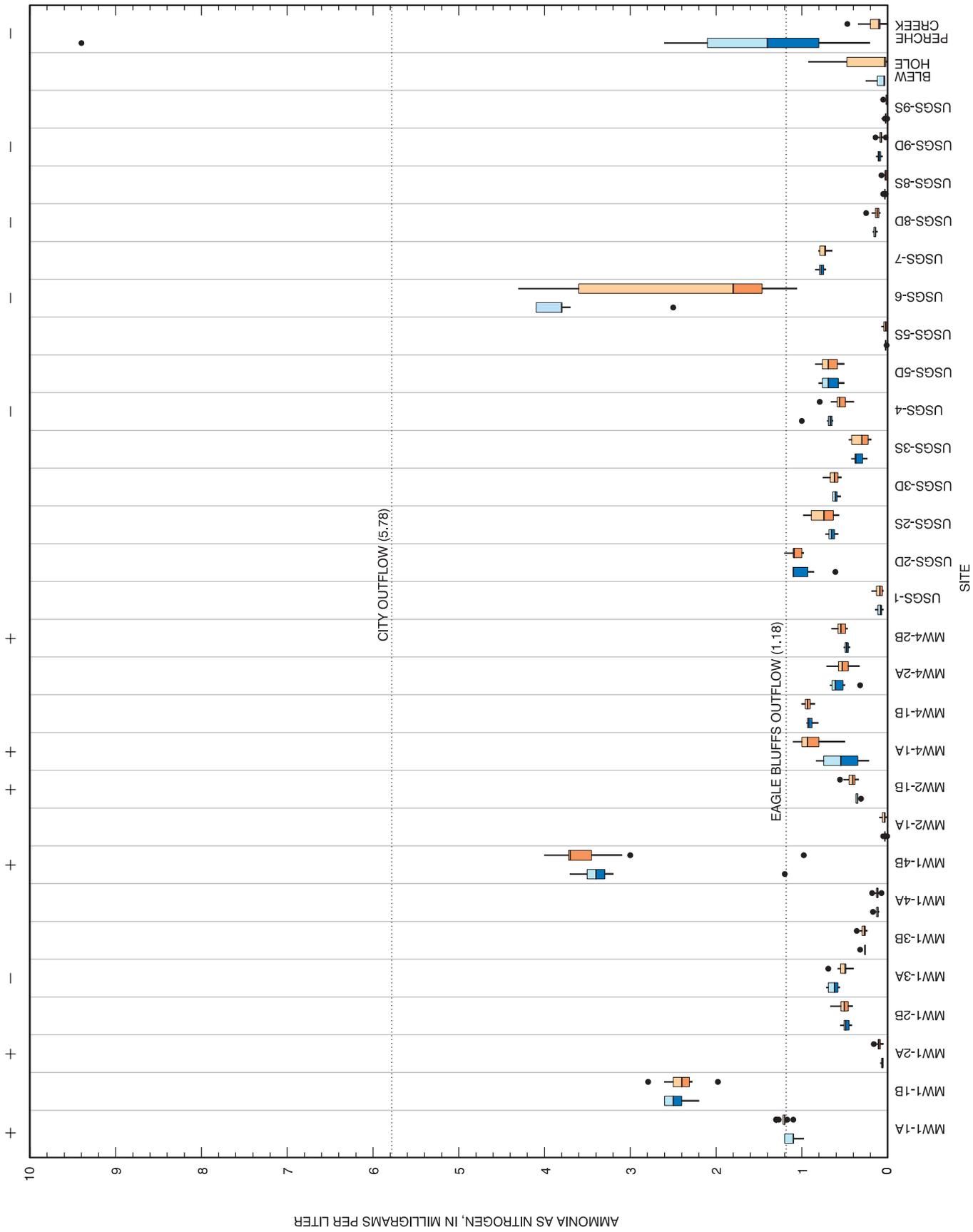


Figure 14. Distribution of ammonia as nitrogen concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

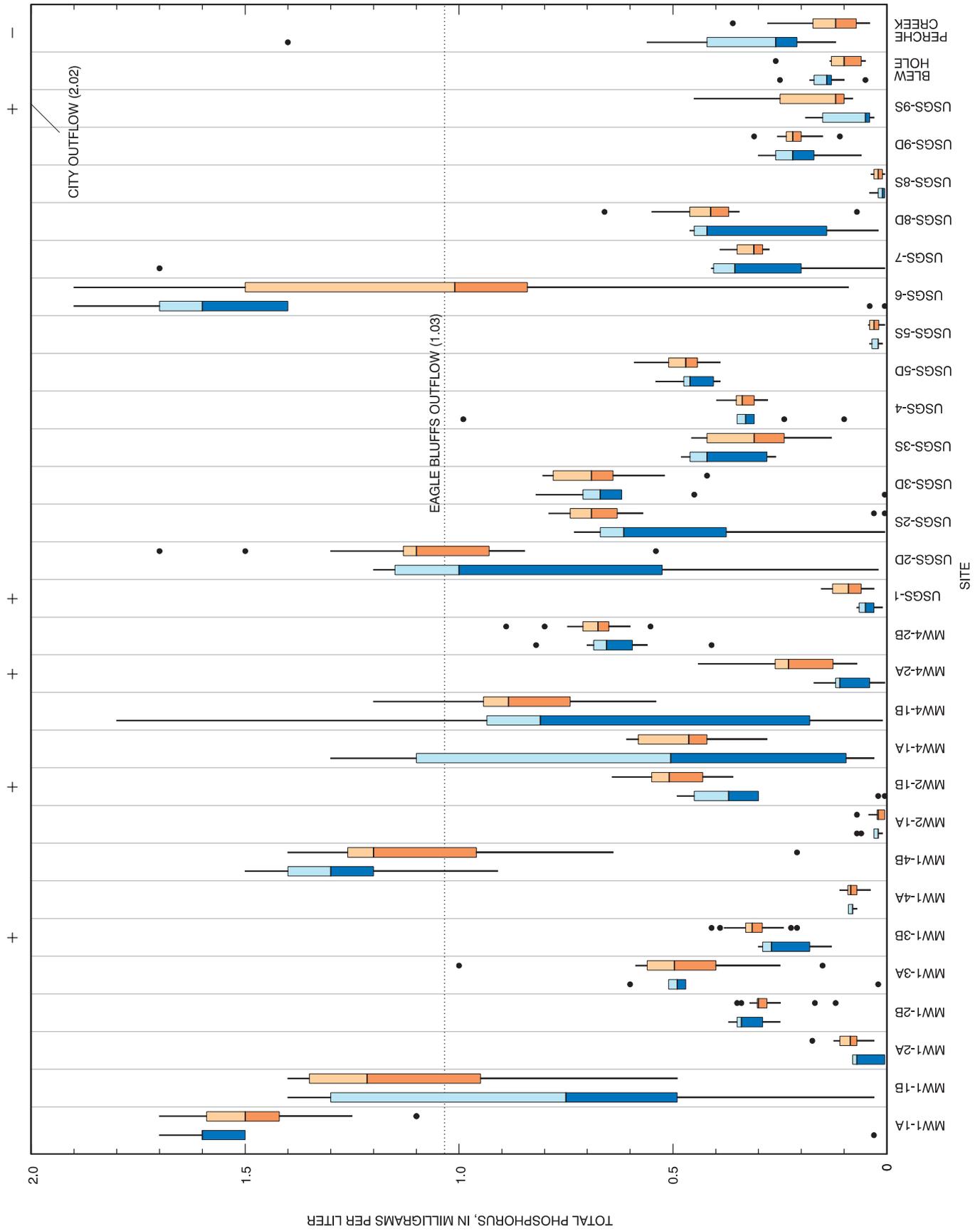


Figure 15. Distribution of total phosphorus concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

the remaining trace constituents were largely at or below their respective detection limits or did not change between the pre- and post-effluent sampling. However, lead has been detected and reported at concentrations as high as 80 µg/L (micrograms per liter) at several sites (Richards, 1995, 1999). During the course of the study (August 1995), the laboratory procedure that was used to determine lead concentrations was changed. The change was made to conform with the laboratory policy for minimum reporting levels (MRLs) that were currently in place for the Inductively Coupled Plasma - Atomic Emission Spectrometric analytical procedure (T.J. Maloney, U.S. Geological Survey, written commun., 1997). The change was from a MRL of 10 µg/L to 100 µg/L. The change in the MRL for lead caused a shift in non-detection (less than) concentrations in the database. The results given in Richards (1995, 1999) for lead concentrations less than 100 µg/L (before August 1995) should be considered non-detections. For example, a concentration of 20 µg/L would be reported as less than 100 µg/L and considered a non-detection. In September 1995, a new method was selected to determine lead concentration in samples collected from sites at the Columbia/Eagle Bluffs Wetland Complex. The new analytical procedure for lead determination used the Graphite Furnace Atomic Adsorption Spectrophotometry method and had a MRL of 1 µg/L. Lead concentrations in samples collected after the change in analytical procedure have been less than the new MRL.

Arsenic concentrations (table 7, fig. 16) significantly decreased at sites MW1-1A, MW1-1B, MW1-3B, USGS-2S, USGS-3D, USGS-3S, and USGS-6 between pre- and post-effluent sampling. The state MCL standard for arsenic in drinking water of 50 µg/L was exceeded in samples from USGS-6 thirteen times throughout the study during both pre- and post-effluent conditions. Based on these data, the large arsenic concentrations were not the result of interaction with treated effluent.

Barium concentrations (table 7, fig. 17) significantly increased at sites MW1-2A, MW1-2B, MW1-3A, MW2-1A, MW2-1B, MW4-1A, MW4-2B, USGS-3D, USGS-5S, USGS-9D, USGS-9S, and the blew hole between pre- and post-effluent sampling. Barium concentrations significantly decreased at sites MW1-1A, MW1-1B, USGS-4, USGS-5D, USGS-7, USGS-8D, and USGS-8S between pre- and post-effluent samples. All barium concentrations were less than the state MCL of 2,000 µg/L.

Boron concentrations (table 7, fig. 18) significantly increased at sites MW1-2A, MW2-1A, USGS-3S, and the blew hole between pre- and post-effluent sampling. Boron concentrations significantly decreased at sites MW1-1B, MW4-1B, MW4-2A, USGS-2S, USGS-4, USGS-5D, USGS-6, and Perche Creek between pre- and post-effluent samples. No state MCL standard exists for boron.

Iron concentrations (table 7, fig. 19) significantly increased at sites MW1-1A, MW1-2A, MW1-2B, MW1-3B, MW1-4A, MW2-1A, MW2-1B, MW4-2B, USGS-3D, and USGS-9D between pre- and post-effluent sampling. Iron concentrations significantly decreased at sites MW1-3A, USGS-4, USGS-8D, USGS-8S, and USGS-9S between pre- and post-effluent samples. Median iron concentration in samples from USGS-6 decreased between pre- and post-effluent conditions (table 7) and a temporal iron concentration decrease is evident (table 2). Iron concentrations exceeded the state drinking-water and ground-water secondary standard MCL of 300 µg/L at least once at all sites except MW1-4A, MW3-1A, USGS-9S, the city outflow, and Eagle Bluffs outflow (table 2). Iron concentrations that exceeded the MCL at ground-water sites were measured in both pre- and post-effluent samples, and these iron concentrations were not the result of interaction with treated effluent.

Lithium concentrations (table 7, fig. 20) significantly increased at MW1-2A, MW1-2B, MW2-1A, MW4-1A, MW4-2B, USGS-3D, and the blew hole between pre- and post-effluent sampling. Lithium concentrations significantly decreased at MW4-2A, USGS-3S, USGS-5D, USGS-7, and USGS-8S between pre- and post-effluent samples. No state MCL standard exists for lithium.

Manganese concentrations (table 7, fig. 21) significantly increased at sites MW1-2A, MW1-2B, MW4-1A, MW4-2B, and USGS-3D between pre- and post-effluent sampling. Manganese concentrations significantly decreased at sites MW1-3A, MW1-3B, MW1-4B, MW2-1B, MW4-2A, USGS-2D, USGS-3S, USGS-4, USGS-5D, and USGS-8S between pre- and post-effluent samples. Manganese concentrations in ground-water samples exceeded the state drinking-water and ground-water MCL standard of 50 µg/L at least once at all sites. Manganese concentrations in surface-water samples exceeded the state drinking-water standard at all sites except Eagle Bluffs outflow. Manganese concentrations that exceeded the MCL at ground-water sites were observed in both pre-

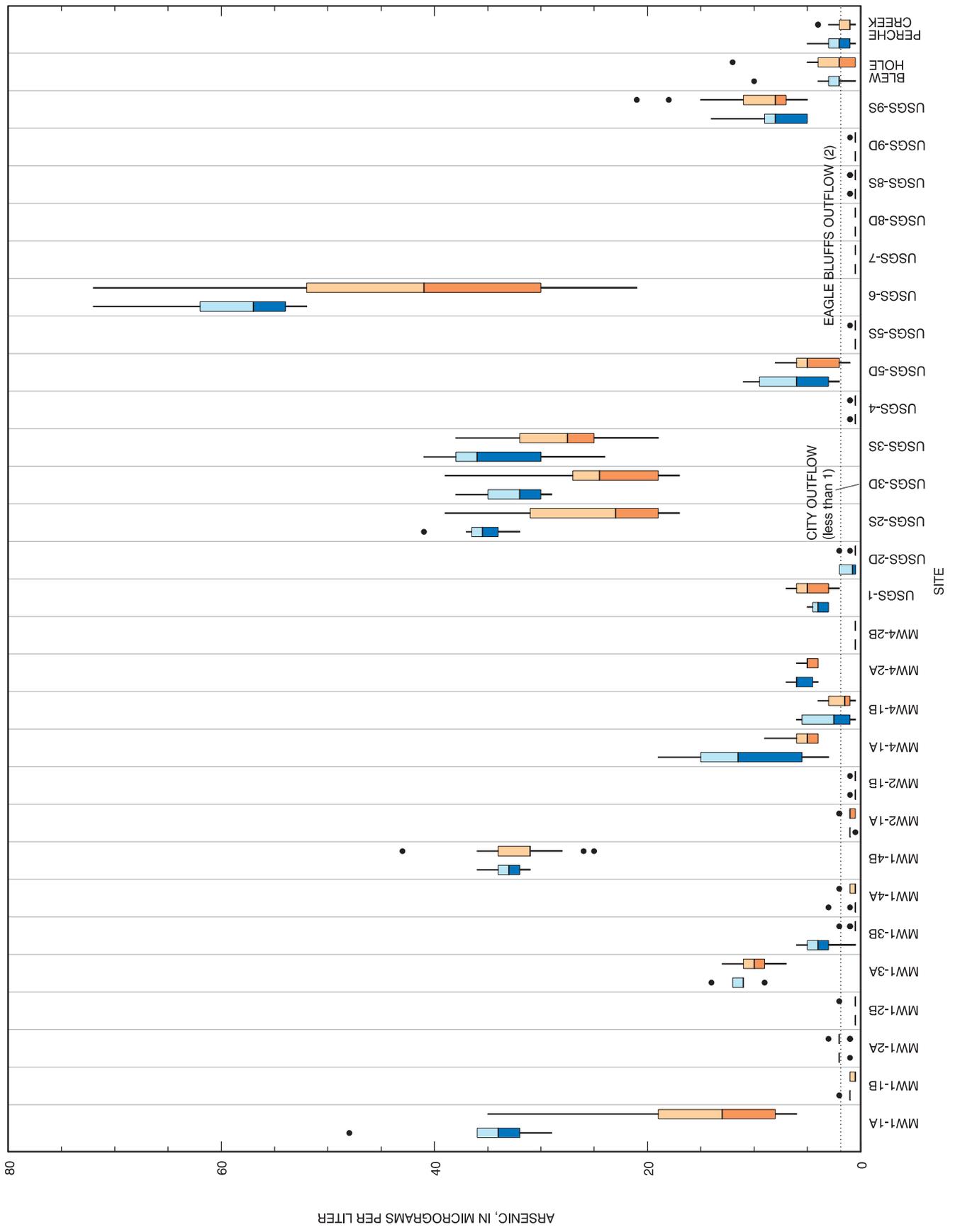


Figure 16. Distribution of arsenic concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

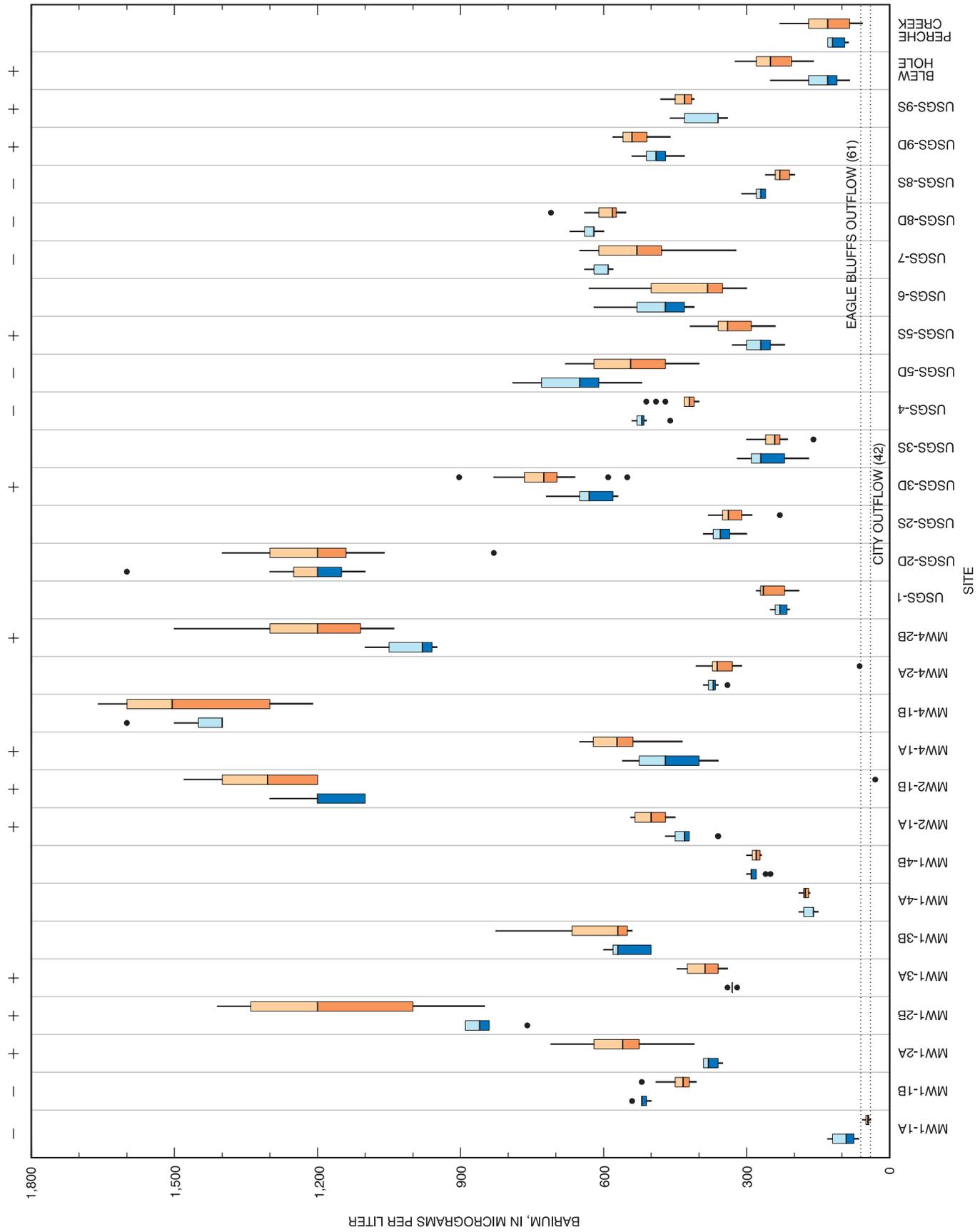


Figure 17. Distribution of barium concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

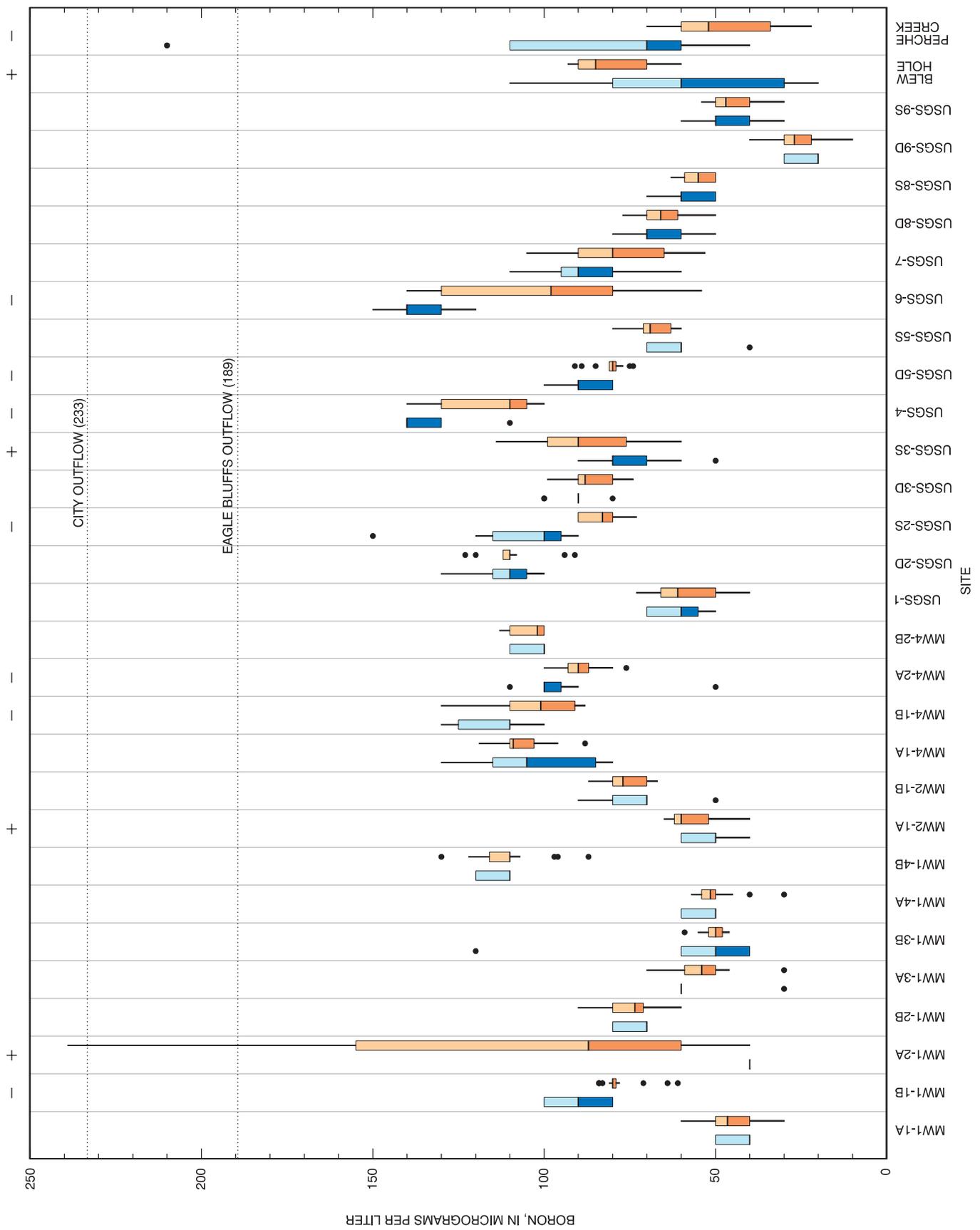


Figure 18. Distribution of boron concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

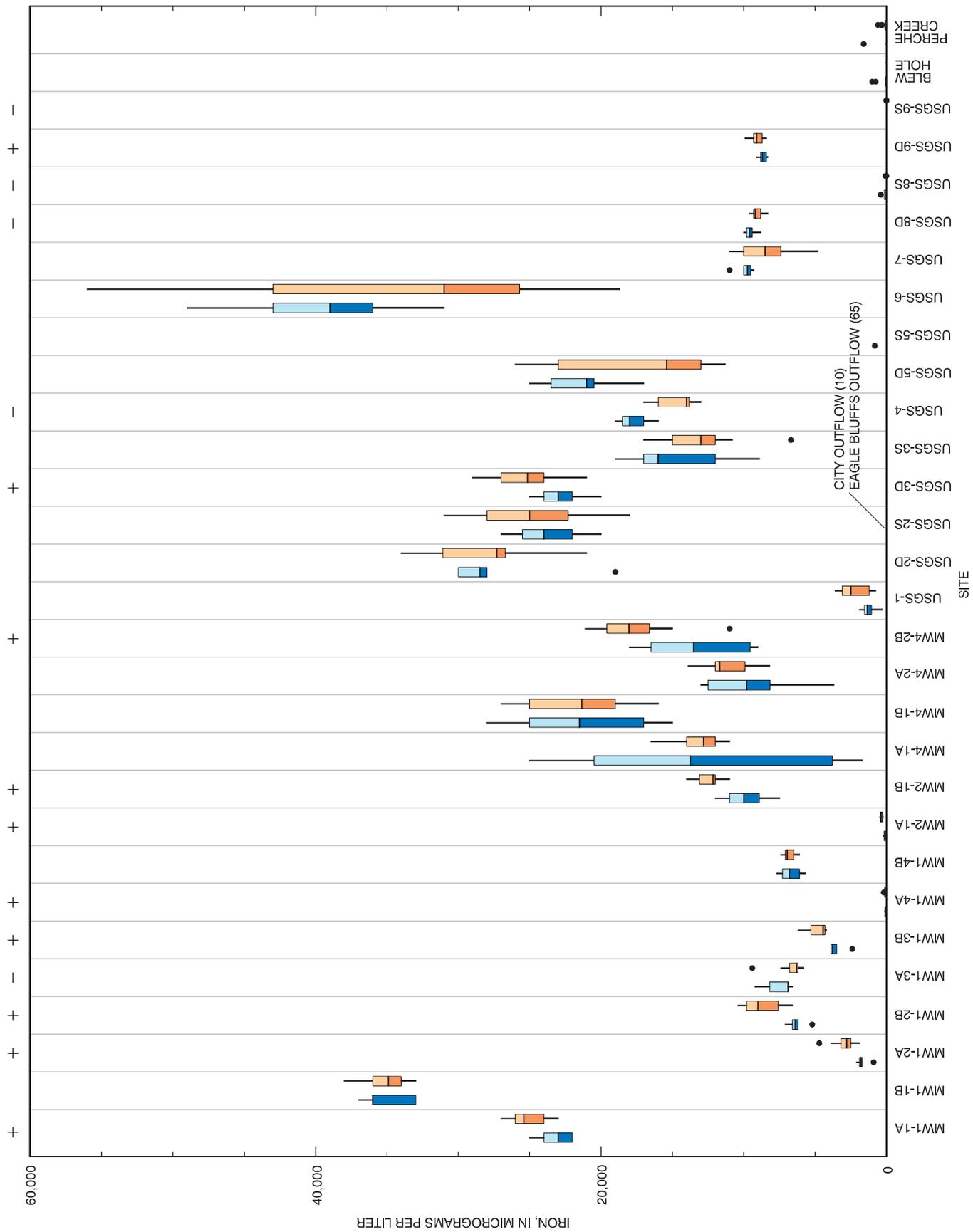


Figure 19. Distribution of iron concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

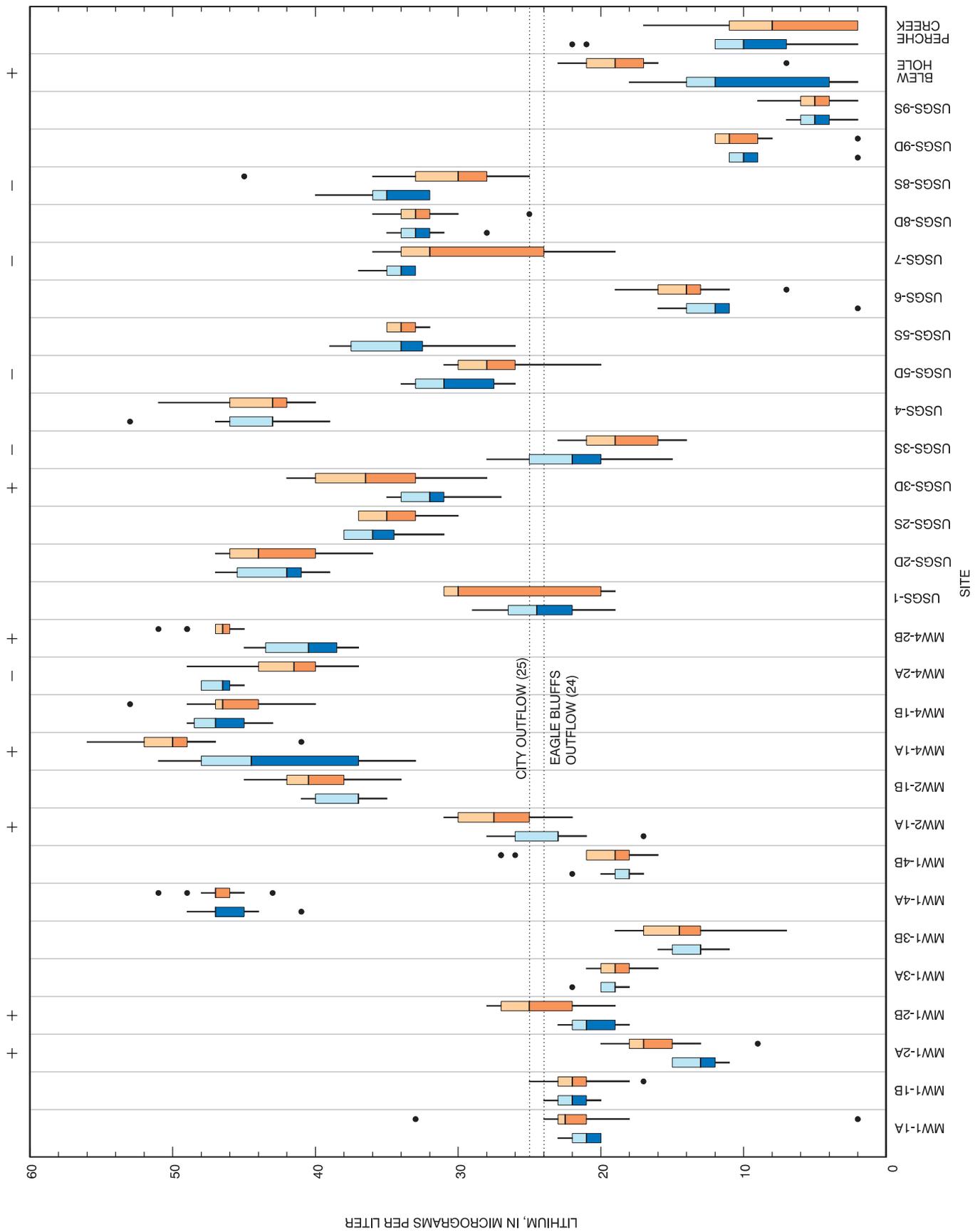


Figure 20. Distribution of lithium concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

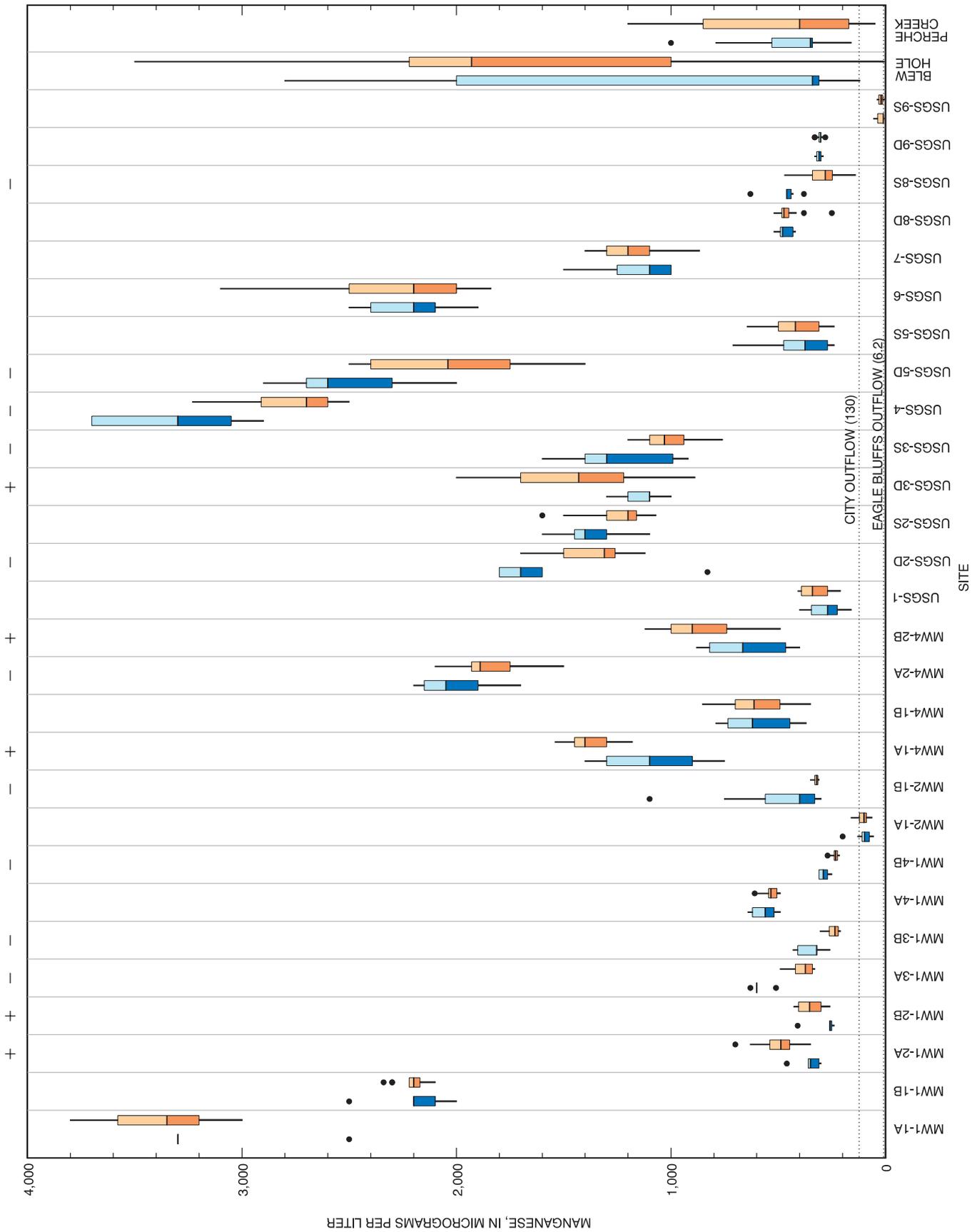


Figure 21. Distribution of manganese concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

and post-effluent samples, and these manganese concentrations were not the result of interaction with treated effluent.

Strontium concentrations (table 7, fig. 22) significantly increased at sites MW1-2A, MW1-2B, MW1-4A, MW1-4B, MW2-1B, MW4-1A, MW4-2B, USGS-5S, USGS-9S, and the blew hole between pre- and post-effluent samples. Strontium concentrations significantly decreased at sites MW1-1B, MW1-3A, USGS-3D, USGS-3S, USGS-4, USGS-5D, USGS-7, USGS-8D, and USGS-8S between pre- and post-effluent samples. No state MCL standard exists for strontium.

Organic Carbon

Dissolved and total organic carbon samples were collected and analyzed from all monitoring sites. At times, the dissolved organic carbon value reported from the laboratory would be higher than the total organic carbon value. These instances are most likely the result of interference from an iron precipitate that forms in nearly all of the ground-water samples collected at the Columbia/Eagle Bluffs Wetland Complex.

Dissolved organic carbon concentrations (table 2, fig. 23) significantly increased at sites MW1-2A, MW1-2B, MW1-4A, and MW2-1B between pre- and post-effluent sampling. Dissolved organic carbon concentrations significantly decreased at sites USGS-4 and the blew hole between pre- and post-effluent samples. Median dissolved organic carbon concentrations for city outflow and Eagle Bluffs outflow were 7.0 and 6.8 mg/L, respectively. Total organic carbon concentrations (table 2, fig. 24) significantly increased at sites MW1-2A, MW1-4A, MW2-1A, MW4-2A, USGS-3S, USGS-5S, and USGS-7 between pre- and post-effluent samples. Total organic carbon concentrations significantly decreased at the blew hole between pre- and post-effluent samples. Median total organic carbon concentrations for city outflow and Eagle Bluffs outflow were 11 and 12 mg/L, respectively.

Organic Compounds

Based on spatial distribution, 8 of the 33 wells were selected to receive detailed organic-compound sampling. Most of the organic compounds were not detected in samples from the wells or the surface-water sites (table 3). Data for the samples from the wells and the surface-water sites that had organic compounds detected are listed in table 4. The MDL (less than val-

ues) in table 4 vary from constituent to constituent and, with time, for the same constituent. An explanation for the variation in the MDL is given in Richards (1999). Sometimes the MDL is the same as the MRL listed in table 3. Estimated values in the water-quality tables are marked with an 'E' remark code.

The organic compounds that were detected were predominantly pesticides and pesticide metabolites. In samples from the city outflow and the Eagle Bluffs outflow, the semi-volatile organic compounds 1,2-dichlorobenzene, 1,4-dichlorobenzene, and 2,4-dichlorophenol were detected in addition to pesticides and pesticide metabolites. 2,4-dichlorophenol was detected in one sample from Perche Creek and anthracene was detected in one sample from USGS-9S. All of these detections were estimated concentrations and were less than the MRLs for the analysis.

Few organic compounds were detected in either of the pre-effluent or the post-effluent samples. Of those compounds that were detected, little or no change was noted in the concentrations of those compounds in the pre- and post-effluent samples. For the data presented in this report, all of the organic compounds detected were less than their respective state MCLs for drinking water and for ground water (Missouri Department of Natural Resources, 1996), with the exception of one sample collected from Perche Creek in May 1997 that had an atrazine concentration of 6.64 µg/L.

WATER-QUALITY TRENDS

Effects of Missouri River Floods of 1993 and 1995

Major flooding occurred during 1993 and 1995, resulting in the entire study area being inundated with Missouri River floodwater for several weeks. A description of the flooding in the Columbia/Eagle Bluffs Wetland Complex is given in Richards (1999). Nutrient and pesticide data were examined in detail in Heimann and others (1997) as a result of the flooding events and indicated that no appreciable persistent changes were detected in the ground-water quality as a result of the flooding.

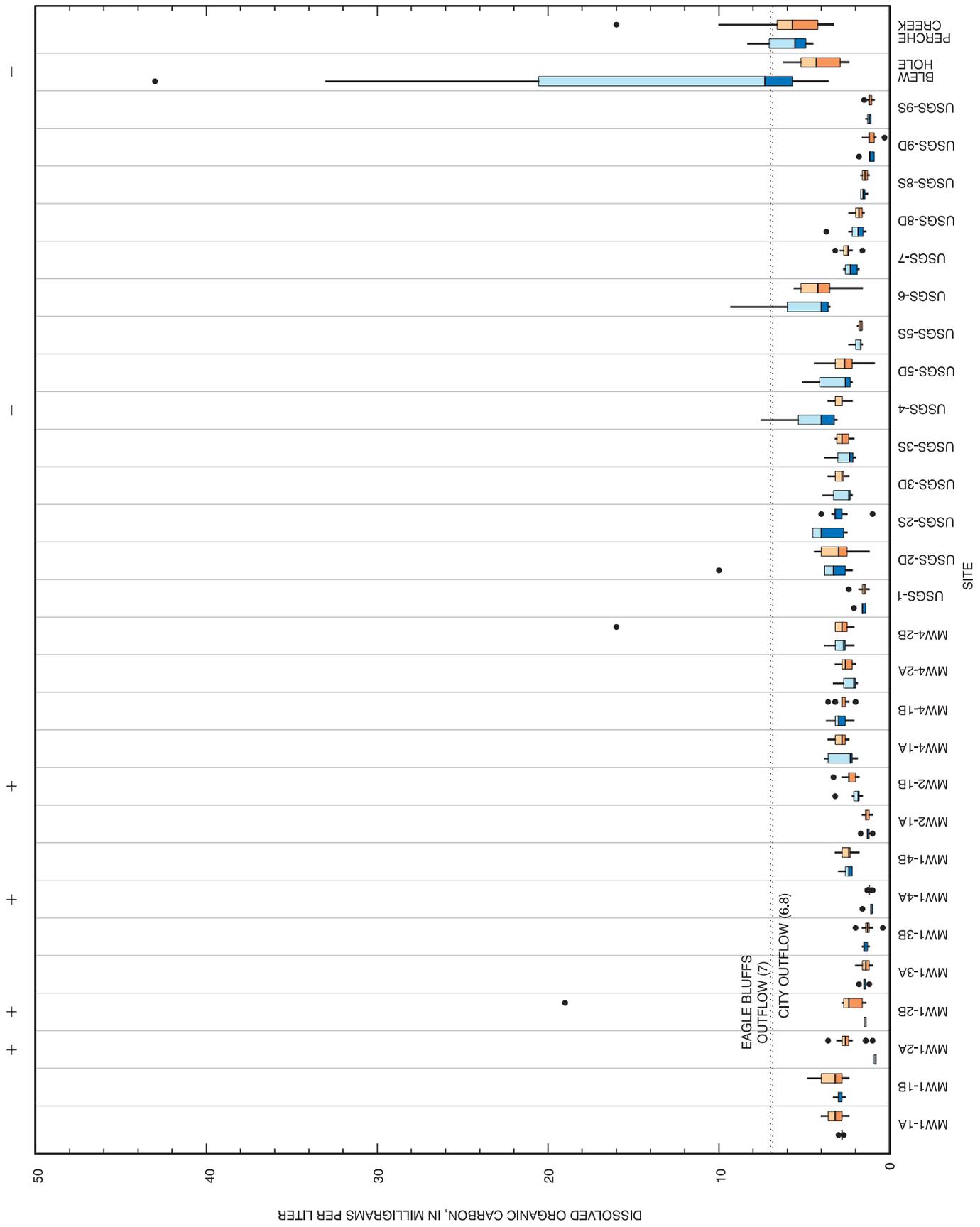


Figure 23. Distribution of dissolved organic carbon concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

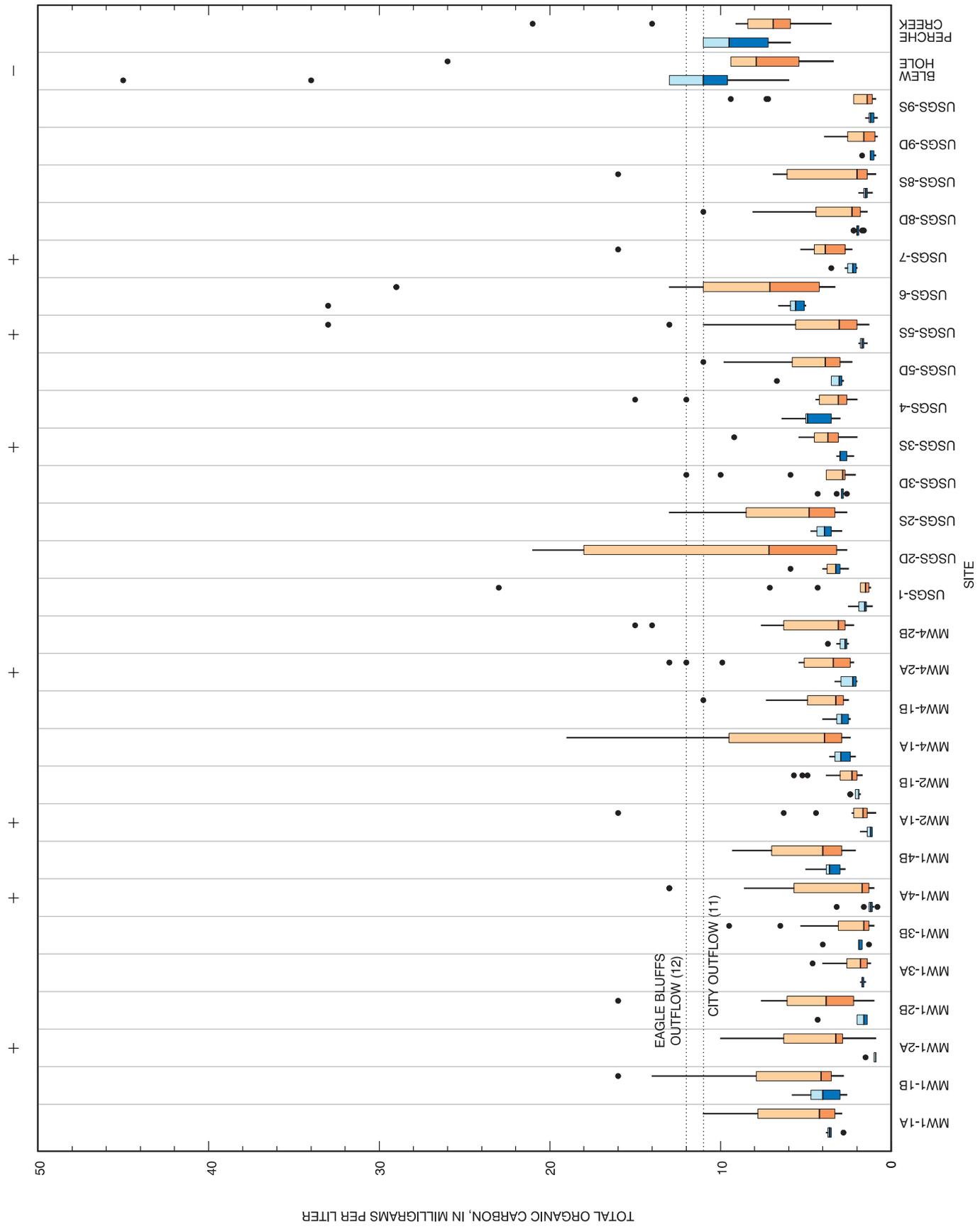


Figure 24. Distribution of total organic carbon concentrations at monitoring sites sampled at the Columbia/Eagle Bluffs Wetland Complex during pre- and post-effluent conditions.

Ground-Water Quality Trends

Major Chemical Constituents

Most of the water-quality changes that were measured between pre- and post-effluent sampling were most pronounced in the major chemical constituents. The concentrations of sodium and calcium had the largest changes for the cations, and the concentrations of sulfate and chloride had the largest changes for the anions. At wells upgradient from the treatment wetland (MW1-4A, MW1-4B, USGS-9D, and USGS-9S), no apparent trends in the concentrations of the pre- and post-effluent major chemical constituents were noted (fig. 25). Also no trends were noted in the pre- and post-effluent major constituent concentrations in the wells USGS-8D and USGS-8S that are located in the southern part of the Columbia municipal-supply well field.

Chloride concentrations had the largest magnitude of change in the ground and surface waters at the Columbia/Eagle Bluffs Wetland Complex. The highest concentration of chloride was 210 mg/L detected in ground water at well MW1-2A. Chloride concentrations in samples from wells MW1-2A, MW1-2B, MW1-3A, MW1-3B, MW4-2A, MW4-2B, USGS-2D, USGS-2S, USGS-3S, USGS-5D, USGS-6, and USGS-7 have increased substantially over pre-effluent values, though all are less than the state MCL.

Chloride concentrations increased in samples from shallow well MW1-2A in early 1995, and chloride concentrations in samples from the deep well MW1-2B increased in late 1995. Chloride concentrations in samples from both wells have stabilized at approximately 200 mg/L. In early 1995, the chloride concentration increased in samples from USGS-3S. In late 1995, chloride concentrations increased in samples from USGS-6 and the blew hole. In early 1996, samples from MW1-3A and USGS-7 began to indicate chloride concentration increases. The chloride concentration increased in samples from MW4-2A, USGS-5D, and USGS-2D in mid- to late-1996, from USGS-2S in early 1997, from MW4-2B in mid-1997, and from USGS-3D in early 1998. The chloride concentration in samples from MW4-2A and USGS-2S decreased to nearly background concentrations in mid-1998. Chloride concentration increased a second time in samples from MW4-2A in early 1999. Associated with the increased chloride concentrations usually is an increase in sulfate concentration and a decrease in alkalinity. Chloride concentrations in samples from

wells MW1-2A, MW1-2B, MW1-3A, and MW1-3B do not conform to the trend of increased concentrations followed by decreased concentrations. The wells are located near the treatment wetland unit 1. Samples from these wells also had increases in specific conductance and dissolved solids concentrations, which indicate that water from these wells have an increased amount of solids in solution. Samples from MW4-2A, USGS-2D, USGS-2S, USGS-3D, USGS-5D, USGS-6, and USGS-7 had little or no changes in specific conductance or dissolved solids concentrations, indicating that the changes in chloride and sulfate concentrations were balanced by the reduction in alkalinity, thus keeping the total amount of solids in solution relatively constant.

In most cases, the concentration increases of the major cations lagged behind the chloride concentration increase by several months. Chloride is a relatively non-reactive constituent and generally is transported at the water velocity. 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 the water velocity. Evidence of this retardation effect can be seen in many of the graphs in figure 25. Concentrations in samples from some wells indicate evidence for surface exchange on clays and organic material. For example, samples from well MW1-2A had an increased chloride concentration at the same time as the calcium concentration increased. However, the concentrations of calcium in the treated effluent and the pre-effluent ground water were both lower 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 increase the calcium concentrations and would account for the calcium concentrations being greater than 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 while the concentrations of sodium and potassium would begin to increase (fig. 25).

The concentrations of the major chemical constituents sodium, potassium, chloride, and sulfate in the treated effluent are large relative to the same constituents in pre-effluent ground water (fig. 25). Between October 1994 and December 1998, personnel from the

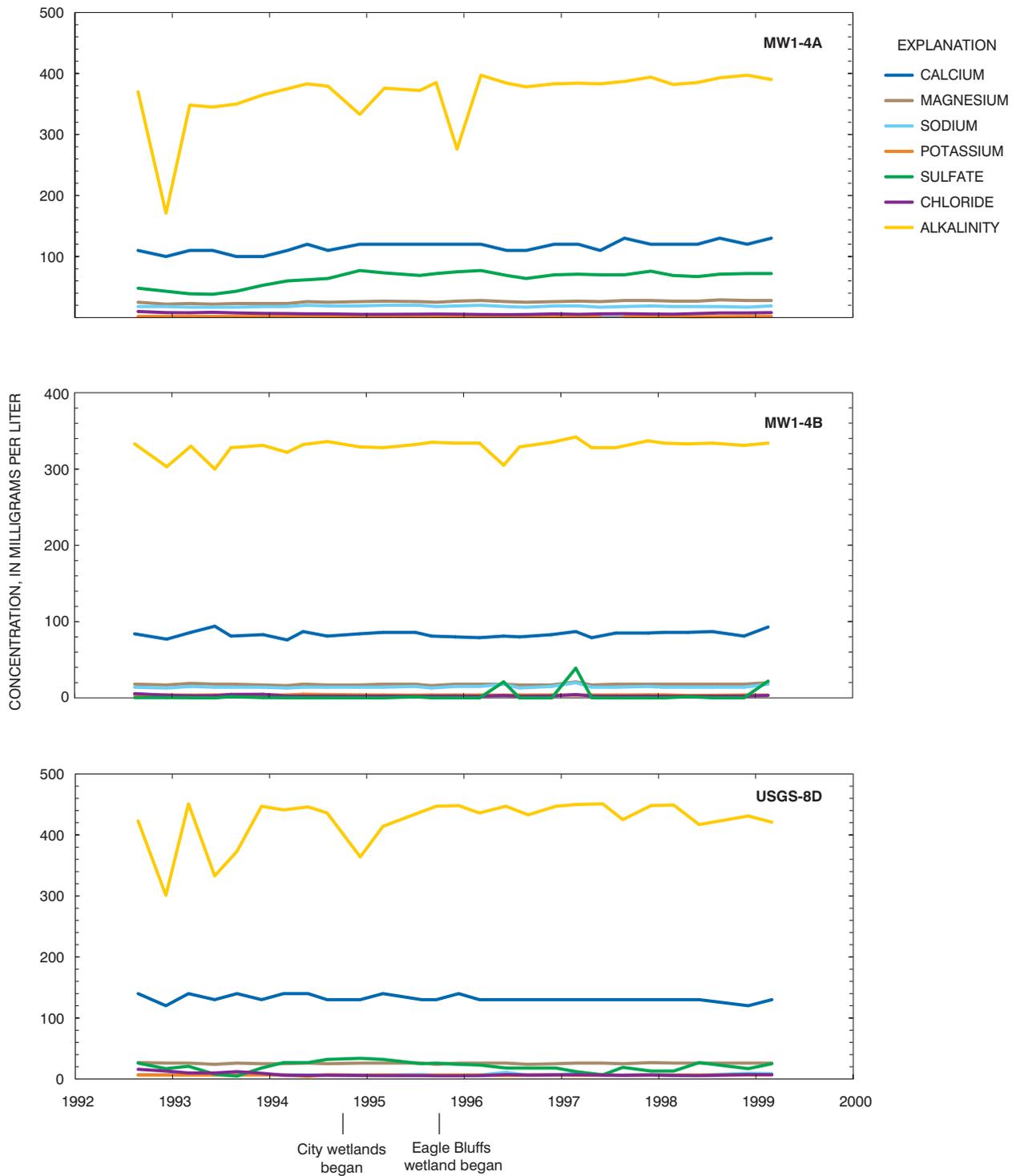


Figure 25. Dissolved calcium, magnesium, sodium, potassium, sulfate, and chloride concentrations and alkalinity values for selected sites at the Columbia/Eagle Bluffs Wetland Complex.

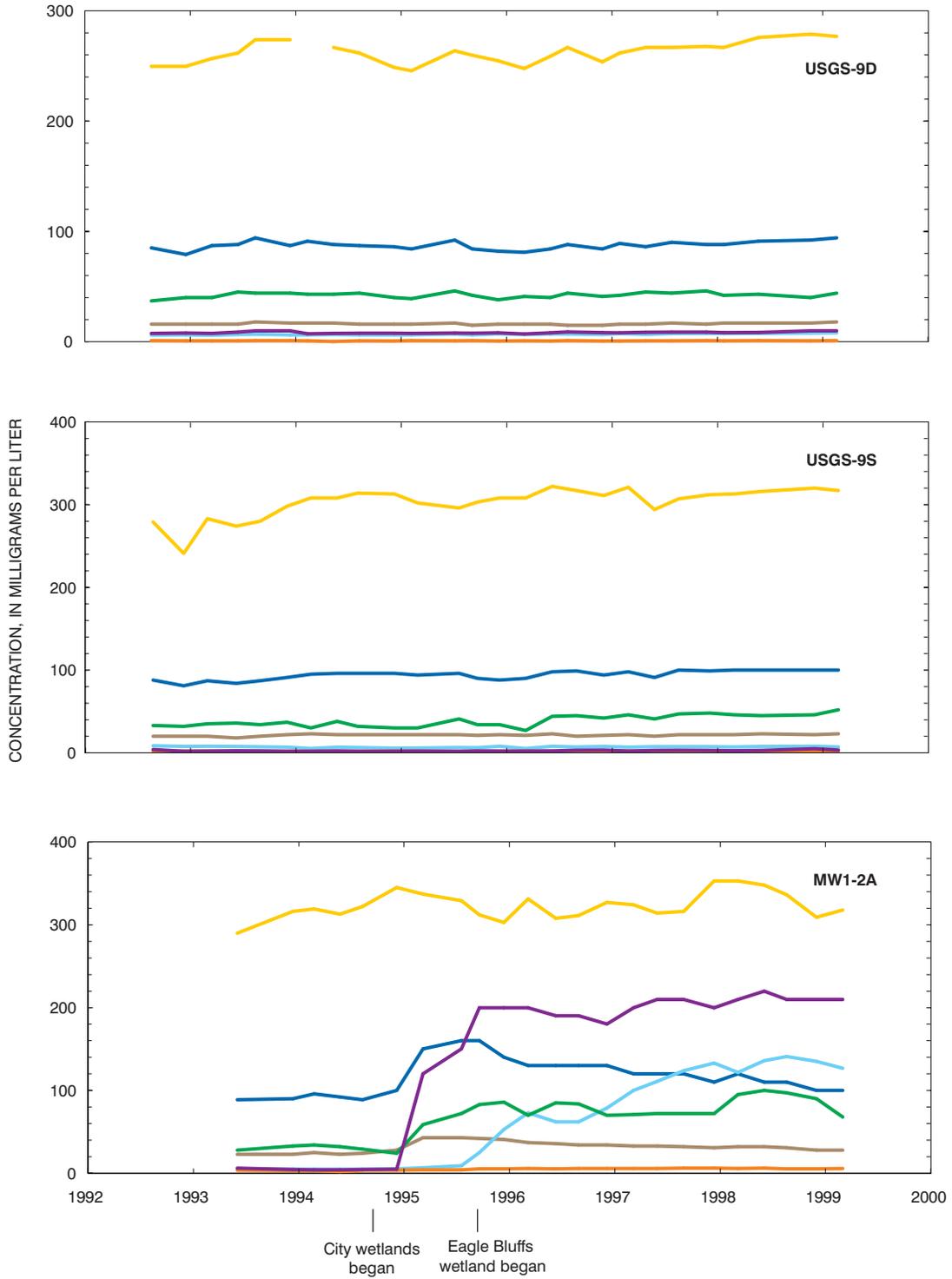


Figure 25. Dissolved calcium, magnesium, sodium, potassium, sulfate, and chloride concentrations and alkalinity values for selected sites at the Columbia/Eagle Bluffs Wetland Complex—Continued.

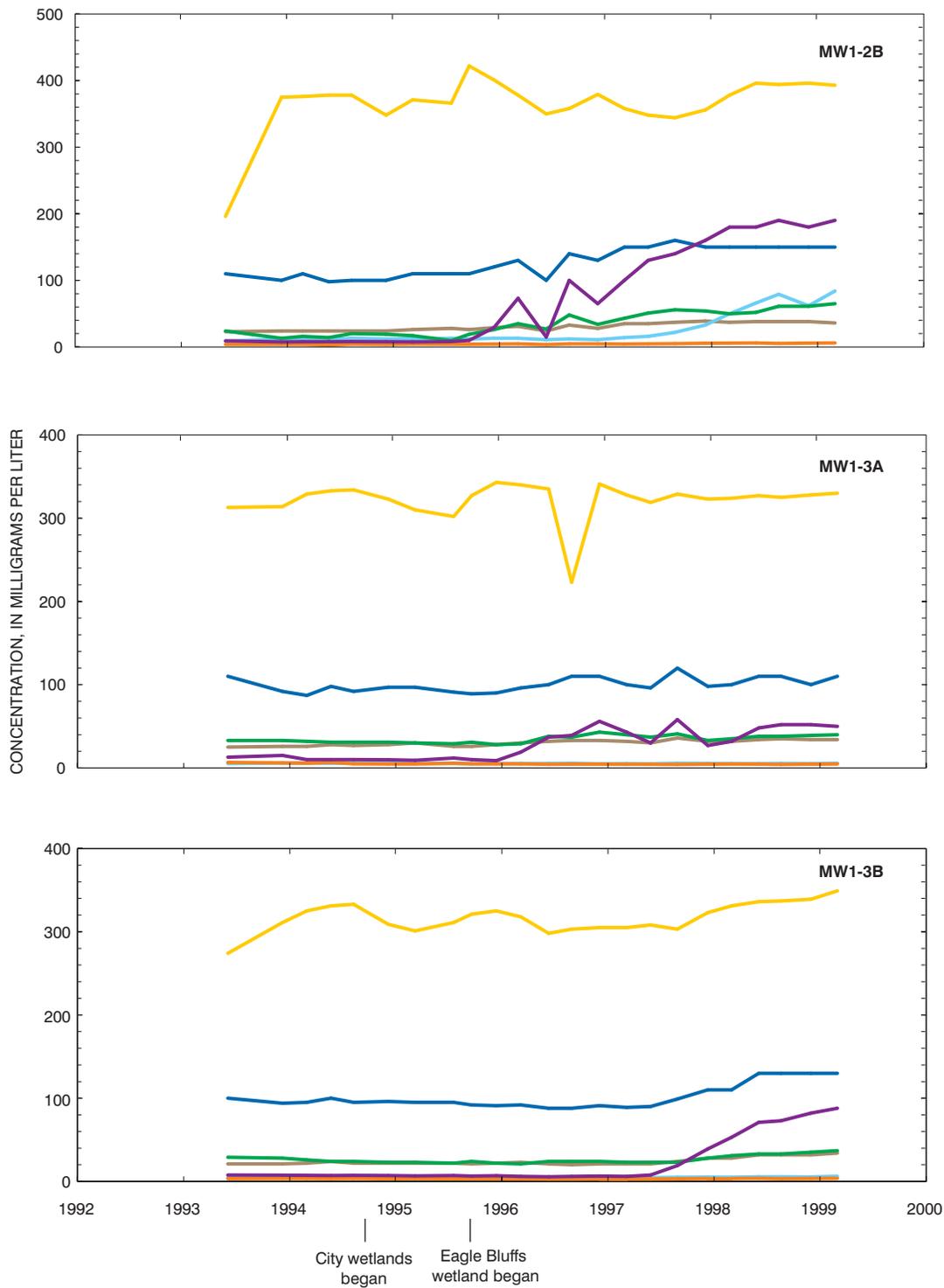


Figure 25. Dissolved calcium, magnesium, sodium, potassium, sulfate, and chloride concentrations and alkalinity values for selected sites at the Columbia/Eagle Bluffs Wetland Complex—Continued.

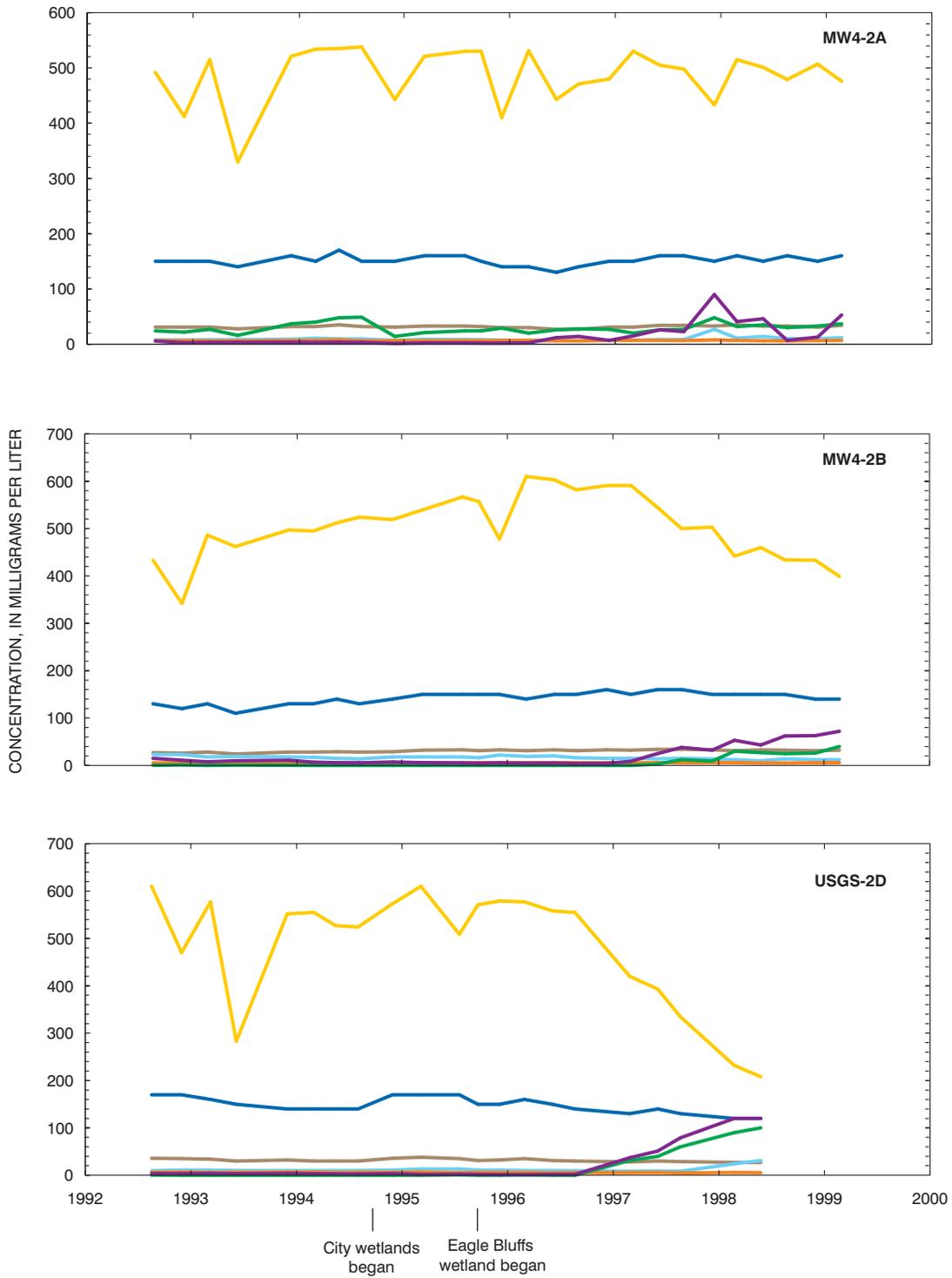


Figure 25. Dissolved calcium, magnesium, sodium, potassium, sulfate, and chloride concentrations and alkalinity values for selected sites at the Columbia/Eagle Bluffs Wetland Complex—Continued.

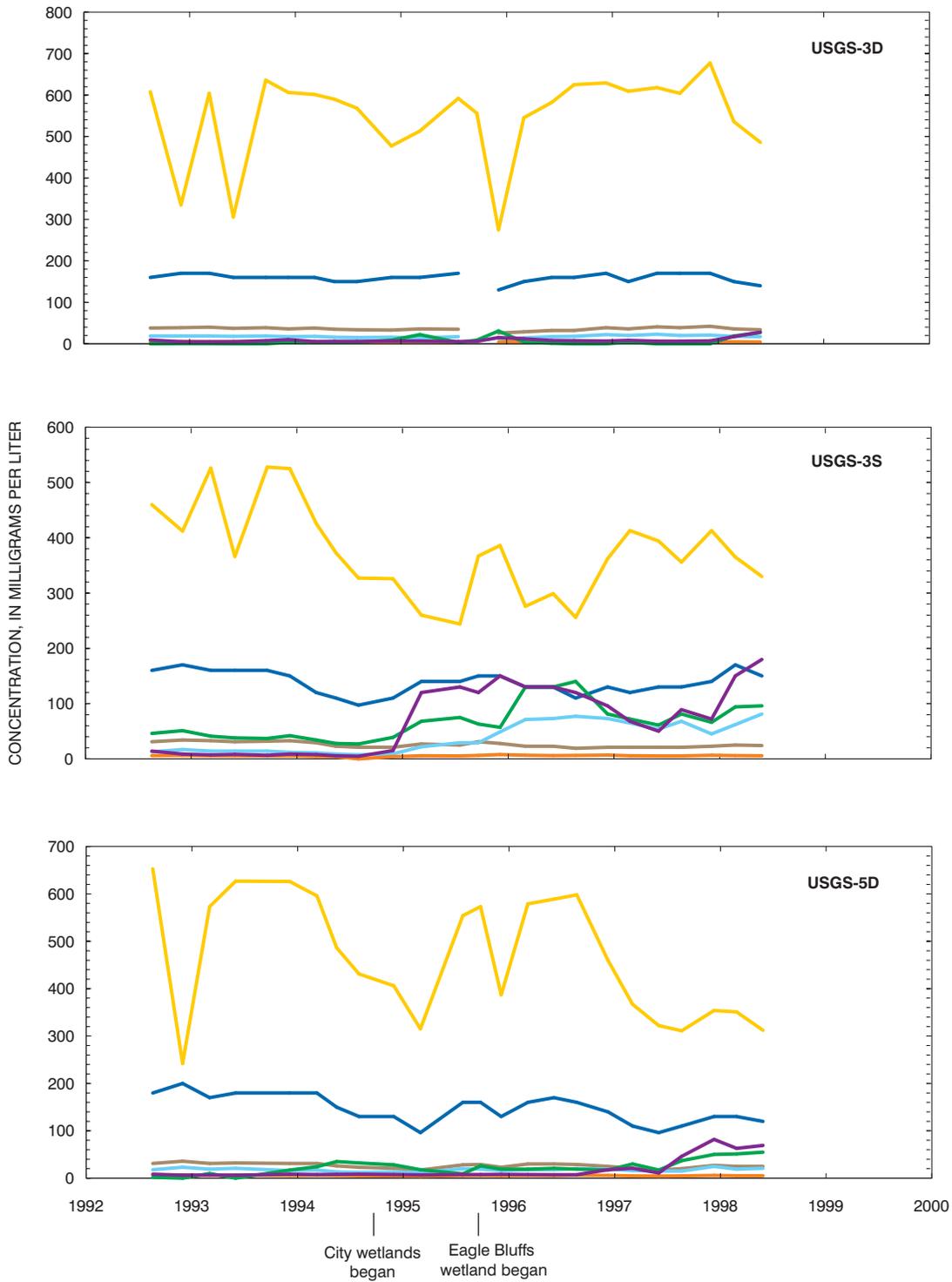


Figure 25. Dissolved calcium, magnesium, sodium, potassium, sulfate, and chloride concentrations and alkalinity values for selected sites at the Columbia/Eagle Bluffs Wetland Complex—Continued.

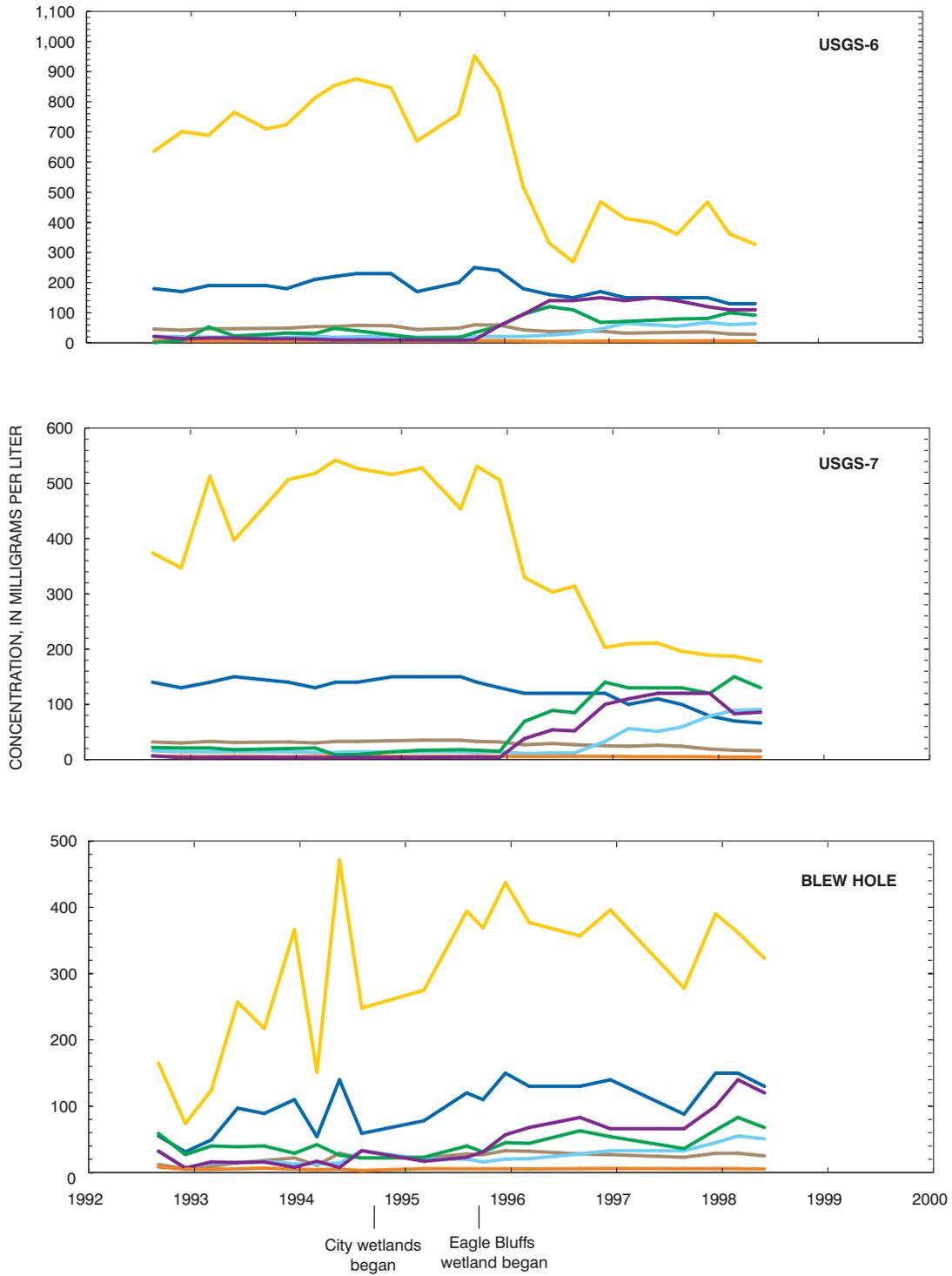


Figure 25. Dissolved calcium, magnesium, sodium, potassium, sulfate, and chloride concentrations and alkalinity values for selected sites at the Columbia/Eagle Bluffs Wetland Complex—Continued.

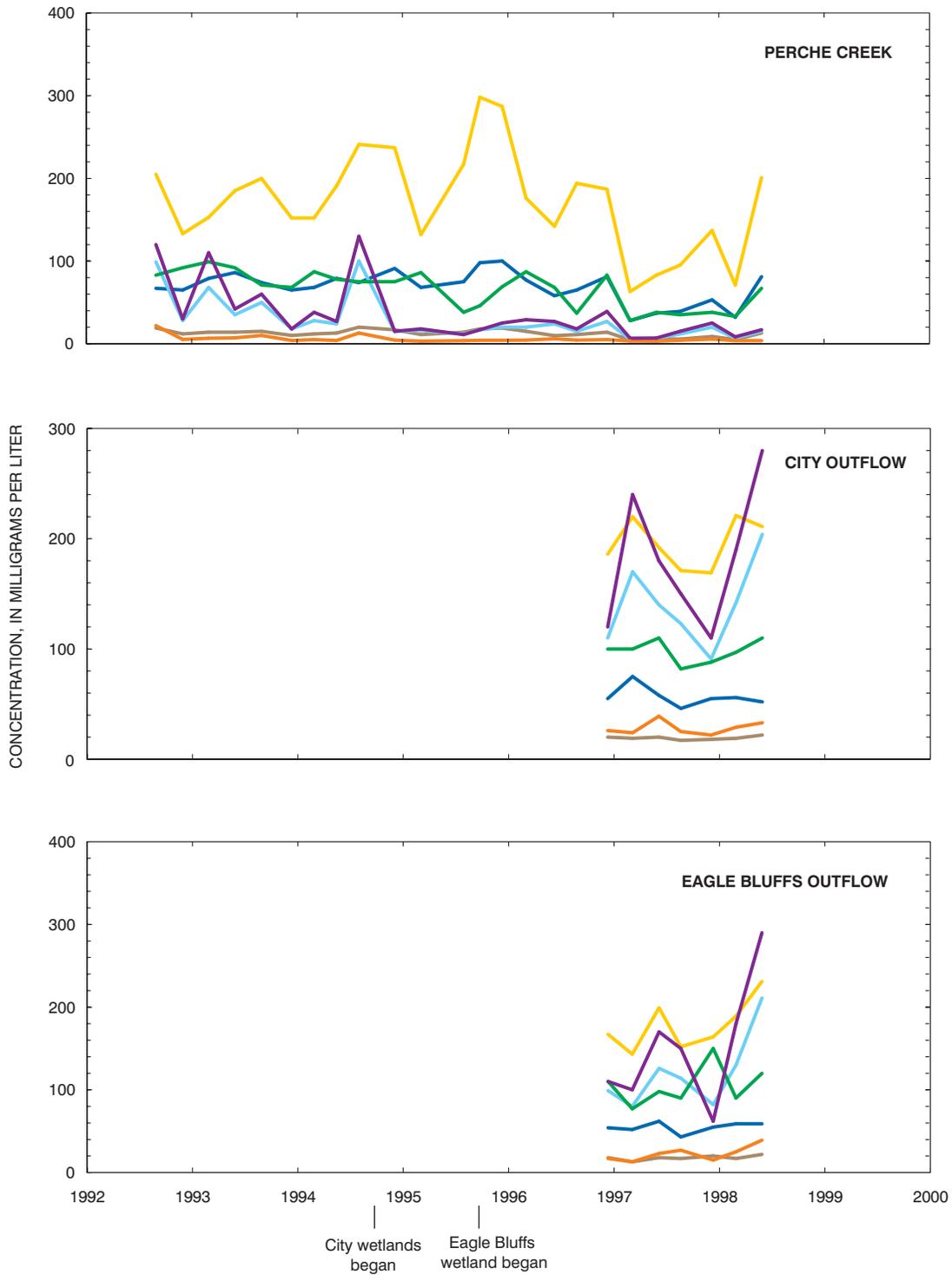


Figure 25. Dissolved calcium, magnesium, sodium, potassium, sulfate, and chloride concentrations and alkalinity values for selected sites at the Columbia/Eagle Bluffs Wetland Complex—Continued.

University of Missouri-Columbia collected monthly samples from several surface-water locations within the wetland complex (M.F. Knowlton, University of Missouri-Columbia, written commun., 1999). Samples collected in the semi-permanent marsh areas near USGS-3S, USGS-3D, and USGS-6 (M.F. Knowlton, written commun., 1999) indicated that a substantial chloride increase occurred in the surface water in late 1994. Even though surface water with high chloride concentrations remained within 100 ft of the wells, chloride concentrations in samples from USGS-3S and USGS-6 did not increase until approximately 1 year later. Chloride concentrations did not increase in samples from USGS-3D until early 1998. Measured water-level altitudes in well pairs differ only slightly, which indicate that the vertical component of the hydraulic gradient is small in the study area. Even though the gradient in the vertical component of flow 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 treated effluent on the surface and the observed constituent changes in the wells. 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 material.

Pre-effluent samples from the ground water indicate that the water was predominantly a calcium-magnesium bicarbonate water type (fig. 26). Post-effluent samples at wells that had increased chloride concentrations indicated a shift toward a predominantly sodium-chloride water type (fig. 27). The concentrations of the major constituents in these wells are on the

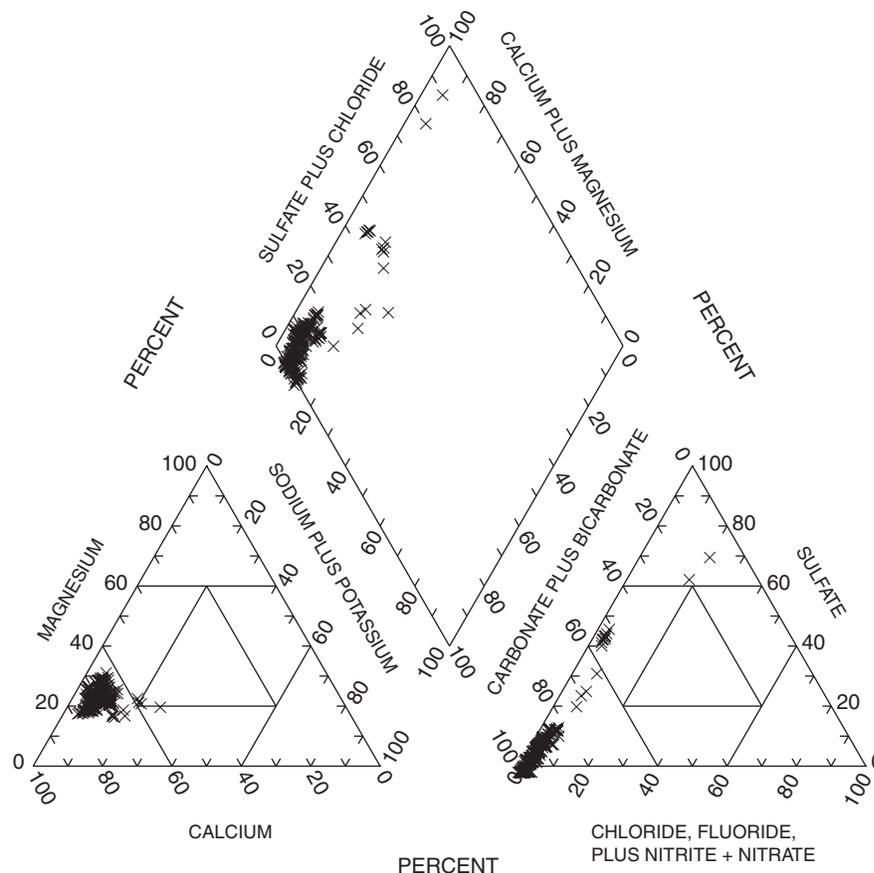


Figure 26. Pre-effluent ground-water samples collected at the Columbia/Eagle Bluffs Wetland Complex.

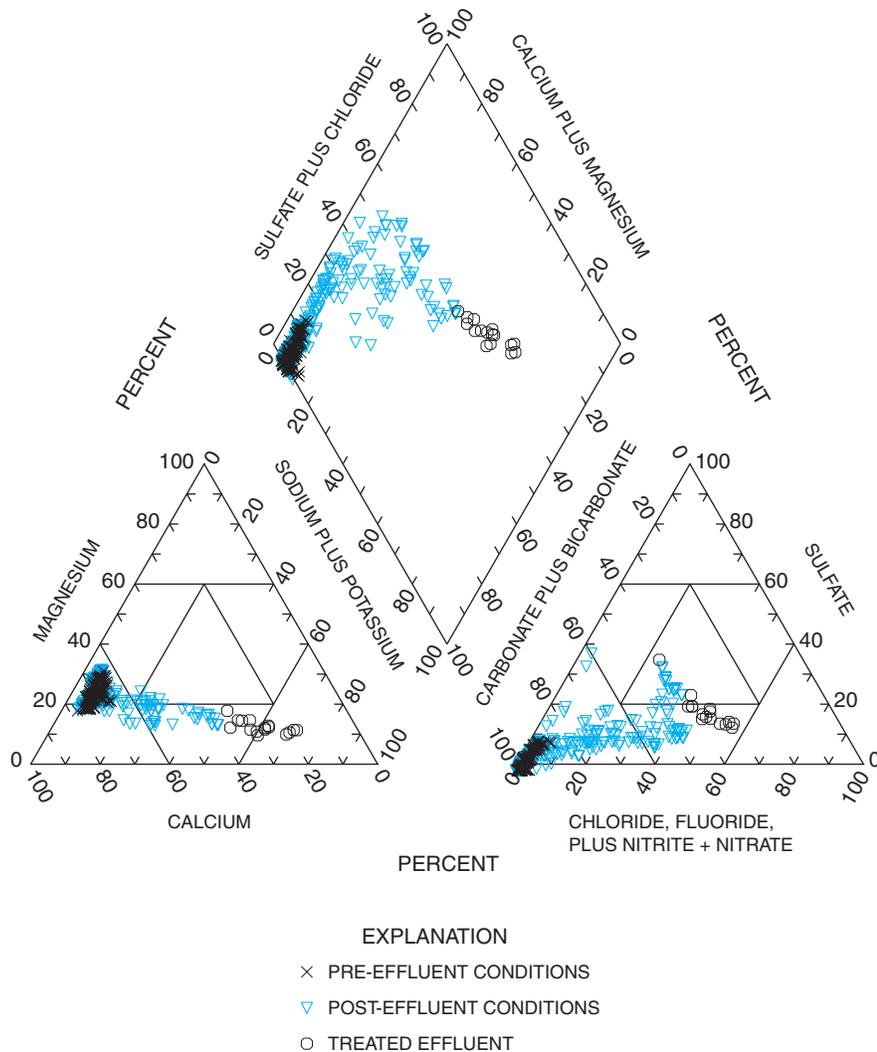


Figure 27. Ground-water samples collected at the Columbia/Eagle Bluffs Wetland Complex that had changes in major chemical constituent concentrations.

mixing continuum between the pre-effluent ground water as one end member and the treated effluent surface water as the other end member.

Forty-two samples collected by personnel from the University of Missouri-Columbia from October 1994 to December 1998 had a mean chloride concentration of 200 mg/L at the city outflow, and 50 samples collected from March 1994 to December 1998 had a mean chloride concentration of 20 mg/L in the Missouri River near Eagle Bluffs (M.F. Knowlton, written commun., 1999). Seven samples collected by the USGS from December 1996 to May 1998 at the city outflow had a mean chloride concentration of 180 mg/L. As part of the state ambient water-quality net-

work, the USGS collected 59 samples from the Missouri River at Hermann between November 1992 and September 1998 (data on file at the U.S. Geological Survey office, Rolla, Missouri). The mean chloride concentration for these samples was 16.8 mg/L. The chloride concentration data collected by the University of Missouri-Columbia are of comparable quality to the USGS data and because of the greater number of samples, are probably more representative of the mean chloride concentration in the treated effluent. Chloride generally is considered a conservative element in ground- and surface-water environments because it does not readily exchange with other anions and is fairly unreactive during normal conditions. 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 arrive at the relative mixture of the source waters. Based on this assumption and using a treated effluent chloride concentration of 200 mg/L, the relative percentage of treated effluent in ground water ranges from 11 percent in USGS-3D to more than 100 percent in MW1-2A (table 8).

Table 8. Estimated relative percentage of treated effluent in the ground water at selected sites at the Columbia/Eagle Bluffs Wetland Complex

[mg/L, milligrams per liter]

Site identifier (fig. 2)	Pre-effluent average chloride concentration (mg/L)	Most recent chloride concentration (mg/L)	Relative percent
Blew hole	18.5	120	56
MW1-2A ^a	4.8	210	105
MW1-2B	8.2	190	95
MW1-3A	11.6	50	20
MW1-3B	7.4	88	42
MW4-2A	3.7	53	25
MW4-2B	9.1	72	33
USGS-2D	3.4	120	59
USGS-2S	2.2	^b 51	25
USGS-3D	6.5	28	11
USGS-3S	7.9	180	90
USGS-5D	7.5	69	32
USGS-6	14.0	110	52
USGS-7	4.1	86	42

^aAverage surface water concentration higher than 200 mg/L in this area.

^bConcentration on 8/21/97.

Trace Constituents

Changes in the median concentrations of some trace constituents (table 7), barium, manganese, and strontium, were observed in samples collected at some sites (MW1-1A, MW1-1B, MW4-1A, USGS-8S, and USGS-9S), but the samples from those sites had few changes in major chemical constituents (table 5). Changes in the trace constituent concentrations without changes in the major chemical constituent concentrations are unlikely if the changes result from mixing ground water and treated effluent. These observations could be the result of natural chemical evolution of the ground water, or changes related to water-level fluctu-

ations, allowing the ground water to be in contact with different aquifer materials. Modification of the oxidation-reduction environment by alteration of the amount of oxygen introduced to the aquifer through natural percolation could potentially be a contributing factor in some of these changes.

Samples from sites MW1-2A, MW1-2B, MW1-3A, MW4-1B, MW4-2B, USGS-2D, USGS-2D, USGS-3D, USGS-3S, USGS-4, USGS-5D, USGS-6, USGS-7, blew hole, and Perche Creek had concentration changes in several of the major chemical constituents (table 5), and samples from many of these sites also had concentration changes in some of the trace constituents (table 7). Samples from monitoring well MW1-2A had a gradual concentration increase in boron similar to the major chemical constituent concentration increases previously discussed. The increase in boron concentration lagged behind the major chemical constituent concentration increases because of the retardation effects previously discussed. Boron in samples from MW1-2A was the only trace constituent that had a consistent temporal change among the sampled wells. Boron naturally occurs in igneous rocks and particularly in the mineral tourmaline, which is strongly resistant to weathering (Hem, 1992). The measured boron concentration increase was not likely from increased dissolution of boron-rich minerals. Boron is also a common ingredient in cleaning aids (sodium tetraborate – borax) and, as a result, may be present in sewage and industrial wastes (Hem, 1992). The median boron concentration was 80 µg/L for all pre-effluent ground-water samples and was 40 µg/L for pre-effluent samples from well MW1-2A. The median boron concentration in the city outflow was 233 µg/L. The boron concentration increase at well MW1-2A is most likely the result of mixing treated effluent with ground water. With the exception of some of the major chemical constituents, nutrients, and boron, the concentrations for the trace constituents in the treated effluent generally were the same or less than the concentrations in the ground water.

Trace constituents are affected by processes such as oxidation and reduction, complexation, and surface exchange with or sorption to clays and organic materials in the aquifer. The resulting trace-element concentrations are most likely from a combination of mixing, natural fluctuations, cation exchange, and chemical changes resulting from water-level fluctuations. The variability in the trace constituent chemical changes

with respect to the depth and spatial distribution of the wells also is partly a reflection of the anisotropy in the aquifer material.

Nutrients, Indicator Bacteria, Total and Dissolved Organic Carbon, and Organic Compounds

Nutrient concentrations, indicator bacteria densities, and total and dissolved organic carbon concentrations did not have any clear temporal trends. Some sites had changes in median concentrations; however, correlating these changes to the interaction of treated effluent with the ground water could not be made. The changes observed for nutrient and organic carbon concentrations are most likely a result of a combination of sample matrix interference during analysis at the laboratory, natural fluctuations, and the alteration of the oxidation and reduction environment as a result of water-level fluctuation.

From the beginning of this study, the pesticides and pesticide metabolites alachlor, carbaryl, metolachlor, propachlor, lindane (total), lindane (dissolved), p,p'-DDE, pendimethalin, trifluralin, chlorpyrifos, diazinon, linuron, tebuthiuron, propargite, DCPA, atrazine, cyanazine, deethylatrazine, prometon, simazine, metribuzin, chlordane, and perthane were detected in ground- or surface-water samples at least once. Atrazine was the most frequently detected pesticide. No temporal trends in detections of organic compounds were identified. No clear correlation exists between the detection of the pesticides, pesticide metabolites, or other organic compounds in ground-water samples and the interaction of treated effluent with ground water.

Surface-Water Quality Trends

The water quality has improved in Perche Creek after the wetland treatment began operation. Perche Creek, before October 1994, was used as the receiving water for the Columbia wastewater-treatment plant. After October 1994, most of the major chemical constituent concentrations decreased in samples collected from the creek. Fecal indicator bacteria densities decreased in samples from the creek.

The water quality in the blew holes is connected to the water quality in the ground water. Water-level changes in the blew hole sampling site appear to coincide with water-level changes in surface and ground water. The blew hole near USGS-3D is isolated from the Eagle Bluffs wetland by a flood control levee, but changes in major chemical constituent concentrations

in samples from the blew hole parallel the changes in concentrations in the ground-water samples from USGS-3D. The resulting changes in ground water have increased the chloride concentration in the blew hole. The maximum chloride concentration detected in the blew hole near USGS-3D was 140 mg/L, which is less than the standard for chloride chronic toxicity in surface water. The trends in chloride concentrations observed in the blew hole can be correlated to the interaction of the ground water with treated effluent that has discharged to the blew hole.

As the treated effluent passes through the Eagle Bluffs wetland, a marked decrease in the concentration of nitrogen species and mean densities of indicator bacteria occur. The concentration of ammonia plus organic nitrogen (as nitrogen) decreased from a mean of 6.1 mg/L at the city outflow to a mean of 2.8 mg/L at the Eagle Bluffs outflow (table 2). Mean concentrations of phosphorus species have a similar trend. Total phosphorus concentrations decreased from a mean of 2.07 mg/L to 1.00 mg/L, and orthophosphorus concentrations decreased from a mean of 1.74 mg/L to 0.709 mg/L between the same two locations (table 2). Processes such as biological uptake and chemical precipitation contribute to this decrease in nutrient concentrations. The mean density of fecal coliform decreased from 2,027 col/100 mL at the city outflow to 65 col/100 mL at the Eagle Bluffs outflow (table 2). The mean density of fecal streptococci was 5,997 col/100 mL at the city outflow and 122 col/100 mL at the Eagle Bluffs outflow (table 2). Natural die off of the fecal bacteria probably account for the majority of the decrease in fecal bacteria densities. With respect to nutrients and fecal indicator bacteria, the Eagle Bluffs wetland seems to be substantially decreasing the concentrations of these constituents in the treated effluent.

GROUND-WATER HYDROLOGY

Synoptic water-level measurements collected between August 1996 and March 1999 are listed in table 9. Daily mean water-level data collected between August 1996 and March 1999 for wells SP 4 and SP 11 are presented in figure 28.

Table 9. Quarterly water-level measurements for wells at the Columbia/Eagle Bluffs Wetland Complex

[Measurements are in feet below measuring point; --, no data]

Site identifier (fig. 2)	8/20/96	12/3/96	2/27/97	5/29/97	8/18/97	12/1/97	2/23/98	5/13/98	8/17/98	11/30/98	2/24/99
MW1-1A	8.98	9.15	7.74	7.80	9.57	9.82	9.30	8.14	8.93	8.45	8.00
MW1-1B	13.78	14.11	10.02	11.17	14.46	15.20	14.72	12.62	13.87	12.97	12.89
MW1-2A	10.79	12.20	8.86	7.82	11.80	13.29	14.14	10.74	11.14	10.70	12.69
MW1-2B	10.89	12.28	8.97	7.90	11.85	13.36	14.23	10.80	11.19	10.76	12.76
MW1-3A	12.79	14.64	12.08	10.13	14.83	16.23	16.90	12.73	13.38	12.81	15.30
MW1-3B	12.81	14.60	12.08	10.18	14.91	16.27	16.95	12.79	13.42	12.85	15.35
MW1-4A	19.72	11.68	10.25	11.20	12.10	12.23	11.42	11.29	12.04	11.86	10.77
MW1-4B	12.13	20.02	14.56	17.00	20.66	21.52	20.68	18.70	20.12	19.12	18.81
MW2-1A	15.37	15.02	13.29	11.74	17.61	16.10	19.01	16.97	17.74	15.75	18.93
MW2-1B	15.18	14.80	13.03	11.46	17.37	15.87	18.80	16.77	17.55	15.52	18.72
MW2-2A	9.22	8.87	5.65	4.98	10.93	10.19	12.57	10.53	11.01	--	--
MW2-2B	8.41	8.68	6.58	5.01	10.66	9.89	12.41	10.42	10.75	--	--
MW3-1A	9.95	8.64	6.80	6.20	12.41	9.03	12.05	10.59	12.17	8.52	12.06
MW3-1B	9.94	8.62	6.82	6.18	12.37	9.02	12.07	10.41	12.15	8.54	12.10
MW4-1A	8.81	6.28	5.28	5.00	11.62	6.16	9.71	9.04	11.22	5.36	9.85
MW4-1B	8.64	6.20	4.97	4.77	11.44	6.02	9.68	9.03	11.12	5.37	9.85
MW4-2A	7.02	4.52	3.40	3.92	9.97	4.19	7.92	8.12	10.51	4.44	7.88
MW4-2B	7.02	4.58	3.43	3.94	9.96	4.20	7.94	8.21	10.53	4.45	7.92
MW13-67	16.19	16.76	15.30	12.26	18.97	17.97	21.78	20.89	--	--	--
USGS-1	7.97	6.06	4.07	4.30	10.18	6.31	9.41	8.20	--	--	--
USGS-2D	6.55	3.92	3.61	4.50	9.97	3.75	6.79	7.40	--	--	--
USGS-2S	6.65	4.00	3.69	4.65	10.07	3.83	6.85	7.50	--	--	--
USGS-3D	5.18	3.66	2.88	3.78	8.69	3.38	5.42	6.02	--	--	--
USGS-3S	5.00	3.42	2.72	3.65	8.49	3.21	5.19	5.80	--	--	--
USGS-4	10.63	9.30	6.86	7.89	13.77	9.66	12.40	12.13	--	--	--
USGS-5D	4.90	3.49	3.50	5.28	9.56	3.59	5.03	6.43	--	--	--
USGS-5S	4.93	3.56	3.58	5.31	9.58	3.64	5.03	6.49	--	--	--
USGS-6	7.95	6.22	4.56	5.58	11.22	6.19	8.78	8.63	--	--	--
USGS-7	9.45	6.26	4.37	5.12	11.85	6.86	9.52	11.18	--	--	--
USGS-8D	12.50	13.15	11.67	8.63	15.32	14.40	18.09	16.36	--	12.72	17.39
USGS-8S	12.89	13.29	11.95	8.72	15.41	14.56	18.03	15.84	--	12.56	17.27
USGS-9D	16.20	17.48	19.94	13.89	18.01	18.65	20.51	15.74	--	15.31	18.77
USGS-9S	16.11	17.42	19.95	13.85	17.96	18.59	20.42	15.59	--	15.21	18.67

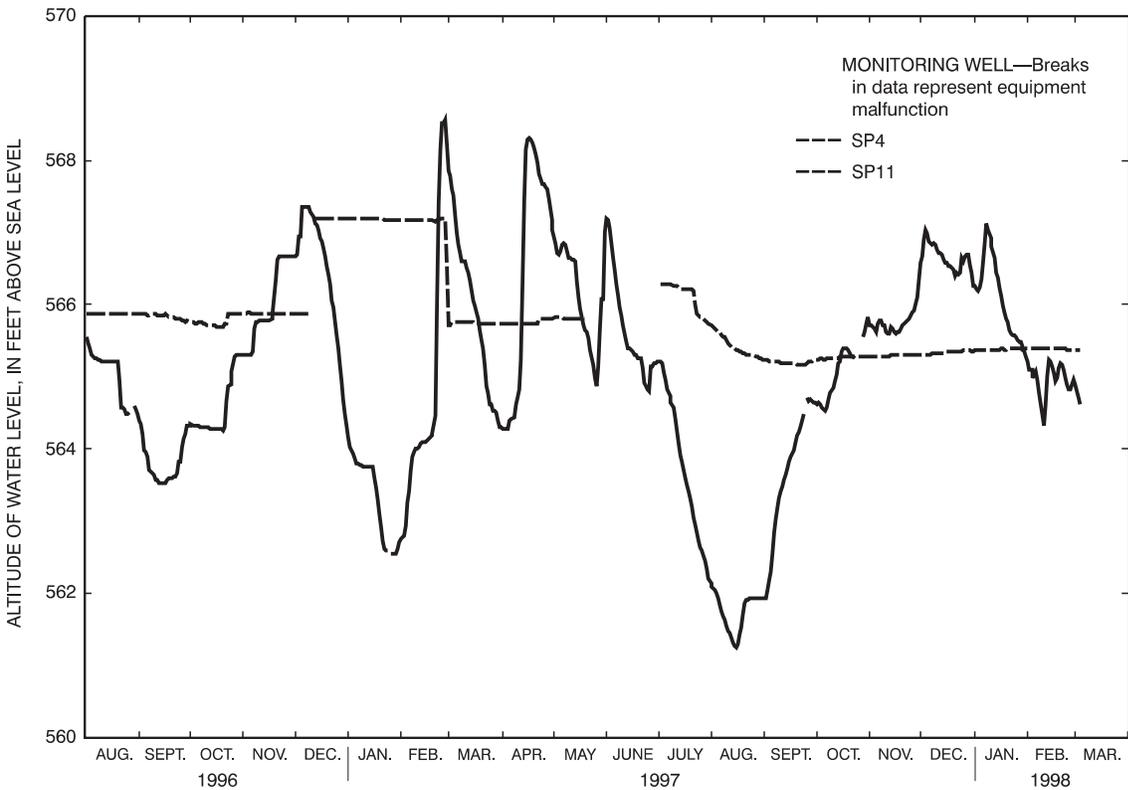


Figure 28. Water-level altitudes in monitoring wells SP4 and SP11, located at the Columbia/Eagle Bluffs Wetland Complex.

Pre-Effluent Ground-Water Levels

Foreman and Sharp (1981) concluded that ground-water levels in the aquifer were largely controlled by Missouri River stage variation and pumping from municipal-supply wells. Recharge from precipitation, seepage into and out of Perche Creek, and recharge from bedrock aquifers were relatively minor factors on the control of ground-water levels. These conclusions still largely are true, but the operation of the wastewater-treatment wetland and the reclamation of wetlands on the Eagle Bluffs Conservation Area further complicate the ground-water flow. The seasonal flooding of the approximately 1,200 wetland acres in the study area for wildlife management provides additional recharge to the aquifer.

Potentiometric-surface (water-level) maps can be used to show the general direction of ground-water flow. Generally, the ground-water flow direction is downgradient and perpendicular to the potentiometric contours. A potentiometric map (fig. 29) constructed from water-level data collected from monitoring wells in August 1978 (before the existence of the wetland

complex) indicates the aquifer received recharge in the north near the bend in the Missouri River and along the west edge of the aquifer and discharged water in the south into the river with some discharge potentially to Perche Creek (Foreman and Sharp, 1981). The general ground-water flow direction in the aquifer was toward the south or southeast, primarily down the river valley and toward the river with some cross-aquifer flow east toward Perche Creek. The ground-water flow direction can be altered periodically by short-term events such as temporary high or low stages in Perche Creek and the Missouri River. Longer-term alterations can be the result of continuous ground-water pumping from municipal-supply wells or long-term climatic periods, such as multi-year droughts or floods.

Potentiometric-surface maps produced from selected seasonal periods both before and after flooding of the wetland complex are shown in figure 30. The distribution of the monitoring wells for this study was not designed to determine the potentiometric surface in the municipal-supply well field area. Available data are insufficient to accurately map the potentiometric surface in the well field or to connect the ground-water

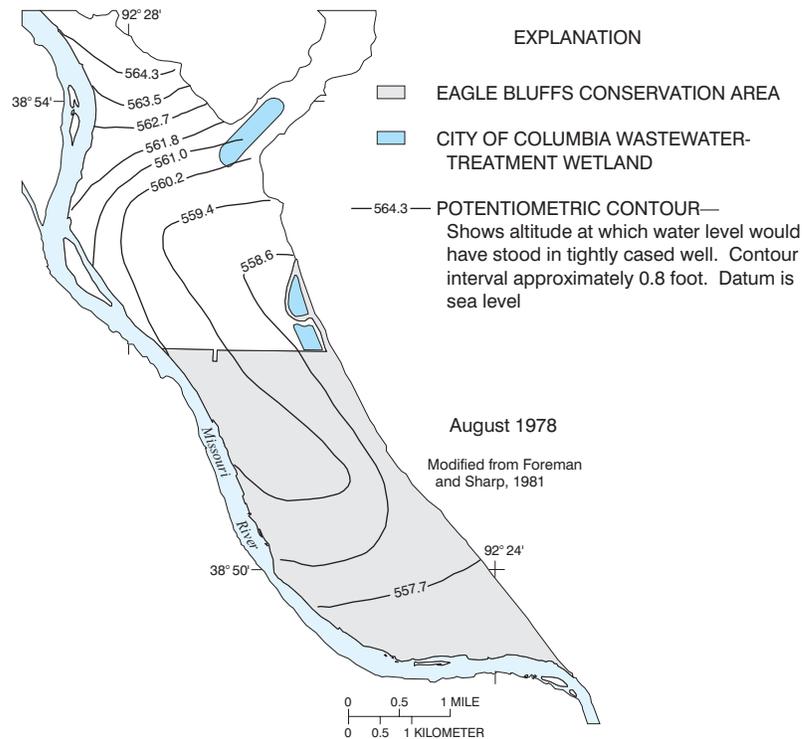


Figure 29. Potentiometric surface in the alluvial aquifer at the Columbia/Eagle Bluffs Wetland Complex, August 1978.

levels to the Missouri River, so the potentiometric contours near the well field and the Missouri River are approximately located. Potentiometric-surface maps constructed for this study differ from Foreman and Sharp (1981) by the ground-water high in the southern part of the study area.

Before wetland flooding in October 1994, the probable direction of ground-water flow in the central and southern part of the Eagle Bluffs Conservation Area was to the south, away from the well field. In the north part of the Eagle Bluffs Conservation Area, flow probably was north toward the well field. Before and after the construction and flooding of the wetland complex, the Missouri River stage has a strong effect on the ground-water levels in the aquifer. The March 1993 and February 1994 maps in figure 30 show possible transient effects of changing Missouri River stage on the potentiometric surface.

Foreman and Sharp (1981) noted two ground-water response zones—a zone of rapidly fluctuating ground-water levels near the river and a zone of predominantly down-valley flow. A comparison of Missouri River stage at Hermann, Missouri, and the ground-water level in well SP 11 from October 1995 to October 1997 shows a correlation between river stage and water-level fluctuations (fig. 31). Well SP 11 is in

the zone identified by Foreman and Sharp (1981) of rapidly fluctuating ground-water levels. The effects of the Missouri River stage fluctuations are attenuated as the distance from the river increases.

Post-Effluent Ground-Water Levels

A ground-water high (fig. 30) is a persistent hydrologic feature beneath the Eagle Bluffs Conservation Area, and to the extent identifiable, beneath the treatment wetland unit 1. Seasonal potentiometric-surface maps indicate that the ground-water high persists throughout the MDC wetland flooding and draining management cycle at the Eagle Bluffs Conservation Area since February 1995. The ground-water high also seems to persist through changes in Missouri River stage, and may dampen the effects of Missouri River stage fluctuation. Water levels in well SP 4, located in the area of the ground-water high, do not track river stage in the same manner as water levels in well SP 11 (fig. 28). The potentiometric surface is highest when the Eagle Bluffs wetland is flooded in the fall and winter months and is lowest in the summer months. The potentiometric surface declines several feet in the summer months when the Eagle Bluffs wetland is drained

and farmed and the Missouri River stage is low. The ground-water flow direction is perpendicular to the potentiometric contours, and in general, is radially away from ground-water highs.

Ground-Water Movement

The potentiometric-surface maps indicate that north of the well field, ground-water flow is to the south. The potentiometric-surface maps indicate that ground-water flow is to the southwest away from the treatment wetland unit 1, and to the north, west, and south from the ground-water high beneath the Eagle Bluffs Conservation Area. The flow is most likely toward the pumping wells and toward the river (depending on the river stage) in the vicinity of the municipal-supply well field, but the flow direction is uncertain because of the limited amount of available data.

A study conducted by Kelly (1996) on the Missouri River alluvium near Kansas City, Missouri, used a ground-water model and a particle-tracking model to simulate the contributing recharge areas for a number of large well fields. Results of this simulation indicated

that most of the contributing recharge areas to well fields near a major river induced flow from the river, and when recharge was induced from a river, the contributing recharge area was skewed toward the river. The simulation also indicated that the ground-water travel times within the contributing recharge area to a well field were affected by vertical anisotropy of hydraulic conductivity in the aquifer.

Based on the geometry of the Columbia municipal-supply well field, the contributing recharge area before wetland construction likely was to the north and west toward the Missouri River. The contributing recharge area possibly intersected the bluffs on the eastern side of the study area and extended into the Perche Creek alluvium. After the construction of the wetland complex and subsequent flooding of the wetland areas, the contributing recharge area likely changed. The recharge area could extend further to the south toward the Eagle Bluffs Conservation Area and toward the Perche Creek alluvium (B.P. Kelly, U.S. Geological Survey, oral commun., 1999). Because of the probable induced flow toward the municipal-supply

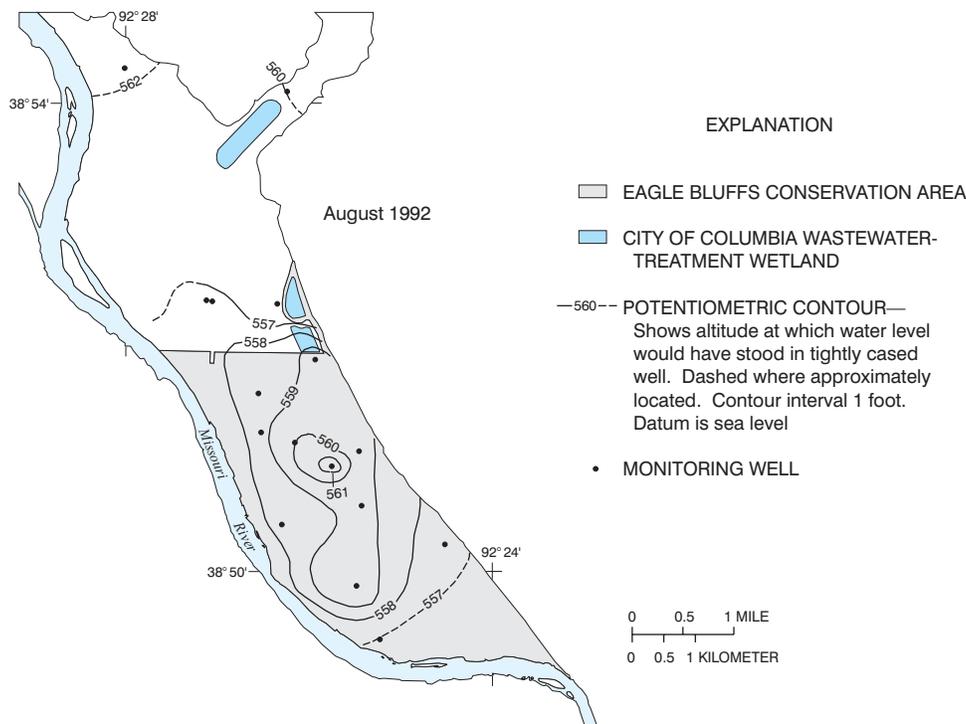


Figure 30. Potentiometric surface in the alluvial aquifer at the Columbia/Eagle Bluffs Wetland Complex for selected dates.

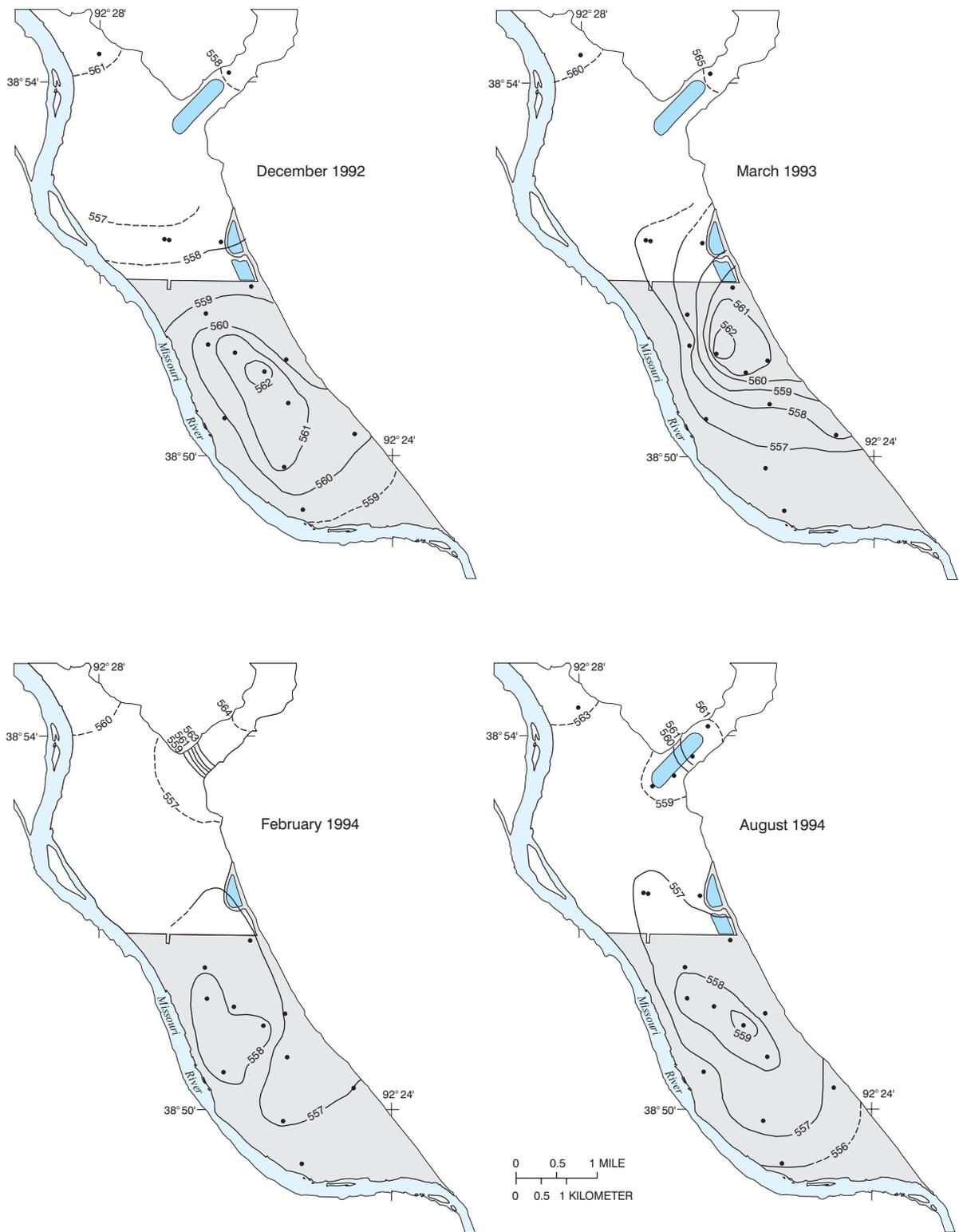


Figure 30. Potentiometric surface in the alluvial aquifer at the Columbia/Eagle Bluffs Wetland Complex for selected dates—Continued.

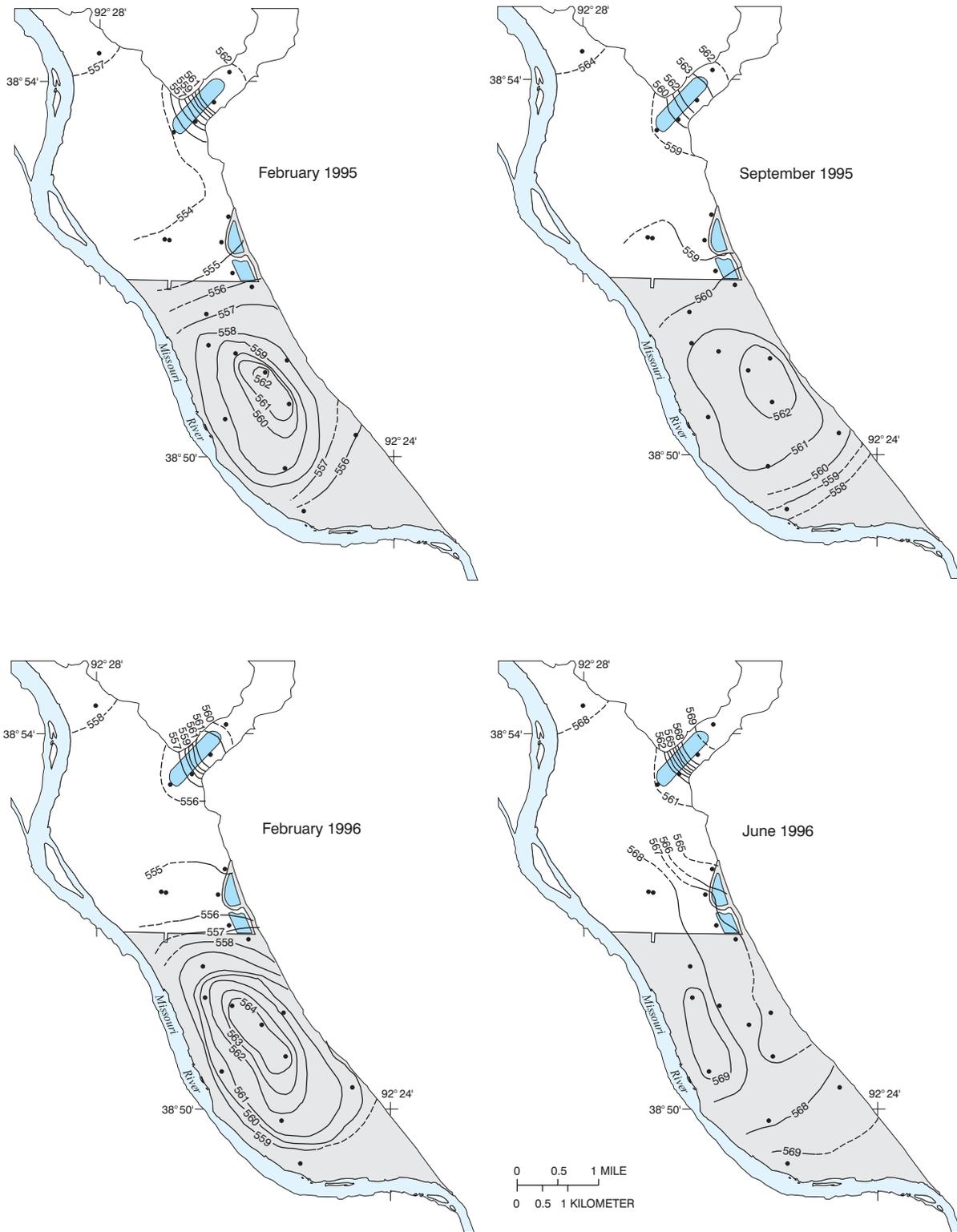


Figure 30. Potentiometric surface in the alluvial aquifer at the Columbia/Eagle Bluffs Wetland Complex for selected dates—Continued.

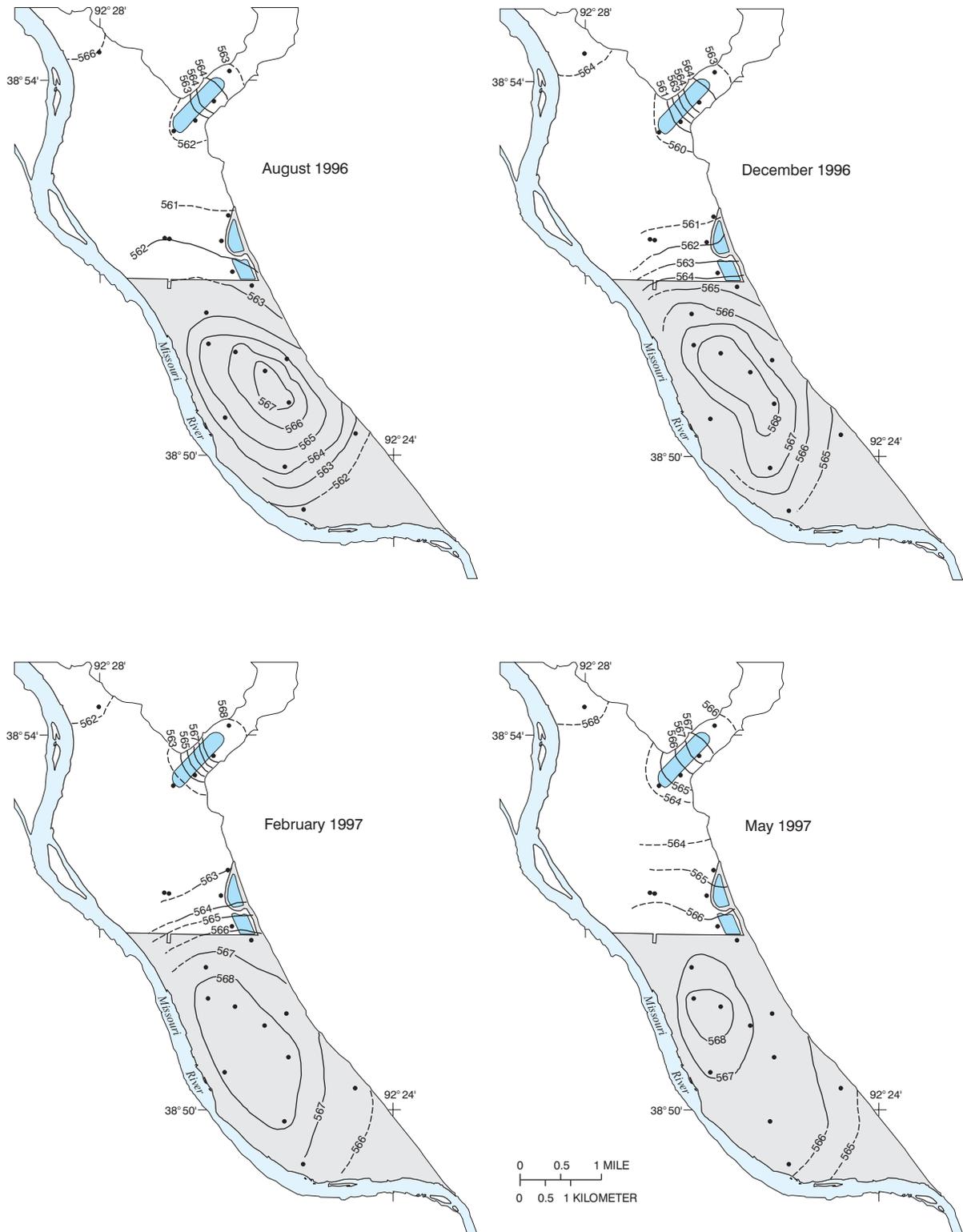


Figure 30. Potentiometric surface in the alluvial aquifer at the Columbia/Eagle Bluffs Wetland Complex for selected dates—Continued.

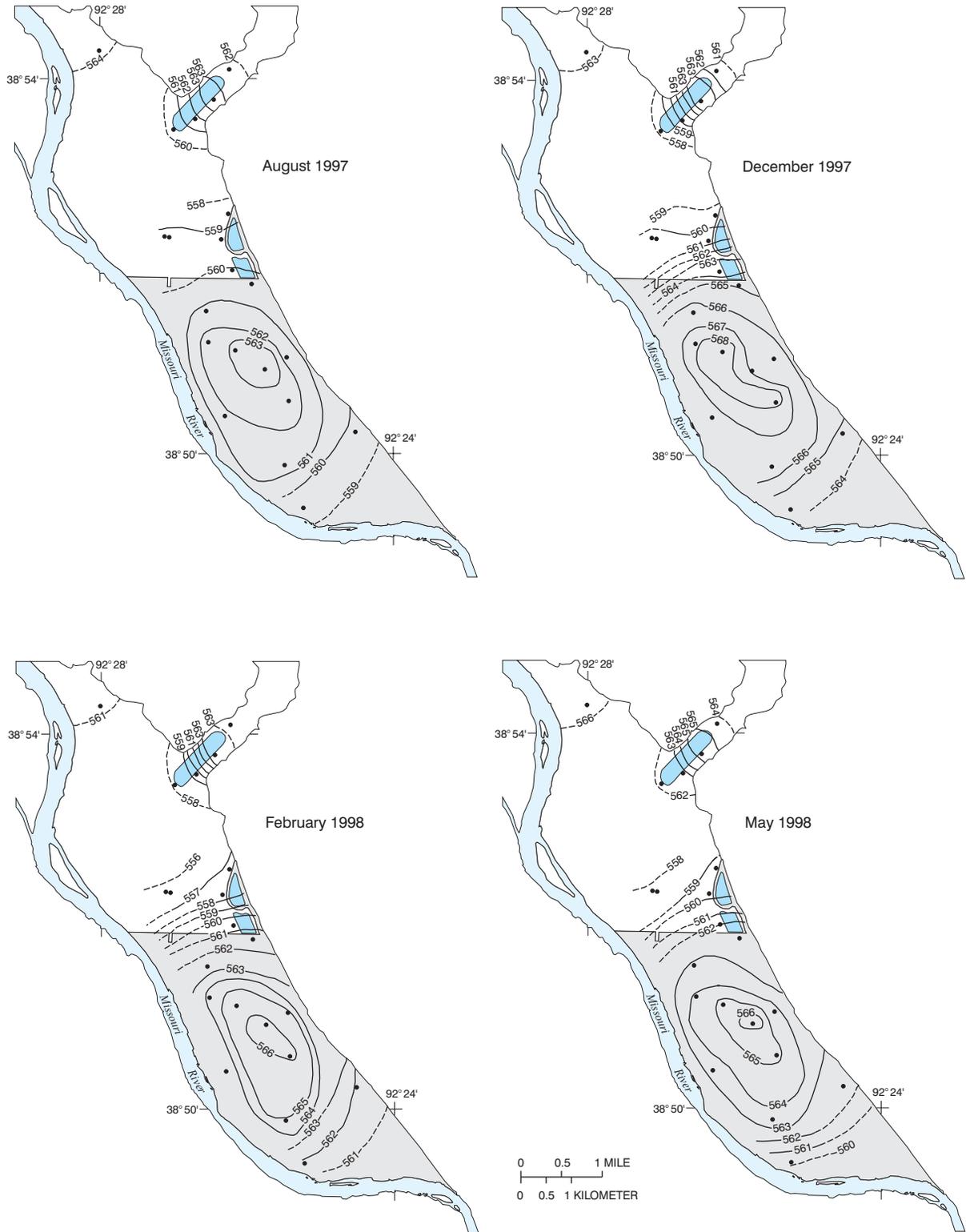


Figure 30. Potentiometric surface in the alluvial aquifer at the Columbia/Eagle Bluffs Wetland Complex for selected dates—Continued.

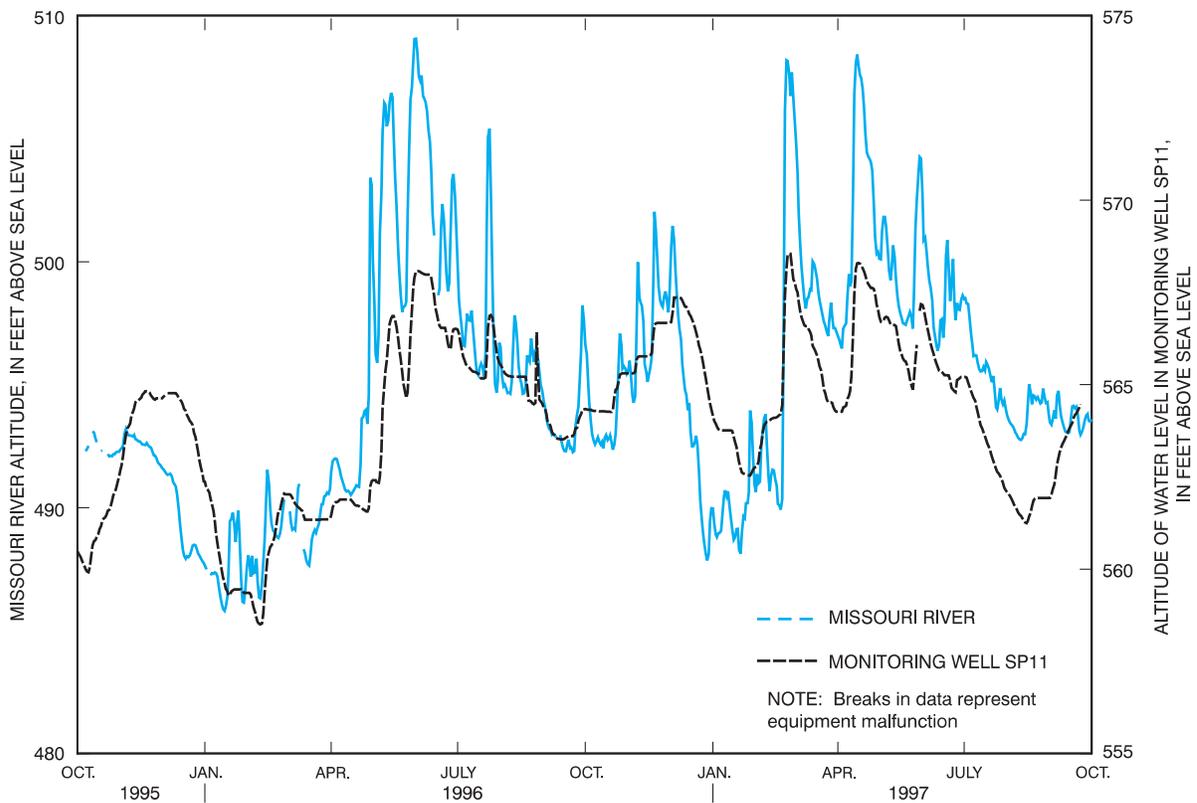


Figure 31. Altitude of the Missouri River at the U.S. Geological Survey gaging station at Hermann and in monitoring well SP11 at the Columbia/Eagle Bluffs Wetland Complex.

wells and the ground-water high beneath the Eagle Bluffs Conservation Area, effluent-enriched ground water could be introduced into the well field.

SURFACE-WATER AND GROUND-WATER INTERACTION

Data collected from Perche Creek and the blew hole in connection with ground-water data collected near these sites can give an insight to the nature of the surface-water and ground-water interaction for these sites. Perche Creek probably is both a discharge and recharge point for ground water, depending on the relative altitudes of the water surface of the creek and the ground-water potentiometric surface. Because concentrations of major chemical constituents remain low in the creek following the introduction of treated effluent to the Eagle Bluffs Conservation Area, the volume of discharge from the ground water to the creek relative to the discharge of the creek probably is small.

The blew hole is isolated from the surface water in the Eagle Bluffs wetland by a flood control levee. Surface water can be introduced into the blew hole through relatively rare occurrences of overland flow from Perche Creek and the Missouri River during high stage. Samples from the blew hole have major chemical constituent concentration trends similar to many of the ground-water sites. Forty-nine samples collected between March 1994 and December 1998 at a different blew hole near well USGS-5D had a similar trend in chloride concentration (M.K. Knowlton, written commun., 1999). The water-quality changes indicate that these blew holes have a hydraulic connection to the ground water. The increasing trends in chloride concentration indicate these blew holes are ground-water discharge points.

To help wildlife managers operate the Eagle Bluffs wetland efficiently and to help them estimate the volume of water necessary to sustain the wetland pools at a particular level, a water budget for the wetland was calculated. A water budget for the wetland can be used to estimate the volume of water that percolates into the

aquifer material. To calculate the volume of water that enters the aquifer as recharge, the following mass balance equation must be solved:

$$\Delta GW = Q_{in} + \text{Precip} - \Delta SW - E - Q_{out}, \quad (1)$$

where ΔGW = the volume change in ground-water storage, in cubic feet per second;

Q_{in} = the volume of surface flow into the wetland, in cubic feet per second;

Precip = the volume of precipitation, in cubic feet per second;

ΔSW = the volume change in surface water storage, in cubic feet per second;

E = the volume of water lost to evapotranspiration, in cubic feet per second; and

Q_{out} = the volume of surface flow out of the wetland, in cubic feet per second.

The period July 13 to July 18, 1997, was selected for calculating the water budget for the Eagle Bluffs Conservation Area. This period was selected because the data needed to perform the calculation were available, or could be easily estimated, and no measurable precipitation fell during this time (Precip = 0). During this period, the city of Columbia produced an average of 9.54 million gallons (C.J. Cuvellier, City of Columbia, written commun., 2000) of treated sewage effluent per day [$Q_{in} = 14.7 \text{ ft}^3/\text{s}$ (cubic feet per second)], which the MDC uses to manage wetland areas on the Eagle Bluffs Conservation Area. The water is placed into different wetland pools at various depths depending on the season. During summer months, the flow is confined mainly to the distribution canal and the semi-permanent marsh areas (approximately 400 acres). During this time, the surface-water level in these areas is maintained at a constant level, so that water is not being placed into surface-water storage ($\Delta SW = 0$). The gage on the Eagle Bluffs outflow records the water altitude and the gate altitude from which an average daily flow can be determined. The average daily flow (Q_{out}) from July 13 to July 18, 1997, was $2.0 \text{ ft}^3/\text{s}$. Of all variables in equation (1), evapotranspiration is the most uncertain and most difficult to obtain. The average potential evapotranspiration rate during this analysis was 0.235 in/day (inch per day) (Mid-West Climate Center, written commun., 2000) at the Columbia Regional Airport. The potential evapotranspiration rate is assumed to be similar at the Eagle Bluffs Conservation Area. From this estimate, the volume of water lost to evapotranspi-

ration (E) is calculated to be $3.9 \text{ ft}^3/\text{s}$. Substituting the values into equation (1), the contributing recharge rate during this time to the ground water is approximately $8.8 \text{ ft}^3/\text{s}$. When averaged over the 400 wetland acres, this rate is equivalent to an infiltration rate of 0.04 ft/day (foot per day). This estimated rate probably is a maximum value because the ground-water levels indicate that the aquifer was not fully saturated. An unsaturated aquifer is able to accept a higher rate of recharge than an aquifer under saturated conditions.

SUMMARY AND CONCLUSIONS

The Missouri Department of Conservation uses the treated effluent from the 91-acre city of Columbia wastewater-treatment wetland as a primary water source for managing 1,200 wetland acres on the Eagle Bluffs Conservation Area. The treatment wetland, planted in cattails, is designed to treat an average flow of 17.68 million gallons of effluent per day. The area is located on the Missouri River alluvium and is bounded to the south and west by the Missouri River and to the north and east by Missouri River bluffs. The city of Columbia pumps water from the alluvial aquifer for its municipal supply using seven pairs of wells located upstream (north) of Eagle Bluffs Conservation Area and adjacent (west) to the treatment wetland.

Water-quality samples were collected between August 1992 and March 1999 from up to 33 ground-water monitoring sites and 4 surface-water sites. Samples were analyzed for an extensive list of physical and water-quality parameters including specific conductance, pH, temperature, dissolved oxygen, fecal indicator bacteria, major chemical constituents, nutrients, trace constituents, and total and dissolved organic carbon. A subset of the ground-water sites (8 wells) and the surface-water sites also were sampled for base/neutral/acid semi-volatile organic compounds, selected pesticides (and metabolites), and selected organochlorine compounds. These eight wells also were analyzed for purgeable volatile organic compounds. Background (before treated effluent flooding) data were collected from August 1992 to August 1994. At some ground-water sites, sulfate (2 sites), nitrate (1 site), and arsenic (1 site) exceeded state maximum contaminant levels for drinking water, and iron (30 sites) and manganese (33 sites) exceeded state maximum contaminant levels for drinking water and ground water. At some surface-water sites, chloride (2 sites) exceeded the maximum contaminant level for the pro-

tection of aquatic life, and iron (2 sites), manganese (3 sites), and atrazine (1 site) exceeded the maximum contaminant level for drinking water and ground water. With the exception of chloride at the surface-water sites and manganese at the outflow from the treatment wetland, values exceeding maximum contaminant levels could not be related to the operation of the treatment wetland or the wetland management of Eagle Bluffs Conservation Area. This is because either the maximum contaminant levels were exceeded before the treatment wetland began operation or the values for these constituents were less than the maximum contaminant levels in the treated effluent.

Changes in major chemical constituent concentrations have been observed at several sampling locations when comparing pre- and post-effluent data. Time series water-quality data indicate that there was an increase in the chloride concentrations at MW1-2A, MW1-2B, MW1-3A, MW4-2A, MW4-2B, USGS-2D, USGS-2S, USGS-3D, USGS-3S, USGS-5D, USGS-6, USGS-7, and the blew hole. The constituents sodium, potassium, calcium, sulfate, and alkalinity 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.

The concentrations of major chemical constituents plot 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 change, assuming chloride is conservative, ranged from 11 percent to more than 100 percent.

In ground water, there were few changes in fecal indicator bacteria, nutrients, total and dissolved organic carbon, and organic constituents and none that could be directly correlated to the application of treated effluent in the wetland complex. Changes were observed in trace element concentrations of arsenic, barium, boron, iron, lithium, manganese, and strontium; with the exception of boron in MW1-2A, these changes could not be correlated to pre- or post-effluent conditions. These changes most likely are ancillary changes brought about by a combination of mixing, natural fluctua-

tions, cation exchange, and chemical changes resulting from water-level fluctuations in the aquifer. The variability in the trace 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.

After the treatment wetland began operation, decreases in median fecal indicator bacteria densities, and sodium, chloride, and nutrient concentrations were observed in Perche Creek. This represents an improvement in the water quality of the creek. Decrease of fecal indicator bacteria densities and nutrient concentrations occurred as treated effluent passed through the Eagle Bluffs Conservation Area wetland, improving the water quality with respect to those constituents.

Persistent ground-water highs have been observed beneath Eagle Bluffs Conservation Area and treatment wetland unit 1 following the flooding of the wetland areas. These ground-water highs occur during the fall and winter months when ground- and surface-water levels are high, and during the spring and summer months when the water levels are lower. The Missouri River stage had a strong effect on the water levels in the aquifer during pre-effluent conditions, but the effect is lessened by the ground-water high. Even though the vertical gradient in the aquifer is small, the permeability of the aquifer material can be high. Water budget calculations using data collected at Eagle Bluffs Conservation Area in July 1997 show that a substantial volume of surface water from the wetland reaches the ground water at an estimated recharge rate of 0.04 foot per day.

Nutrient concentrations and bacteria densities are reduced as treated effluent flows through the Eagle Bluffs wetland. Except for chloride concentrations in surface-water samples, treated effluent is not responsible for the ground- or surface-water samples exceeding maximum contaminant levels. Direct effects of the interaction of treated effluent on ground water are the increase of some constituent concentrations (notably sodium, chloride, and sulfate) in ground water and the formation of a ground-water high beneath Eagle Bluffs. The configuration of the potentiometric surface is uncertain in and near the municipal-supply well field area, but a sufficient amount of data exist outside the well field to indicate flow toward the well field. Because of the inferred gradient toward the well field and the probable induced flow toward the municipal-supply wells, effluent-enriched ground water could be introduced into the well field.

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