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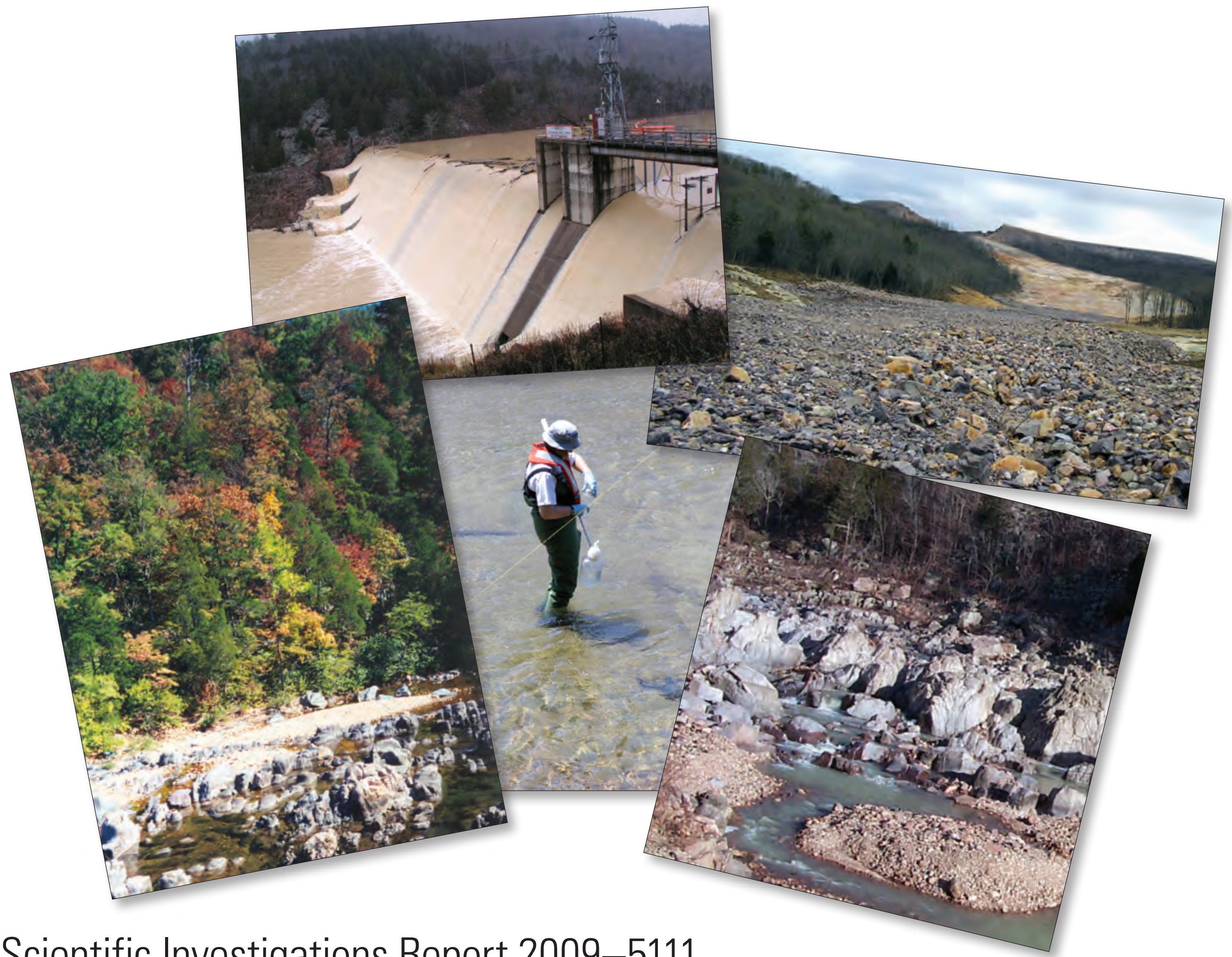
Effects of the Upper Taum Sauk Reservoir Embankment Breach on the Surface-Water Quality and Sediments of the East Fork Black River and the Black River, Southeastern Missouri—2006–07



Scientific Investigations Report 2009–5111

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

Spillway of the lower Taum Sauk reservoir one day after the upper Taum Sauk reservoir embankment breach.

Wall scour and flow path of the upper Taum Sauk reservoir embankment breach.

Johnson's Shut-Ins State Park before embankment breach.

U.S. Geological Survey hydrographer collecting surface-water quality samples.

Sediment and debris deposited in Johnson's Shut-Ins State Park after the upper Taum Sauk reservoir embankment breach.

Front cover

Effects of the Upper Taum Sauk Reservoir Embankment Breach on the Surface-Water Quality and Sediments of the East Fork Black River and the Black River, Southeastern Missouri—2006–07

By Miya N. Barr

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

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Contents

Figures

Tables

Conversion Factors and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton per day (ton/d)	0.9072	metric ton per day

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

°F= (1.8×°C) +32

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

°C= (°F-32)/1.8

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

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

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

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

Water year in U.S. Geological Survey reports dealing with surface-water supply is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2007, is called the “2007 water year”.

Effects of the Upper Taum Sauk Reservoir Embankment Breach on the Surface-Water Quality and Sediments of the East Fork Black River and the Black River, Southeastern Missouri—2006–07

By Miya N. Barr

Abstract

On December 14, 2005, a 680-foot wide section of the upper reservoir embankment of the Taum Sauk pump-storage hydroelectric powerplant located in Reynolds County, Missouri, suddenly failed. This catastrophic event sent approximately 1.5 billion gallons of water into the Johnson's Shut-Ins State Park and into the East Fork Black River, and deposited enormous quantities of rock, soil, and vegetation in the flooded areas. Water-quality data were collected within and below the impacted area to study and document the changes to the riverene system. Data collection included routine, event-based, and continuous surface-water quality monitoring as well as suspended- and streambed-sediment sampling. Surface water-quality samples were collected and analyzed for a suite of physical and chemical constituents including: turbidity; nutrients; major ions such as calcium, magnesium, and potassium; total suspended solids; total dissolved solids; trace metals such as aluminum, iron, and lead; and suspended-sediment concentrations. Suspended-sediment concentrations were used to calculate daily sediment discharge. A peculiar blue-green coloration on the water surface of the East Fork Black River and Black River was evident downstream from the lower reservoir during the first year of the study. It is possible that this phenomenon was the result of "rock flour" occurring when the upper reservoir embankment was breached, scouring the mountainside and producing extremely fine sediment particles, or from the alum-based flocculent used to reduce turbidity in the lower reservoir. It also was determined that no long-term effects of the reservoir embankment breach are expected as the turbidity and concentrations of trace metals such as total recoverable aluminum, dissolved aluminum, dissolved iron, and suspended-sediment concentration graphically decreased over time. Larger concentrations of these constituents during the beginning of the study also could be a direct result of the alum-based flocculent used in the lower reservoir. Suspended-sediment concentrations and turbidity measurements were largest at the site downstream from the lower reservoir. This is because of the large amounts of debris deposited in the lower reservoir from the breach, which in turn were redeposited into the East Fork Black River during releases. When these constituents were plotted over time, the concentrations decreased and were similar to the other two sites in the study. Trend analyses were studied at one site with historical data. No major trends were discovered for streamflow, turbidity, suspended-sediment concentrations, or suspended-sediment discharges before or after the event. Although long-term effects of the elevated turbidity, major trace metals, and suspended sediments in the study area as a result of the reservoir embankment breach are not expected, there could possibly be other effects not measured during this study that could potentially affect the surface-water quality, such as loss of riparian habitat, changes in biological ecosystems, and large-scale reworking of sediments.

Introduction

The Taum Sauk pump-storage hydroelectric powerplant, owned and operated by Ameren United Electric (UE) Company, was completed in July 1963 and went into commercial operation in December 1963. The powerplant, named "Taum Sauk" after an Indian chief who once ruled tribes in the area, utilized reversible turbines that operated as pumps and hydroelectric generators. The turbines used power from other electric powerplants to pump water from a lower reservoir to an upper reservoir on top of 1,590-foot (ft) high Proffit Mountain during "off-peak" hours such as nights and weekends. When electricity demand was high, the pumping process was reversed and the pumps became turbine-generators as water was released from the upper reservoir to the lower reservoir through a 7,000-ft tunnel, producing electricity in the same manner as a conventional hydroelectric powerplant (Rydlund, 2006).

Johnson's Shut-Ins State Park, managed by the Missouri Department of Natural Resources (MDNR), is located along the East Fork Black River adjacent to Proffit Mountain (figs. 1, 2). The "shut-ins" within the State park boundary are approximately 1 mile (mi) downstream from State Highway N. The term "shut-ins" is used to describe narrow, steep-sided gorges

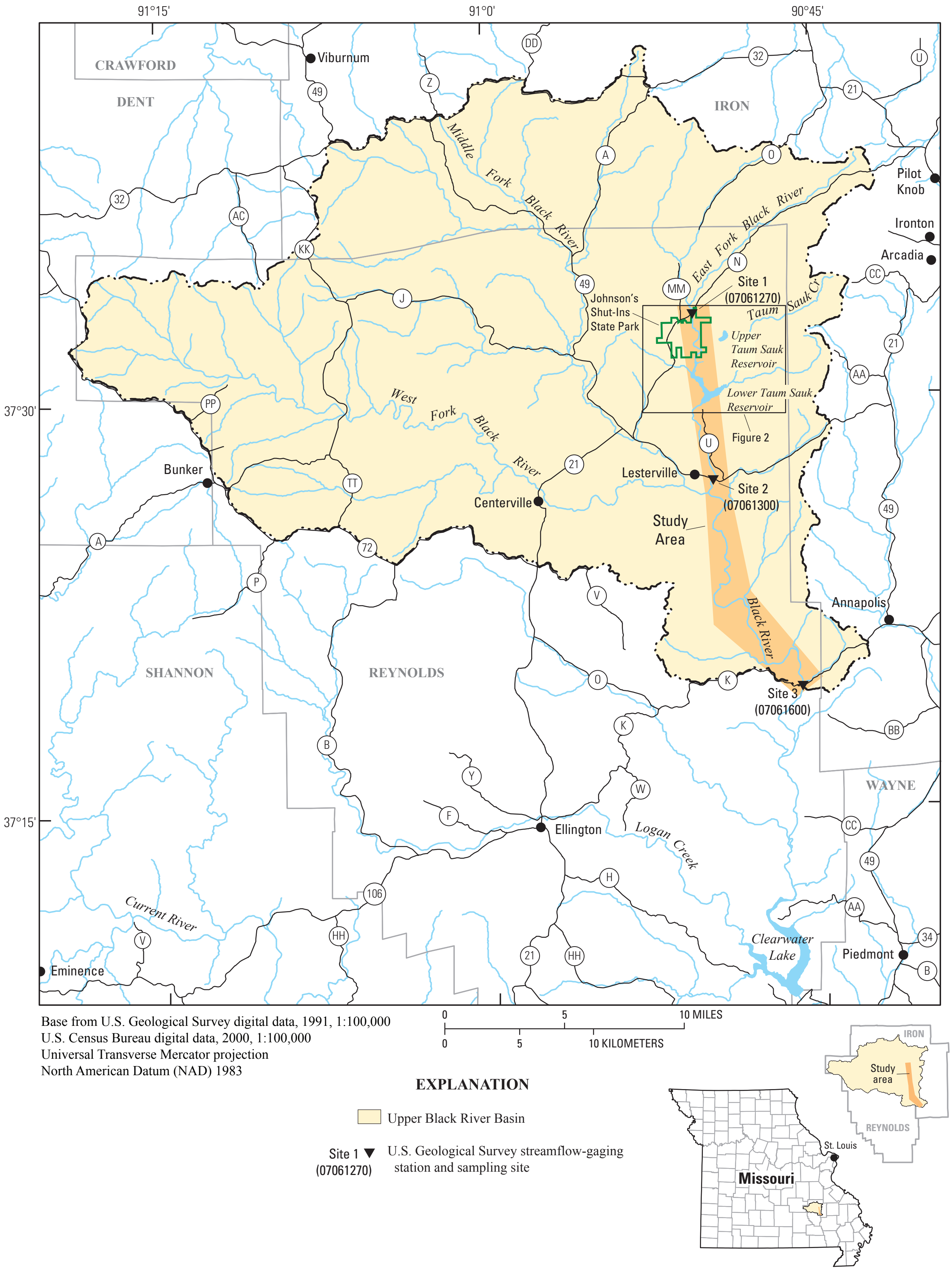


Figure 1. Location of study area.

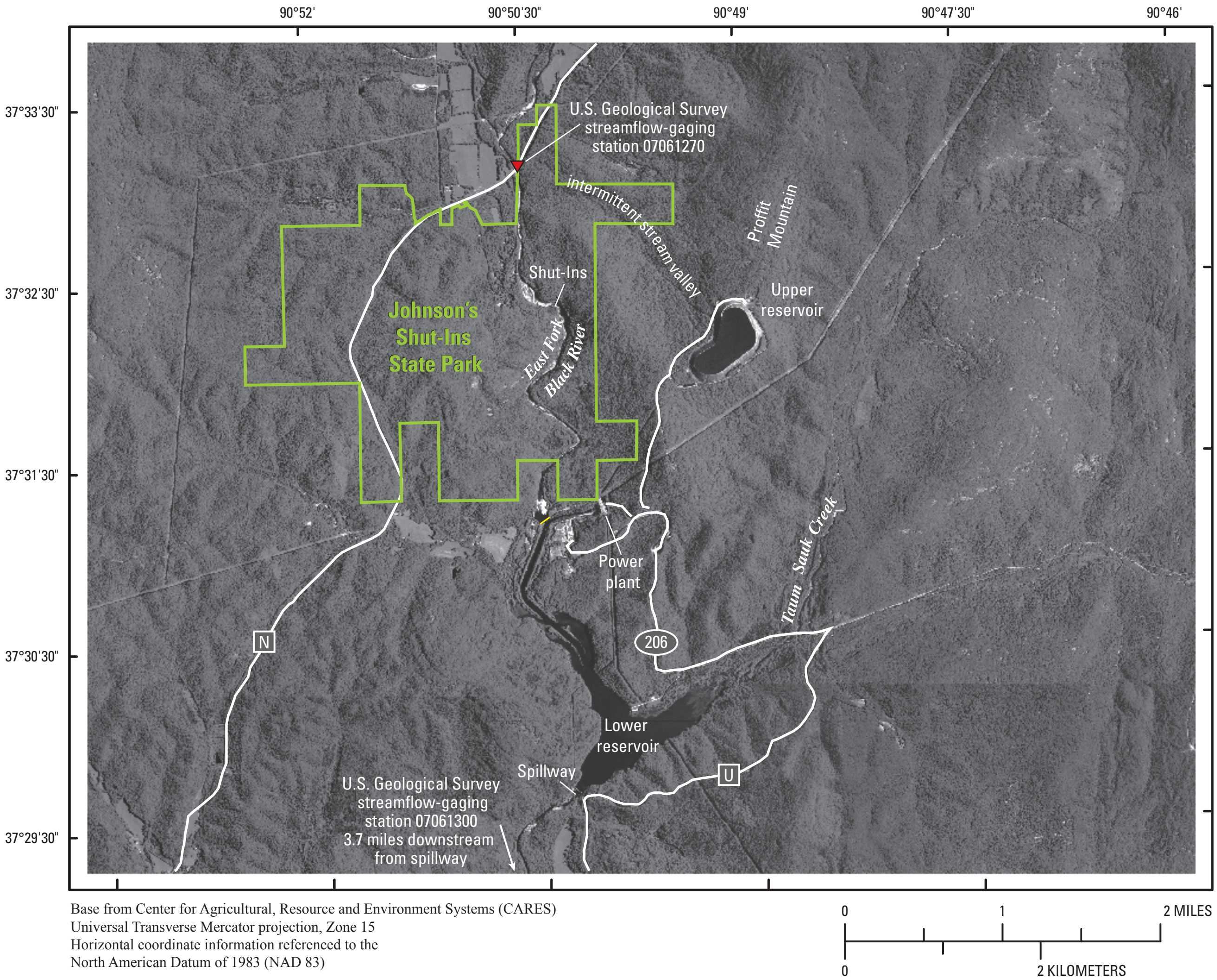


Figure 2. Location of Johnson's Shut-Ins State Park boundary and Taum Sauk pump-storage hydroelectric power plant facility.

along the course of an otherwise wide and shallow stream valley where a river becomes confined, or "shut-in," to a narrow channel. Erosion of the exposed rhyolite bedrock produced unique formations such as gorges, chutes, and potholes throughout the state park (fig. 3). Johnson's Shut-Ins is one of the most popular parks in Missouri, with nearly 250,000 annual visitors (River Valley Region Association, 2008).

At 5:16 a.m. on December 14, 2005, the embankment of the 55-acre upper reservoir failed. Overfilling during the "off peak" pumping cycle resulted in a 680-ft wide embankment breach, which caused approximately 1.5 billion gallons of water to spill down a steep intermittent stream valley along the western side of Proffit Mountain into and across the East Fork Black River (fig. 2). The flood wave occurred within 25 minutes of the embankment breach (Hendron and others, 2006). At the base of Proffit Mountain, the flood wave parted when it impacted the western valley wall of the East Fork Black River. The flood wave, which flowed upstream, removed a residential structure from the foundation, washed a tractor-trailer truck off State Highway N, and damaged a U.S. Geological Survey (USGS) streamflow-gaging station (hereinafter referred to as gaging station) located at the State Highway N crossing of East Fork Black River (fig. 4). The gaging station recorded the last stage measurement at 5:15 a.m. on December 14, 2005. The force of the flood wave stripped overburden from the western slope of Proffit Mountain, exposed bedrock (fig. 5) and deposited clay, silt, sand, gravel, and woody debris along the East Fork Black River from State Highway N to the lower reservoir. The deposited sediments ranged from approximately 0.5 to 3 ft thick. The volume of area affected by the flood deposits ranged from approximately 133,000 to 2,700,000 acre-ft (Rydlund, 2006).

Floods of large magnitude, such as the one produced by the embankment failure, disrupt ecological and fluvial systems by altering channel configurations, substrate, and sediment discharge and present unique opportunities to analyze and document flood effects on water quality within the surrounding watershed. To address this opportunity, the USGS in collaboration with Ameren United Electric Company conducted a study in 2006 and 2007 on the East Fork Black River and a

Figure 3. Rhyolite formations in Johnson's Shut-Ins State Park.

downstream Black River site to monitor the changes in water quality resulting from the embankment failure.

Purpose and Scope

The purpose of this report is to evaluate environmental effects that occurred in the East Fork Black River and the Black River in response to the breach of the upper Taum Sauk reservoir embankment. Surface-water quality, continuous water-quality, and sediment data were collected from January 2006 through December 2007. Physical properties were collected every 15 minutes, transmitted hourly, and displayed publically by the National Water Information System website (NWISWeb, *http://waterdata.usgs.gov/nwis*).

Description of Study Area

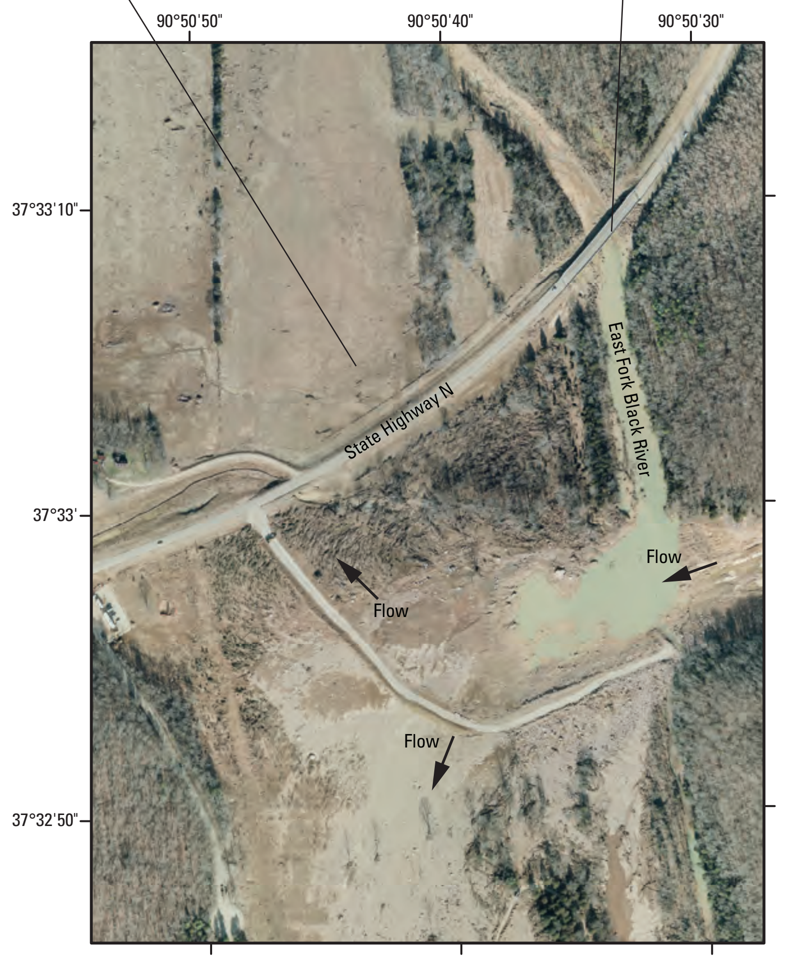
The Taum Sauk pump-storage hydroelectric powerplant is located in Reynolds County, Missouri, approximately 5 mi north of Lesterville and approximately 90 mi southwest of St. Louis (fig. 1). The study area is located in the Ozark Plateaus physiographic province (Fenneman, 1938). The study area is heavily wooded, and has steep, rugged topography with narrow valleys, dendritic drainages, and main channel gradients steeper than most channels in Missouri. Elevations in this region range from about 800 to 1,700 ft (Alexander and Wilson, 1995). The upper reservoir, on top of Proffit Mountain, has an average basin bottom elevation of approximately 1,505 ft. The lower reservoir is at the junction of the East Fork Black River and Taum Sauk Creek (fig. 2; Rydlund, 2006).

The northern part of the study area is in the St. Francois Mountains. The St. Francois Mountains are an area of about 1,000 square miles (mi^2) composed of exposed Precambrian igneous knobs and valleys underlain by Paleozoic sedimentary rocks, such as dolomite and sandstone (Fenneman, 1938). Many streams in the St. Francois Mountains flow on Paleozoic rocks in valleys between the igneous knobs. At Johnson's Shut-Ins State Park, however, the East Fork Black River flows on and has eroded the harder exposed Precambrian granite and rhyolite, creating the canyon-like gorges known as "shut-ins" or "narrows" (Hayes and Beveridge, 1961).

Population in the study area is sparse, approximately 25 persons per square mile (University of Missouri, 2001). Land use is primarily forested with some grazing pastures for livestock (Missouri Spatial Data Information Service, 2005).

Tractor-trailer truck washed off State Highway N (photograph courtesy of Ken Beck, Reynolds County Courier, 2005).

Damage sustained at original U.S. Geological Survey streamflow-gaging station on the East Fork Black River at State Highway N (site 1), outside of Johnson's Shut-Ins State Park.



Base from Surdex Inc, proprietary to MacTec Engineering and Consulting Inc.
One-half foot pixel resolution, January 2006
Universal Transverse Mercator projection, Zone 15
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 4. Flood damage and flow path during upper Taum Sauk reservoir embankment breach.

View looking upstream from the flood path towards the upper reservoir.

View from upper reservoir looking downstream along the flood path.

Figure 5. Damage to the western slope of Proffit Mountain during the upper Taum Sauk reservoir embankment breach.

The study area has a temperate climate with average annual precipitation of approximately 40 inches per year (in/yr) and a mean annual air temperature of 60 degrees Fahrenheit (°F; National Oceanic and Atmospheric Administration, 2006, 2007). Bunker, Missouri, approximately 30 mi west of the study area, and Arcadia, Missouri, approximately 15 mi east of the study area, are the two nearest climatological stations (fig. 1). Monthly precipitation during the study period (January 2006 through December 2007), generally was below average at Bunker and Arcadia (fig. 6; National Oceanic and Atmospheric Administration, 2006, 2007). Average monthly precipitation values for the study area were calculated from monthly precipitation data available for the two climatological stations. Daily precipitation data were recorded at two USGS gaging stations during the study period (USGS identifiers 07061300 and 07061600; fig. 7).

Methods of Study

To determine the effects of the Taum Sauk reservoir embankment breach on surface-water quality, a network of three sampling sites were established at the USGS gaging stations. The sampling network included discrete surface-water-quality samples, suspended-sediment and streambed-sediment samples, and continuous surface-water quality monitoring.

Description of Sampling Network

An existing gaging station, East Fork Black River near Lesterville at State Highway N (USGS identifier 07061270; fig. 1), was used to provide baseline data for the East Fork Black River. The gage is located upstream from Johnson Shut-Ins State Park, approximately 1/8 mi outside the park entrance, and has been in operation from October 2001 to September 2002, and from October 2003 to the current year (2008). The maximum recorded water-surface elevation of 838.6 ft occurred May 12, 2002, and the mean annual streamflow recorded for the period of record is 70.4 cubic feet per second (ft^3/s) (U.S. Geological Survey, 2007).

Construction was ongoing during the study period in Johnson's Shut-Ins State Park to repair damages from the embankment breach. Extensive construction was performed to repair the East Fork Black River stream reach that flows through the park. MDNR began restoring the East Fork Black River in early 2007 to its original flow path by constructing point bars, high stream banks, and stream bends, to recreate typical eastern Ozark stream features (Missouri Department of Natural Resources, 2008).

To monitor effects of the flood on the lower Taum Sauk reservoir after the embankment failure, a discontinued gaging station was reactivated in January 2006 on the East Fork Black River at Lesterville (USGS identifier 07061300; fig. 1) on State Route 21. This site previously was operated as a gaging station from January 1960 through September 1990.

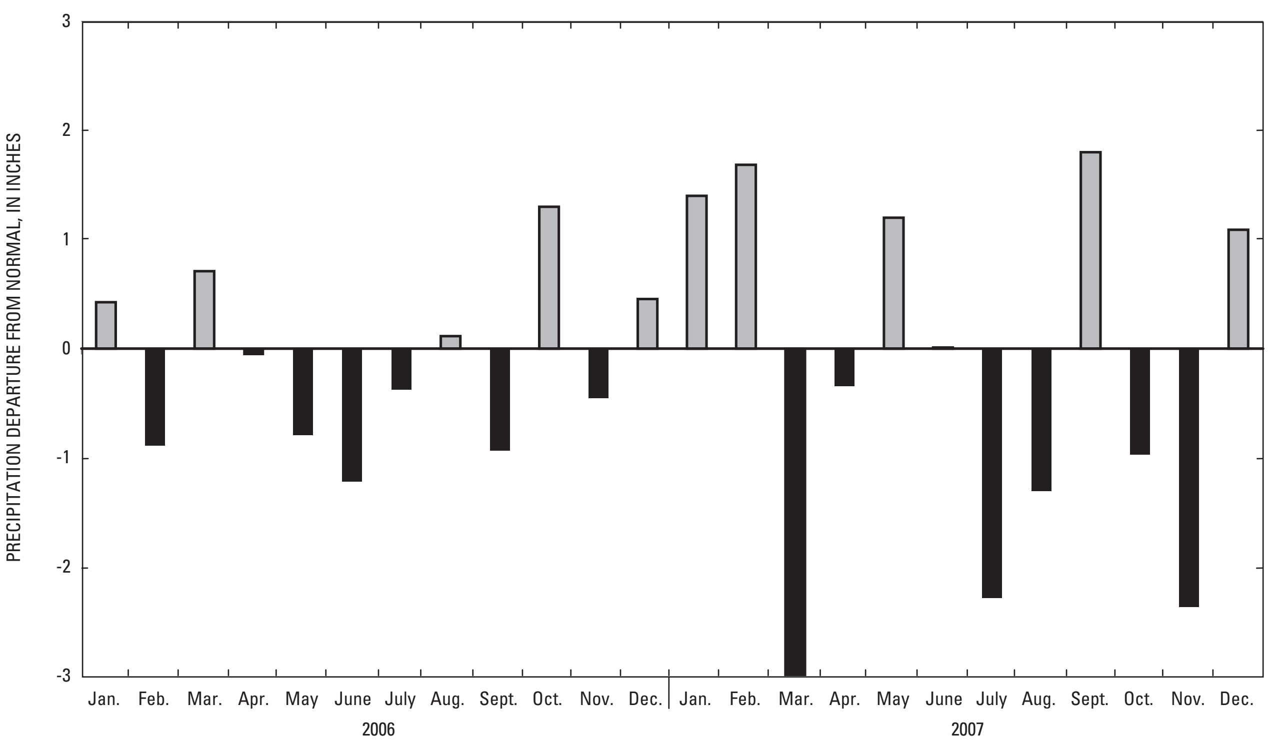


Figure 6. Departure from average monthly precipitation, January 2006 through December 2007.

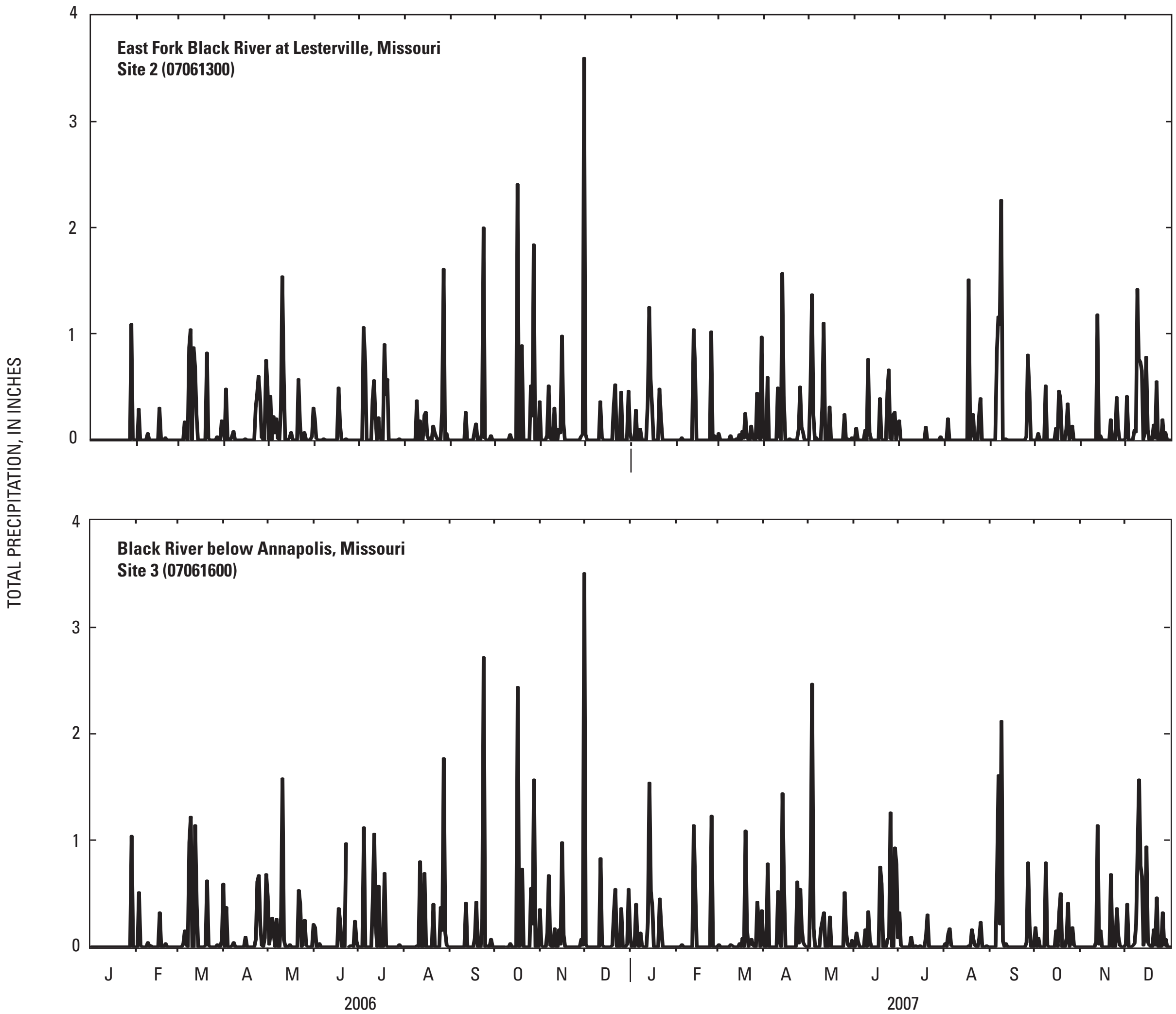


Figure 7. Daily precipitation recorded at two U.S. Geological Survey streamflow-gaging stations, January 2006 through December 2007.

Five surface-water quality samples were collected at the site from June 1963 through June 1964. The constituents sampled included pH, specific conductance, major ions, total dissolved solids (TDS), whole-water alkalinity (acid-neutralizing capacity), dissolved nitrate, total iron, and dissolved manganese. The maximum recorded water-surface elevation of 667.68 ft occurred on November 19, 1985. The mean annual streamflow for the period of record is 120 ft^3/s (U.S. Geological Survey, 2007).

Construction also occurred at the lower Taum Sauk reservoir during the study period. Because the lower reservoir captured much of the sediments transported during the upper reservoir embankment breach, the lower reservoir became very turbid with suspended particles. An alum-based flocculent was added to the lower reservoir by Ameren UE to aid in the settling of the finer clay particles. The flocculent removed the electrostatic charge of the particles, which caused the particles to group together and once large enough, fall from suspension. The alum-based flocculent used to reduce turbidity in the lower reservoir primarily is used for drinking-water treatment (Federal Energy Regulatory Commission, 2006), and was composed of aluminum sulfate ($Al_2O_{12}S_3$). During the flocculation period, excess water was released from the lower reservoir to reduce the water level to the normal pool elevation, which resulted in the release of some flocculent into the East Fork Black River. Removal of the settled sediments from the bottom of the lower reservoir by dredging also occurred during the study period. Much of the water in the lower reservoir was released into the East Fork Black River before dredging began. Water was released through the sluice rather than over the spillway prior to dredging. After dredging, limited releases of water took place in order to restore the lower reservoir back to its normal pool.

The lower part of the study area is located on the main stem of the Black River. A gaging station was installed along State Highway K (USGS identifier 07061600; fig. 1) downstream from Annapolis on the main stem of the Black River, downstream from the junction with the East, Middle, and West Forks Black River, and upstream from Clearwater Lake (fig 1). The mean annual streamflow for the period of record (January

2006 to September 2007) is 639 ft^3/s (U.S. Geological Survey, 2007). The USGS has been collecting water-quality data bimonthly at the State Highway K sampling site as part of the Missouri ambient stream water-quality monitoring program since November 1999 (U.S. Geological Survey, 1999). Water-quality data were first collected at this site as part of the National Water-Quality Assessment (NAWQA) program, Ozark Plateaus study unit from May 1993 through September 1995 (Davis and others, 1995). This sampling site was used in the current study because of its historical dataset and to observe the effects of the East Fork Black River on the main stem of the Black River after it joined the West and Middle Forks.

Continuous water-quality monitors (CWQM) were installed at each gaging station to measure physical properties (specific conductance, pH, water temperature, dissolved oxygen, and turbidity). The CWQM measured the physical properties every 15 minutes and transmitted the data every hour by satellite telemetry to the USGS National Water Information System (NWIS) database. Each water-quality sampling site also was equipped with an automatic pumping sampler to collect daily suspended-sediment samples. Surface-water quality samples were collected monthly at each site during the first year of the study. Storm event water-quality samples also were collected at each site. During the second year, the frequency of sampling decreased to bimonthly. Constituents analyzed included the physical properties listed above, indicator bacteria [fecal coliform and *Escherichia coli (E. coli)*], chemical oxygen demand (COD), nutrients such as nitrogen and phosphorous, major ions such as calcium and magnesium, and select trace metals such as aluminum, iron, and lead. Streambed-sediment samples also were collected four times during the first year of the study. These samples were sieved for size analyses and the fine-grained fractions less than 0.063 millimeters (mm) were analyzed for major ions and trace metals by inductively coupled argon plasma-mass spectrometry (ICP-MS).

Sample Collection and Analysis Methods

Data for this study were collected by many different techniques described further in the following sections. Surface-water and suspended-sediment samples were collected to evaluate changes in the water quality during the study period. Streambed sediments were collected to evaluate the chemical composition and transport of sediments during and after the embankment breach. In addition, CWQMs were placed at each sampling site to measure physical properties in realtime.

Hereinafter, the three sampling sites will be referred to in their downstream order, therefore, East Fork Black River near Lesterville (07061270) will be referred to as site 1, East Fork Black River at Lesterville (07061300) as site 2, and Black River below Annapolis (07061600) as site 3 (fig. 1).

Surface-Water Quality

Discrete surface-water quality sampling was performed monthly during 2006 and bimonthly during 2007. Storm event sampling also was performed during 2006. Field properties were measured and indicator bacteria samples were collected and analyzed by standard USGS methods as described in Wilde (variously dated). Water-quality samples also were collected according to standard USGS sample collection and processing protocols described by Wilde and others (2004). All chemical analyses were performed by the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, according to established procedures (table 1).

Water-quality samples were collected by the equal-width increments (EWI) method. This method is used to collect samples representative of the entire stream width in a fixed location because the streams have relatively uniform depth and streamflow velocities (U.S. Geological Survey, 2006a). The water samples consisted of approximately 10 subsamples collected within the designated cross section. During low- to medium-flow conditions, samples were collected with a handheld DH-81 isokinetic sampler (fig. 8). During high flows, such as during storm events when wading was not possible, samples were collected from the bridge by the EWI method using either a D-95 sampler or a D-96 collapsible bag sampler (U.S. Geological Survey, 2006a). All subsamples were composited in a polypropylene churn before processing.

Dissolved oxygen, specific conductance, and water temperature were measured in-situ at three equally spaced sections in the stream to acquire a median value representative of the sampling cross section. An additional specific conductance measurement was performed on an aliquot from the churn to account for any degradation that may have occurred after collection. Measurements of pH and acid-neutralizing capacity (ANC) also were performed on aliquots from the churn. Indicator bacteria samples were collected in a separate 500-milliliter (mL) polypropylene bottle at the centroid of the stream and chilled until processed by the membrane filtration method described in Myers and others (2007). All constituents listed in table 1 were extracted from the churn, processed, and prepared for shipment to the NWQL for chemical analysis. Water-quality results were published in the USGS annual water data reports for 2006 and 2007 (U.S. Geological Survey, 2006b, 2007) and also are available in table 2 (at the back of the report).

Both suspended-sediment concentrations (SSC) and total suspended solids (TSS) concentrations were collected during the study period and are mentioned in this report extensively. However, there is a difference between these constituents and may not be considered comparable because of collection and analytical differences. SSC data are calculated by measuring the dry weight of all sediment from a known volume of a water and sediment sample. A TSS analysis is performed by measuring the dry weight of sediment from a known volume of a subsample of a composited sample (Gray and others, 2000). Organic particles are removed from suspended-

Table 1. Analytical methods and method reporting levels used by the U.S. Geological Survey National Water Quality Laboratory.

[NTRU, nephelometric turbidity ratio unit; ICP, inductively coupled argon plasma; mg/L, milligram per liter; AES, atomic emission spectroscopy; IC, ion chromatography; ASF, automated-segmented flow; N, nitrogen; P, phosphorous; MS, mass spectrometry; µg/L, microgram per liter; AF, atomic fluorescence]

Analyte	Analytical method	Method number	Method reporting level
Turbidity	Broad band light[a]	2130	2 NTRU
Calcium, dissolved	ICP[b]	I-147287	0.04 mg/L
Magnesium, dissolved	ICP-AES[b]	I-147287	.008 mg/L
Potassium, dissolved	ICP-AES[a]	3210-ICP	.16 mg/L
Sodium, dissolved	ICP-AES[b]	I-147287	.1 mg/L
Chloride, dissolved	IC[c]	I-205785	.2 mg/L
Fluoride, dissolved	ASF Ion-selective Electrode[c]	I-232789	.1 mg/L
Sulfate, dissolved	IC[c]	I-205785	.18 mg/L
Residue, total suspended solids (TSS)	Gravimetric[c]	I-376589	10 mg/L
Residue, total dissolved solids (TDS)	Gravimetric[c]	I-175089	10 mg/L
Ammonia + organic nitrogen, total as N	Colorimetry, ASF, Microkjeldahl[d]	I-451591	.1 mg/L
Ammonia, dissolved as N	Colorimetry[b]	I-252290	.04 mg/L
Nitrate + nitrite, dissolved as N	Colorimetry, ASF[b]	I-254590	.06 mg/L
Nitrite, dissolved as N	Colorimetry[b]	I-254090	.008 mg/L
Orthophosphate, dissolved as P	Colorimetry[b]	I-269190	.018 mg/L
Phosphorous, dissolved as P	Colorimetry, ASF, Microkjeldahl[d]	I-261099	.04 mg/L
Phosphorous, total as P	Colorimetry, ASF, Microkjeldahl[d]	I-261099	.04 mg/L
Chemical Oxygen Demand (COD)	Colorimetry[c]	I-356189	10 mg/L
Aluminum, dissolved	ICP-MS[e]	I-247792	1.6 µg/L
Aluminum, total	ICP-MS[g]	I-447197	2 µg/L
Arsenic, dissolved	ICP-MS[h]	I-202005	.06 µg/L
Boron, dissolved	ICP-AES[i]	I-147295	1.2 µg/L
Cadmium, dissolved	ICP-MS[e]	I-447197	.04 µg/L
Cadmium, total	ICP-MS[f]	I-247792	.014 µg/L
Copper, dissolved	ICP-MS[g]	I-202005	.04 µg/L
Iron, dissolved	ICP-AES[b]	I-147287	6 µg/L
Lead, dissolved	ICP-MS[f]	I-247792	.08 µg/L
Lead, total	ICP-MS[g]	I-447197	.06 µg/L
Lithium, dissolved	ICP-AES[b]	I-147287	.04 µg/L
Manganese, dissolved	ICP-AES[b]	I-147287	.6 µg/L
Mercury, total	AF, Cold Vapor[h]	I-446401	.01 µg/L
Selenium, dissolved	ICP-MS[h]	I-202005	.04 µg/L
Strontium, dissolved	ICP-AES[b]	I-147287	1 µg/L
Zinc, dissolved	ICP-MS[h]	I-202005	.6 µg/L
Zinc, total	ICP-MS[h]	I-402005	2 µg/L

[a]American Public Health Association and others, 1998.

[b]Fishman, 1993.

[c]Fishman and Friedman, 1989.

[d]Patton and Truitt, 2000.

[e]Faires, 1993.

[f]Garabino and Struzeski, 1998.

[g]Garbarino and others, 2006.

[h]Struzeski and others, 1996.

[i]Garabino and Damrau, 2001.

Figure 8. A U.S. Geological Survey hydrographer collecting a discrete surface-water quality sample using the equal-width increment (EWI) method.

sediment samples prior to analysis, while suspended-solids concentrations can include organics. SSC are considered the most accurate measurement of the actual stream-sediment concentrations because of the representative sampling and analytical techniques used (Davis and others, 1995). Although SSC is more accurate, TSS concentrations also were collected during this study because the State standards for Missouri are based on suspended-solids concentrations.

Suspended and Streambed Sediment

Suspended-sediment samples also were collected during monthly and bimonthly water-quality sampling. Collection techniques were designed to obtain a cross-sectional representation of the SSC using standard USGS protocols as described in Edwards and Glysson (1999). During wadeable stream conditions, suspended-sediment samples were collected by the EWI method at approximately 10 subsections in the cross section using a DH-48 sediment sampler. Suspended-sediment samples also were collected on the rise, peak, and fall of storm events to define the SSC to streamflow relation. Storm event samples typically were collected from the bridge by EWI method using either a D-74 or D-95 sampler.

Daily suspended-sediment samples also were collected at each site during the study using a programmable automatic sampler (fig. 9). In an effort to determine the large sediment fluxes that occurred as a result of the reservoir embankment breach, automatic samplers were programmed to collect a single sample twice daily during the first 3 months of the study. After the 3-month period, the automatic samplers were programmed to collect one sample per day. Twenty-four samples could be stored in the automatic sampler, which were removed from the sampler during CWQM calibration visits. All cross-section suspended-sediment samples and daily suspended-sediment samples were analyzed by the Missouri Water Science Center Sediment Laboratory in Rolla, Missouri, using standard USGS procedures as described in Guy (1969). Mean daily suspended-sediment discharges and concentrations were published in the USGS annual water data reports for 2006 and 2007 (U.S. Geological Survey, 2006b, 2007).

Streambed-sediment samples were collected during the first year to analyze sediment-size distribution and trace metal content. Monthly streambed-sediment samples were collected from May through August 2006. Samples were collected from approximately 10 to 20 subsamples in the wadeable stream reach surrounding the cross-section location using a sterile Nalgene cup. The subsamples were composited into one large plastic zip-lock bag and shipped to the USGS Mineral Resource Laboratory in Lakewood, Colorado, for size and chemical analysis of trace metals by ICP-MS.

Continuous Water Quality

The CWQM's were placed at all three sampling sites to measure field properties and supply the public with real-time stream conditions by the internet. The CWQM's were cleaned and calibrated following USGS standard methods and procedures as described in Wagner and others (2006). Sites were visited approximately every 2 weeks to maintain calibrations

Figure 9. U.S. Geological Survey hydrographers collecting daily suspended-sediment samples from automatic sampler.

and service equipment. Fouling and drift corrections were applied to the recorded data based on standard criteria as noted in table 3. These field calibration data are on file at the USGS Missouri Water Science Center in Rolla, Missouri.

Each CWQM sensor measures a different property: specific conductance, pH, water temperature, dissolved oxygen, and turbidity (fig. 10). The sensors also have individual ranges of operation, but none were exceeded during the study. The CWQM's were deployed at each site through a 4-inch PVC pipe near the gaging station orifice line to protect from damage and to keep the monitor in a fixed location during the study period.

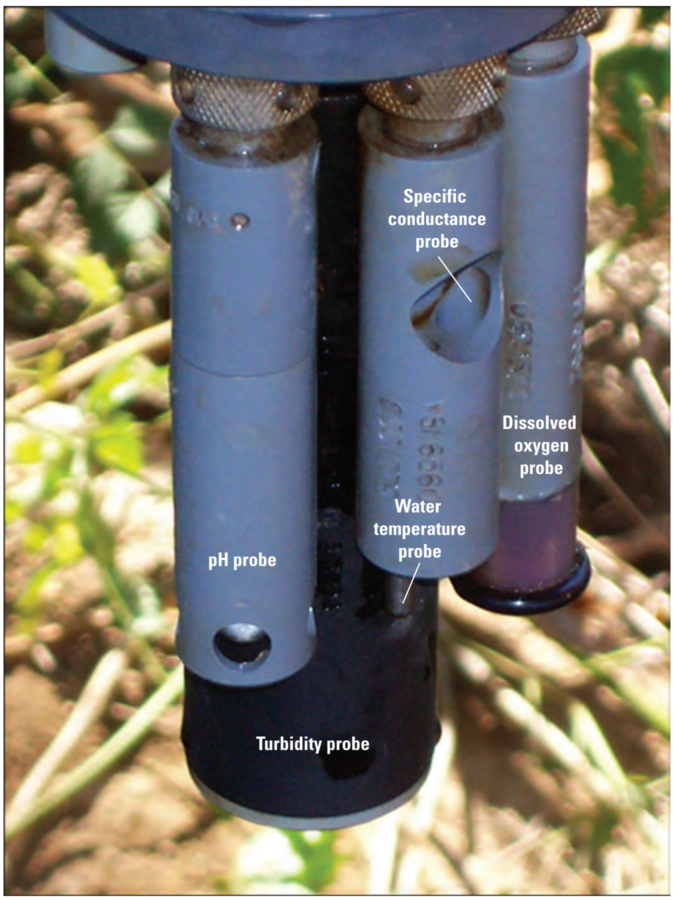


Figure 10. Water-quality monitor used to measure field properties.

The CWQM data for each property were processed after each site visit. Corrections based on sensor fouling and calibration drift were calculated and applied when necessary to correct data between site visits. If the data exceeded the maximum allowable correction limits as listed in table 3, the data were not published. Other reasons for missing data also included equipment failure, interference with aquatic biota, low flow conditions causing monitors to be out of the water, and ice conditions. Corrections were applied to the data as soon after the site visit as possible to keep accurate data available on the NWISweb. No data were estimated. Missing data or data not published were minimal for all properties, accounting for only 13 percent or less of the total days data were collected from January 2006 to December 2007 at all sites. Publication procedures were followed as described in Wagner and others (2006). Daily mean values for each physical property (median values for pH) were published in the USGS annual water data reports for 2006 and 2007 (U.S. Geological Survey, 2006b and 2007).

Quality Assurance and Quality Control

Surface-water quality-assurance samples were collected at all three sampling sites during the study period. A total of five samples were collected; three replicate samples and two field blank samples. The replicate samples were collected to determine the laboratory precision of the environmental data. Field blank samples were collected to detect any contamination of equipment between sites. All blank constituent concentrations were at or below the reporting level used by each analytical method as listed in table 1. Differences between replicate and environmental sample concentrations were within the laboratory analytical error. Field blank and replicate data were published in the USGS annual water data reports for 2006 and 2007 (U.S. Geological Survey, 2006b and 2007) and also are available in table 2.

Quality control procedures also were applied to the physical properties collected by cross-sectional samples and the CWQM to ensure both datasets were comparable. Table 4 shows cross-section measurements and the CWQM recordings of physical properties collected within the same hour. The relative percent difference (RPD) between cross-section and continuous data also are shown in the table. RPD is a measure of precision for two different collection methods of the same constituent. RPD was calculated as the absolute difference between the cross-section and CWQM data divided by the average of the two values and expressed as a percentage. A RPD of 162 percent is noted for turbidity measurements on January 29, 2006, at site 2. The CWQM became silted inside the deployment pipe on this date during the release of water from the lower reservoir and did not function properly. The CWQM data were rated poor, but were not deleted from the dataset. The SSC for the January 29, 2006, collection have a RPD of only 1 percent, indicating an error only in the turbidity measurements from the CWQM.

The average RPDs for pH, specific conductance, and water temperature were less than 10 percent at all sites, and the median RPDs were also less than 10 percent. Average dissolved oxygen RPDs were 12 percent except site 3, which was 6 percent. The median RPD for dissolved oxygen was 11 percent or less for all three sites. The average and median RPDs for turbidity and SSC varied between sites. The turbidity RPD between cross-section samples and the CWQM readings were not calculated for samples at or below the reporting level because the analytical methods vary between the two datasets. The average turbidity RPD at site 1 (when cross-section measurements were greater than the reporting level) was 88 percent and the median was 27 percent, site 2 had an

Table 3. Calibration criteria, correction criteria, maximum allowable limits, and ratings of accuracy for continuous water-quality monitor data.

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; ±, plus or minus; %, percent; SC, specific conductance; ≤, less than or equal to value; >, greater than; °C, degrees Celsius; mg/L, milligram per liter; NTU, nephelometric turbidity unit]

Physical property	Calibration criteria	Data-correction criteria	Maximum allowable limits	Rating acccuracy[1]			
				Excellent	Good	Fair	Poor
Specific conductance, µS/cm	± 5% for SC ≤ 100 µS/cm or ± 3% for SC > 100 µS/cm	± 5% for SC ≤ 100 µS/cm or ± 3% for SC > 100 µS/cm	± 30%	≤ ± 3%	> ± 3–10%	> ± 10–15%	> ± 15%
pH, standard unit	± 0.1 pH units	± 0.1 pH units	± 2.0	≤ ± 0.2	> ± 0.2–0.5	> ± 0.5–0.8	> ± 0.8
Temperature, °C	± 1% or ± 0.5 °C for liquid-filled thermometers; ± 0.2 °C for thermisters	± 1% or ± 0.5 °C for liquid-filled thermometers; ± 0.2 °C for thermisters	± 2.0	≤ ± 0.2	> ± 0.2–0.5	> ± 0.5–0.8	> ± 0.8
Dissolved oxygen, mg/L	Lesser of 5% or ± 0.3 mg/L	Lesser of 5% or ± 0.3 mg/L	± 2.0 or 20%, whichever is greater	≤ ± 0.3 or ≤ ± 5%, whichever is greater	> ± 0.3–0.5 or > 5–10%, whichever is greater	> ± 0.5–0.8 or > ± 10–15%, whichever is greater	> ± 0.8 or > ± 15%, whichever is greater
Turbidity, NTU	± 0.5 NTU or ± 5%	± 0.5 NTU or ± 5%	± 3.0 or ± 30%, whichever is greater	≤ ± 0.5 or ≤ ± 5%, whichever is greater	> ± 0.5–1.0 or > ± 5–10%, whichever is greater	> ± 1.0–1.5 or > ± 10–15%, whichever is greater	> ± 1.5 or > ± 15%, whichever is greater

[1]Ratings of accuracy are based on combined absolute values of fouling and drift corrections applied to record.

Table 4. Cross-section physical property measurements, continuous water-quality monitor (CWQM) data, and automatic sampler data collected within the same hour, January 2006 through December 2007.

[NTU, nephelometric turbidity unit; mg/L, milligram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; RPD, relative percent difference; --, no data available; <, less than]

Sample date	Sample time	Turbidity (NTU)			Dissolved oxygen (mg/L)			pH (standard units)			Specific conductance (µS/cm)			Water temperature (°C)			Suspended-sediment concentration (mg/L)		
		Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	Automatic sampler	RPD
East Fork Black River near Lesterville, Missouri; site 1																			
1/27/2006	1215	2.8	2.7	4	11.9	13.4	12	7.8	7.8	0	151	146	3	7.1	6.9	3	13	--	--
1/31/2006	1600	2.2	2.9	27	10.6	13.8	26	7.0	7.7	10	124	114	8	7.6	8.4	10	8	27	109
2/14/2006	1130	<2	.2	--	14.0	--	--	7.6	7.7	1	146	134	9	12.7	4.8	90	--	8	--
3/8/2006	1100	<2	.1	--	10.8	--	--	7.3	8.1	10	160	153	4	8.8	9.1	3	14	15	7
4/17/2006	1700	<2	.7	--	9.1	8.6	6	7.8	7.9	1	148	158	7	21.7	21.7	0	9	11	20
5/10/2006	1745	19	20	5	10.0	8.7	14	7.4	7.5	1	69	85	21	15.2	15.5	2	68[a]	57	18
6/20/2006	0945	<2	0	--	8.1	8.9	9	7.2	8.3	14	179	180	1	26.5	26.0	2	5	--	--
7/11/2006	1230	<2	6.3	--	7.9	8.7	10	7.6	8.0	5	168	215	25	24.3	24.8	2	7	36	135
8/2/2006	1455	<2	--	--	8.2	7.8	5	8.0	8.3	4	245	246	0	35.8	34.1	5	2	--	--
9/12/2006	1320	<2	3.8	--	8.8	--	--	8.1	8.2	1	226	261	14	23.7	23.7	0	3	9	100
10/24/2006	0950	3.7	-.2	223	9.7	11.2	14	7.7	8.0	4	222	214	4	9.2	9.9	7	6	10	50
11/14/2006	0850	<2	.2	--	10.0	11.0	10	7.8	7.9	1	168	179	6	10.6	10.5	1	3	10	108
12/5/2006	1130	<2	.7	--	12.7	12.0	6	7.2	7.7	7	107	112	5	6.7	6.9	3	<.5	113	--
1/4/2007	0850	<2	.2	--	11.4	12.0	5	6.9	7.8	12	115	114	1	6.8	6.9	1	1	8	156
3/27/2007	1520	<2	.9	--	9.3	10.4	11	7.5	8.2	9	145	140	4	17.4	17.6	1	1	483	199
5/21/2007	1245	2.1	.1	182	8.8	9.0	2	6.6	8.0	19	144	137	5	20.6	20.9	1	11	5	75
7/17/2007	1415	<2	.4	--	7.3	10.3	34	7.7	8.3	8	211	202	4	30.9	31.0	0	7	20	96
9/10/2007	1200	<2	1.5	--	8.1	9.0	11	7.4	7.5	1	164	152	8	21.9	22.2	1	2	4	67
11/27/2007	1630	<2	0	--	10.7	11.9	11	8.1	8.0	1	211	214	1	9.6	9.4	2	2	--	--
Average RPD				88			12			6			7			7			88
Median RPD				27			10			4			5			2			96

Table 4. Cross-section physical property measurements, continuous water-quality monitor (CWQM) data, and automatic sampler data collected within the same hour, January 2006 through December 2007.—Continued

[NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; RPD, relative percent difference; --, no data available; <, less than]

Sample date	Sample time	Turbidity (NTU)			Dissolved oxygen (mg/L)			pH (standard units)			Specific conductance (µS/cm)			Water temperature (°C)			Suspended-sediment concentration (mg/L)		
		Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	Automatic sampler	RPD
East Fork Black River near Lesterville, Missouri; site 2																			
1/27/2006	1410	23	27	16	11.9	12.1	2	7.4	7.5	1	149	134	11	6.7	6.5	3	22	31	34
1/29/2006	1740	180	19	162	12.8	13.1	2	7.4	7.1	4	157	151	4	6.3	6.9	9	474	469	1
2/1/2006	1340	24	22	9	12.2	11.8	3	7.5	7.6	1	138	142	3	8.6	7.8	10	27	40	39
2/15/2006	1030	15	26	54	13.1	12.9	2	7.1	7.8	9	140	141	1	4.2	4.5	7	28	20	33
3/8/2006	1330	9.2	12	26	10.9	12.4	13	7.3	7.9	8	160	156	3	9.2	9.4	2	14	35	86
4/17/2006	1300	18	20	11	8.8	11.7	28	7.8	7.7	1	137	132	4	18.9	19.6	4	25	37	39
5/9/2006	1645	11	--	--	9.3	--	--	7.5	--	--	133	134	1	18.4	18.4	0	15	--	--
5/10/2006	2130	31	--	--	7.4	--	--	7.4	--	--	122	99	21	17.1	17.0	1	99	70	34
6/19/2006	1245	16	17	6	8.0	8.3	4	7.6	7.8	3	158	157	1	26.6	26.1	2	21	68	106
7/11/2006	1620	13	16	21	6.9	7.7	11	7.6	7.8	3	142	178	23	24.2	24.2	0	16	--	--
8/2/2007	1030	8.4	6.6	24	6.0	7.4	21	7.6	8.0	5	233	232	0	27.9	28.2	1	16	--	--
9/12/2006	1135	8.3	5.4	42	5.6	8.4	40	7.7	7.8	1	231	249	8	23.2	22.9	1	13	20	42
10/23/2006	1520	9.4	6.6	35	9.2	--	--	7.6	8.0	5	250	245	2	12.2	12.6	3	11	204	180
11/13/2006	1615	4.2	5.6	29	9.3	--	--	7.7	8.0	4	180	192	6	11.8	11.6	2	9	13	36
12/5/2006	1500	43	45	5	12.1	12.3	2	6.8	7.5	10	69	71	3	7.3	6.9	6	30	152	134
1/3/2007	1245	2.9	3	3	12.6	11.3	11	6.9	7.9	14	117	115	2	6.5	6.1	6	3	245	195
3/27/2007	1120	4.2	6.2	38	9.6	10.3	7	7.2	7.8	8	149	146	2	16.0	16.2	1	9	9	0
5/21/2007	1630	6.9	--	--	9.0	10.0	11	6.8	7.8	14	119	112	6	22.5	22.7	1	47	16	98
7/17/2007	1155	5.8	6.9	17	6.1	7.6	22	7.1	7.7	8	156	150	4	25.5	26.4	3	11	15	31
9/11/2007	0945	7.4	8.6	15	6.9	7.8	12	7.6	7.6	0	158	153	3	22.9	23.0	0	10	12	18
11/27/2007	1315	2.6	1.8	36	10.4	12.7	20	8.0	7.9	1	167	168	1	8.9	8.6	3	6	7	14
Average RPD				30			12			5			5			3			62
Median RPD				22			11			4			3			2			38

Table 4. Cross-section physical property measurements, continuous water-quality monitor (CWQM) data, and automatic sampler data collected within the same hour, January 2006 through December 2007.—Continued

[NTU, nephelometric turbidity unit; mg/L, milligram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; RPD, relative percent difference; --, no data available; <, less than]

Sample date	Sample time	Turbidity (NTU)			Dissolved oxygen (mg/L)			pH (standard units)			Specific conductance (µS/cm)			Water temperature (°C)			Suspended-sediment concentration (mg/L)		
		Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	CWQM data	RPD	Cross-section measurement	Automatic sampler	RPD
Black River below Annapolis, Missouri; site 3																			
1/27/2006	1140	3	3	0	11.3	12.2	8	7.8	8.1	4	278	278	0	6.7	6.6	2	5	59	169
1/29/2006	1730	57	56	2	11.3	11.2	1	7.4	8.0	8	232	220	5	9.6	9.6	0	122	101	19
2/2/2006	0855	8	10	22	10.9	11.0	1	7.9	7.9	0	236	230	3	8.4	8.3	1	14	35	86
2/13/2006	1315	2.6	2.7	4	11.6	13.6	16	7.5	8.0	6	257	249	3	4.8	4.8	0	4	79	181
3/7/2006	1230	3	1.7	55	12.2	11.9	2	7.5	8.1	8	279	274	2	9.2	8.7	6	11	39	112
4/18/2006	1145	2.1	2.2	5	10.3	9.8	5	8.0	8.1	1	257	263	2	18.2	18.8	3	5	81	177
5/11/2006	1545	49	51	4	8.9	10.0	12	7.0	7.6	8	143	153	7	15.0	15.0	0	104	201	64
6/20/2006	1445	<2	2.4	--	8.0	--	--	7.8	8.0	3	279	282	1	26.9	27.1	1	7	709	196
7/12/2006	1030	<2	.6	--	8.3	8.5	2	7.9	8.1	2	178	273	42	22.1	22.4	1	4	137	189
8/3/2007	1025	<2	1.3	--	8.2	7.5	9	7.8	8.0	3	293	290	1	26.2	26.3	0	3	75	185
9/11/2006	1525	5.2	.3	178	9.7	8.5	13	7.4	8.1	9	307	296	4	21.9	22.1	1	2	152	195
10/23/2006	1135	3.5	.3	168	9.8	10.7	9	7.9	8.1	2	357	350	2	12.3	12.6	2	1	79	195
11/13/2006	1310	<2	.5	--	11.4	11.3	1	7.8	8.2	5	291	302	4	11.9	11.8	1	4	243	194
12/19/2006	0940	2.5	1	86	10.6	11.3	6	7.3	8.1	10	234	226	3	9.3	9.3	0	1	3	100
1/4/2007	1245	<2	.9	--	11.5	12.2	6	7.1	8.1	13	223	220	1	7.8	7.6	3	2	--	--
2/12/2007	1400	--	.1	--	12.8	--	--	7.6	8.2	8	244	241	1	6.1	6.0	2	--	--	--
3/29/2007	1145	<2	2.3	--	10.2	10.1	1	7.8	7.6	3	271	264	3	15.1	15.4	2	12	271	183
4/3/2007	1025	--	1.9	--	9.9	9.9	0	7.5	7.4	1	235	230	2	15.0	15.3	2	--	--	--
5/22/2007	0910	<2	.7	--	8.6	9.4	9	7.3	8.0	9	235	231	2	18.5	18.4	1	83	10	157
6/12/2007	1000	--	--	--	8.7	--	--	7.8	8.1	4	273	266	3	20.1	20.6	2	1	260	198
7/17/2007	0910	<2	--	--	6.8	7.8	14	7.6	7.9	4	309	300	3	23.8	24.1	1	2	195	196
9/10/2007	1530	8.5	5	52	7.7	7.8	1	7.6	7.7	1	279	271	3	24.3	24.4	0	6	517	195
11/27/2007	0945	<2	0	--	11.4	12.4	8	8.2	8.1	1	339	333	2	8.7	8.7	0	2	7	111
Average RPD				64			6			5			4			1			162
Median RPD				52			6			4			3			1			184

[a]A value of 166 mg/L was previously published for this sample date in the 2006 U.S. Geological Survey Water Resources Data of the United States, annual water data report, WDR–US–2006. After further review, it was discovered that one subsample appeared too high, because the sampler possibly hit the streambed during collection. The subsample was removed from the cross-sectional average and recalculated.

average turbidity RPD of 30 percent and median of 22 percent, and site 3 had an average RPD of 64 percent and median of 52 percent. The average SSC RPD at site 1 was 88 percent and the median RPD was 96 percent. Site 2 had an average RPD of 62 percent and a median RPD of 38 percent for SSC, while site 3 had an average RPD of 162 percent and a median RPD of 184 percent. The large RPDs of the SSC samples could have been caused by the location of the automatic sampler at each site. The automatic samplers were placed on a streambank approximately 1 ft from the edge of water at each site. It is possible that sediments were more concentrated along these streambanks where the stream velocity is typically less than in the centroid of the stream.

Differences between the average and median RPDs for dissolved oxygen, pH, specific conductance, and water temperature were 5 percent or less for all sites. Differences between the average and median turbidity RPDs were 61 percent at site 1, 8 percent at site 2, and 12 percent at site 3. Differences in average and median RPDs for SSC were 8 percent at site 1, 24 percent at site 2, and 22 percent at site 3.

Figures 11 through 13 show the physical property measurements for the cross-section samples plotted with the daily mean CWQM data and daily mean streamflow. Most CWQM measurements show a good relation with the corresponding field property. The pH data from the cross-section samples do not appear to have a good relation with the CWQM data. This is because the cross-section samples represent a single pH value collected from the churn while the CWQM data are a daily median value.

Data Analysis Methods

Data collected at each site were analyzed for statistical significance using a variety of methods. Cross-section water-quality samples were tested for correlation between parameters using Kendall's tau. The correlations measure the strength of association between two constituents (Helsel and Hirsch, 1992). A nonparametric test known as the Kruskal-Wallis t-test was performed on all constituents to test for significant differences in distributions. Constituents were determined to be significantly different when the "attained significance level" (p-value) was less than 0.05. If significant differences were noted, the Tukey's multiple comparison test was performed on the rank-transformed data to identify similarities between the three sites (Helsel and Hirsch, 1992). A two-way analysis of variance test (ANOVA) also was performed on the rank-transformed data of selected parameters to determine the relation between sites as well as seasonal differences.

Boxplots are used to graphically display the distribution of a selected constituent at multiple sites (Helsel and Hirsch, 1992). Boxplots provide a visual summary of the 25^{th}, 50^{th}, and 75^{th} percentiles and any extreme values in the distribution (fig. 14). The boxplots consists of the median value (50^{th} percentile) plotted as a horizontal line, and a box is drawn from the 25^{th} percentile to the 75^{th} percentile. The box length, also known as the interquartile range (IQR), represents one-half of the data values. The IQR is insensitive to the presence of extreme values in the distribution. If a median value does not divide the box into two equal parts, it indicates asymmetry in the data distribution. Adjacent values are located outside the box and, if within 1.5 times the IQR, are shown as whisker lines. The length of the whisker connected to the 75^{th} percentile represents the value of the largest adjacent point; the length of the whisker connected to the 25^{th} percentile represents the smallest adjacent value. Values which are more extreme in either direction than the adjacent values are plotted individually. The values equal to 1.5 to 3.0 times the IQR are called "far-out values" and are represented by an 'x' (D.R. Helsel, U.S. Geological Survey, written comm., 1989). Values greater than the "far-out values" are represented by a circle. If the median data equals the 25^{th} percentile, no center line is shown. If the median of the data equals both the 25^{th} and 75^{th} percentiles, the box will be plotted as a single line. Any boxplots made with censored data (data reported as less than a given value) were modified by making the lower limit of the box equal to the reported value.

All SSC determined by daily sediment samples were used to calculate the suspended-sediment discharge in tons per day (tons/d) using the USGS Graphical Constituent Loading Analysis System (GCLAS) following methods described in Porterfield (1972) and Koltun and others (2006). Daily mean SSC and daily suspended-sediment discharges were published in the USGS annual water data report (U.S. Geological Survey, 2006b, 2007). SSC for missing days were estimated when applicable by using a transport curve to best-fit estimated data. The SSC determined from cross-section suspended-sediment samples were used to calibrate the SSC of the daily samples by applying a coefficient. A coefficient is the ratio of the cross-section SSC to the daily SSC. Coefficients were applied by time between cross-section collections and also were adjusted by the streamflow. During 2006, coefficients ranged from 0.1 to 1.09 at site 1, 0.07 to 1.38 at site 2, and 0.01 to 1.08 at site 3. Coefficients applied to daily samples during 2007 ranged from 0.12 to 3 at site 1, 0.13 to 2.94 at site 2, and 0.01 to 0.33 at site 3.

Assessment of Surface-Water Quality Effects

Statistical analyses were performed on the data obtained from water-quality sampling, suspended-sediment samples, and CWQMs. This section describes results of statistical tests applied to historical and current data used to identify trends in surface-water quality data from before and after the upper reservoir embankment breach. Statistical summaries also were computed for the CWQM data from each site.

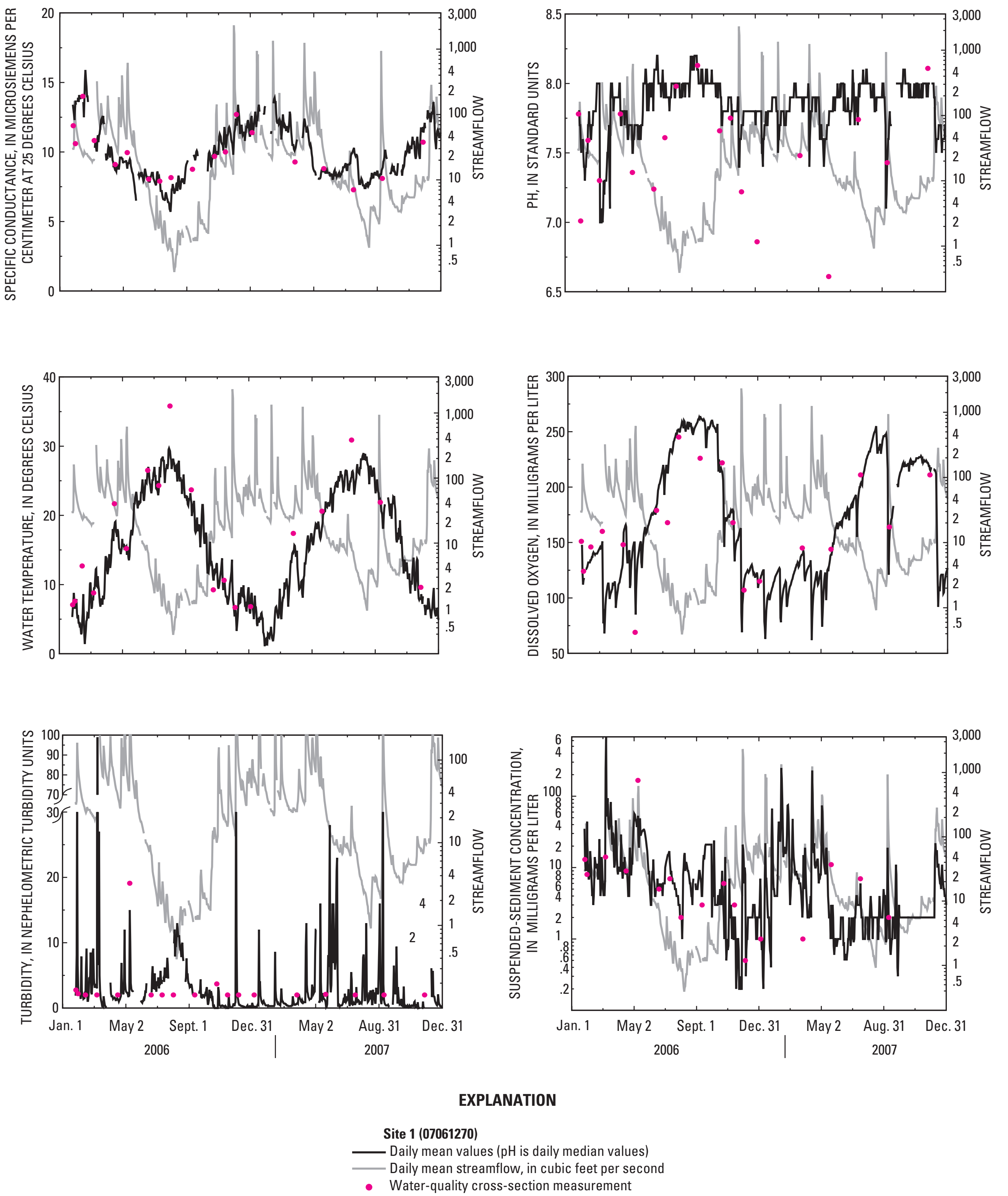


Figure 11. Comparison of continuous data, cross-section measurements, and streamflow from East Fork Black River near Lesterville, Missouri, January 2006 through December 2007.

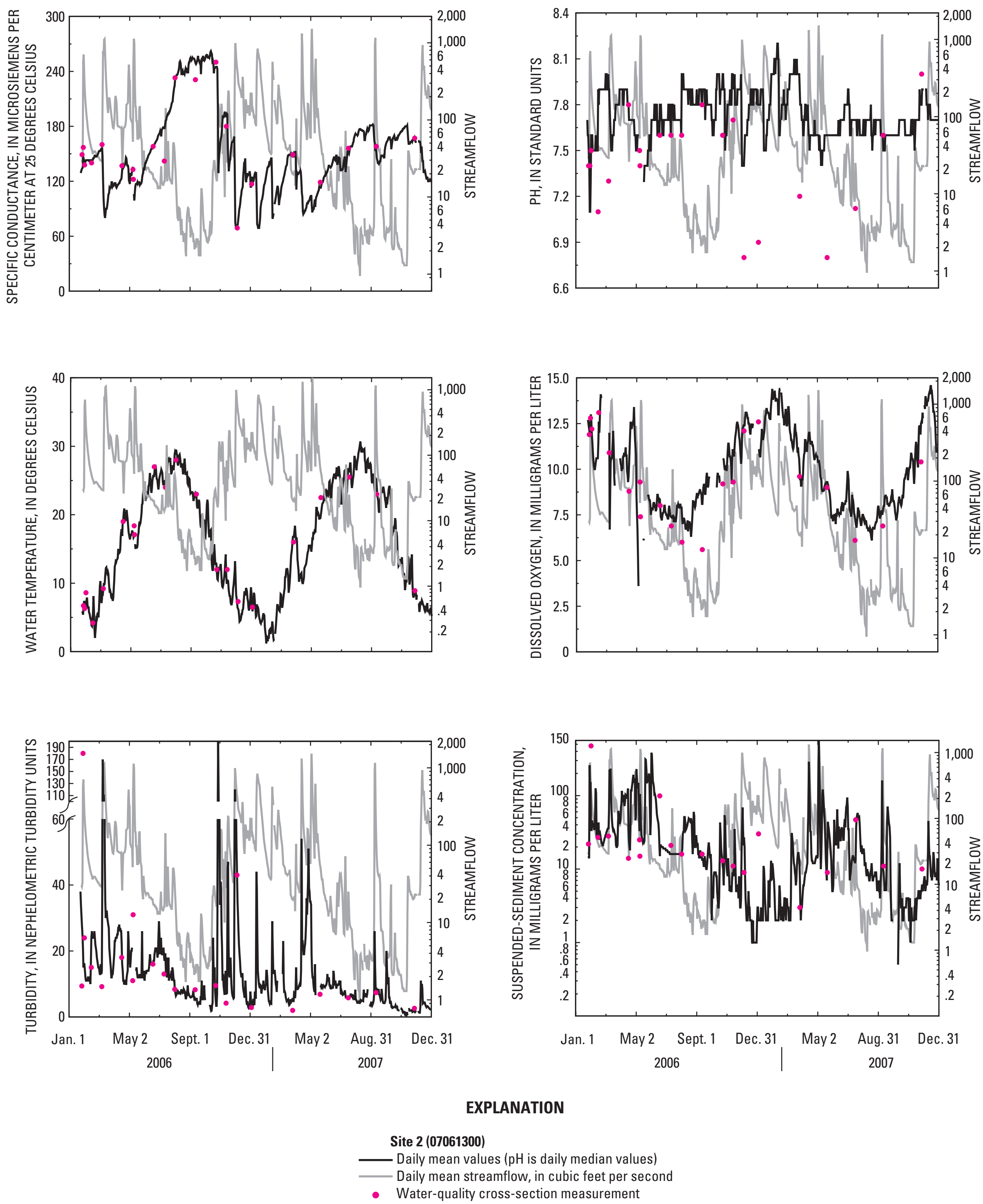


Figure 12. Comparison of continuous data, cross-section measurements, and streamflow from East Fork Black River at Lesterville, Missouri, January 2006 through December 2007.

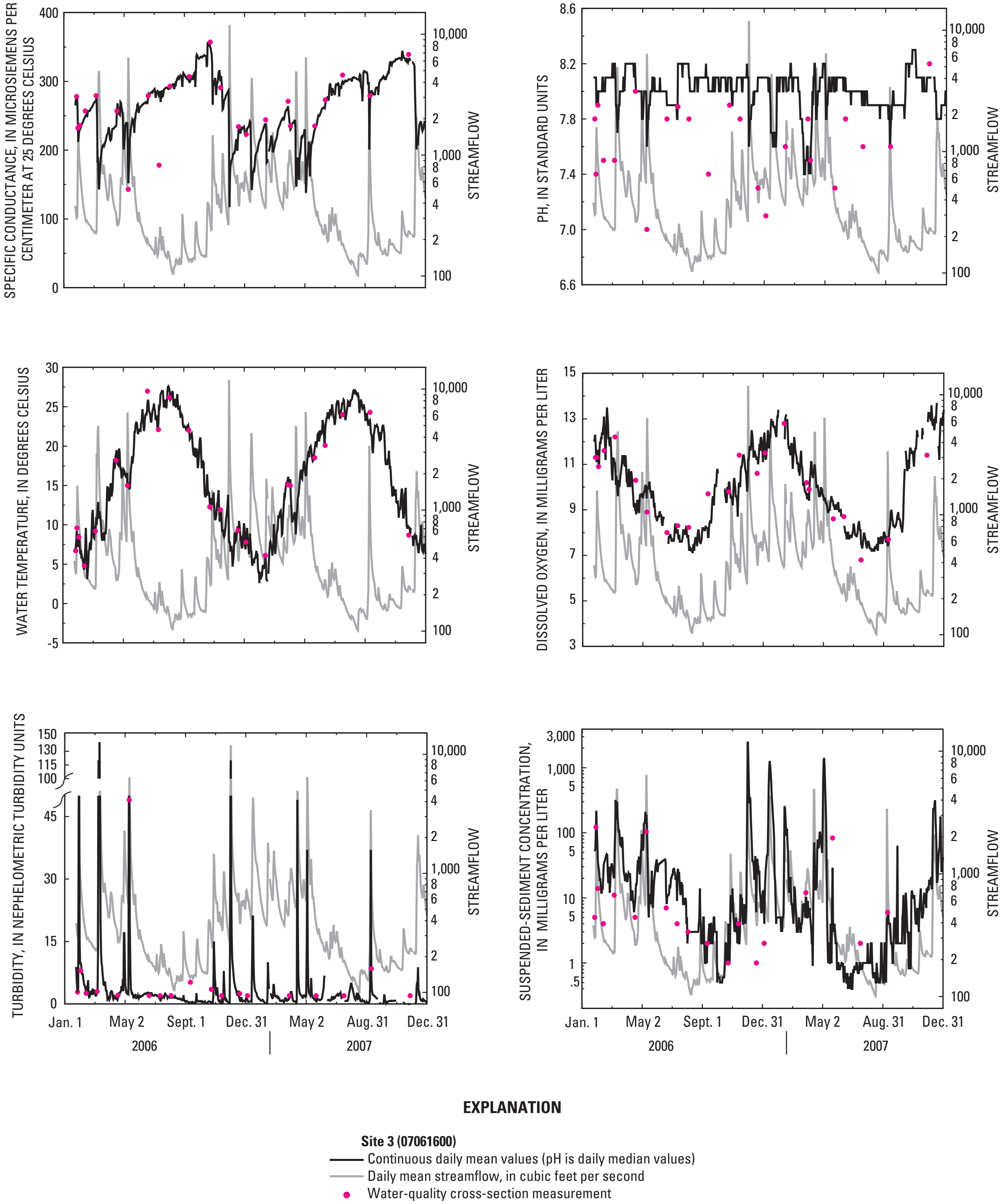


Figure 13. Comparison of continuous data, cross-section measurements, and streamflow from Black River below Annapolis, Missouri, January 2006 through December 2007.

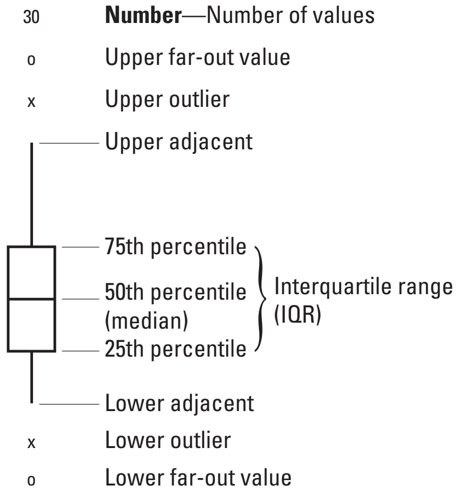


Figure 14. Example of a boxplot.

Surface-Water Quality

Summary statistics for selected water-quality constituents are found in table 5. The non-parametric Kruskal-Wallis t-test indicated that several constituents were significantly different between sites (p-value < 0.05). To better define these differences, the multiple comparison Tukey test was performed.

Streamflow and turbidity were significantly different at each of the three sites (p-value < 0.05; fig. 15). These findings were expected because all three sites have different streambed characteristics and upstream influences such as land use, drainage area, and the lower reservoir for sites 2 and 3. There were no significant differences between sites 1 and 3 and between sites 2 and 3 for TSS and SSC. However, the TSS and SSC were statistically different between sites 1 and 2. The differences in TSS and SSC between sites 1 and 2 could be caused by the presence of the lower reservoir between the two sites. Because the lower reservoir was drained to remove sediments captured from the upper reservoir embankment breach during the early months of the study, a large amount of suspended sediments likely was introduced into the East Fork Black River. Additionally, dredging of sediment that had settled out during the flocculation process also may have influenced concentration values during the first year. It is likely that site 3 also would have been influenced by the release of suspended solids from the lower reservoir, though the data would not have equivalent concentrations as site 2 because of the larger drainage area for site 3. Historical TSS and SSC data available for site 3 also were compared to data collected during 2006-07 at site 1. It was determined that data from both datasets were statistically similar (SSC p-value = 0.51, TSS p-value = 0.40).

Cross-section water-quality data from sites 1 and 2 were similar in hardness, sulfate, total dissolved solids, and nitrate plus nitrite concentrations. The similarities in the dissolved constituents seem reasonable because sites 1 and 2 are along the same stream reach, and these constituents would not be expected to change as rapidly as suspended solids. Site 3 has additional influences of dissolved constituents from the West and Middle Fork Black Rivers.

In addition to determining similarities between sites, seasonal trends also were investigated. The seasons were defined as four 3-month periods for winter, spring, summer, and fall. Winter months were December through February, spring months were March through May, summer months were June through August, and the fall months were September through November. A two-way ANOVA test was used to identify differences between sites and seasons simultaneously on the ranked data. Few constituents showed statistically similar seasonal trends for all sites. However, a significant seasonal decrease from winter to fall was observed for turbidity and dissolved and total recoverable aluminum at sites 1 and 2. The decrease in turbidity and dissolved and total recoverable aluminum, especially at site 2, could be attributed to the alum flocculent used to reduce turbidity from suspended sediments in the lower reservoir during January 2006. The alum flocculent was made of aluminum sulfate, and as the flocculent was removed from the lower reservoir and diluted in the East Fork Black River, the concentrations of aluminum and sulfate would also be expected to decrease. Another possible source of the larger concentrations during the study period could be the upper reservoir embankment breach itself. Because aluminum occurs as aluminosilicate clay minerals in the soils of the study area, the embankment breach would have released aluminum to the East Fork Black River, which over time would have moved through the study area. A seasonal decrease from winter to fall in suspended sediments was observed for site 2, while an increase was observed for site 1 (fig. 16). The increase in SSC at site 1 is thought to be caused by the river reconstruction that took place during the spring and summer months. The river reconstruction involved the removal and stabilization of streambank material. Heavy equipment also was observed crossing the East Fork Black River just downstream from site 1 during base-flow conditions. The reconstruction efforts caused backflow and the deposition of point bars, affecting the water quality at site 1 during the summer and fall months of the study.

Linear correlation analyses were performed on several constituents at each site using Kendall's tau. The correlation measures the strength of association between two constituents (Helsel and Hirsch, 1992). All sites had coefficients (R^2) greater than 0.70 between dissolved oxygen and water temperature, specific conductance and water hardness, specific conductance and TDS, and turbidity and SSC, indicating good correlation. Correlations between turbidity and TSS and TSS and SSC had large coefficients ($R^2 > 0.70$) indicating strong correlation, but because of a limited data set and numerous TSS concentrations at the detection limit, the correlation coefficients could be skewed. Data collected at site 1 had larger correlation coefficients (R^2 = 0.80 to 0.99) than the data collected at the other two sites. Site 3, the most downstream site and largest drainage area, had the smallest correlation coefficients (R^2 = 0.70 to 0.98).

Table 5. Summary statistics for selected physical properties, inorganic constituents, nutrients, and trace metals in the East Fork Black River and Black River, January 2006 through December 2007.

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity unit; mg/L, milligram per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; col, colonies; mL, milliter; µg/L micrograms per liter; all concentrations are dissolved unless otherwise indicated]

	Discharge (ft^3/s)	Turbidity (NTU)	Dissolved oxygen (mg/L)	pH	Specific conductance (µS/cm)	Water temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)	Total dissolved solids (mg/L)	Total suspended solids (mg/L)
East Fork Black River near Lesterville, Missouri; site 1													
Number of samples	19	19	19	19	19	19	19	19	19	19	19	19	19
Minimum	.9	2	7.3	6.6	69	6.7	33	6.9	3.8	.8	4.4	57	10
25th percentile	9	2	8.5	7.3	145	9.0	66	13.6	7.8	.9	5.5	82	10
Median	24	2	9.7	7.6	160	15.2	72	15.3	8.4	1.0	6.4	90	10
Mean	67	3.04	9.9	7.5	163	16.7	81	16.9	9.6	1.0	6.3	99	11
75th percentile	46	2.05	10.8	7.8	195	22.8	105	21.8	12.4	1.1	7.1	124	10
Maximum	749	19	14.0	8.1	245	35.8	130	26.8	15.7	1.4	8.1	147	36
Standard deviation	167	3.88	1.8	.4	44.8	8.9	26.2	5.4	3.2	.2	1.2	25	6
East Fork Black River at Lesterville, Missouri; site 2													
Number of samples	21	21	21	21	21	21	21	21	21	21	21	21	21
Minimum	2.4	2.6	5.6	6.8	69	4.2	30	6.1	3.5	.9	5.0	43	10
25th percentile	20	6.9	7.4	7.2	137	8.6	61	12.6	7.1	1.0	6.4	84	10
Median	30	9.4	9.3	7.5	149	16.0	69	14.4	8.2	1.1	6.9	86	10
Mean	158	21	9.4	7.4	155	15.5	74	15.5	8.7	1.2	9.1	93	33
75th percentile	113	18	11.9	7.6	160	22.9	85	17.6	9.7	1.3	9.7	96	16
Maximum	1,090	180	13.1	8.0	250	27.9	120	25.2	14.9	1.7	25.7	152	395
Standard deviation	298	38	2.4	.33	41.5	7.8	22.3	4.7	2.8	.24	5.1	25	84
Black River below Annapolis, Missouri; site 3													
Number of samples	25	20	25	25	25	25	22	22	22	22	22	22	25
Minimum	134	2.0	6.8	7.0	143	4.8	71	15.1	8.1	.9	11	97	10
25th percentile	225	2.0	8.7	7.5	235	8.7	123	24.1	14.4	1.0	18	142	10
Median	305	2.3	10.3	7.6	273	13.4	135	27.1	16	1.0	22	159	10
Mean	689	8.1	10.2	7.6	267	14.5	136	27.4	16	1.0	23	161	17
75th percentile	614	3.9	12.8	7.8	293	20.1	147	29.9	17.3	1.1	26.1	171	10
Maximum	6,830	57	26.0	8.2	357	26.9	180	35.9	22.7	1.3	39.2	207	103
Standard deviation	1313	16	1.6	.29	48.9	6.8	24.5	4.8	3.1	.11	7.6	29	22

Table 5. Summary statistics for selected physical properties, inorganic constituents, nutrients, and trace metals in the East Fork Black River and Black River, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity unit; mg/L, milligram per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; col, colonies; mL, milliter; µg/L micrograms per liter; all concentrations are dissolved unless otherwise indicated]

	Ammonia (mg/L as N)	Nitrite plus nitrate (mg/L as N)	Chemical oxygen demand (mg/L)	Fecal coliform (col/100 mL)	Aluminum (µg/L)	Aluminum, total recoverable (µg/L)	Iron (µg/L)	Lead (µg/L)	Lead, total recoverable (µg/L)	Manganese (µg/L)	Zinc (µg/L)	Zinc, total (µg/L)	Suspended-sediment concentration (mg/L)
East Fork Black River near Lesterville, Missouri; site 1													
Number of samples	19	19	19	19	19	19	19	19	19	19	19	19	19
Minimum	.008	.040	10	1	.9	2.0	4	.05	.04	2	.3	1	.5
25th percentile	.019	.055	10	4	2	13	7.5	.08	.07	7	.6	2	2
Median	.020	.060	10	12	2	17	10	.09	.12	14	1	2	6
Mean	.034	.081	11.05	136	4	43	30.5	.11	.32	26	1	2	9
75th percentile	.040	.060	10	30	2.1	48	33	.12	.19	36.2	1.4	2	9
Maximum	.216	.340	20	2,000	33.4	303	158	.30	2.70	106	1.9	4	68
Standard deviation	.045	.078	3.15	455	7.4	69	45.4	.05	.63	27.5	.5	.6	16
East Fork Black River at Lesterville, Missouri; site 2													
Number of samples	21	21	21	20	21	21	21	21	21	21	21	21	21
Minimum	.010	.040	10	1	1	28	3	.04	.08	4	.30	1	3
25th percentile	.020	.050	10	3.5	4	165	5	.08	.40	14	.6	1	11
Median	.040	.060	10	7	6	290	6	.08	.49	27	.7	2	16
Mean	.040	.080	10	22.4	7.8	497	7.4	.09	1.0	45	.9	2	45
75th percentile	.040	.070	10	21.3	10	585	8	.12	.84	40.2	1.4	2	27
Maximum	.147	.230	10	110	35.3	2,190	28	.12	6.97	156	1.8	8	474
Standard deviation	.030	.056	0	35	7.3	547	5.4	.03	1.45	45.4	.5	1.7	103
Black River below Annapolis, Missouri; site 3													
Number of samples	25	25	20	24	22	22	22	22	22	22	22	22	20
Minimum	.010	.070	10	1	1	4	3	.04	.04	.2	.3	1	1
25th percentile	.020	.100	10	4	2	18	4	.08	.08	1.7	1	2	3
Median	.020	.160	10	12	2	33	6	.08	.10	2.5	1	2	5
Mean	.025	.163	10.5	30.2	3.8	109	5.6	.10	.54	3.9	1	2	20
75th percentile	.040	.200	10	29	4.8	72.5	6	.12	.19	4.2	1	2	11
Maximum	.050	.380	20	290	19.7	807	12	.12	6.71	15.2	6	8	122
Standard deviation	.012	.077	2.23	59.5	4.4	207	2.1	.02	1.45	3.7	1.1	1.6	37

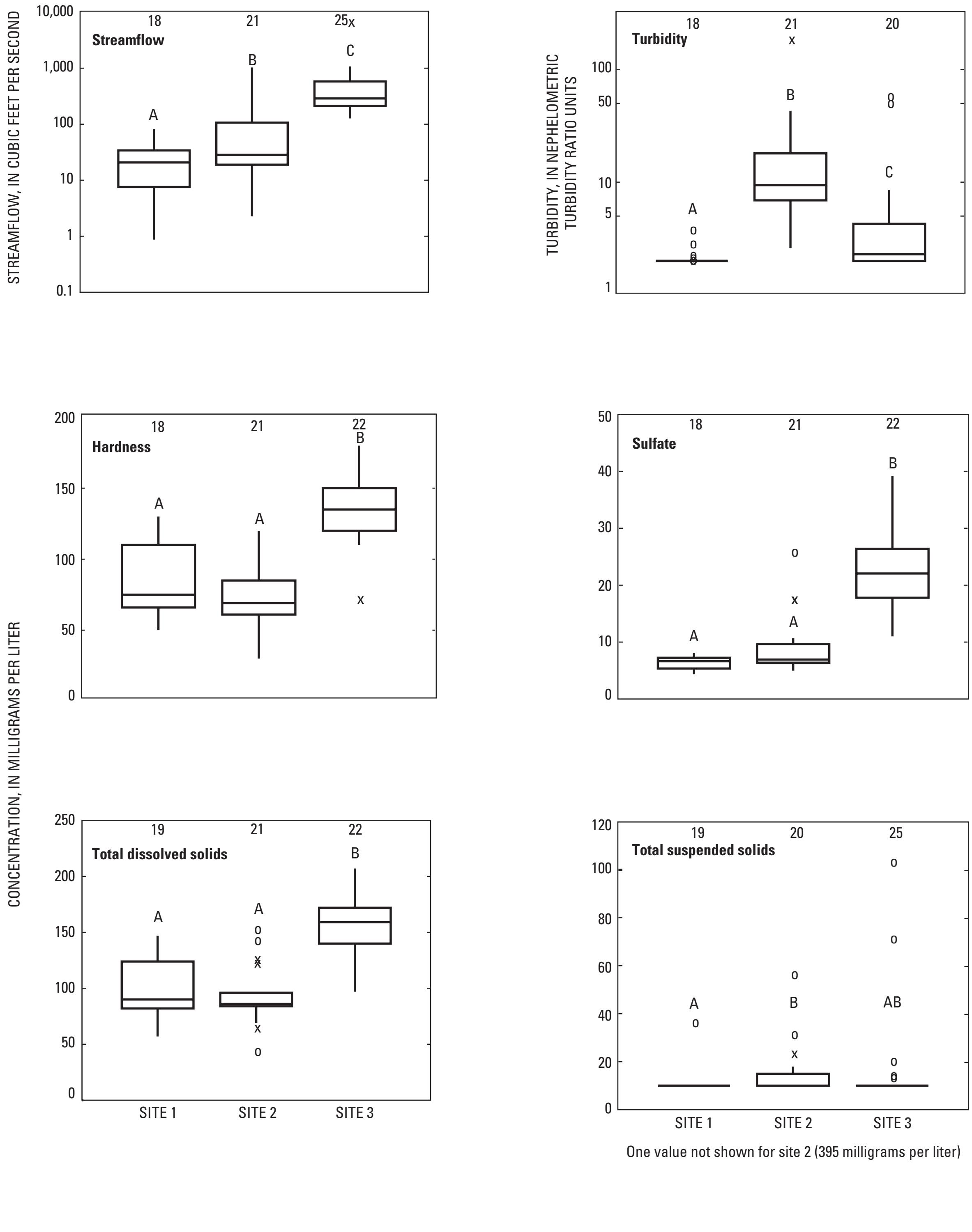


Figure 15. Streamflow, general water-quality, trace elements, and suspended-sediment concentrations for three sampling sites, January 2006 through December 2007.

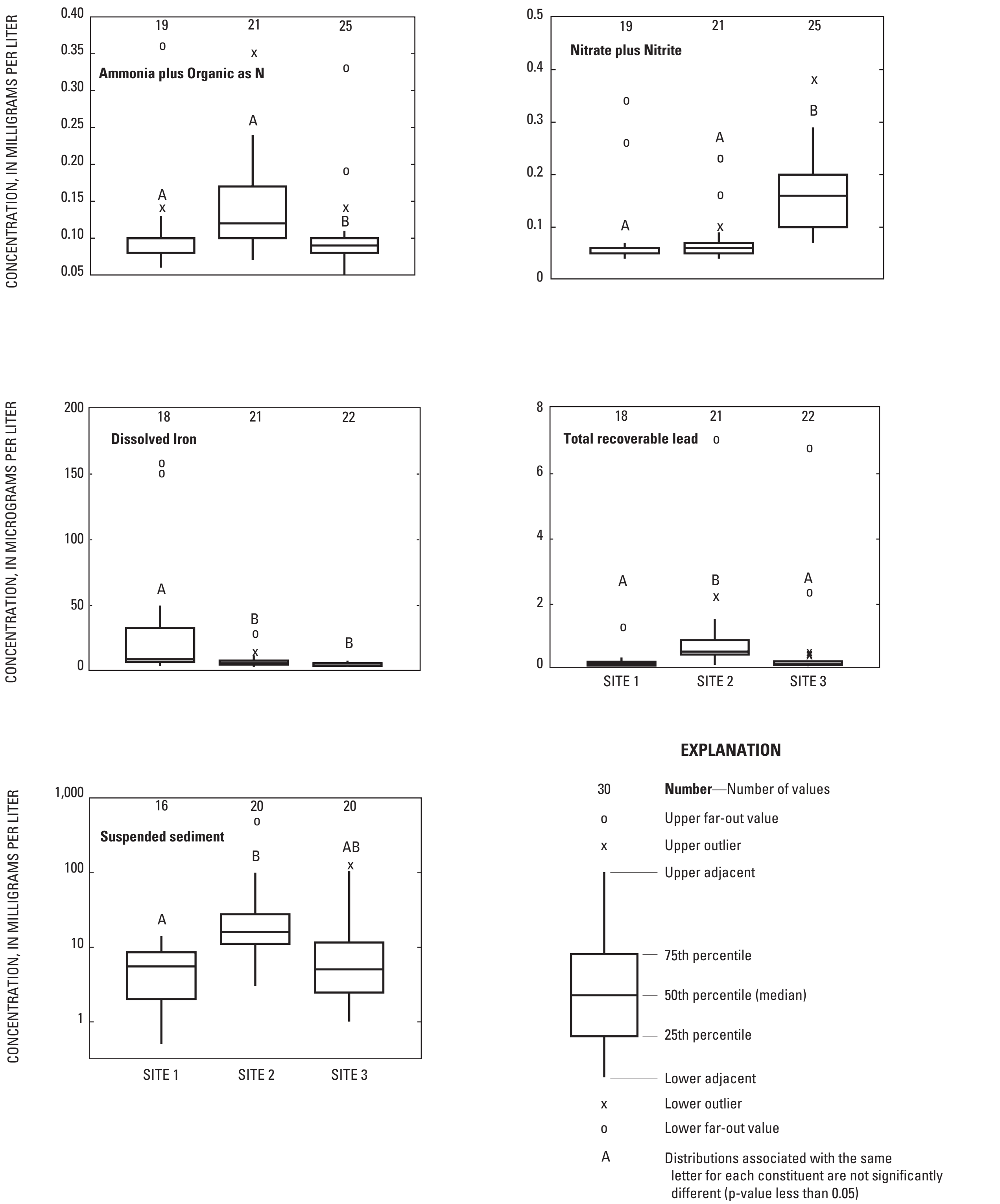


Figure 15. Streamflow, general water quality, trace elements, and suspended-sediment concentrations for three sampling sites, January 2006 through December 2007.—Continued

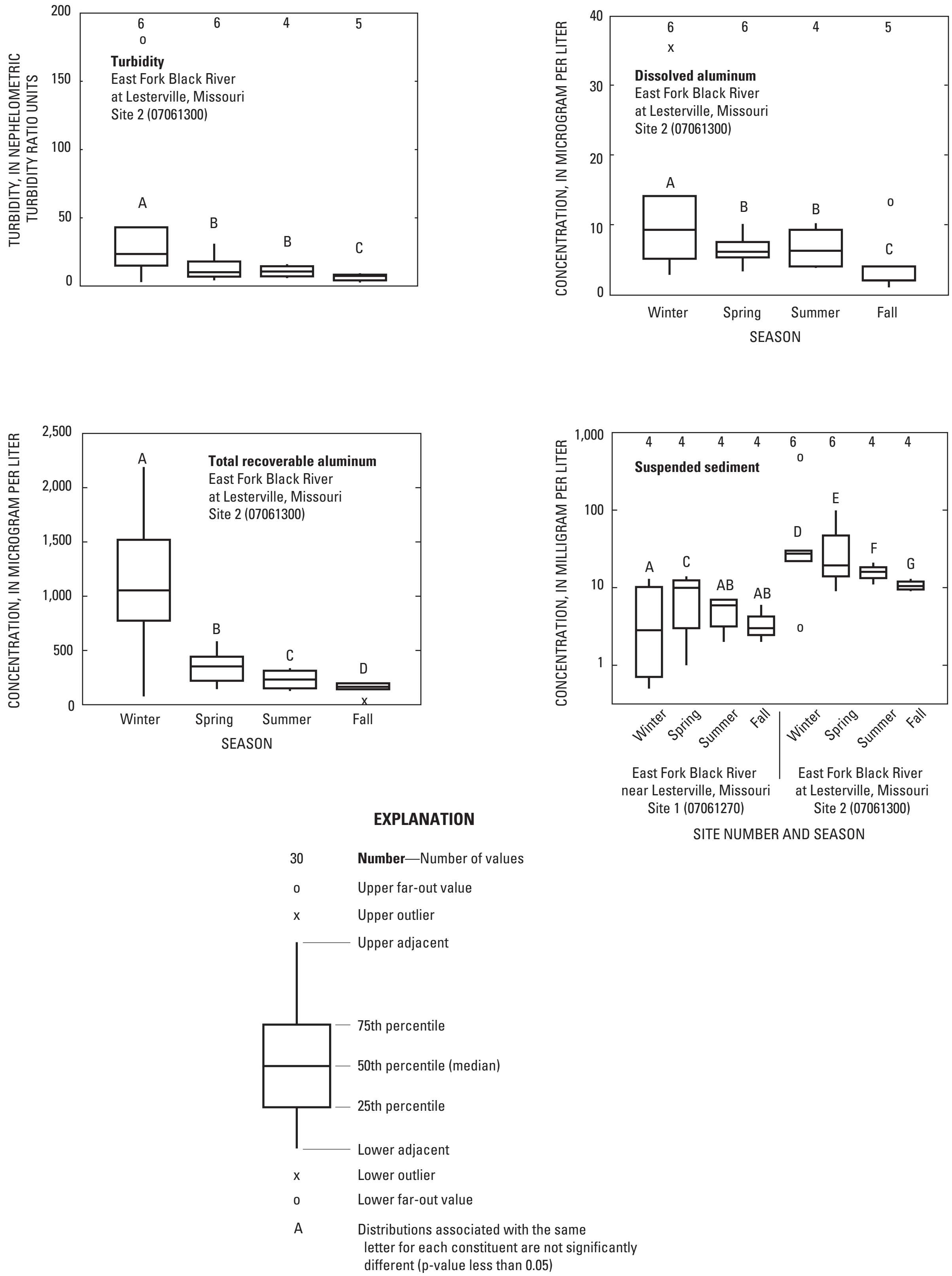


Figure 16. Seasonal trends of discrete surface-water quality cross-section data for turbidity, dissolved and total recoverable aluminum, and suspended-sediment concentrations at sites 1 and 2, January 2006 through December 2007.

Dissolved and total recoverable aluminum had strong correlation at site 1 (R^2 = 0.91) and site 3 (R^2 = 0.78). The correlation coefficient between dissolved and total aluminum at site 2 was only 0.39. However, a good correlation was observed between sulfate and total recoverable aluminum (R^2 = 0.73) at site 2 (fig. 17). It is possible that the alum-based flocculent used in the lower reservoir was introduced to the East Fork Black River during water releases. If the flocculent was released into the river, it may have been diluted when it reached the main stem of the Black River as there was no correlation between sulfate and total recoverable aluminum at site 3 (R^2 = -0.17). Correlation analyses also were performed between the daily mean turbidity data and the cross-section SSC for each site (fig. 17). The correlation coefficient for site 1 was largest (R^2 = 0.95), and the correlation coefficient for site 2 was smallest (R^2 = 0.72). One data point was removed from the dataset for the correlation analysis for site 2, which made the R^2 value more representative of the entire dataset. Before this data point was removed, the correlation was poor (R^2 = 0.04).

Water hardness, TDS, TSS, and SSC were graphically compared to instantaneous streamflow during the study (fig. 18). Generally all three sites show a decrease in water hardness and TDS as the streamflow increased. TSS and SSC increased at sites 2 and 3 as streamflow increased, with the higher concentrations measured during storm events in January and May 2006. Concentrations of 395 mg/L for TSS and 474 mg/L for suspended sediment were measured at site 2 in January 2006. No large concentration for either constituent was measured upstream at site 1 in January 2006. The high concentrations for these constituents at site 2 are likely caused by the large amounts of water released from the lower reservoir which tended to cause particles to resuspend in the stream, especially early in the study period, when water was released from the lower sluice. The released water would have carried a large amount of the sediments and debris that flowed downstream into the lower reservoir from the upper reservoir during the embankment breach. Site 3 downstream from site 2 on the Black River had approximately 30 percent less TSS concentration (103 mg/L) and SSC (122 mg/L) than were present at site 2 in January 2006; the East Fork Black River is likely the primary source of these constituents to the main stem of the Black River but become diluted by the influence of the Middle and West Forks.

During the May 2006 event, the SSC at site 1 was approximately 8 times greater than the average SSC of the cross-section samples during the entire study period. The TSS concentration collected during the same event at site 1 was only three times greater than the average concentration during the study period. SSC and TSS concentrations collected at sites 2 and 3 during the same storm event in May 2006 are similar. The large difference in the concentrations of these constituents at site 1 may be because of the difference between analytical methods. It is also possible that the SSC was biased if the sampler touched the streambed at one or more of the subsections causing streambed sediment to enter the sampler nozzle.

Suspended and Streambed Sediments

The SSC and suspended-sediment discharge data varied during the study period. During the 2006 water year (October 2005 through September 2006), the cross-section SSC ranged from 2 to 68 mg/L at site 1 and decreased to a range of less than 0.5 to 11 mg/L during the 2007 water year (October 2006 through September 2007; tables 2, 4, and 5). The total annual sediment discharge for the 2006 water year was 1,240 tons/yr with a maximum monthly discharge of 870 tons/month in March and a minimum monthly discharge of 0.51 tons/month in August. In water year 2007, the total annual sediment discharge increased to 3,100 tons/yr with a maximum monthly discharge of 1,400 tons/month in February and a minimum monthly discharge of 0.49 tons/month in August (U.S. Geological Survey, 2006b, 2007; fig. 19).

At site 2, the 2006 water year cross-section SSC ranged from 2 to 166 mg/L and decreased during the 2007 water year, ranging from 3 to 47 mg/L. (tables 2, 4, and 5). The total annual sediment discharge for water year 2006 was 6,100 tons/yr with a maximum monthly discharge of 2,300 tons/month in March and a minimum monthly discharge of 5.39 tons/month in September. During water year 2007, the total annual sediment discharge increased to 8,100 tons/yr with a maximum monthly discharge of 4,600 tons/month in May and a minimum discharge of 0.61 tons/month in October (U.S. Geological Survey 2006b, 2007; fig. 19).

The mean annual (average of both water years) sediment discharge at site 3 was 15 times greater than site 2 and 40 times greater than the mean annual sediment discharge at site 1. It is likely that sediment discharges at site 3 are larger because of the influence of the Middle and West Forks of the Black River. The 2006 water year total annual sediment discharge was 29,300 tons/yr with a maximum monthly discharge of 16,000 tons/month in March and a minimum monthly discharge of 39 tons/month in September. For water year 2007, the total annual sediment discharge increased to 174,000 tons/yr with a maximum monthly discharge of 64,000 tons/month in December and a minimum monthly discharge of 11 tons/month in August (U.S. Geological Survey, 2006b, 2007; fig. 19). The cross-section SSC ranged from 1 to 122 mg/L during the 2006 water year and stayed similar during the 2007 water year, ranging from 1 to 83 mg/L (tables 2, 4, and 5).

The increase in sediment discharge data from water year 2006 to 2007 at all sites could be attributed to several factors: the restoration of the East Fork Black River near site 1, which began approximately April 2006 and continued after the study period; the dredging of the lower Taum Sauk reservoir in August 2006; an increase in storm events from November 2006 through March 2007; and because suspended sediment was not collected from October 2005 through mid-January 2006. It is possible that streambank sediment removed during

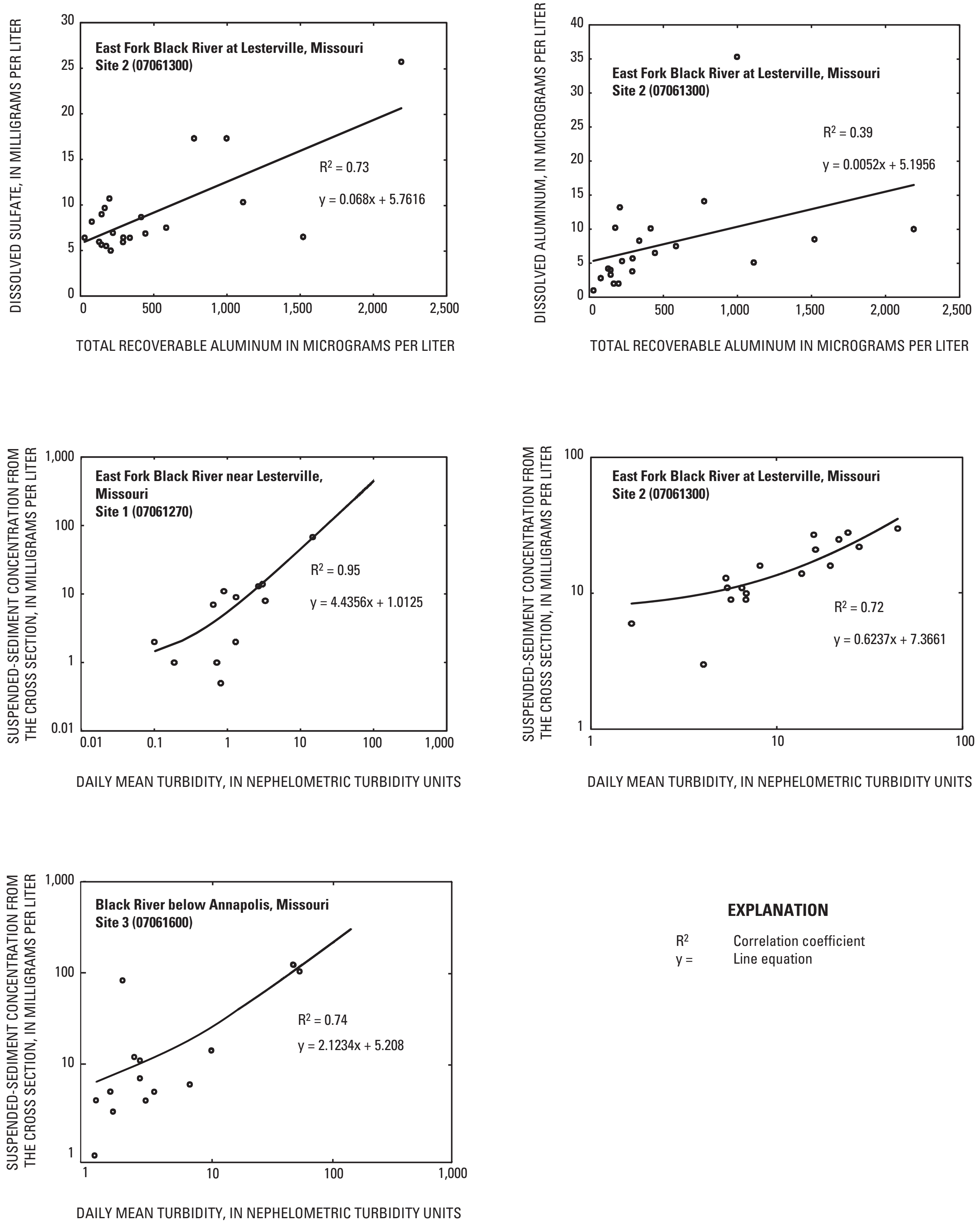
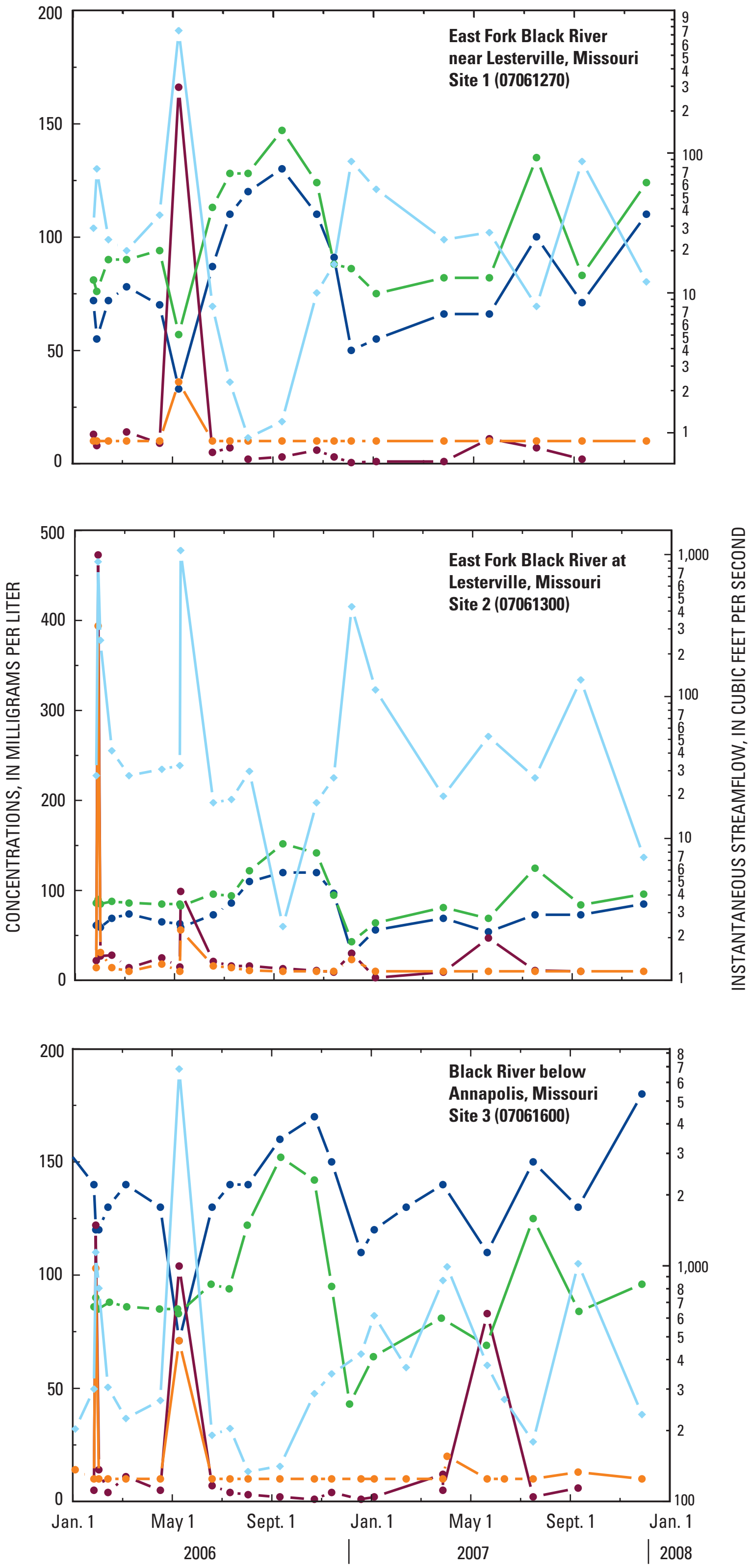


Figure 17. Correlation plots of various surface-water quality constituents.



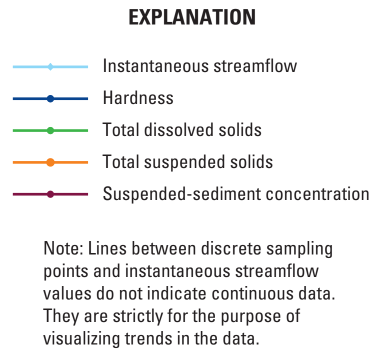


Figure 18. Comparison of surface-water quality constituents with streamflow, January 2006 through December 2007.

the East Fork Black River reconstruction, as well as bottom materials resuspended during the lower reservoir dredging, could have been remobilized in the stream reaches by runoff during large storm events in November 2006 to January 2007. Figure 19 also shows hydrographs of the daily mean streamflow for each site during the study period. The hydrographs indicate more high-flow events during the 2007 water year than during the 2006 water year. The increase in high flows could have caused more runoff, increasing the suspended-sediment discharge in the second year of the study. Because no sediment data were collected at the three sites during the first three months of the 2006 water year, the annual sediment discharge for the first year of the study may not represent the actual sediment discharge. Sediment discharges would likely be larger during December 2005 and January 2006 because of the upper reservoir embankment breach.

Suspended-sediment and streambed-sediment samples were sent to the USGS Mineral Resource Laboratory in Lakewood, Colorado, for ICP-MS chemical analysis (table 6). A suspended-sediment sample also was collected from the surface of the lower Taum Sauk reservoir shortly after the embankment breach to document early surface-water quality. Larger concentrations of calcium, potassium, aluminum, and iron were measured in the lower reservoir suspended-sediment sample compared to the suspended-sediment samples from the sampling network. The suspended-sediment sample from the lower reservoir was collected prior to the use of the alum flocculent. The suspended-sediment samples from the three sampling sites were collected after the alum flocculent was used and after the lower reservoir release of captured water during the upper reservoir embankment breach.

The suspended-sediment samples were collected during storm events and the streambed sediment was collected during low-flow periods in the summer of 2006. The suspended-sediment aluminum concentrations from site 2 were about 1.4 times larger than the streambed-sediment aluminum concentrations, which

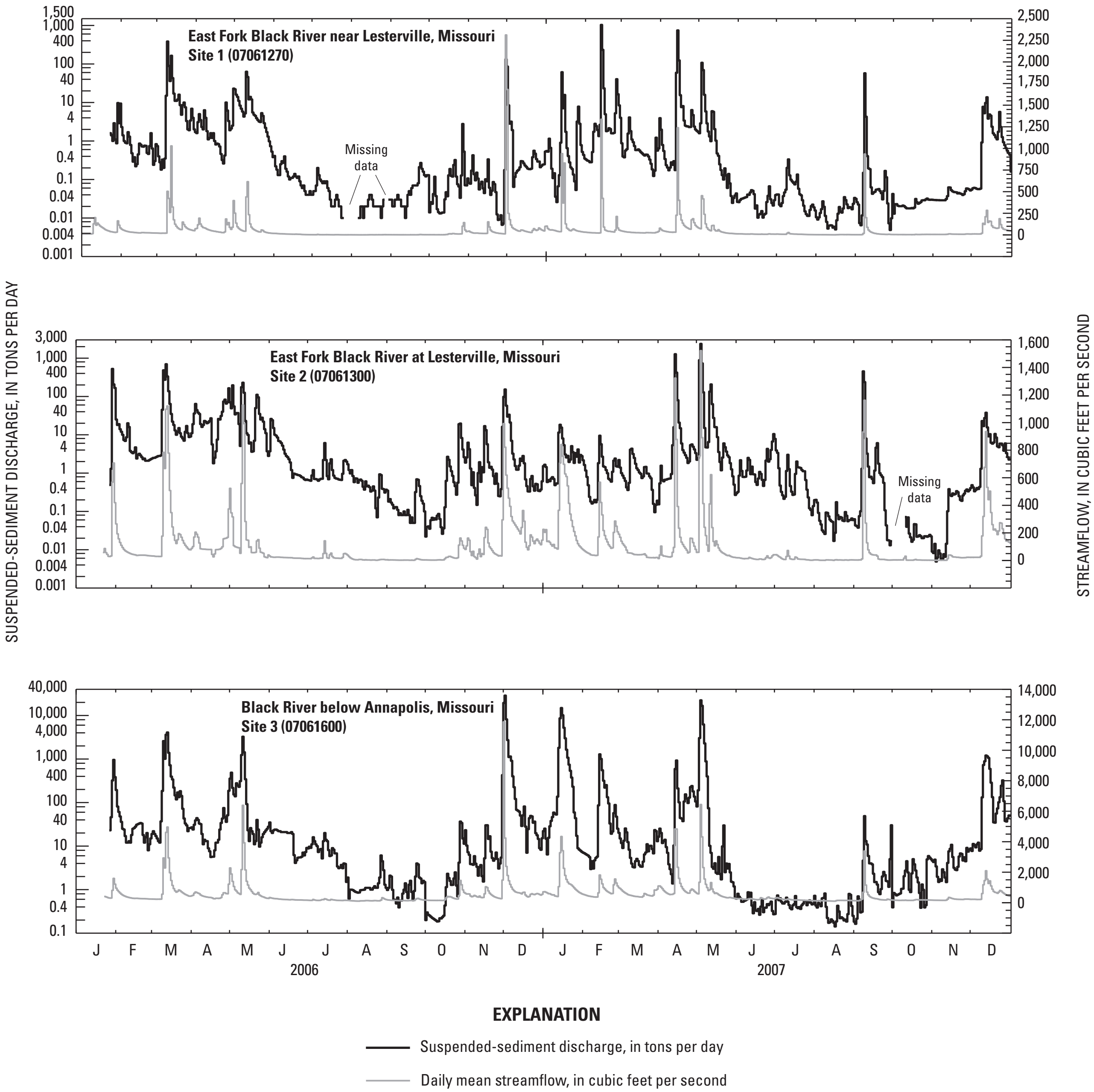


Figure 19. Suspended-sediment discharge in relation to daily mean streamflow, January 2006 through December 2007.

is likely the result of the alum flocculent in the lower reservoir. The suspended-sediment samples collected in October 2006 and January 2007 at sites 1 and 2 show larger concentrations of calcium, arsenic, and strontium than the streambed-sediment samples. The cause of the larger concentrations in the suspended sediments is unknown.

Particle-size analyses of the streambed-sediment samples also were performed, and the results are shown in table 7. The first sample collected in May 2006 at sites 1 and 2 had the largest silt and clay content. Later samples had much less silt and clay, indicating that much of the finer material had been transported during storm events.

Site 3 has the longest period of record in this study. Historical sediment data from the 1993–97 NAWQA study were available for several of the same constituents analyzed during this study (Davis and others, 1995). These data and data from the current study were analyzed together to identify any trends before or after the embankment breach. The instantaneous streamflow values and SSC data collected in the cross section were used to calculate suspended-sediment discharge.

The nonparametric Kendall's tau test was performed to determine if there was a significant difference (p-value < 0.05) in the SSC and suspended-sediment discharge with time. There was no significant difference found between the historical data and the current data (p-value $= 0.69$) for suspended-

Table 6. Results of inductively coupled argon plasma-mass spectrometry of suspended sediment collected during storm events and streambed sediment collected during low-flow periods.

[mg/kg, milligram per kilogram; <, less than]

Sample date	Sample medium	Silver, mg/kg	Aluminum, mg/kg	Arsenic, mg/kg	Barium, mg/kg	Beryllium, mg/kg	Bismuth, mg/kg	Calcium, mg/kg	Cadmium, mg/kg	Cerium, mg/kg	Cobalt, mg/kg	Chromium, mg/kg	Cesium, mg/kg
East Fork Black River near Lesterville, Missouri; site 1													
04/24/06	Suspended	4.5	35,300	8.3	177	1.8	0.09	3,090	1.5	41.5	9	39	2.2
10/27/06	Suspended	<1	66,800	405	899	3.5	10.3	30,100	1.7	112	38.5	72.9	6
05/30/06	Streambed	<1	82,400	47.2	580	2.5	.24	1,930	.20	184	14.2	44.4	6.6
06/19/06	Streambed	<1	68,200	45.2	581	2.6	.21	5,570	1.8	157	30.1	48.3	5.1
07/11/06	Streambed	<1	78,000	50.4	580	3	.24	4,820	.37	161	24.9	60.2	5.8
08/02/06	Streambed	<1	81,100	60.7	639	2.9	.25	3,580	.41	178	31.6	54.1	5.9
East Fork Black River at Lesterville, Missouri; site 2													
05/10/06	Suspended	1.7	103,000	53.6	690	3.2	0.29	4,160	0.85	160	23.6	57.3	7.4
10/26/06	Suspended	<1	102,000	256	750	3.8	3.73	16,500	1	158	24.7	61.2	7.6
01/08/07	Suspended	<1	100,000	288	698	4.1	7.64	22,000	1	165	25.1	82.4	7.6
05/30/06	Streambed	<1	62,000	43.5	564	2.1	.17	2,390	.34	155	14.3	38.8	4.4
06/19/06	Streambed	<1	69,600	44.1	617	3.6	.26	5,250	108	172	40.4	65.3	5.4
07/11/06	Streambed	<1	77,100	41.9	608	4.6	.29	6,050	1.1	136	33.4	58.6	6
08/02/06	Streambed	<1	70,300	44.5	618	3.2	.27	2,890	.67	151	29.2	55.6	5.4
Black River below Annapolis, Missouri; site 3													
05/11/06	Suspended	<1	69,400	22.5	486	2.8	0.26	4,370	1.1	102	33.9	54.2	5.4
05/31/06	Streambed	<1	52,800	19.8	373	2.4	.22	4,810	1.1	116	35.9	69.9	4.1
06/20/06	Streambed	<1	56,100	27.5	460	2.7	.28	3,100	2.2	137	53.9	72	4.4
07/12/06	Streambed	<1	52,600	18.5	471	2.7	.26	4,330	.88	107	43.4	105	4.1
08/03/06	Streambed	<1	63,200	29.7	451	2.6	.33	2,380	.55	124	35.3	50.6	5.2
Lower Taum Sauk Reservoir near Lesterville, Missouri													
12/27/05	Suspended	<3	93,200	58	529	3.3	0.3	2,260	.31	195	16.8	48.2	7.4

Table 6. Results of inductively coupled argon plasma-mass spectrometry of suspended sediment collected during storm events and streambed sediment collected during low-flow periods.—Continued

[mg/kg, milligram per kilogram; <, less than]

Sample date	Sample medium	Copper, mg/kg	Iron, mg/kg	Gallium, mg/kg	Potassium, mg/kg	Lanthanum, mg/kg	Lithium, mg/kg	Magnesium, mg/kg	Manganese, mg/kg	Molybdenum, mg/kg	Sodium, mg/kg	Niobium, mg/kg	Nickel, mg/kg
East Fork Black River near Lesterville, Missouri; site 1													
04/24/06	Suspended	38.1	20,000	8.4	5,134	20.1	14.6	3,392	393	0.55	283	< 0.1	30.3
10/27/06	Suspended	46.5	44,900	16.2	17,100	52.7	44.8	11,300	6,460	1.9	2,300	16	51.9
05/30/06	Streambed	26.1	30,100	23.1	34,000	94.8	32.2	3,580	717	1.8	2,230	27	21.7
06/19/06	Streambed	40.2	37,800	20	33,900	67.1	22.7	4,830	1,860	1.8	2,130	23	30.1
07/11/06	Streambed	33.4	38,100	22.2	39,000	77.4	26.8	4,900	1,520	3	1,900	24	35.4
08/02/06	Streambed	33.9	43,200	24.1	40,800	75.7	25.3	4,080	2,810	2.8	1,970	27	32.9
East Fork Black River at Lesterville, Missouri; site 2													
05/10/06	Suspended	40.4	37,700	24.2	32,904	75.3	34.1	6,082	3,070	1.7	2,561	27	34.5
10/26/06	Suspended	36.9	40,000	24.4	23,800	74.1	49.9	9,250	3,400	2.1	1,960	21	41.2
01/08/07	Suspended	44.4	38,500	24.2	24,600	77.3	51.5	8,830	1,990	2.1	1,790	22	49.2
05/30/06	Streambed	24.9	23,300	16.8	33,900	76.7	20.1	2,720	1,040	1.2	2,930	19	17.9
06/19/06	Streambed	67.6	40,500	19.9	26,000	79.3	27.6	5,170	7,320	2.1	1,980	20	55.2
07/11/06	Streambed	50.7	36,600	20.7	23,900	66.6	33.3	6,210	6,110	1.8	1,930	24	46
08/02/06	Streambed	54.4	32,500	19.8	26,300	70.1	27.6	3,940	5,350	1.9	1,980	22	40.2
Black River below Annapolis, Missouri; site 3													
05/11/06	Suspended	40.2	31,800	16.7	16,904	50.2	34.4	5,102	1,720	1.4	1,831	19	54.8
05/31/06	Streambed	47	30,900	13.8	14,600	56.9	27	4,180	2,250	2	1,400	15	51.1
06/20/06	Streambed	87.4	38,100	15.7	15,600	62.7	30.9	3,530	5,270	2.3	1,300	16	76.5
07/12/06	Streambed	57.5	28,400	13.9	14,000	51.5	28	4,010	3,240	3.8	1,340	17	65.7
08/03/06	Streambed	43.3	31,200	17.6	18,800	61.3	33.3	3,470	2,490	1.6	1,450	21	43.2
Lower Taum Sauk Reservoir near Lesterville, Missouri													
12/27/05	Suspended	33.7	34,000	25	29,000	86.1	36.9	4,820	916	1.9	1,840	21	43.2

Table 6. Results of inductively coupled argon plasma-mass spectrometry of suspended sediment collected during storm events and streambed sediment collected during low-flow periods.—Continued

[mg/kg, milligram per kilogram; <, less than]

Sample date	Sample medium	Phosphorous, mg/kg	Lead, mg/kg	Rubidium, mg/kg	Antimony, mg/kg	Scandium, mg/kg	Strontium, mg/kg	Thorium, mg/kg	Titanium, mg/kg	Thallium, mg/kg	Uranium, mg/kg	Vanadium, mg/kg	Yttrium, mg/kg	Zinc, mg/kg
East Fork Black River near Lesterville, Missouri; site 1														
04/24/06	Suspended	692	29	30	0.55	8.8	19.4	5.14	1,240	.02	1.33	51.6	21.2	102
10/27/06	Suspended	924	107	75	17.7	10.2	234	11.4	2,980	.76	3.16	72.5	44.4	272
05/30/06	Streambed	375	28.6	162	4.4	13.2	71.3	14.6	5,150	1.09	4.13	79.2	58.6	87
06/19/06	Streambed	494	165	136	4.5	12	61	13.6	4,860	.87	3.83	83.7	57.1	126
07/11/06	Streambed	456	177	150	5.2	13	64.2	14.6	4,560	.97	3.91	78.4	60.8	115
08/02/06	Streambed	493	108	166	5.3	13.2	64.8	15.2	4,450	.97	3.84	78.2	63.1	122
East Fork Black River at Lesterville, Missouri; site 2														
05/10/06	Suspended	496	38	161	4.2	15	79.4	16.5	4,430	0.84	3.81	92.1	68.8	108
10/26/06	Suspended	701	63.9	137	11.9	14.6	164	15.3	3,660	1.04	3.55	98.6	54.4	223
01/08/07	Suspended	746	82.6	126	13.5	15.5	280	15.4	4,040	1.05	4.24	99.1	62.2	236
05/30/06	Streambed	300	38.2	131	3.5	9.8	64.8	11.8	3,990	.81	3.56	54.1	52.4	69
06/19/06	Streambed	663	390	118	2.7	13.3	59.4	13.2	4,070	.93	4.05	90.7	65.8	231
07/11/06	Streambed	496	391	121	3.0	13	60.5	14.3	3,930	1.04	3.88	91.2	58.5	222
08/02/06	Streambed	510	400	127	2.7	11.6	60.2	14.4	3,470	.96	4.12	71.2	59.4	150
Black River below Annapolis, Missouri; site 3														
05/11/06	Suspended	550	86	97	1.7	12.2	75.3	12.4	3,110	0.58	2.92	93	49.9	172
05/31/06	Streambed	626	72.8	73.3	1.4	10.5	44	10.5	3,510	.66	2.78	83	45.7	159
06/20/06	Streambed	778	122	82	2	11	43.2	11.4	3,160	.76	2.89	87.2	49.5	236
07/12/06	Streambed	571	264	75	2	9.4	43.2	11.5	3,320	.75	3.15	69.3	44.6	310
08/03/06	Streambed	591	663	105	2.6	11	51.4	13.6	3,390	.86	3.52	75.5	51.3	134
Lower Taum Sauk Reservoir near Lesterville, Missouri														
12/27/05	Suspended	420	33.3	163	4.3	14.5	66.6	16.8	3,800	1.2	4.6	89.1	61.8	102

sediment discharge. Kendall's tau was not applicable to the SSC data because of numerous tied (identical) values in the dataset at the minimum reporting level (MRL) of 0.5 mg/L. The historical SSC, TSS, and suspended-sediment discharge data were statistically compared to the current data by using the Wilcoxon rank-sum test to look for trends (fig. 20). Large p-values (0.29 for SSC, 0.57 for TSS, and 0.74 for suspended-sediment discharge) indicated that no significant differences were present between the historical and current data. Few differences appear between the streamflow boxplots for site 3 from before and after the reservoir embankment breach in December 2005 (p-value = 0.45). More data outliers are evident before the breach, most of which are from flood events during 1993. Although the SSC data were not significantly different before and after the breach, the median SSC increased and the median suspended-sediment discharge decreased slightly after the embankment breach. The median streamflow did not change before or after the embankment breach. Because the suspended-sediment discharge decreased after the embankment breach while SSC increased, the suspended-sediment discharge seems to be more influenced by streamflow, possibly because the stream velocity is large enough to rapidly transport suspended sediments out of the system.

SSC also were plotted based on instantaneous streamflow ranges (base flow, median flow and high flow) at site 3 to better observe changes that may have occurred from before to after the reservoir embankment breach (fig. 21). The three ranges of streamflow were based on the summary statistics for site 3 (table 5). Most sediment samples collected during the 1993–95 study at site 3 were collected at a median flow (300 to 1,000 ft^3/s). The samples collected during the 2006–07 study were evenly distributed between base (less than 300 ft^3/s) and median flows. Few data are available from both studies for high flows (greater than 1,000 ft^3/s). The base flow SSC for both studies are similar in concentration, with median values of 20 mg/L for the 1993–95 collection period and 4 mg/L for the 2006–07 period. A slight increase in SSC at median flow is evident, but only half as many samples were collected in this streamflow range during the current study than in the historical dataset. The median concentration could be skewed slightly in the 2006–07 data because fewer samples were collected than the 1993–95 dataset. A similar situation also is detected for the high streamflow data. The upper far-out value is shown in figure 21 for the historical data set, but the rest of the data are equally distributed in the data range. The current study data have only three values and are shown as individual values in figure 21. The largest SSC measured at site 3 was 270 mg/L at a streamflow of 28,800 ft^3/s in 1994. The highest measured concentration during the current study was 122 mg/L with a streamflow of 1,140 ft^3/s in January 2006.

It was noted from January 2006 to approximately November 2007 that the East Fork Black River downstream from the lower Taum Sauk reservoir and the lower reservoir itself appeared to have a peculiar color ranging from blue-green to dark brown (fig. 22). This discoloration may have been caused by a phenomenon known as “rock flour”, which

Table 7. Results of sediment particle-size analyses of streambed sediments used in inductively coupled argon plasma-mass spectrometry analyses.

[%, percent; <, less than; mm, millimeter]

Sample date	Weights in grams: Total recovered	Sand	Silt	Clay	Percent (normalized to 100%): Sand (<2–0.063 mm)	Silt (0.063–0.002 mm)	Clay (<0.002 mm)
East Fork Black River near Lesterville; site 1							
5/30/2006	31.3	8.0	15.8	7.5	25.4	50.6	24
6/19/2006	74.2	70.2	2.8	1.2	94.6	3.7	1.7
7/11/2006	31.3	29.3	1.4	.6	93.6	4.4	2.0
8/2/2006	29.8	27.8	1.4	.6	93.4	4.5	2.1
East Fork Black River at Lesterville; site 2							
5/30/2006	31.8	7.6	20.8	3.5	23.9	65.2	10.9
6/19/2006	65.7	64.2	.9	.5	97.8	1.4	.8
7/11/2006	28.0	25.6	1.5	.9	91.4	5.4	3.2
8/2/2006	32.1	31.0	.8	.4	96.4	2.3	1.3
Black River below Annapolis; site 3							
5/31/2006	52.4	50.3	1.3	.9	95.9	2.5	1.6
6/20/2006	90.7	90.3	.2	.2	99.5	.3	.2
7/11/2006	30.3	29.7	.3	.3	98.1	1.0	.8
8/3/2006	26.8	26.3	.2	.2	98.4	.8	.7

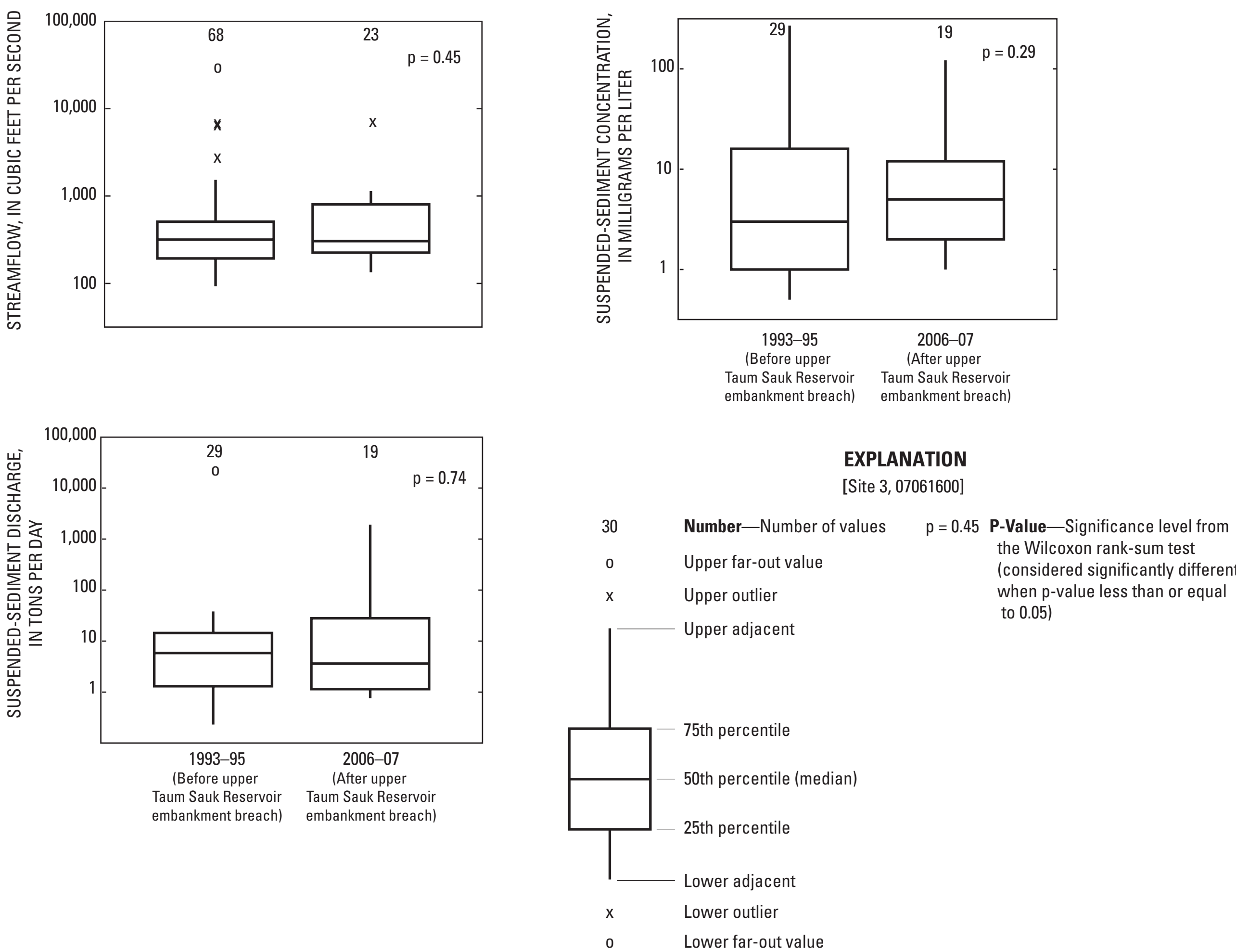


Figure 20. Streamflow, suspended-sediment concentration, and suspended-sediment discharge from Black River below Annapolis, Missouri, 1993–95 and 2006–07.

is defined as the presence of fine-grained, silt and clay-sized sediments formed by a mechanical erosion of bedrock. When the extremely small sediment particles stay suspended in the water, the water body can appear brown, gray, irridecent blue-green, or milky white (Molina, 2004). Rock flour is typically a glacial term, but the large amount of water that grinded the bedrock of Proffit Mountain during the upper reservoir embankment breach could be the source of the fine silt and clay particles in the East Fork Black River and the lower reservoir. The extremely fine sedment particles stayed suspended in the lower reservoir, which resulted in suspension of the particles in the riverine system downstream as water from the reservoir was released into the stream. The discoloration also could be attributed to the alum-based flocculent that was added to the lower reservoir to rapidly settle out suspended sediments that became trapped in the lower reservoir after the embankment breach. Aluminum sulfate-based flocculent can have a green to white coloration (U.S. Department of Commerce, 2009). Because no baseline data are available for the East Fork Black River prior to the embankment breach, it is difficult to determine the source of the discoloration.

Continuous Water Quality

The continuous data collected at each site were used to observe daily changes during the study period. These data were published in the USGS annual water data reports summarized as daily extremes (maximum, minimum, mean, and or median; U.S. Geological Survey, 2006b, 2007). Monthly median values were calculated from each daily mean value and used to determine any seasonal trends at the three sites (fig. 23). The streamflow hydrographs showed similar trends at all three sites, but with different flow rates. Similar seasonal trends in both water temperature and dissolved oxygen monthly median values were identified at all three sites. Because all three sites are regionally proximate, the observations are expected. Specific conductance has a seasonal trend at each site with site 3 having values approximately one order of magnitude larger than the other two sites. This may be because site 3 is located on the main stem of the Black River downstream from the junction of the East, Middle, and West Fork Black Rivers. Associated with larger specific conductance measurements at site 3 are increased calcium,

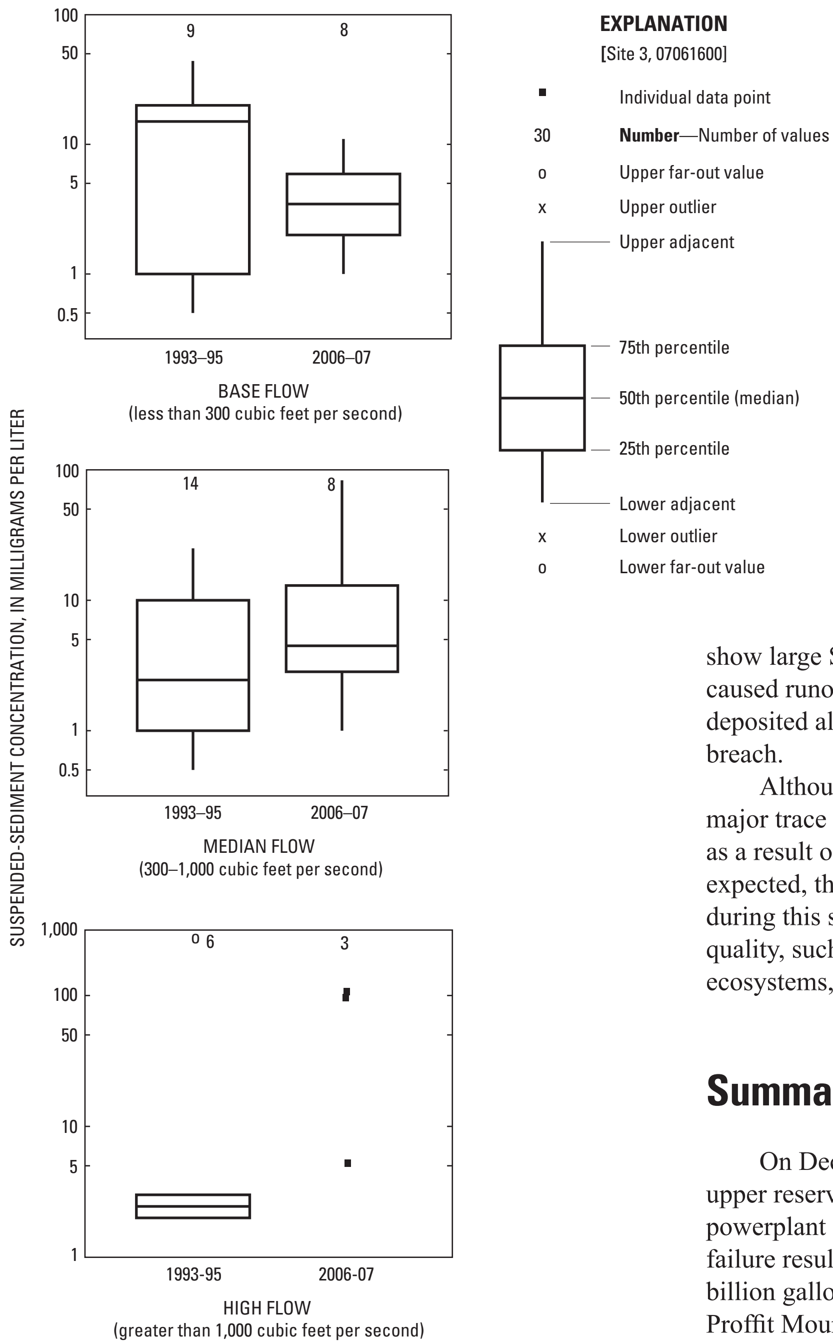


Figure 21. Suspended-sediment concentration data from Black River below Annapolis, Missouri, May 1993 through December 2007.

magnesium, potassium, sulfate, and TDS concentrations (table 5). Water temperature values were higher in the summer months and lower in the winter months. Dissolved oxygen, which is affected by water temperature, was larger in the winter months and smaller in the summer months.

Monthly median turbidity and SSC values were different at each site. These constituents are affected by streamflow, which varies at each site. Monthly median turbidity values were similar at sites 1 and 3; however, site 2 had much larger turbidity values. The larger turbidity values could have been caused by the sediments that were captured in the lower Taum Sauk reservoir during the upper Taum Sauk reservoir embankment breach or by the of the alum-base flocculent. Large amounts of water released from the lower reservoir tended to cause particles to resuspend in the stream, especially early in the study period, when water was released from the lower sluice. Over time, the turbidity at this site began to steadily decrease as construction at the lower reservoir also decreased. Monthly median SSC values were much higher at site 2, which also could be caused by the large amounts of sediment or flocculent released from the lower reservoir. SSCs at site 3 were generally smaller than at site 2 because of dilution by the inflow of the Middle and West Fork Black Rivers. All three sites show large SSCs early in the study during storm events, which caused runoff and reintroduced fine sediments that had been deposited along the banks from the reservoir embankment breach.

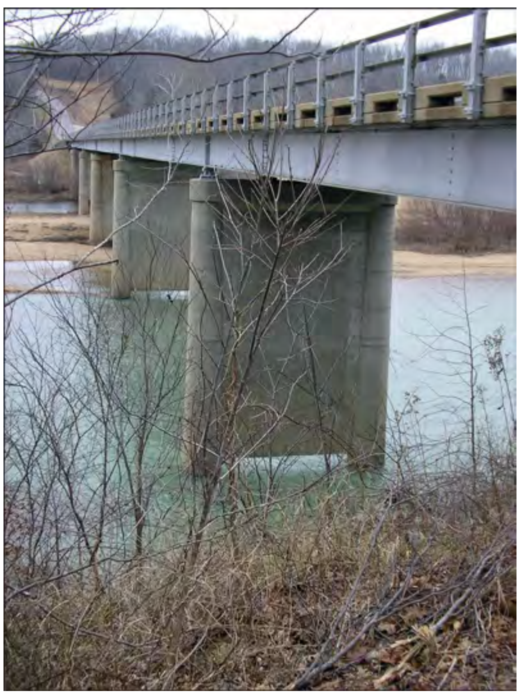
Although long-term effects of the elevated turbidity, major trace metals, and suspended-sediments in the study area as a result of the upper reservoir embankment breach are not expected, there could possibly be other effects not measured during this study that could potentially affect the surface-water quality, such as loss of riparian habitat, changes in biological ecosystems, and large-scale reworking of sediments.

Summary

On December 14, 2005, a 680-ft wide section of the upper reservoir embankment at the Taum Sauk hydroelectric powerplant located in Reynolds County, Missouri, failed. This failure resulted in the sudden release of approximately 1.5 billion gallons of water from the upper reservoir at the top of Proffit Mountain, down the western slope of the mountain, and into and across the East Fork Black River. The flood wave deposited large quantities of soil, rock, and vegetation into Johnson's Shut-Ins State Park and the downstream reaches of the East Fork Black River. The U.S Geological Survey in collaboration with Ameren United Electric Company evaluated the effects of the embankment breach on the surface-water quality and sediments of the East Fork Black River and the Black River.

The data collection performed by the U.S. Geological Survey encompassed routine, event-based, and continuous surface-water quality monitoring as well as suspended- and streambed-sediment sampling. Surface-water quality samples collected monthly during the first year and bimonthly during the second year, were analyzed for a

Lower Taum Sauk reservoir near sediment catchment. Note the extreme color difference.



Black River below Annapolis, Missouri, (site 3) at State Highway K, from the left edge of water.

Black River below Annapolis, Missouri, (site 3) at State Highway K, looking upstream.

Black River below Annapolis, Missouri, (site 3) at State Highway K, looking downstream.

Figure 22. Photographs of selected stream reaches.

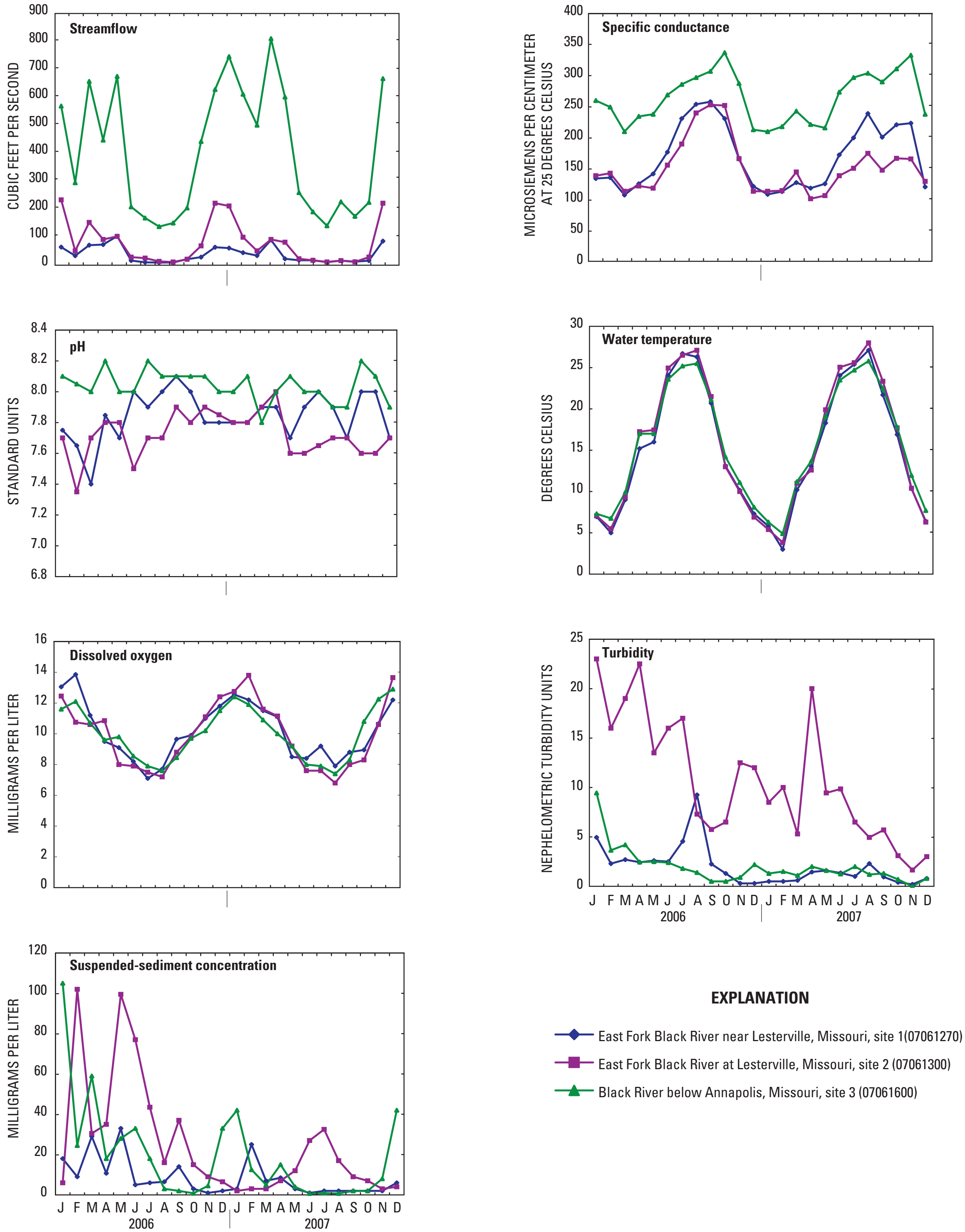


Figure 23. Monthly median values for streamflow, continuous water-quality constituents, and suspended-sediment concentrations.

suite of physical and chemical constituents including: turbidity; nutrients; major ions such as calcium, magnesium, and potassium; total suspended solids; total dissolved solids; trace metals such as aluminum, iron, and lead; and suspended-sediment concentrations. Daily suspended-sediment discharges were calculated from daily and cross-section suspended-sediment samples. The real-time water-quality monitoring data were provided to the public through the internet on the U.S. Geological Survey's National Water Information System website.

Some similarities in various constituents existed between the sites but not all sites had the same relations. Seasonal trends were evident, mostly at site 2, for turbidity, dissolved and total recoverable aluminum, and suspended sediment. These constituents showed a gradual decrease from winter to fall collections. Dissolved aluminum showed a slight increase in concentrations during the summer months. This increase could have been from the dredging activity at the lower reservoir which occurred during August 2006. Surface-water cross-section data showed good correlation with related properties, such as streamflow and turbidity, water temperature and dissolved oxygen, and specific conductance and water hardness, which were expected.

Daily SSC were collected at all three sites and used to compute daily suspended-sediment discharge. The range of cross-section SSC decreased at each site over the study period, while the total annual suspended-sediment discharges and annual mean streamflow increased during 2007. The increase in suspended-sediment discharge could be attributed to the large amount of construction along the East Fork Black River in the State park boundary, which began approximately April 2006 and continued after the study ended; dredging of the lower reservoir in August 2006; increased storm events in the spring of 2007; or the few data available during the 2006 water year.

Concentrations of trace metals and major ions also were measured in suspended- and streambed-sediment samples. No significant differences between the suspended-sediment and bed-material data were observed. Samples collected at site 2 showed some elevated concentrations of calcium, phosphorous, aluminum, and strontium in suspended-sediment samples collected during events in October 2006 and January 2007, which could have been caused by the alum-based flocculent used to settle suspended sediments in the lower Taum Sauk reservoir.

Data collected at Black River below Annapolis (site 3), the furthest downstream site, were compared to historical data collected at this site to identify any existing trends in the data from the event. Suspended-sediment concentrations (SSC) were not significantly different before and after the breach, however, the median SSC slightly increased as the median suspended-sediment discharge decreased slightly after the event. The median streamflow showed no change before to after the embankment breach and seems to have a greater influence on the suspended-sediment discharge than the SSC values, possibly because the stream velocity is high and tends to rapidly transport suspended sediments out of the system.

SSC also were observed by three ranges of streamflow; base, median, and high flow, using step- trend analysis with available data before and after the embankment breach. Median SSC collected at base-flow conditions decreased after the embankment breach and increased in median-flow conditions. High-flow conditions were not as easy to determine because only three event samples were collected after the embankment breach.

A peculiar blue-green to brown color was evident along the lower reaches of the East Fork Black River, the lower reservoir, and the Black River from January 2006 to approximately November 2007. It is possible this phenomenon was caused by "rock flour" a result of mechanical erosion of silt and clay-sized sediments as approximately 1.5 billion gallons of water scoured the side of Proffit Mountain during the upper reservoir embankment breach. The coloration could also have been from the alum-based flocculent used to reduce turbidity in the lower Taum Sauk reservoir. The flocculent used was composed primarily of aluminum sulfate, which can have a green to white color. The flocculent may have been introduced to the downstream portion of the East Fork Black River during water releases from the lower reservoir.

The continuous water-quality monitor data were analyzed and proved to be good representations of the entire stream reach at each site, as cross-section measurements of field parameters correlated well with the continuous water-quality monitor data. Median monthly values for specific conductance, water temperature, and dissolved oxygen show similar seasonal trends. Streamflow, turbidity, and SSC were significantly different for each site, mainly because of stream size, deposition, drainage area, and the influence of the lower reservoir. Site 2, located downstream from the lower Taum Sauk reservoir, showed the largest range of turbidity and SSC. The largest turbidity values and SSC were observed in high streamflow samples collected between January and June 2006, then decreased from July 2006 to December 2007, as most of the sediments and debris from the embankment breach were removed from the riverene system.

Although long-term effects of the elevated turbidity, major trace metals, and suspended-sediments in the study area as a result of the upper reservoir embankment breach are not expected, there could possibly be other effects not measured during this study that could potentially affect the surface-water quality, such as loss of riparian habitat, changes in biological ecosystems, and large-scale reworking of sediments.

References

Alexander, T.W., and Wilson, G.L., 1995, Techniques for estimating the 2- to 500-year flood discharges on unregulated streams in rural Missouri: U.S. Geological Survey Water-Resources Investigations Report 95–4231, 33 p.

American Public Health Association, American Water Works Association, and Water Environment Federation, 1998, Standard methods for the examination of water and wastewater (20th ed.): Washington, D.C., V.2130, p. 2–8 to 2–11.

Davis, J.V., Petersen, J.C., Adamski, J.C., Freiwald, D.A, 1995, Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma—Analysis of information on nutrients, suspended sediment, and suspended solids, 1970–92: U.S. Geological Survey Water-Resources Investigations Report 95–4042, 120 p.

Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 89 p.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92–634, 28 p.

Federal Energy Regulatory Commission, 2006, FERC Taum Sauk investigation team staff report, Report of findings on the overtopping and embankment breach of the upper dam—Taum Sauk pumped storage project: FERC No. 2277, 239 p., accessed November 2008 from *http://www.ferc.gov/industries/hydropower/safety/projects/taum-sauk/staff-rpt/full-rpt.pdf*

Fenneman, N.M., 1938, Physiography of eastern United States: New York, McGraw-Hill Book Co., Inc., 689 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Garbarino, J.R., and Damrau, D.L., 2001, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of organic plus inorganic mercury in filtered and unfiltered natural water with cold vapor-atomic fluorescence spectrometry: U.S. Geological Survey Water-Resources Investigations Report 01–4132, 16 p.

Garbarino, J.R., Kanagy, L.K., and Cree, M.E., 2006, Determination of elements in natural-water, biota, sediment, and soil samples using collision/reaction cell inductively coupled plasma-mass spectrometry: U.S. Geological Survey Techniques and Methods, book 5, section B, chap. 1, 88 p.

Garbarino, J.R., and Struzeski, T.M., 1998, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of elements in whole-water digests using inductively coupled plasma-optical emission spectrometry and inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 98–165, 101 p.

Gray, J.R., Glysson, G.D, Turcois, L.M., and Schwarz, G.E., 2000, Comparability of suspended-sediment concentration and total suspended solids data: U.S. Geological Survey Water-Resources Investigations Report 00–4191, 20 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.

Hayes, W.C., and Beveridge, T.R., 1961, Guidebook to the geology of the St. Francois Mountain area: Report of investigations No. 26, October, 1961, State of Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, 137 p.

Helsel, D. R., and Hirsch, R.M., 1992, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p.

Hendron, A.J., Ehasz, J.L., and Paul, K., 2006, Technical reasons for the breach of December 14, 2005, Taum Sauk Upper Dam Breach: FERC No. P-2277, 134 p.

Koltun, G.F, Eberle, Michael, Gray, J.R., and Glysson, G.D., 2006. User's manual for the Graphical Constituent Loading Analysis System (GCLAS): U.S. Geological Survey Techniques and Methods, book 4, Chap. C1, 51 p.

Molina, B.F., 2004, Glossary of glacier terminology: A glossary providing the vocabulary necessary to understand the modern glacier environment: U.S. Geological Survey Open File Report 2004–1216, accessed October 2008 from *http://pubs.usgs.gov/of/2004/1216/*.

Missouri Department of Natural Resources, 2008, Missouri state parks and historic sites website, accessed January 2009 from *http://www.mostateparks.com/jshutins/recovery.htm*

Missouri Spatial Data Information Service, 2005, Land use/land cover data: Columbia, Missouri, accessed May 2008 from *http://msdis.missouri.edu/*.

Myers, D.N., Stoeckel, D.M., Bushon, R.N., Francy, D.S., and Brady, A.M.G., 2007, Fecal indicator bacteria: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, section 7.1, (ver. 2.0) accessed May 2008 at *http://pubs.water.usgs.gov/twri9A7/*.

National Oceanic and Atmospheric Administration, 2006, Climatologic data annual summary, Missouri: Asheville, North Carolina, National Climatic Data Center.

National Oceanic and Atmospheric Administration, 2007, Climatologic data monthly summaries, January through December, Missouri: Asheville, North Carolina, National Climatic Data Center.

Patton, C.J., and Truitt, E.P., 2000, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of ammonium plus organic nitrogen by a Kjeldahl digestion method and an automated photometric finish that includes digest cleanup by gas diffusion: U.S. Geological Survey Open-File Report 00–170, 31 p.

Porterfield, G., 1972. Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C3, 66 p.

River Valley Region Association, 2008, Missouri vacations website, accessed December 2008 at *http://missouri-vacations.com/johnson's-shutins-state-park/index.htm*

Rydlund, Jr., P.H., 2006. Peak discharge, flood profile, flood inundation, and debris movement accompanying the failure of the upper reservoir at the Taum Sauk pump storage facility near Lesterville, Missouri: U.S. Geological Survey Scientific Investigations Report 2006–5284, 48 p.

Struzeski, T.M., DeGiacomo, W.J., and Zayhowski, E.J., 1996, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of dissolved aluminum and boron in water by inductively coupled plasma-atomic emission spectrometry: U.S. Geological Survey Open-File Report 96–149, 17 p.

University of Missouri, 2001, Population for Missouri counties, municipalities, and legislative districts 1990 and 2000: Office of Social and Economic Data Analysis, accessed May 2008 at *http://mcdc.missouri.edu*

U.S. Department of Commerce, 2009, National Oceanic and Atmospheric Administration, Office of Response and Restoration, CAMEO chemical database, accessed February 2009 at *http://cameochemicals.noaa.gov/chemical/8226#section5*

U.S. Geological Survey, 1999, Water resources data—Missouri, water year 1999, U.S. Geological Survey Water-Data Report MO–99–1.

U.S. Geological Survey, 2006a, Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, September, accessed April 2008 at *http://pubs.water.usgs.gov/twri9A4/.*

U.S. Geological Survey, 2006b, Water resources data of the United States, annual water data report, WDR–US–2006, accessed May 2008 at *http://wdr.water.usgs.gov/.*

U.S. Geological Survey, 2007, Water resources data of the United States, annual water data report, WDR–US–2007, accessed May 2008 at *http://wdr.water.usgs.gov/.*

Wagner, R.J. Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Site operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1—D3, 51 p. plus 8 attachments; accessed April 2008 at *http://pubs.water.usgs.gov/tm1d3*

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., eds., 2004, Processing of water samples (version 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, April, accessed April 2008 at *http://pubs.water.usgs.gov/twri9A5/.*

Wilde, F.D., ed., chapter sections variously dated, Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, accessed April 2008 at *http://pubs.water.usgs.gov/twri9A6*

Table 2

Table 2. Surface-water quality data, January 2006 through December 2007.

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Discharge (ft^3/s)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen, percent of saturation	pH	Specific conductance (µS/cm)	Water temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Magnesium (mg/L)
07061270—East Fork Black River near Lesterville, Missouri; site 1											
January 27, 2006	Environmental[a]	29	2.8	11.9	100	7.8	151	7.1	72	15.3	8.2
January 31, 2006	Environmental	77	2.2	10.6	90	7.0	124	7.6	55	11.3	6.6
February 14, 2006	Environmental	24	<2.0	14.0	136	7.6	146	12.7	72	15.0	8.4
March 8, 2006	Environmental	20	<2.0	10.8	97	7.3	160	8.8	78	16.1	9.2
April 17, 2006	Environmental	36	<2.0	9.1	108	7.8	148	21.7	70	14.7	8.1
May 10, 2006	Environmental	749	19.0	10.0	103	7.4	69	15.2	33	6.9	3.8
June 20, 2006	Environmental	8	<2.0	8.1	103	7.2	179	26.5	87	17.9	10.4
July 11, 2006	Environmental	2	<2.0	7.9	97	7.6	168	24.3	110	22.7	12.9
July 11, 2006	Field blank[b]	--	<2.0	--	--	--	--	--	M	E.02	E.01
August 2, 2006	Environmental	1	<2.0	8.2	123	8.0	245	35.8	120	25.0	14.3
September 12, 2006	Environmental	1	<2.0	8.8	106	8.1	226	23.7	130	26.8	15.7
October 24, 2006	Environmental	10	3.7	9.7	86	7.7	222	9.2	110	22.6	13.3
November 14, 2006	Environmental	16	<2.0	10.0	94	7.8	168	10.6	91	18.9	10.7
December 5, 2006	Environmental	87	<2.0	12.7	106	7.2	107	6.7	50	10.3	5.9
January 4, 2007	Environmental	55	<2.0	11.4	97	6.9	115	6.8	55	11.4	6.6
March 27, 2007	Environmental	24	<2.0	9.3	100	7.5	145	17.4	66	13.8	7.7
May 21, 2007	Environmental	27	2.1	8.8	101	6.6	144	20.6	66	13.4	7.8
July 17, 2007	Environmental	8	<2.0	7.3	102	7.7	211	30.9	100	21.1	11.9
September 10, 2007	Environmental	87	<2.0	8.1	95	7.4	164	21.9	71	14.7	8.3
September 10, 2007	Replicate[c]	--	<2.0	8.1	95	7.5	164	21.9	72	E.02	E.01
November 27, 2007	Environmental	12	<2.0	10.7	96	8.1	211	9.6	110	22.9	13.4

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Potassium (mg/L)	Sodium (mg/L)	ANC, fixed end point (mg/L as $CaCO_3$)	ANC, incremental titration (mg/L as $CaCO_3$)	Bicarbonate, incremental titration (mg/L as $CaCO_3$)	Carbonate, incremental titration (mg/L as $CaCO_3$)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Total dissolved solids (mg/L)
January 27, 2006	Environmental	0.81	1.65	82	82	100	<1	1.86	<.10	6.96	81
January 31, 2006	Environmental	.80	1.61	47	48	58	<1	1.55	<.10	7.35	76
February 14, 2006	Environmental	.81	1.85	64	64	78	<1	2.00	E.05	7.29	90
March 8, 2006	Environmental	.89	1.82	75	76	92	<1	1.79	<.10	6.96	90
April 17, 2006	Environmental	1.07	1.76	66	66	79	<1	1.87	<.10	6.22	94
May 10, 2006	Environmental	1.00	1.19	26	26	32	<1	.97	<.10	5.80	57
June 20, 2006	Environmental	1.10	2.01	82	84	103	<1	1.59	E.06	5.37	113
July 11, 2006	Environmental	1.17	2.15	100	102	123	<1	1.83	<.10	4.73	128
July 11, 2006	Field blank	<.16	<.20	--	--	--	--	<.2	<.10	<.18	<10
August 2, 2006	Environmental	1.36	2.30	118	119	143	<1	1.79	<.10	4.37	128
September 12, 2006	Environmental	1.24	2.13	112	112	137	<1	1.84	<.10	4.42	147
October 24, 2006	Environmental	1.06	2.10	90	92	112	<1	2.23	E.07	8.11	124
November 14, 2006	Environmental	.97	2.01	76	78	95	<1	2.38	<.10	7.91	88
December 5, 2006	Environmental	.89	1.52	49	50	61	<1	1.83	<.10	6.93	86
January 4, 2007	Environmental	.79	1.52	52	52	63	<1	1.58	<.10	7.25	75
March 27, 2007	Environmental	.93	1.73	59	59	72	<1	1.85	<.10	6.88	82
May 21, 2007	Environmental	1.02	1.75	61	61	E74	<1	1.30	<.10	5.66	82
July 17, 2007	Environmental	1.11	2.15	93	95	115	<1	1.72	E.05	4.61	135
September 10, 2007	Environmental	1.24	1.81	73	72	88	<1	1.75	E.06	6.43	83
September 10, 2007	Replicate	1.29	1.85	--	--	--	--	1.81	E.07	6.45	85
November 27, 2007	Environmental	1.05	2.11	104	102	123	<1	2.27	<.12	6.41	124

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft³/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Total suspended solids (mg/L)	Ammonia plus organic nitrogen (mg/L as N)	Ammonia (mg/L as N)	Nitrate plus nitrite (mg/L as N)	Nitrite (mg/L as N)	Orthophophate (mg/L as P)	Phosphorous (mg/L)	Phosphorus, total (mg/L)
January 27, 2006	Environmental	10	E.07	<.040	E.05	<.008	<.09	<.04	<.04
January 31, 2006	Environmental	<10	<.10	<.040	E.04	<.008	<.02	<.04	<.04
February 14, 2006	Environmental	<10	<.10	<.040	E.04	<.008	<.02	<.04	<.04
March 8, 2006	Environmental	<10	<.10	<.040	<.06	<.008	<.02	<.04	<.04
April 17, 2006	Environmental	<10	E.06	<.040	<.06	<.008	<.02	<.04	<.04
May 10, 2006	Environmental	36	.36	<.040	<.06	<.008	<.09	<.04	E.04
June 20, 2006	Environmental	<10	.10	E.008	<.06	<.002	<.006	<.04	<.04
July 11, 2006	Environmental	<10	E.09	.021	<.06	E.001	E.004	<.04	<.04
July 11, 2006	Field blank	<10	<.10	.014	<.06	<.002	.010	<.04	<.04
August 2, 2006	Environmental	<10	E.10	.018	<.06	<.002	E.005	<.04	<.04
September 12, 2006	Environmental	<10	<.10	.010	<.06	<.002	E.005	<.04	<.04
October 24, 2006	Environmental	<10	E.08	E.012	<.06	E.001	<.006	<.04	<.04
November 14, 2006	Environmental	<10	.13	<.020	E.04	<.002	E.003	<.04	<.04
December 5, 2006	Environmental	<10	E.08	.216	.34	<.002	E.005	<.04	<.04
January 4, 2007	Environmental	<10	E.06	<.020	.07	<.002	<.006	<.04	<.04
March 27, 2007	Environmental	<10	<.10	<.020	<.06	<.002	E.003	<.04	<.04
May 21, 2007	Environmental	<10	<.10	E.014	<.06	<.002	<.006	<.04	<.04
July 17, 2007	Environmental	<10	E.06	<.020	<.06	E.001	<.006	<.04	<.04
September 10, 2007	Environmental	<10	.11	<.020	.26	E.002	E.004	<.04	E.02
September 10, 2007	Replicate	<10	.12	E.012	.27	E.002	E.005	<.04	<.04
November 27, 2007	Environmental	<10	<.14	<.020	<.04	<.002	<.006	<.04	<.04

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Chemical oxygen demand, high level (mg/L)	*E. coli*, (col/100 mL)	Fecal coliform (col/100 mL)	Aluminum, total (µg/L)	Aluminum, total recoverable (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Cadmium, total (µg/L)	Copper (µg/L)
January 27, 2006	Environmental	<10	E1	E4	2.1	102	E.11	.04	0.06	0.4
January 31, 2006	Environmental	<10	E2	E5	1.9	81	.13	<.04	<.04	<.4
February 14, 2006	Environmental	<10	<1	<1	E1.2	40	.18	<.04	<.04	E.4
March 8, 2006	Environmental	<10	E4	E13	E1.4	18	.12	E.03	<.04	10
April 17, 2006	Environmental	<10	E1	<1	2.7	2	.15	<.04	<.04	E.4
May 10, 2006	Environmental	20	450	2,000	33.4	303	.17	<.04	E.04	1
June 20, 2006	Environmental	<10	E12	24	3.2	13	.19	<.04	<.04	.40
July 11, 2006	Environmental	<10	E13	E18	1.9	13	.39	.04	<.04	.89
July 11, 2006	Field blank	<10	--	--	<1.6	<2	<.12	<.04	<.04	<.40
August 2, 2006	Environmental	20	180	200	2.0	16	.47	<.04	E.02	<.40
September 12, 2006	Environmental	<10	11	36	<1.6	14	.32	<.04	<.04	E.33
October 24, 2006	Environmental	<10	E4	E13	E.9	6	.19	<.04	<.02	E.27
November 14, 2006	Environmental	<10	E3	E12	<1.6	17	E.11	<.04	E.01	E.26
December 5, 2006	Environmental	<10	E4	E10	1.9	56	E.11	<.04	.07	.78
January 4, 2007	Environmental	<10	31	37	E.9	22	E.10	<.04	E.01	E.28
March 27, 2007	Environmental	<10	E1[d]	E3	1.9	12	.15	<.04	<.02	E.28
May 21, 2007	Environmental	<10	E1[d]	E3	1.7	17	.19	<.04	<.02	E.34
July 17, 2007	Environmental	<10	E11[d]	E12	2.0	15	.26	<.04	.04	E.27
September 10, 2007	Environmental	<10	E33[d]	E180	9.3	69	.19	<.04	<.02	.45
September 10, 2007	Replicate	<10	--	--	5.6	58	.18	<.04	E.01	E.39
November 27, 2007	Environmental	<10	E4[d]	E4	<1.6	5	.09	<.04	<.01	<1.0

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft³/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Iron (µg/L)	Lead (µg/L)	Lead, total recoverable (µg/L)	Manganese (µg/L)	Mercury, total recoverable (µg/L)	Selenium (µg/L)	Zinc (µg/L)	Zinc, total recoverable (µg/L)	Suspended-sediment concentration (mg/L)
January 27, 2006	Environmental	8	<0.08	0.31	36.4	<.010	0.09	E0.5	E1	13
January 31, 2006	Environmental	<6	<.08	.18	13.9	<.010	.08	1.1	<2	8
February 14, 2006	Environmental	6	<.08	.11	42.5	<.010	E.04	1.3	<2	--
March 8, 2006	Environmental	16	<.08	<.06	31.2	<.010	E.06	.6	<2	14
April 17, 2006	Environmental	15	E.05	<.06	14.2	<.010	E.05	1.0	<2	9
May 10, 2006	Environmental	33	.30	2.7	8.0	E.007	E.06	1.8	4	68[e]
June 20, 2006	Environmental	50	E.07	.13	35.9	<.010	<.08	1.2	<2	5
July 11, 2006	Environmental	158	.09	.10	106	<.010	E.05	1.9	3	7
July 11, 2006	Field blank	<6	<.08	<.06	<.6	<.010	<.08	E.49	<2	--
August 2, 2006	Environmental	150	E.06	1.23	72	<.010	E.04	.6	E2	2
September 12, 2006	Environmental	38	<.08	.17	54.1	<.010	<.08	1.1	<2	3
October 24, 2006	Environmental	7	<.12	E.04	13.8	<.010	E.06	E.5	<2	6
November 14, 2006	Environmental	10	<.12	.29	9.9	<.010	E.06	.8	<2	3
December 5, 2006	Environmental	8	.16	.12	2.9	E.007	.09	1.8	E2	<.5
January 4, 2007	Environmental	E4	<.12	.08	2.2	E.010	E.04	.6	<2	1
March 27, 2007	Environmental	8	<.12	E.04	4.7	<.010	E.06	.7	<2	1
May 21, 2007	Environmental	7	<.12	.07	5.0	<.010	E.05	1.5	E1	11
July 17, 2007	Environmental	33	<.12	.14	19.2	<.010	E.06	E.3	<2	7
September 10, 2007	Environmental	15	<.12	.20	6.6	<.010	.11	E.6	<2	2
September 10, 2007	Replicate	E6	<.12	.25	5.7	<.010	.11	E.44	E1.1	2
November 27, 2007	Environmental	E8	<.08	<.06	7.0	<.010	.05	<1.8	<2	2

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Discharge (ft^3/s)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen, percent of saturation	pH	Specific conductance (µS/cm)	Water temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Magnesium (mg/L)
07061300—East Fork Black River near Lesterville, Missouri; site 2											
January 27, 2006	Environmental	28	23	11.9	99	7.4	149	6.7	61	12.6	7.07
January 29, 2006	Environmental	906	180	12.8	107	7.4	157	6.3	63	13.5	7.13
February 1, 2006	Environmental	253	24	12.2	108	7.5	138	8.6	59	12.1	6.96
February 15, 2006	Environmental	42	15	13.1	102	7.1	140	4.2	69	14.4	7.92
March 8, 2006	Environmental	28	9.2	10.9	98	7.3	160	9.2	74	15.2	8.70
April 17, 2006	Environmental	31	18	8.8	98	7.8	137	18.9	65	13.6	7.52
May 9, 2006	Environmental	33	11	9.3	103	7.5	133	18.4	63	13.6	7.14
May 10, 2006	Environmental	1,090	31	7.4	80	7.4	122	17.1	59	12.5	6.71
June 19, 2006	Environmental	18	16	8.0	102	7.6	158	26.6	73	15.2	8.41
July 11, 2006	Environmental	19	13	6.9	85	7.6	142	24.2	86	17.6	10.10
August 2, 2006	Environmental	30	8.4	6.0	79	7.6	233	27.9	110	23.3	13.20
September 12, 2006	Environmental	2.4	8.3	5.6	67	7.7	231	23.2	120	25.1	14.90
October 23, 2006	Environmental	18	9.4	9.2	88	7.6	250	12.2	120	25.2	14.90
November 13, 2006	Environmental	27	4.2	9.3	88	7.7	180	11.8	97	20.2	11.40
December 5, 2006	Environmental	437	43	12.1	102	6.8	69	7.3	30	6.1	3.54
January 3, 2007	Environmental	113	2.9	12.6	104	6.9	117	6.5	56	11.5	6.71
March 27, 2007	Environmental	20	4.2	9.6	100	7.2	149	16.0	69	14.2	8.15
March 27, 2007	Replicate	--	<2	--	--	--	--	--	--	<.02	<.01
May 21, 2007	Environmental	53	6.9	9.0	106	6.8	119	22.5	54	11.1	6.26
July 17, 2007	Environmental	27	5.8	6.1	77	7.1	156	25.5	73	15.2	8.52
September 11, 2007	Environmental	133	7.4	6.9	82	7.6	158	22.9	73	15.2	8.56
November 27, 2007	Environmental	7.4	2.6	10.4	90	8.0	167	8.9	85	17.9	9.70

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Potassium (mg/L)	Sodium (mg/L)	ANC, fixed end point (mg/L as $CaCO_3$)	ANC, incremental titration (mg/L as $CaCO_3$)	Bicarbonate, incremental titration (mg/L as $CaCO_3$)	Carbonate, incremental titration (mg/L as $CaCO_3$)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Total dissolved solids (mg/L)
January 27, 2006	Environmental	1.02	4.71	51	50	62	<1	1.72	<0.10	17.3	86
January 29, 2006	Environmental	1.10	6.58	44	43	53	<1	1.77	<.10	25.7	90
February 1, 2006	Environmental	.96	4.12	45	44	54	<1	1.66	E.05	17.3	85
February 15, 2006	Environmental	.88	2.30	57	58	71	<1	1.74	<.10	10.3	88
March 8, 2006	Environmental	.90	1.85	72	72	88	<1	1.72	<.10	8.7	86
April 17, 2006	Environmental	1.02	1.68	59	57	69	<1	1.63	<.10	7.5	85
May 9, 2006	Environmental	1.05	1.69	57	57	70	<1	1.72	<.10	6.9	85
May 10, 2006	Environmental	1.06	1.62	53	52	64	<1	1.30	E.05	6.9	83
June 19, 2006	Environmental	1.17	1.76	67	67	82	<1	1.36	E.06	6.4	96
July 11, 2006	Environmental	1.28	1.76	81	83	101	<1	1.51	<.10	5.9	94
August 2, 2006	Environmental	1.70	2.04	108	108	131	<1	1.65	E.08	5.5	122
September 12, 2006	Environmental	1.74	2.13	102	104	127	<1	3.49	E.05	5.0	152
October 23, 2006	Environmental	1.47	2.08	106	107	130	<1	2.21	E.07	9.7	142
November 13, 2006	Environmental	1.18	2.01	81	81	99	<1	2.48	<.10	10.7	95
December 5, 2006	Environmental	1.14	1.08	24	24	30	<1	1.10	E.05	6.5	43
January 3, 2007	Environmental	.85	1.48	37	41	E51	<1	1.60	<.10	8.2	64
March 27, 2007	Environmental	.96	2.00	59	60	73	<1	1.67	<.10	9.0	81
March 27, 2007	Replicate	<.04	<.20	--	--	--	--	<.12	<.10	<.18	<10
May 21, 2007	Environmental	1.14	1.57	46	46	56	<1	1.15	<.10	6.4	69
July 17, 2007	Environmental	1.20	1.56	64	65	79	<1	1.16	<.10	6.0	125
September 11, 2007	Environmental	1.25	1.56	68	67	82	<1	1.26	E.07	5.6	84
November 27, 2007	Environmental	1.39	1.70	78	77	93	<1	1.59	<.12	6.4	96

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Total suspended solids (mg/L)	Ammonia plus organic nitrogen (mg/L as N)	Ammonia (mg/L as N)	Nitrate plus nitrite (mg/L as N)	Nitrite (mg/L as N)	Orthophophate (mg/L as P)	Phosphorous (mg/L)	Phosphorus, total (mg/L)
January 27, 2006	Environmental	14	E0.10	<0.04	0.07	<0.008	<0.18	<0.04	<0.04
January 29, 2006	Environmental	395	.35	<.04	E.05	<.008	<.18	<.04	.11
February 1, 2006	Environmental	31	.11	<.04	E.04	<.008	<.02	<.04	<.04
February 15, 2006	Environmental	14	E.07	<.04	E.05	<.008	<.02	<.04	<.04
March 8, 2006	Environmental	<10	E.09	<.04	E.05	<.008	<.02	<.04	<.04
April 17, 2006	Environmental	18	.12	<.04	E.04	<.008	<.02	<.04	<.04
May 9, 2006	Environmental	<10	E.10	<.04	E.04	<.008	<.09	<.04	<.04
May 10, 2006	Environmental	56	.17	<.04	<.06	<.008	<.02	<.04	E.03
June 19, 2006	Environmental	16	.15	<.01	<.06	<.002	<.006	<.04	<.04
July 11, 2006	Environmental	14	.20	.01	<.06	E.002	E.003	<.04	<.04
August 2, 2006	Environmental	11	.21	.07	.09	.003	E.005	<.04	<.04
September 12, 2006	Environmental	<10	E.10	.02	.23	E.002	E.005	<.04	<.04
October 23, 2006	Environmental	<10	.16	.06	.23	.005	<.006	<.04	<.04
November 13, 2006	Environmental	<10	.12	.02	.16	<.002	E.004	<.04	<.04
December 5, 2006	Environmental	23	.24	.15	.10	E.001	E.005	<.04	E.03
January 3, 2007	Environmental	<10	E.07	<.02	E.05	<.002	<.006	<.04	<.04
March 27, 2007	Environmental	<10	<.10	<.02	<.06	<.002	<.006	<.04	<.04
March 27, 2007	Replicate	<10	<.10	.05	<.06	<.002	<.006	<.04	<.04
May 21, 2007	Environmental	<10	.10	.07	<.06	<.002	<.006	<.04	<.04
July 17, 2007	Environmental	<10	E.07	<.02	<.06	E.002	.009	<.04	<.04
September 11, 2007	Environmental	<10	.21	<.02	.06	.002	E.004	<.04	E.02
November 27, 2007	Environmental	<10	E.12	<.02	.06	<.002	<.006	<.04	<.04

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Chemical oxygen demand, high level (mg/L)	*E. coli,* (col/100 mL)	Fecal coliform (col/100 mL)	Aluminum, total (µg/L)	Aluminum, total recoverable (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Cadmium, total (µg/L	Copper (µg/L)
January 27, 2006	Environmental	<10	E4	E7	35.3	997	0.44	<0.04	<0.04	E0.40
January 29, 2006	Environmental	<10	E15	E20	10	2,190	.54	E.03	.11	.50
February 1, 2006	Environmental	<10	E1	<1	14.1	775	.46	E.03	.05	.50
February 15, 2006	Environmental	<10	E1	E2	5.1	1,110	.33	<.04	<.04	E.40
March 8, 2006	Environmental	<10	E2	E8	10.1	414	.40	.11	<.04	E.30
April 17, 2006	Environmental	<10	E3	<1	7.5	585	.63	<.04	<.04	.80
May 9, 2006	Environmental	<10	E4	30	5.3	221	.47	<.04	<.04	.50
May 10, 2006	Environmental	<10	--	--	6.5	443	.65	<.04	E.02	.50
June 19, 2006	Environmental	<10	E2	E7	8.3	337	1.00	<.04	<.04	.50
July 11, 2006	Environmental	<10	78	110	3.8	290	1.00	.06	.11	.51
August 2, 2006	Environmental	<10	E13	E8	10.2	175	1.60	<.04	<.04	E.38
September 12, 2006	Environmental	<10	E16	E14	13.2	206	.87	<.04	<.04	.48
October 23, 2006	Environmental	<10	E20	E5	2	165	.53	<.04	E.02	E.32
November 13, 2006	Environmental	<10	E2	E6	2	197	.33	<.04	E.01	E.33
December 5, 2006	Environmental	10	25	25	8.5	1,520	.39	<.04	.04	.72
January 3, 2007	Environmental	<10	<1	E2	2.8	77	.18	<.04	E.02	E.27
March 27, 2007	Environmental	<10	E3[d]	E4	3.3	144	.42	E.02	.02	.51
March 27, 2007	Replicate	<10	--	--	<1.6	<2	<.12	<.04	<.02	<.40
May 21, 2007	Environmental	<10	E6[d]	E6	5.7	292	.53	<.04	.02	.46
July 17, 2007	Environmental	<10	40[d]	E100	4.2	127	.75	<.04	.04	E.31
September 11, 2007	Environmental	<10	52[d]	90	4	143	1.10	<.04	.02	.45
November 27, 2007	Environmental	<10	E2[d]	E2	E1.0	28	.49	<.04	<.01	<1.00

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Iron (µg/L)	Lead (µg/L)	Lead, total recoverable (µg/L)	Manganese (µg/L)	Mercury, total recoverable (µg/L)	Selenium (µg/L)	Zinc (µg/L)	Zinc, total recoverable (µg/L)	Suspended-sediment concentration (mg/L)
January 27, 2006	Environmental	<6	<0.08	0.54	64.6	<0.010	E.07	<0.6	E2	22
January 29, 2006	Environmental	<6	<.08	6.97	156	.023	E.07	E.3	8	474
February 1, 2006	Environmental	E4	<.08	1.03	120	E.008	.08	.6	3	27
February 15, 2006	Environmental	<6	<.08	.76	141	<.010	<.08	.8	2	28
March 8, 2006	Environmental	<6	<.08	.39	106	<.010	E.07	1.4	E1	14
April 17, 2006	Environmental	<6	<.08	.66	34.1	<.010	.08	<.6	E1	25
May 9, 2006	Environmental	E6	E.04	.49	26.5	<.010	E.06	1.5	E1	15
May 10, 2006	Environmental	8	<.08	1.49	32.6	E.006	E.04	1.1	3	99
June 19, 2006	Environmental	E3	E.05	.84	40.2	<.010	E.05	1.5	E2	21
July 11, 2006	Environmental	<6	<.08	.67	26	<.010	.09	1.8	4	16
August 2, 2006	Environmental	E5	<.08	.46	33	<.010	.11	<.6	E1	16
September 12, 2006	Environmental	14	E.07	1.31	26.2	<.010	E.07	1.6	2	13
October 23, 2006	Environmental	<6	<.12	.38	36.1	<.010	.08	E.4	E1	11
November 13, 2006	Environmental	E4	<.12	.29	13.6	<.010	.10	.7	E2	9
December 5, 2006	Environmental	28	<.12	2.15	23.3	.012	.08	.9	5	30
January 3, 2007	Environmental	E5	<.12	.17	14.7	.010	E.04	.6	E1	3
March 27, 2007	Environmental	E4	<.12	.47	12.7	<.010	.08	1.6	E2	9
March 27, 2007	Replicate	<6	<.12	<.06	<.2	<.010	<.08	<.6	<2	--
May 21, 2007	Environmental	12	<.12	.45	10	<.010	.08	.7	E1.8	47
July 17, 2007	Environmental	E4	<.12	.40	13.6	<.010	E.07	E.3	E1	11
September 11, 2007	Environmental	8	<.12	.42	11.1	<.010	.08	.7	<2	10
November 27, 2007	Environmental	<8	<.08	.08	3.9	<.010	.07	E1.0	<2	6

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft³/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Discharge (ft³/s)	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen, percent of saturation	pH	Specific conductance (µS/cm)	Water temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)	Magnesium (mg/L)
07061600—East Fork Black River near Lesterville, Missouri; site 3											
January 27, 2006	Environmental	300	3	11.3	93	7.8	278	6.7	140	27.2	16.9
January 29, 2006	Environmental	1,140	57	11.3	103	7.4	232	9.6	120	23.4	14.1
February 2, 2006	Environmental	802	8	10.9	96	7.9	236	8.4	120	23.4	14.0
February 13, 2006	Environmental	305	2.6	11.6	91	7.5	257	4.8	130	25.9	16.4
March 7, 2006	Environmental	225	3.0	12.2	110	7.5	279	9.2	140	28.0	16.9
April 18, 2006	Environmental	268	2.1	10.3	113	8.0	257	18.2	130	26.3	15.5
May 11, 2006	Environmental	6,830	49	8.9	91	7.0	143	15.0	71	15.1	8.1
June 20, 2006	Environmental	191	<2	8.0	102	7.8	279	26.9	130	26.9	16.4
July 12, 2006	Environmental	204	2	8.3	97	7.9	178	22.1	140	28.0	16.5
August 3, 2006	Environmental	134	<2	8.2	104	7.8	293	26.2	140	29.0	17.1
August 3, 2006	Replicate	--	<2	8.2	104	--	293	26.2	140	29.4	17.3
September 11, 2006	Environmental	141	5.2	9.7	115	7.4	307	21.9	160	31.7	19.0
October 23, 2006	Environmental	287	3.5	9.8	93	7.9	357	12.3	170	35.2	20.9
November 13, 2006	Environmental	348	<2	11.4	108	7.8	291	11.9	150	31.1	18.5
December 19, 2006	Environmental	422	2.5	10.6	93	7.3	234	9.3	110	22.8	13.5
January 4, 2007	Environmental	614	<2	11.5	99	7.1	223	7.8	120	23.1	14.2
February 12, 2007	Environmental	370	--	12.8	105	7.6	244	6.1	130	25.5	15.8
March 29, 2007	Environmental	866	<2	10.2	103	7.8	271	15.1	140	29.0	16.8
March 29, 2007	Replicate	--	<2	10.2	--	7.8	271	15.1	140	28.3	16.3
April 3, 2007	Environmental	990	--	9.9	101	7.5	235	15.0	--	--	--
May 22, 2007	Environmental	378	<2	8.6	93	7.3	235	18.5	110	23.6	13.5
June 12, 2007	Environmental	271	--	8.7	97	7.8	273	20.1	--	--	--
July 17, 2007	Environmental	179	<2	6.8	83	7.6	309	23.8	150	30.3	17.3
September 10, 2007	Environmental	1,020	8.5	7.7	95	7.6	279	24.3	130	26.3	14.8
November 27, 2007	Environmental	234	<2	11.4	98	8.2	339	8.7	180	35.9	21.3

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft³/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Potassium (mg/L)	Sodium (mg/L)	ANC, fixed end point (mg/L as $CaCO_3$)	ANC, incremental titration (mg/L as $CaCO_3$)	Bicarbonate, incremental titration (mg/L as $CaCO_3$)	Carbonate, incremental titration (mg/L as $CaCO_3$)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Total dissolved solids (mg/L)
January 27, 2006	Environmental	0.86	3.38	107	108	132	<1	4.19	E0.06	27.2	160
January 29, 2006	Environmental	.99	4.29	77	77	93	<1	3.08	<.10	24.9	127
February 2, 2006	Environmental	1.03	3.70	87	86	105	<1	3.28	E.06	23.3	132
February 13, 2006	Environmental	.91	3.26	105	105	128	<1	3.38	E.06	22.5	156
March 7, 2006	Environmental	.96	3.27	118	120	146	<1	3.89	E.09	25.2	159
April 18, 2006	Environmental	1.05	2.98	111	112	135	<1	3.12	E.08	17.8	149
May 11, 2006	Environmental	1.02	1.80	55	55	68	<1	2.02	E.08	11	97
June 20, 2006	Environmental	1.07	2.81	122	123	150	<1	3.10	E.07	17	164
July 12, 2006	Environmental	.97	2.62	125	126	153	<1	2.79	<.10	15.6	154
August 3, 2006	Environmental	1.16	2.80	128	129	156	<1	3.06	<.10	14.8	159
August 3, 2006	Replicate	1.14	2.84	--	--	--	--	3.10	E.06	14.9	163
September 11, 2006	Environmental	1.11	3.38	125	128	156	<1	4.16	E.06	21.3	168
October 23, 2006	Environmental	1.13	4.43	122	122	149	<1	5.35	E.10	38.8	207
November 13, 2006	Environmental	1.05	3.95	122	121	148	<1	4.62	E.06	30.6	172
December 19, 2006	Environmental	.97	2.82	102	103	E125	<1	3.03	.11	20.8	127
January 4, 2007	Environmental	.89	2.84	91	95	E116	<1	2.88	E.08	19.2	133
February 12, 2007	Environmental	.85	2.85	100	100	122	<1	3.09	E.08	20.1	140
March 29, 2007	Environmental	1.14	3.48	107	107	129	<1	3.30	E.07	22.6	169
March 29, 2007	Replicate	1.07	3.34	--	--	--	--	3.29	E.07	22.6	161
April 3, 2007	Environmental	--	--	--	--	--	--	--	--	--	--
May 22, 2007	Environmental	.98	2.52	97	97	118	<1	2.19	E.08	15.3	195
June 12, 2007	Environmental	--	--	--	--	--	--	--	--	--	--
July 17, 2007	Environmental	1.09	3.08	131	133	161	<1	3.20	.10	21.6	205
September 10, 2007	Environmental	1.25	3.39	107	108	131	<1	3.52	E.10	26.4	157
November 27, 2007	Environmental	1.11	4.46	132	129	156	1	5.17	<.12	36.5	198

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft³/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Total suspended solids (mg/L)	Ammonia plus organic nitrogen (mg/L as N)	Ammonia (mg/L as N)	Nitrate plus nitrite (mg/L as N)	Nitrite (mg/L as N)	Orthophophate (mg/L as P)	Phosphorous (mg/L)	Phosphorus, total (mg/L)
January 27, 2006	Environmental	<10	<0.10	<0.04	0.21	<0.008	<0.090	<0.04	<0.04
January 29, 2006	Environmental	103	.19	.050	.15	<.008	<.180	<.04	E.04
February 2, 2006	Environmental	<10	E.06	<.040	.18	<.008	<.020	<.04	<.04
February 13, 2006	Environmental	<10	E.06	<.040	.20	<.008	<.020	<.04	<.04
March 7, 2006	Environmental	<10	E.08	<.040	.16	<.008	<.020	<.04	<.04
April 18, 2006	Environmental	10	E.06	<.040	.11	<.008	<.020	<.04	<.04
May 11, 2006	Environmental	71	.33	<.040	.09	<.008	<.020	<.04	.07
June 20, 2006	Environmental	<10	E.08	<.010	.08	E.001	<.006	<.04	<.04
July 12, 2006	Environmental	<10	E.08	.011	.10	E.002	E.003	E.02	<.04
August 3, 2006	Environmental	<10	E.08	.014	.09	<.002	E.004	<.04	<.04
August 3, 2006	Replicate	<10	.11	.013	.09	<.002	E.004	<.04	<.04
September 11, 2006	Environmental	<10	<.10	.010	.07	<.002	E.005	<.04	<.04
October 23, 2006	Environmental	<10	E.08	<.020	.18	E.001	<.006	<.04	<.04
November 13, 2006	Environmental	<10	.11	<.020	.23	<.002	E.003	<.04	<.04
December 19, 2006	Environmental	<10	E.08	<.020	.29	<.002	<.006	<.04	<.04
January 4, 2007	Environmental	<10	E.08	E.012	.16	<.002	<.006	<.04	<.04
February 12, 2007	Environmental	<10	<.10	<.020	.20	<.002	<.006	<.04	E.03
March 29, 2007	Environmental	<10	.10	<.020	.19	<.002	E.003	<.04	<.04
March 29, 2007	Replicate	<10	E.07	0.03	.19	<.002	E.004	<.04	<.04
April 3, 2007	Environmental	20	E.05	<.020	.15	<.002	E.004	<.04	<.04
May 22, 2007	Environmental	<10	<.10	<.020	.07	<.002	<.006	<.04	<.04
June 12, 2007	Environmental	<10	<.10	<.020	.08	<.002	E.004	<.04	<.04
July 17, 2007	Environmental	<10	<.10	<.020	.10	E.002	<.006	<.04	<.04
September 10, 2007	Environmental	13	.11	<.020	.38	.002	E.004	<.04	<.04
November 27, 2007	Environmental	<10	<.14	E.013	.19	<.002	<.006	<.04	<.04

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft^3/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Chemical oxygen demand, high level (mg/L)	*E. coli*, (col/100 mL)	Fecal coliform (col/100 mL)	Aluminum, total (µg/L)	Aluminum, total recoverable (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Cadmium, total (µg/L)	Copper (µg/L)
January 27, 2006	Environmental	<10	<1	E10	5.6	106	0.13	<0.04	<0.04	0.5
January 29, 2006	Environmental	<10	E13	28	19.7	817	.22	<.04	E.03	.50
February 2, 2006	Environmental	<10	E11	33	7.7	241	.21	<.04	E.03	.50
February 13, 2006	Environmental	<10	<1	<1	2.0	84	E.08	<.04	<.04	.60
March 7, 2006	Environmental	<10	E1	E1	2.4	49	.14	E.03	<.04	E.3
April 18, 2006	Environmental	<10	E4	E13	2.0	55	.17	<.04	<.04	2.3
May 11, 2006	Environmental	10	E12	E290	6.1	630	.25	<.04	.07	.80
June 20, 2006	Environmental	<10	E1	E3	2.2	48	.20	<.04	<.04	E.4
July 12, 2006	Environmental	<10	E7	32	E1.1	23	.17	<.04	<.04	<.40
August 3, 2006	Environmental	<10	E2	E11	1.9	28	.26	E.02	<.04	<.40
August 3, 2006	Replicate	<10	E2	E9	2.0	28	.26	<.04	<.04	<.40
September 11, 2006	Environmental	<10	E6	E16	10.7	23	.18	E.02	<.04	.52
October 23, 2006	Environmental	<10	<10	--	2.0	10	.14	<.04	<.02	E.38
November 13, 2006	Environmental	<10	E1	E1	E.9	17	.16	<.04	<.02	E.23
December 19, 2006	Environmental	<10	E6	E11	5.5	38	.14	<.04	<.02	E.24
January 4, 2007	Environmental	<10	E6	E10	1.6	21	.12	<.04	E.01	E.31
February 12, 2007	Environmental	--	E2	E1	E1.0	10	.13	E.02	.05	E.28
March 29, 2007	Environmental	<10	E17[d]	46	1.6	56	.20	<.04	.02	E.35
March 29, 2007	Replicate	<10	--	--	E1.3	45	.18	<.04	.02	E.27
April 3, 2007	Environmental	--	E12[d]	E28	--	--	--	--	--	--
May 22, 2007	Environmental	<10	E8[d]	E7	2.4	25	.23	<.04	E.01	E.21
June 12, 2007	Environmental	--	E13[d]	E14	--	--	--	--	--	--
July 17, 2007	Environmental	20	E14[d]	E18	E1.1	17	.20	<.04	.05	<.40
September 10, 2007	Environmental	<10	54[d]	100	2.6	78	.35	<.04	.02	.56
November 27, 2007	Environmental	<10	E3[d]	E4	<1.6	E4	.12	<.04	<.01	<1.0

Table 2. Surface-water quality data, January 2006 through December 2007.—Continued

[ft³/s, cubic feet per second; NTU, nephelometric turbidity units; mg/L, milligrams per liter; pH, in standard units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; N, nitrogen; P, phosphorous; *E. coli*, *Escherichia coli*; col, colonies; mL, milliliter; µg/L, micrograms per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified, concentrations dissolved unless otherwise indicated]

Sample date	Sample type	Iron (µg/L)	Lead (µg/L)	Lead, total recoverable (µg/L)	Manganese (µg/L)	Mercury, total recoverable (µg/L)	Selenium (µg/L)	Zinc (µg/L)	Zinc, total recoverable (µg/L)	Suspended-sediment concentration (mg/L)
January 27, 2006	Environmental	<6	<0.08	0.14	3.0	<0.010	0.09	E0.5	<2	5
January 29, 2006	Environmental	E4	<.08	2.28	12.9	E.007	E.07	1.7	4	122
February 2, 2006	Environmental	<6	<.08	.45	15.2	E.006	.10	2.1	E1	14
February 13, 2006	Environmental	<6	<.08	.09	6.7	<.010	.08	1.3	<2	4
March 7, 2006	Environmental	E3	<.08	E.05	2.6	<.010	.08	1.0	<2	11
April 18, 2006	Environmental	<6	<.08	.09	4.0	<.010	E.07	E.4	<2	5
May 11, 2006	Environmental	12	.12	6.71	6.4	E.009	E.07	1.3	8	104
June 20, 2006	Environmental	<6	<.08	.18	3.8	<.010	E.04	.70	<2	7
July 12, 2006	Environmental	<6	<.08	.12	2.5	<.010	.08	.89	<2	4
August 3, 2006	Environmental	E6	<.08	.14	3.5	<.010	E.07	.87	<2	3
August 3, 2006	Replicate	E3	<.08	.14	3.4	<.010	.09	1.3	E1	--
September 11, 2006	Environmental	8	E.04	.08	4.2	<.010	E.07	1.5	E2	2
October 23, 2006	Environmental	<6	<.12	E.04	1.3	<.010	E.07	5.5	6	1
November 13, 2006	Environmental	<6	<.12	.07	1.2	<.010	.09	E.54	E1	4
December 19, 2006	Environmental	E3	E.11	.10	1.8	E.006	E.06	.98	<2	1
January 4, 2007	Environmental	<6	<.12	.09	1.7	E.009	E.04	1.3	3	2
February 12, 2007	Environmental	<6	<.12	.19	1.5	<.010	.09	1.1	E1	--
March 29, 2007	Environmental	E4	<.12	.39	2.2	<.010	.10	1.1	2	12
March 29, 2007	Replicate	E4	<.12	.32	2.3	<.010	.09	.87	3	--
April 3, 2007	Environmental	--	--	--	--	--	--	--	--	--
May 22, 2007	Environmental	E3	<.12	.08	1.8	<.010	.10	E.43	<2	83
June 12, 2007	Environmental	--	--	--	--	--	--	--	--	1
July 17, 2007	Environmental	<6	<.12	.10	2.4	<.010	.09	<.60	<2	2
September 10, 2007	Environmental	E3	<.12	.36	4.8	<.010	.10	E.34	<2	6
November 27, 2007	Environmental	<8	<.08	<.06	E.2	<.010	.07	E1.7	<2	2

[a]Environmental samples are primary samples which are routinely collected.

[b]Field blanks are samples processed from a blank solution that is subjected to all aspects of sample collection, field processing, preservation, transportation, and laboratory handling as an environmental sample, ensuring no contamination is present.

[c]Replicate samples are a group of samples collected in a manner such that the samples are essentially identical in composition, typically consisting of two samples collected sequentially.

[d]Values derived by modified *E. coli* medium (M-TEC) method (Myers and others, 2007).

[e]A Value of 166 mg/L was previously published for this sample date in the 2006 U.S. Geological Survey Water Resources Data of the United States, annual water data report, WDR–US–2006. After further review, it was discovered that one subsample appeared too high, because the sampler possibly hit the streambed during collection. The subsample was removed from the cross-sectional average and recalculated.

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