Prepared in cooperation with the City of Kansas City, Missouri, Water Services Department

Character and Trends of Water Quality in the Blue River Basin, Kansas City Metropolitan Area, Missouri and Kansas, 1998 through 2007

Scientific Investigations Report 2009–5169

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

Cover photograph. Brush Creek community rain garden in Kansas City, Missouri adjacent to site 16 (photograph by Donald H. Wilkison, U.S. Geological Survey).

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Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

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

$$°F=(1.8×°C)+32$$

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

Horizontal coordinate information is referenced to 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).

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Abstract

Water-quality and ecological character and trends in the metropolitan Blue River Basin were evaluated from 1998 through 2007 to provide spatial and temporal resolution to factors that affect the quality of water and biota in the basin and provide a basis for assessing the efficacy of long-term combined sewer control and basin management plans. Assessments included measurements of stream discharge, pH, dissolved oxygen, specific conductance, turbidity, nutrients (dissolved and total nitrogen and phosphorus species), fecal-indicator bacteria (*Escherichia coli* and fecal coliform), suspended sediment, organic wastewater and pharmaceutical compounds, and sources of these compounds as well as the quality of stream biota in the basin.

Because of the nature and myriad of factors that affect basin water quality, multiple strategies are needed to decrease constituent loads in streams. Strategies designed to decrease or eliminate combined sewer overflows (CSOs) would substantially reduce the annual loads of nutrients and fecal-indicator bacteria in Brush Creek, but have little effect on Blue River loadings. Nonpoint source reductions to Brush Creek could potentially have an equivalent, if not greater, effect on water quality than would CSO reductions. Nonpoint source reductions could also substantially decrease annual nutrient and bacteria loadings to the Blue River and Indian Creek. Methods designed to decrease nutrient loads originating from Blue River and Indian Creek wastewater treatment plants (WWTPs) could substantially reduce the overall nutrient load in these streams.

For the main stem of the Blue River and Indian Creek, primary sources of nutrients were nonpoint source runoff and WWTPs discharges; however, the relative contribution of each source varied depending on how wet or dry the year was and the number of upstream WWTPs. On Brush Creek, approximately two-thirds of the nutrients originated from nonpoint sources and the remainder from CSOs. Nutrient assimilation processes, which reduced total nitrogen loads by approximately 13 percent and total phosphorus loads by double that amount in a 20-kilometer reach of the Blue River during three synoptic base-flow sampling events between August through September 2004 and September 2005, likely are limited to selected periods during any given year and may not substantially reduce annual nutrient loads.

Bacteria densities typically increased with increasing urbanization, and bacteria loadings to the Blue River and Indian Creek were almost entirely the result of nonpoint source runoff. WWTPs contributed, on average, less than 1 percent of the bacteria to these reaches, and in areas of the Blue River that had combined sewers, CSOs contributed only minor amounts (less than 2 percent) of the total annual load in 2005. The bulk of the fecal-indicator bacteria load in Brush Creek also originated from nonpoint sources with the remainder from CSOs. From October 2002 through September 2007, estimated daily mean *Escherichia coli* bacteria density in upper reaches of the Blue River met the State of Missouri secondary contact criterion standard approximately 85 percent of the time. However, in lower Blue River reaches, the same threshold was exceeded approximately 45 percent of the time.

The tributary with the greatest number of CSO discharge points, Brush Creek, contributed approximately 10 percent of the bacteria loads to downstream reaches. The tributary Town Fork Creek had median base-flow *Escherichia coli* densities that were double that of other basin sites and stormflow densities 10 times greater than those in other parts of the basin largely because approximately one-fourth of the runoff in the Town Fork Creek Basin is believed to originate in combined sewers. Genotypic source typing of bacteria indicated that more than half of the bacteria in this tributary originated from human sources with two storms contributing the bulk of all bacteria sourced as human. However, areas outside of the combined sewer system also contributed substantially to elevated bacteria densities in basin streams.

From 1998 through 2007, flow-adjusted concentration trends at six sites in the basin were determined for as many as 22 constituents using fitted linear regression models that included concentration, flow, time, and in some cases, yearly or seasonal terms. Flow-adjusted concentration trends were not significant for approximately two-thirds of the constituents indicating that, in general, basin-level changes did not affect many constituent concentrations from 1998 through

2007. Where statistically significant flow-adjusted trends were detected, most (88 percent) were declines. Trend declines occurred primarily in flow-adjusted suspended sediment concentrations and water-quality constituents that have strong associations with suspended sediment. Flow-adjusted concentration declines may be related to a number of measures implemented in the basin since 1998 that were designed to control erosion and reduce sediment in runoff.

Nutrient and organic wastewater compound loads in the effluent-dominated Blue River were on average about 20 times greater than for the CSO-dominated Brush Creek. Seasonally, the largest contributions of nutrients, caffeine, n,n-diethyl-meta-toluamide (DEET), sterol (cholesterol plus coprostanol), and triclosan occurred between March to August, in part, because this mirrored the basin precipitation pattern and runoff was a primary component of loads. In effluent-dominated stream reaches of the Blue River and Indian Creek, reductions in WWTP removal efficiencies from December to February likely resulted in increased contributions during winter months, and increased biogeochemical activity during the summer resulted in increased efficiencies and proportionally smaller contributions. Peaks in DEET loads corresponded to the period (June to August) when expected use would be the highest.

Biological assessments included measurements of macroinvertebrate community diversity and abundance, habitat assessments, and toxicity evaluations. The diversity of benthic aquatic communities in the upper Blue River stream reaches was similar to sites in adjacent Johnson County, Kansas, which were least impacted by human disturbance. However, no stream reaches in the Blue River Basin or the outside control site met the criteria for full support of aquatic life from 2002 to 2007. Sites in lower basin reaches had the least diversity, the largest percentage of pollution tolerant organisms, and were considered nonsupportive of biologic life. Declines in aquatic community and health followed a pattern of increasing urbanization and, in general, these trends were reflected by similar declines in stream physical habitat quality. Channel modifications and riparian habitat loss accounted for the greatest difference between physical habitat scores at sites. Low-head dams in Brush Creek reduced stream circulation, increased sediment accumulation, and resulted in significantly lower median monthly dissolved-oxygen concentrations in Brush Creek than on the Blue River. Sediment trapping in Brush Creek impoundments likely resulted in median monthly turbidity values on the Blue River being approximately twice that of those measured in Brush Creek. The median monthly specific conductance on the Blue River was double that of Brush Creek because treated effluent comprised a large percentage of the flow in the Blue River and increased impervious cover in Brush Creek resulted in reduced infiltration and greater runoff. Large spikes in specific conductance values followed the application of road deicers and subsequent runoff events.

Introduction

Kansas City, Missouri, is 1 of approximately 750 municipalities in the United States with a combined storm and sanitary sewer system (CSS) and is preparing plans for the long-term control of sewage discharges from the system into receiving waters (U.S. Environmental Protection Agency, 1999). Control plans provide strategies for reduction in the frequency and volume of these discharges, termed combined sewer overflows (CSOs), into receiving streams, provide data on the current (2009) status of the system, and provide information on the expected benefits from system alterations (City of Kansas City, Missouri, 2008). Also, CSO receiving streams may frequently receive inputs from a variety of other sources that have the potential to degrade water quality.

Streams in the largely urban basin receive inputs from a variety of sources including, and most predominantly, nonpoint-source runoff, CSOs, and discharges from wastewater treatment plants (WWTPs). These sources overlap in many parts of the basin, which compounds the deleterious water-quality effects of individual inputs. Channel modifications designed to convey floodwaters have resulted in the loss of riparian and instream habitat, altered hydrologic regimes, and degraded stream ecological quality (Wilkison and others, 2006).

To better understand factors that affect the water quality of receiving streams in the CSS area of Kansas City, Missouri, the U.S. Geological Survey (USGS) in cooperation with the city of Kansas City, Missouri, Water Services Department initiated studies designed to characterize water quality from a basinwide perspective, identify sources of selected constituents in the basin, and evaluate trends in selected water-quality physical properties and constituents (Wilkison and others, 2002; 2005; 2006).

Background

Approximately 20 percent [67 square kilometers (km^2)] of Kansas City, Missouri, is served by a CSS. All but 3 percent of the CSS area is located south of the Missouri River, with approximately two-thirds of the CSS situated in the Blue River Basin. The remaining area of the city (approximately 680 km^2) is served by separate storm and sanitary sewer systems. Unlike a separate sanitary system, CSSs are designed to carry wastewater and storm runoff and are designed to function differently during dry and wet weather conditions.

In dry weather, a CSS is designed to operate exactly like a separate system and convey sewage from homes, businesses, and industry to a WWTP for treatment. After undergoing treatment, the water is discharged to a receiving stream in accordance with applicable water-quality standards.

During wet weather, the CSS carries part of the stormwater runoff and sewage to the WWTP where the combination is treated and discharged. If the storm runoff and sewage volume exceed pipe or treatment-plant capacities, the excess is diverted into receiving streams. All of this excess flow, a mixture of stormwater and sewage—regardless of the relative ratio of the two components, is considered to be part of the CSO. There are approximately 160 diversion structures that drain to 100 stream outfall points in Kansas City, Missouri. Approximately 90 percent of these outfalls are located in the Blue River Basin (City of Kansas City, Missouri, 2008).

Long-term control plans are designed to implement strategies that will reduce the volume and frequency of these events in order to comply with Federal clean water statutes and applicable water-quality standards (U.S. Environmental Protection Agency, 1994; Missouri Department of Natural Resources, 2007). Previous work (Wilkison and others, 2002; 2005; 2006) has demonstrated that the combination of many urban-related factors, including inputs from CSOs, have produced deleterious effects on water quality in many stream reaches in the Blue River Basin.

Purpose and Scope

The purpose of this report is to characterize stream-water quality from a basin perspective; identify sources of selected constituents in the Blue River Basin, including portions of Kansas City, Missouri, that receive urban nonpoint runoff, CSOs, and treated wastewater effluent; and identify trends and patterns in stream-water and biological quality in the basin. This includes summaries of continuous pH, water temperature, specific conductance, dissolved oxygen, and turbidity measurements recorded from July 1998 through December 2007. Also included are results from discrete water samples collected from August 2004 through December 2007. These samples, collected during both base-flow and stormflow conditions, provided data for total and dissolved nutrients, fecal-indicator bacteria, suspended sediment, organic wastewater compounds, and selected over-the-counter and prescription drugs. Genotypic microbial source-tracking results also are presented for stream samples collected from February 2002 through August 2007. Data from this report, together with previously published work (Wilkison and others, 2002; 2005; 2006) are used to develop trend and load estimation models for a selected number of constituents at basin sites from 1998 through 2007. Measurements of aquatic macroinvertebrate community diversity and abundance are presented for 2002 through 2007, along with stream habitat assessments and toxicity screenings of stream-water and bottom sediment samples. The results presented may be used to better understand the relative contribution of point and nonpoint sources to stream contaminants, to better understand the role that season and stream discharge have in determining concentration and load patterns and how those patterns change with time, and to provide a baseline for evaluating the effectiveness of long-term CSO control and basin management plans to meet water-quality standards and protect designated stream uses.

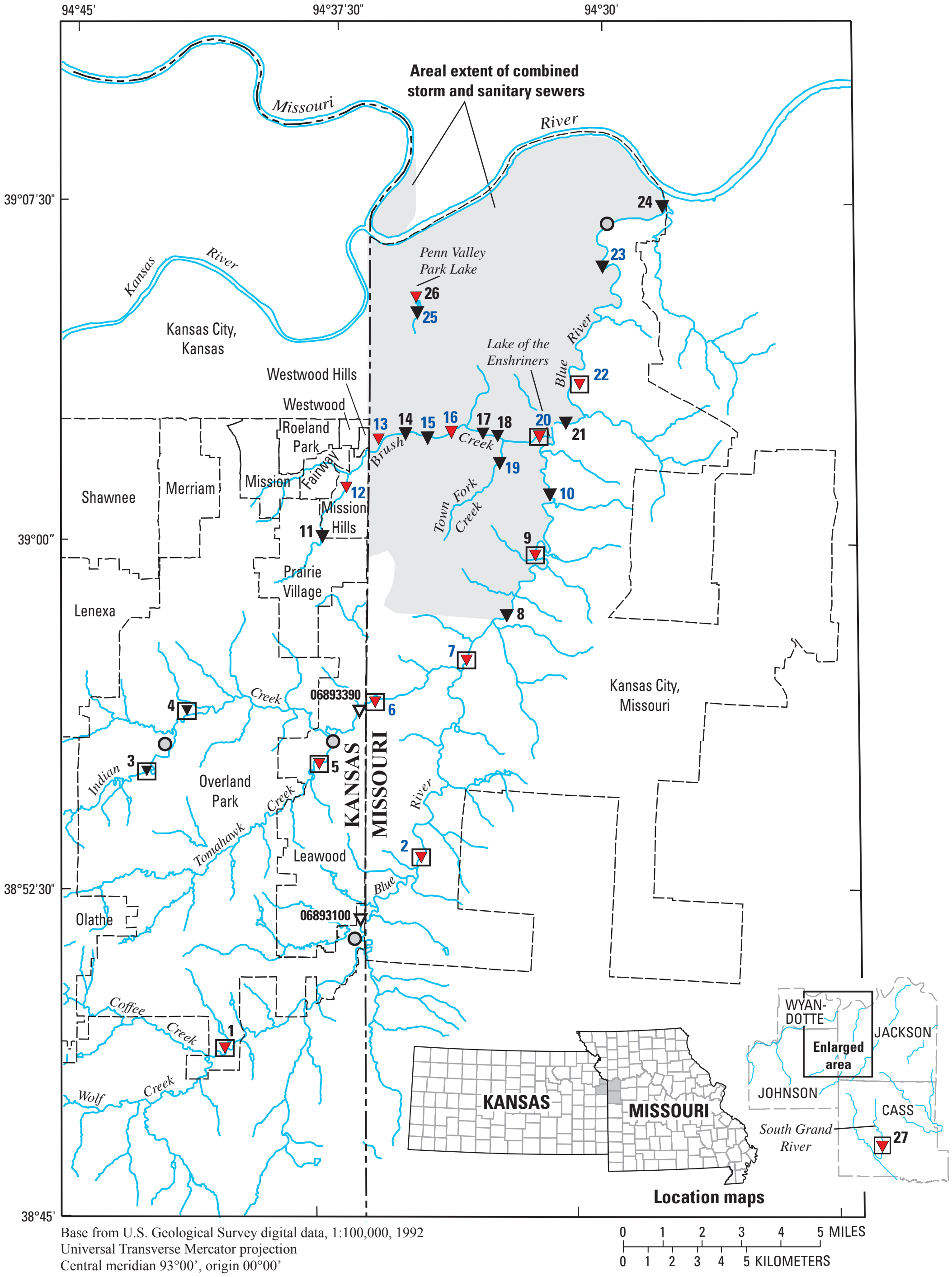
Study Area Description

The study area includes 24 surface-water sampling sites in the Blue River Basin and primarily encompasses reaches of the Blue River, Brush Creek, Indian Creek, and Town Fork Creek (fig. 1). These data were supplemented by data from two additional sites in the basin sampled as part of other studies (Poulton and others, 2007; Rasmussen and others; 2008). The Blue River Basin encompasses 725 km^2 and about one-half of the Kansas City metropolitan area south of the Missouri River (fig. 2). The interjurisdictional basin extends through 2 states (Missouri and Kansas), 4 counties (Johnson and Wyandotte in Kansas; Jackson and Cass in Missouri), and 11 municipalities. Fifty-four percent of the basin is located in Kansas and 46 percent in Missouri. Data for additional sites that also may receive CSOs including George Washington Lake in Penn Valley Park (hereafter referred to in this report as Penn Valley Lake; fig. 1, site 26) and the unnamed tributary to this lake (site 25) also were sampled as part of this study. One stream site in the basin, Tomahawk Creek (site 5), and one outside the basin, South Grand River near Freeman (site 27), were sampled as control sites for aquatic biota measurements. A control site was chosen because it was an urban site without apparent wastewater sources (site 5) or it was a nonurban site within the same ecoregion (site 27).

Previous Studies

Streamflow measurement began in the basin in 1939 at site 7 (Blue River near Kansas City, Missouri; fig. 1) and continues through the present (2009). Previous studies (Becker, 1990; Becker and others, 1983; Blevins, 1986; Wilkison and others; 2002; 2005; Lee and others, 2005; Rasmussen and others, 2008) have established other gages throughout the basin, many of which are still in use today and were part of this study. Streamflow and continuous water-quality data are published annually in reports by the U.S. Geological Survey (2007; 2008a) and current and historical data are made available online (U.S. Geological Survey, 2009a; 2009b).

Blevins (1986) examined stream reaches in lower Brush Creek and the middle and lower Blue River and determined that CSOs occasionally degraded stream water quality, especially in small storms that followed dry, antecedent conditions. This work was conducted prior to a number of channel modifications that were implemented around 1996 along Brush Creek and the lower Blue River to mitigate the effects of large floods in the basin (Hauth and others, 1981; Becker and others, 1983; U.S. Army Corps of Engineers, 2008). The effects of wastewater contaminant loadings were characterized for selected stream reaches in the CSS area (fig. 1) from 1998 to 2000 (Wilkison and others, 2002). This work focused on stream reaches in the CSS area and identified those most affected by the discharge of wastewater-related compounds. The most intensely developed parts of the CSS area were the most affected, and impounded reaches of Brush Creek were



EXPLANATION

1 ▼ **Water-quality sampling site and number**—Blue number indicates stormwater sampling site. Open triangle, sites 06893100 and 06893390, from concurrent studies (Poulton and others, 2007; Rasmussen and others, 2008)

14 ▼ **Water-quality and bottom sediment sampling site and number**—Blue number indicates stormwater sampling site

☐ **Biologic sampling site**

◯ **Wastewater-treatment plant**

Figure 1. Location of study area, sampling sites, wastewater-treatment plants, and area of combined storm and sanitary sewers.

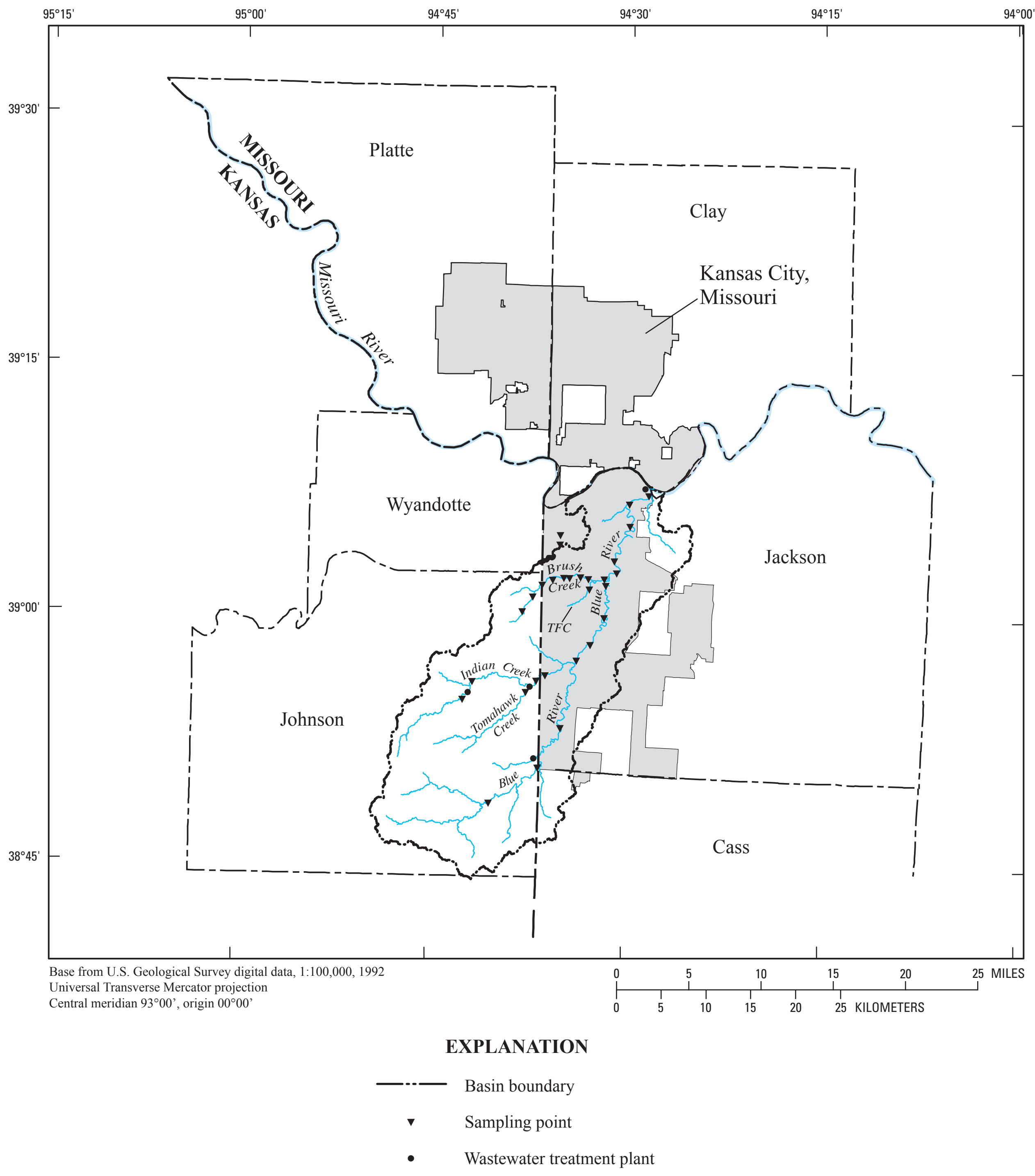


Figure 2. Location of Blue River Basin in relation to Kansas City, Missouri, municipal area.

shown to trap and limit the downstream movement of sediment and associated contaminants. Based upon those results, a basin-wide approach was undertaken to characterize the water-quality data from a larger perspective than just the CSS area (Wilkison and others, 2005; 2006) and to evaluate the quality of aquatic benthic biota in the basin. These studies indicated that approximately 60 percent of the nutrients (nitrogen and phosphorus) in the middle and lower Blue River originated from the Indian Creek tributary, smaller amounts (16 to 28 percent) from the upper Blue River, and less than 5 percent from Brush Creek. Bacteria were largely the result of nonpoint-source contributions during storms, although sewage originating from CSOs was estimated to contribute as much as 40 percent of the bacteria load in selected reaches. Presumptive sources of *Escherichia coli* (*E. coli*) were largely attributable to domestic pets and humans (about one-half to three-fourths of the total), with lesser contributions from waterfowl and unknown sources. Declines in macroinvertebrate abundance and diversity were correlated with several, interrelated urbanization factors including percent impervious cover, nutrient enrichment, and the prevalence of organic wastewater compounds and pharmaceuticals (Wilkison and others, 2006).

Additional work conducted in Johnson County, Kansas, included evaluations of the headwater reaches of the Blue River (upstream from site 2) and middle portions of Indian Creek upstream from site 6. Lee and others (2005) used a variety of analyses, including fecal-indicator bacteria, nutrients, metals, organic wastewater and pharmaceutical compounds, and pesticides in water and sediments to examine the role of point and nonpoint-source contributions on stream water quality. These data indicated that during base-flow conditions, WWTPs contributed the bulk of the flow, nutrients, organic wastewater compounds, and pharmaceuticals to downstream reaches, but did not substantially contribute bacteria. Consequently, concentrations of suspended sediment and indicator bacteria were much larger in stormflow. Poulton and others (2007) evaluated the biological condition of streams in Johnson County and determined that upstream Blue River sites were among the least impacted streams in the county, whereas middle and downstream reaches of Indian and Tomahawk Creek, the Blue River, and Brush Creek were the most affected by human disturbance. More recently, Rasmussen and others (2008) estimated constituent concentrations, loads, and yields in relation to various basin characteristics in Johnson County streams, including the upper Blue River and lower Indian Creek. Increased yields of sediment, chloride, and indicator bacteria in streams were positively correlated with increased urban density and impervious cover. Large storm events were responsible for most (greater than 97 percent) of the annual bacteria load in 2005 and 2006, and the majority of this was attributable to nonpoint-source runoff. WWTP discharge contributed substantial portions (from 66 to more than 90 percent) of the downstream nutrient loads in Indian Creek and notable amounts (from 25 to 70 percent) to downstream Blue River reaches.

Methods

A network of 27 water-quality and streamflow sites was established in the basin (table 1) as part of this study and designed to complement and utilize existing gages whenever possible. Water-quality and streamflow data were collected from July 1998 through December 2007 (Wilkison and others, 2002; 2005; 2006). Data included instantaneous and continuous streamflow; discrete and continuous water-quality properties; discrete water samples analyzed for nutrients, organic wastewater and pharmaceutical compounds, fecal-indicator bacteria and bacteria sources, and suspended sediment in base-flow and stormflow samples; assessments of aquatic macroinvertebrates and stream habitat; and toxicity screening (table 1).

Sampling and Laboratory Protocols

Sampling sites generally were selected to provide a comprehensive assessment of the effects of point and nonpoint sources within the basin, to identify water-quality trends, and to assess the biologic integrity of selected stream reaches within the Blue River Basin and the factors that might be affecting stream biota. Locations were based upon a variety of factors including accessibility, security, geographic location, and proximity to tributaries, CSS areas, or WWTPs (table 2). Samples were collected during base-flow (defined as streamflow unaffected by runoff) and stormflow events. Descriptions of the streamflow and water-quality sampling methods employed in this study have been previously described in considerable detail (Wilkison and others, 2002; 2005; 2006). A summary description follows.

Streamflow was determined by discharge measurements made at the time of sample collection or from established stage-discharge relations (ratings) using USGS procedures outlined by Rantz and others, (1982a; 1982b) and Simpson (2001). Ratings were periodically updated throughout the course of the study as additional measurements and analysis of the stage-discharge relations warranted. Daily mean streamflow and water-quality data were published annually (Hauck and Nagel, 2000; 2001; 2002; 2003; 2004; Hauck and Harris, 2005; U.S. Geological Survey, 2007; 2008a) or in previous reports (Wilkison and others, 2002; 2005; 2006) and are available in the USGS National Water Information System (U.S. Geological Survey, 2009a; 2009b).

Physical properties, including pH, water temperature, specific conductance, dissolved oxygen , and turbidity were measured continuously (15-minute intervals) at a site on the main stem of the Blue River (site 7) and at one site on the tributary Brush Creek (site 16) from early spring to late fall (generally the first of April to the beginning of December each year) using multiparameter probes designed for continuous instream measurement. Data were not collected during winter months because of the potential for probe freezing and instrument damage.

All water-quality samples were collected and processed using protocols designed to prevent contamination. Collection and processing equipment were comprised of inert materials—glass, fluorocarbon polymer, or stainless steel (Lane and others, 2003; Wilde, 2004; 2005; Wilde and others, 2004). Base-flow samples were depth- and width-integrated across streams unless depth or width limitations necessitated the collection of grab samples from the centroid of flow (U.S. Geological Survey, 2006). Stormflow samples were collected using automatic samplers programmed by a remote data logger to collect flow-weighted samples after minimum stage thresholds were exceeded. Sample programs were based on the shape and duration of precipitation events expected to be of

Table 1. Location of sample sites and type of water-quality and streamflow data collected from 1998 through 2007.

[fig., figure; ID, identification number; BQW, base-flow water quality; SQW, stormflow water quality; CQW, continuous water quality; MST, mircrobial source-tracking; IQW, benthic macroinvertebrates; HABITAT, stream physical habitat; TOX, toxicity; QI, instantaneous discharge; QC, continuous discharge; --, no data or not applicable]

Site number (fig. 1)	Station name	Station ID	Latitude/ Longitude	Water-quality data							Streamflow		Bottom sediment
				BQW	SQW	CQW	MST	IQW	HABITAT	TOX	QI	QC	BQW/ TOX
1	Blue River near Stanley, Kansas	06893080	384845/0944031	X	X	--	--	X	X	X	--	X	X
2	Blue River at Blue Ridge Boulevard Extension, Kansas City, Misssouri	06893150	385324/0943452	X[1]	X	--	X	X	X	X	--	X	X
3	Indian Creek at 69 Highway, Overland Park, Kansas	06893270	385513/0944216	X	--	--	--	X	X	--	X	--	--
4	Indian Creek at Farley, Overland Park, Kansas	06893280	385600/0944139	X	--	--	--	X	X	--	X	--	--
5	Tomahawk Creek near 111th Street, Johnson County, Kansas	385539094372100	385539/0943721	X	--	--	--	X	X	X	X	--	X
6	Indian Creek at 103rd Street, Kansas City, Misssouri	06893400	385631/0943616	X[1]	X	--	X	X	X	X	--	X	X
7	Blue River near Kansas City, Misssouri	06893500	385726/0943331	X[1]	X	X	X	X	X	X	--	X	X
8	Blue River at Prospect, Kansas City, Misssouri	385818094325301	385818/0943253	X[1]	--	--	--	--	--	--	--	--	--
9	Blue River near Gregory Boulevard, Kansas City, Misssouri	06893520	385958/0943139	X[1]	--	--	--	X[2]	X[2]	X	X	--	--
10	Blue River at Blue Parkway, Kansas City, Misssouri	06893552	390206/0943136	X	X	--	--	--	--	--	X	--	X
11	Brush Creek at Mission, Johnson County, Kansas	390109094370301	390109/0943703	X[1]	--	--	--	--	--	--	X	--	--
12	Brush Creek at Belinder Avenue, Johnson County, Kansas	390127094365800	390127/0943658	X	X	--	--	--	--	X	X	--	X
13	Brush Creek at Ward Parkway, Kansas City, Misssouri	06893557	390159/0943619	X[1]	X	--	X	--	--	X	--	X	X
14	Brush Creek at Summit Avenue, Kansas City, Misssouri	06893558	390220/0943555	X[1]	--	--	--	--	--	--	X	--	--
15	Brush Creek at Kansas City, Misssouri	06893560	390222/0943504	X[1]	X	--	X	--	--	--	--	X	--
16	Brush Creek at Rockhill Road, Kansas City, Misssouri	06893562	390221/0943443	X[1]	X	X	X	--	--	X	--	X	X
17	Brush Creek at Woodland Avenue, Kansas City, Misssouri	390234094334901	390234/0943349	X[1]	--	--	--	--	--	--	X	--	--
18	Brush Creek at Benton Boulevard, Kansas City, Misssouri	390227094331501	390227/0943315	X[1]	--	--	--	--	--	--	X	--	--
19	Town Fork Creek at Satchel Paige Memorial Stadium, Kansas City, Misssouri	06893563	390202/0943242	X[1]	X	--	X	--	--	X	--	X	--
20	Brush Creek at Elmwood Avenue, Kansas City, Misssouri	06893564	390211/0943152	X[1]	--	--	X	X[3]	X[3]	X	X	--	X
21	Blue River at Coal Mine Road, Kansas City, Misssouri	06893566	390240/0943045	X[1]	--	--	--	--	--	--	X	--	--
22	Blue River at Stadium Drive, Kansas City, Misssouri	06893578	390330/0943042	X[1]	X	--	X	X	X	X	X	X	X
23	Blue River near St. John Avenue, Kansas City, Misssouri	06893592	390652/0942956	X[1]	--	--	--	--	--	--	X	--	--
24	Blue River near mouth of Missouri River, Kansas City, Misssouri	390720094272101	390736/0942927	X[1]	--	--	--	--	--	--	X	--	--
25	Unnamed tributary at Penn Valley Park, Kansas City, Misssouri	390436094563001	390436/0945630	X[1]	X	--	--	--	--	--	X	--	--
26	Penn Valley Park Lake, Kansas City, Misssouri	390440094353301	390440/0943533	X	--	--	--	--	--	X	--	--	X
27	South Grand River near Freeman, Missouri	06921582	383520/0942630	X	X	--	--	X	X	X	X	--	X

[1]Synoptic base-flow sampling between August 2004 and August 2005.

[2]Sampled near 63rd Street.

[3]Sampled in free-flowing section below dam.

Table 2. Stream reach and wastewater source categories for sites sampled in the Blue River Basin.

[WWTP, wastewater-treatment plant; CSO, combined sewer overflow; --, not applicable]

Site number (figure 1)	Station name	Stream reach category	Wastewater source category
1	Blue River near Stanley, Kansas	Upper Blue River	Other[1]
2	Blue River at Blue Ridge Boulevard Extension, Kansas City, Missouri	Upper Blue River	WWTP
3	Indian Creek at 69 Highway, Overland Park, Kansas	Upper Indian Creek	Other[1]
4	Indian Creek at Farley, Overland Park, Kansas	Middle Indian Creek	WWTP
5	Tomahawk Creek near 111th Street, Johnson County, Kansas	Lower Tomahawk Creek	Other[1]
6	Indian Creek at 103rd Street, Kansas City, Missouri	Lower Indian Creek	WWTP
7	Blue River near Kansas City, Missouri	Middle Blue River	WWTP
8	Blue River at Prospect, Kansas City, Missouri	Middle Blue River	WWTP/CSO
9	Blue River near Gregory Boulevard, Kansas City, Missouri	Middle Blue River	WWTP/CSO
10	Blue River at Blue Parkway, Kansas City, Missouri	Middle Blue River	WWTP/CSO
11	Brush Creek at Mission, Johnson County, Kansas	Upper Brush Creek	Other[1]
12	Brush Creek at Belinder Avenue, Johnson County, Kansas	Upper Brush Creek	Other[1,2]
13	Brush Creek at Ward Parkway, Kansas City, Missouri	Middle Brush Creek	Other[1,2]
14	Brush Creek at Summit Avenue, Kansas City, Missouri	Middle Brush Creek	Other[1,2]
15	Brush Creek at Kansas City, Missouri	Middle Brush Creek	CSO[2]
16	Brush Creek at Rockhill Road, Kansas City, Missouri	Middle Brush Creek	CSO[2]
17	Brush Creek at Woodland Avenue, Kansas City, Missouri	Lower Brush Creek	CSO[2]
18	Brush Creek at Benton Boulevard Kansas City, Missouri	Lower Brush Creek	CSO[2]
19	Town Fork Creek at Satchel Paige Memorial Stadium, Kansas City, Missouri	Lower Brush Creek	CSO
20	Brush Creek at Elmwood Avenue, Kansas City, Missouri	Lower Brush Creek	CSO[2]
21	Blue River at Coal Mine Road, Kansas City, Missouri	Lower Blue River	WWTP/CSO
22	Blue River at Stadium Drive, Kansas City, Missouri	Lower Blue River	WWTP/CSO
23	Blue River near St. John Avenue, Kansas City, Missouri	Lower Blue River	WWTP/CSO
24	Blue River near mouth of Missouri River, Kansas City, Missouri	Lower Blue River	WWTP/CSO
25	Unnamed tributary at Penn Valley Park, Kansas City, Missouri	--	CSO
26	Penn Valley Park Lake, Kansas City, Missouri	--	CSO
27	South Grand River near Freeman, Missouri	South Grand River[3]	Other[3]

[1]Site upstream from municipal wastewater-treatment plants and combined sewer system area.

[2]Site downstream from high-rate treatment plant with occassional bypass flows.

[3]Outside basin control site.

sufficient duration and intensity to trigger overflow events in the CSS area. Characterization of the magnitude and duration of overflow events was not part of this study. Every attempt was made to sample the complete hydrograph during storms; however, this was not always the case, and not all sites were sampled during every event, especially where storms triggered events in parts of the basin, but not in other parts.

Stream samples were analyzed for physical properties, nutrients, fecal-indicator bacteria (*E. coli* and fecal coliform), suspended sediment, organic wastewater and pharmaceutical compounds, major ions, and trace metals. Nutrients analyzed included total ammonia plus organic nitrogen (N), dissolved ammonia (NH_4), dissolved nitrate (NO_3), dissolved nitrite (NO_2), total N (sum of total and dissolved N species), orthophosphate (PO_4), and dissolved (DP) and total phosphorus (TP). Organic wastewater compounds included a suite of 72 common household and industrial chemicals, including, but not limited to, detergent surfactants and surfactant metabolites, the antimicrobial compound triclosan, the insect repellant DEET, plasticizers, musks, and fragrance compounds. Table 3 lists the organic wastewater compounds analyzed and their general category of use. Pharmaceutical compounds analyzed included common over-the-counter medications such as the analgesic acetaminophen; the anticonvulsant carbamazepine; antibiotics sulfamethoxazole and trimethoprim; cardiac and anticlotting medications dehydronifidipine, diltiazem, and warfarin; the cholesterol regulator gemfibrozil; the narcotic codeine; and the stimulants caffeine and cotinine, a metabolite of nicotine.

E. coli and total coliform bacteria samples were enumerated in three dilutions using defined enzyme substrate methodology (Eaton and others, 2005), and the results were reported as the measurement average. Fecal coliform bacteria samples were enumerated using multiple dilutions (a minimum of three) to ensure that the count density fell in the optimal range as prescribed by Myers and others (2007). When enumeration and densities fell outside of tolerance limits, densities were estimated based upon nonideal counts using standardized criteria (Myers and others, 2007).

Subsets of bacteria samples collected from selected base flow and storm samples were analyzed for presumptive host sources using previously described methods (Wilkison and others, 2005). The genetic similarity of *E. coli* isolated from water samples was compared to *E. coli* isolated from three hosts—dogs, geese, and humans—all of which were known to be present in the basin based on previous data (Wilkison and others, 2002; 2006), field observations, and knowledge of potential contaminant sources. Repetitive extragenic pallindromic-PCR (rep-PCR) genetic fingerprint patterns of samples were developed and matched against a locally based host-source library for source determination (Carson and others, 2003).

Benthic macroinvertebrates were sampled in accordance with biological assessment protocols established in Missouri and Kansas for the evaluation of the biological condition of wadeable streams (Rabeni and others, 1997; Kansas Department of Health and Environment, 2000; Sarver, 2003a). Samples collected in 2002, 2006, and 2007 were obtained from standard habitats, typically coarse-mineral substrate at riffles, with a D-frame kicknet. Samples were split in a gridded tray with organisms sorted from sample debris and enumerated until a target threshold of 600 organisms was reached. Samples were obtained in 2003 and 2004 from all habitats present at a site in proportion to the total present with the dominant habitat at each site being coarse-grained substrate and the number of target organisms being 200. The intent of both procedures was to quantify the abundance and diversity of organisms at any given site. All samples were indentified and enumerated in USGS laboratories using microscopy to the lowest practical taxonomic level, generally species.

Habitat assessments were conducted in 2006 at 11 sites previously sampled for macroinvertebrates in 2002, 2003, and 2004. This rapid assessment procedure evaluated the physical habitat of a site through measurement of features designed to assess the quality of stream habitat to support the biological community (Sarver, 2003b) and identify potential limits on site attainability. The stream physical habitat procedure incorporates measures of channel and flow characteristics, bank stability, sedimentation, and vegetative characteristics that would be expected to affect health, diversity, and abundance of stream biota.

Toxicity screenings were conducted in 2007 using a tiered approach designed to evaluate potential deleterious effects that water quality might have on aquatic community health by utilizing acute and short-term chronic toxicity tests that represent multiple biotic levels. This was done for a number of reasons. Surface waters and bottom sediments in the area contain constituent concentrations that are known or suspected to have endocrine effects (Wilkison and others, 2006). The synergistic effect of these chemicals is unknown and previous studies have documented declines in aquatic communities with movement downstream in the basin. The cause of these declines was positively correlated to urbanization factors and to some sample constituents (Wilkison and others, 2006). Toxicity analyses were done at the USGS laboratory in Lee's Summit, Missouri, according to methods described by Personne and others (2000), Hoffman and others (2003), Johnson (2005), and Waara and Färm (2008).

Bottom sediment samples were collected using a stainless steel Ponar dredge sampler in accordance with standard procedures (Radtke, 2005). A minimum of 5 separate randomly spaced samples were collected from the upper 10 centimeters (cm) of recently deposited sediments and composited into an 11-liter (L) stainless steel bowl. The sample was thoroughly mixed prior to subsampling aliquots [approximately 500 milligrams (mg)] for further analysis.

Sediment volume in an impounded reach of Brush Creek (Lake of the Enshriners, adjacent to site 20; fig. 1) was determined by using real-time kinematic surveying linked to a global-positioning system (Heimann and Richards, 2003). Universal Transverse Mercator coordinates and an elevation were established from a nearby known benchmark, and these data points were then used to construct digital surfaces of the impoundment bottom and sediment layer in order to determine accumulation volume.

Water and bottom sediment samples were analyzed at the USGS National Water Quality Laboratory, Denver, Colorado, using established USGS procedures (Faries, 1993; Fishman, 1993; Fishman and Friedman, 1989; Moulton and others, 2000; Burkhardt and others, 2005; 2006; Zaugg and others, 2006; Furlong and others, 2008) with the exception of *E. coli* microbial source-tracking samples. Microbial source-tracking samples were analyzed at the University of Missouri Veterinary Pathobiology Laboratory in Columbia, Missouri, using procedures outlined in Carson and others (2001; 2003; 2005).

The wastewater and pharmaceutical analytical methods provide data at extremely low chemical concentrations (micrograms per liter) and are extremely sensitive to the detection of target analytes. Both methods are termed "information-rich" (Childress and others, 1999) because enhanced analyte identification capabilities provide qualified low-concentration data for interpretation and statistical analysis. Therefore, reported concentrations of some analytes may be marked as estimated (E) if they occur at concentrations outside of instrument calibration ranges or if the compounds exhibit poor recovery analytical and method recovery.

Table 3. General use categories for organic wastewater compounds analyzed in this report.

[PAH, polycyclic aromatic hydrocarbon; AHTN, acetyl-hexamethyl-tetrahydro-naphthalene; HHCB, Hexa-hydro-hexamethyl-cyclopenta-benzopyran; categories modified from Wilkison and others, 2006]

Antioxidant	Detergent	Disinfectant	Fire retardant	Flavoring or fragrance	PAH or combustion by-product
5-Methyl-1H-benzotriazole	4-Cumylphenol	Phenol	Tributylphosphate	3-Methyl-1H-indole (skatol)	1-Methylnaphthalene
3-tert-Butyl-4-hydroxyanisole (BHA)	4-Nonylphenol	Tribromomethane	Tris (2-chloroethyl) phosphate	Acetophenone	2,6-Dimethylnaphthalene
	4-*n*-Octylphenol	Triclosan	Tris (dichlorisopropyl) phosphate	AHTN	2-Methylnaphthalene
	4-*tert*-octylphenol			Camphor	Anthracene
	Nonylphenol monoethoxylate			*d*-Limonene	Benzo[*a*]pyrene
	Nonylphenol diethoxylate			HHCB	Fluoranthene
	Octylphenol monoethoxylate			Indole	Naphthalene
	Octylphenol diethoxylate			Isoquinoline	*para*-Cresol
				Menthol	Phenanthrene
				Methylsalicylate	Pyrene
Pesticide	**Plastics**	**Solvent**	**Sterol or stanol**	**Stimulant**	
1,4-Dichlorobenzene	Bis(2-ethylhexyl) phthalate	Isophorone	3-*b*-Coprostanol	Caffeine	
3,4-Dichlorophenyl isocyanate	Bisphenol A	Isopropylbenzene (cumene)	Cholesterol	Cotinine	
Anthraquinone	Diethylphthalate	Tetrachloroethylene	Sitosterol		
Atrazine	Triethyl citrate		Stigmastanol		
Benzophenone	Triphenyl phosphate				
Bromacil	Tris (2-butoxyethyl) phosphate				
Carbaryl					
Carbazole					
Chlorpyrifos					
Diazinon					
Dichlorvos					
Metalaxyl					
Metolachlor					
N,N-diethyl-*meta*-toluamide (DEET)					
Pentachlorophenol					
Prometon					

Quality Control and Assurance

Approximately 10 percent of all field samples collected consisted of quality control and assurance samples designed to ensure the integrity of the water-quality data analyzed in this report. Field equipment blank samples were used to detect sample contamination during field collection, sample processing and cleaning, or from lack of sterility (in the case of bacteria samples) of sampling and processing equipment.

Field replicate samples were collected to determine the effect that variability in sample collection and processing procedures may have on the precision of environmental concentrations. Quality assurance results for data collected in previous studies have been utilized in this report and have been reported elsewhere (Wilkison and others, 2002; 2005; 2006). A summary of these data and values for data collected from October 2004 through December 2007 are presented in tables 4 through 6 (at the back of this report). The average percent difference between 638 replicate sample pair analyses for dissolved constituents was 5.2 percent. The average percent difference for over 3,600 whole-water sample pair analyses was 15 percent. Median values of relative percent difference were much lower, 0 percent for dissolved constituents and 2 percent for whole-water analyses indicating that the central tendency of sample replicates was considerably less than the average percent difference.

Field equipment blanks were collected by passing highly purified water through the same equipment used to collect and process water-quality samples. The samples were then stored, shipped, and analyzed by the identical methods that were used for environmental samples. Measureable concentrations in blank water can result from trace amounts of constituents in the purified water, as well as residual material in sample processing or analytical equipment. Most compounds were not detected in field equipment blanks; if detected, the reported concentrations were near the detection limit for the compounds and environmental concentrations were many times greater. Analytical results for field equipment blank samples collected from October 2004 through December 2007 are reported in tables 7 through 13 (at the back of this report) adjacent to the results from environmental sample collected sequential to the blank samples. Among the blank samples collected for nutrient analysis, one sample had a concentration of ammonia plus organic N estimated at 0.05 mg/L and an orthophosphate concentration of 0.02 mg/L. This same sample had a reported concentration of 0.4 mg/L for dissolved organic carbon and an estimated concentration of 0.3 mg/L for total organic carbon. These concentrations are equivalent (for nutrients) or slightly above (for organic carbon) to the reporting limit for these compounds; environmental concentrations of these constituents were generally two to three orders of magnitude greater than those determined in blank samples. For the organic wastewater compounds there were estimated detections of 0.01 micrograms per liter (µg/L) for 1-methyl-napthalene and 2-methyl-napthalene, 0.03 µg/L for naphthalene, and 0.16 µg/L for DEET in one blank sample. There were no detections of pharmaceutical compounds detected in any of the blank samples.

For bacteria analyses one storm sample field equipment blank had reported *E. coli* densities of 2 colonies per 100 milliliters (col/100mL), fecal coliform densities of 6 col/100 mL and total coliform densities of 307 col/100 mL. Environmental storm samples had bacteria densities three to five orders of magnitude greater than that observed in this blank, indicating the potential for sample bias was minimal. Additionally, a laboratory equipment blank was processed before and after every environmental sample (approximately 250 samples; data not shown) to ensure the sterility of filtering equipment and to evaluate cross-contamination potential. No bacteria colonies were observed in any of the equipment blanks.

The USGS National Water Quality Laboratory utilizes additional quality assurance procedures designed to assess potential sample contamination as well as to quantify method performance, bias, variability, and to verify analytical instrument sensitivity and calibration. Laboratory quality assurance data and methods are documented (U.S. Geological Survey, 2008b) and in Childress and others (1999), Zaugg and others (2002; 2006), Cahill and others (2004), and Furlong and others (2008).

The precision and accuracy of the microbial source-tracking methods employed in this study are described by Carson and others (2003). To assess the method's ability to determine unknown sources, 25 percent of sample isolates were held from the source library and then presented as unknowns. The rate of correct classification for ribotyping of unknown samples from source categories used in this study was determined to be 70 percent for dog, 82 percent for human, and 80 percent for geese. When rep-PCR methods were used, the rate of correct classification for these same three categories increased to 100, 100, and 90 percent (Carson and others, 2003). A sensitivity analysis on 1 nanogram of genetic material was used to evaluate the ability of the *Bacteroides thetaiotaomicron* marker to verify human fecal contamination. The marker was recovered in 96 percent of human samples, 16 percent of dog samples, and 0 percent of geese samples. Positive detections in dog samples indicated there may be the potential for some sharing of enteric bacteria between humans and their canine pets but not for other types of wildlife (Carson and others, 2005).

These data indicate that the combination of sampling and analytical variability, especially for dissolved constituents, contribute only small amounts of uncertainty to analytical results. These data also indicate that a slightly higher degree of uncertainty resulted when compounds were determined from whole-water samples, likely because of slight differences in suspended sediment or organic matter, or because constituents were mediated by biologic activity between the time of sample collection and analysis.

Data Analysis

Water-quality data were analyzed for various factors that may have been expected to affect concentrations, loads, trends, and patterns observed in stream samples and at sites over the course of the study. These factors included physical stream properties, constituent concentrations and sources, biological integrity, and how these factors may have varied temporally and spatially in the basin.

Continuous Water-Quality Monitors

Continuous measurements (every 15 minutes) of water temperature, specific conductance, dissolved oxygen, pH, and turbidity were evaluated, corrected, and computed using established protocols (Wagner and others, 2006). This approach involves daily analysis of the record in order to identify and minimize data loss or erroneous data related to equipment malfunction, fouling, and drift. Routinely—generally every 2 weeks—sensors were cleaned, serviced, and calibrated. Field values were verified during these visits through the use of comparison readings using independently calibrated equipment. These data were used to correct the record for calibration drift and sensor-fouling errors and to ensure that quality assurance criteria were met before final record computation and publication of the data. Data that were outside of tolerance limits (less than 2 percent of the total) were not included in the record computation.

Loads

Instantaneous loads of selected constituents at stream sites were determined by multiplying the measured concentration in discrete samples by the streamflow (discharge) at the time of sample collection and then by an appropriate conversion factor to keep units consistent. Daily, monthly, seasonal, and annual load estimates for selected constituents were determined from load estimation models using minimum variance unbiased estimation techniques, a form of multiple linear regression analysis, and the S-LOADEST computer program (Runkel and others, 2004) in S-Plus (version 7.0, release 6, TIBCO Software, Inc., Palo Alto, California). For model development, the dependent variable was constituent concentration, and the independent variables were streamflow, decimal time, and season. If appropriate, ladders of power transformation of streamflow (Helsel and Hirsch, 1992) and breakpoints in streamflow were considered. These procedures were designed to account for nonnormal distributions, seasonal or annual cycles, censored data, biases associated with logarithmic transformation, and serial correlation of the residuals (Cohn, 1988; Cohn and others, 1989).

Model selection was done according to the following criteria. From evaluation of the Akaike information criteria (Akaike, 1981), the best-fit model was selected using combinations of streamflow, natural logarithm of streamflow, square of streamflow, square of the natural logarithm of streamflow, decimal time, square of decimal time, sine and cosine of time, and square of the sine and cosine of time. Residual plots were evaluated for homoscedasticity (constant variance) and normality. Models that failed these critical assumptions were rejected, and additional combinations of the above variables were examined for linearity based upon the rank of the Akaike information criteria. Failing that test, an additional step involved examination of models that incorporated breakpoints in streamflow in combination with the aforementioned time terms.

Each observation in the data set was used to develop a best-fit model, which was then used to estimate daily loads. Loads were then summed to provide monthly, seasonal, and annual estimates. Yield estimates were determined by dividing the constituent load determined at the site by the site's drainage area. Flow-weighted concentrations were calculated from the estimated loads by dividing the daily mean load by the daily mean streamflow.

Estimates of monthly mean contaminant loads from WWTPs were determined by multiplying the monthly mean concentration of selected contaminant loads by the reported monthly mean plant discharge (U.S. Environmental Protection Agency, 2005; 2008) and then by an appropriate conversion factor to normalize units. Annual load estimates from CSOs were determined by multiplying the average concentration determined in CSO samples discharging into given stream reaches by the average annual CSO discharge for those reaches and then by an appropriate conversion factor.

Trends

Trends in constituent concentrations in streams can be affected by natural and anthropogenic processes. Seasonal and annual precipitation variations induce changes in streamflow, which affect concentrations of nutrients, suspended sediment, fecal-indicator bacteria, and other constituents. Human factors such as land-use changes, advanced treatment technologies, and the implementation of best-management strategies, also may affect instream concentrations. Flow-adjusted trends in concentrations remove the variability associated with streamflow to allow changes with time caused by human factors to be properly assessed. Flow-adjusted trend was determined from the coefficient of the LOADEST model decimal time term using a significance level of 0.05 (Sprague and others, 2006). Constituent trends were only reported where a valid model was calibrated; however, not all reported trends were determined to be statistically significant.

Flow-adjusted trend in concentration is expressed as the average percent change over the time modeled and calculated from the following formula (Sprague and others, 2006):

$$\%\Delta FAC = 100 * (e^{(2\beta_{DT}(T_m - T_a) + \beta_T) * T})-1 \qquad (1)$$

where

%ΔFAC	is the flow-adjusted trend in concentration, expressed as the average percent change per year;
e	is exponential;
β_{DT}	is the coefficient of the decimal time squared term;
T_m	is the decimal time at the midpoint of the period of record;
T_a	is the decimal time centered so that the linear and quadratic time variables are orthogonal;
T	is the decimal time of the period of record; and
β_T	is the coefficient of the decimal time term.

Trends were considered significant if the p-value of the decimal time term was equal to or less than 0.05. The trend was bracketed with a 95 percent confidence interval by applying 2 times the standard deviations of the time terms (β_{DT} and β_T) to the above equation to achieve the upper and lower bounds of the trend. β_{DT} was set to zero if the term, decimal time squared, did not appear in the final model.

Bacteria Source-Tracking

Genetic characteristics of *E. coli* isolated from water samples were compared to a library of *E. coli* isolates from three known hosts in the basin–dogs, geese, and humans (Wilkison and others, 2002; 2006) to determine the amount of *E. coli* from each host. The host-source library was developed from fecal samples collected at sites adjacent to the stream that could be expected to contribute instream bacteria. Adjacent stream sites sampled for host-source library samples included dog kennels, sanitary sewers, and parks where geese congregate in large numbers. Genetic fingerprint rep-PCR patterns of samples were determined only after a four-step confirmation process that ensured isolates were fecal *E. coli* strains. Bionumerics software (version 3.0, Applied Maths, Kortrijk, Belgium) was used to determine the similarity of water-borne *E. coli* rep-PCR patterns to those in the library (Carson and others, 2003). Samples with greater than 75 percent similarity to those of a known host were assigned to that host group, and samples outside of the limits were presumed to be from unknown sources. A 75 percent similarity cutoff was chosen so that data collected during 2005 to 2006 could be pooled with previously collected data from 1999 to 2004; however, the actual similarity measured was greater than 75 percent (81 percent for those identified as humans, 82 percent for those identified as geese, and 83 percent for those identified as dogs). Human-host source contamination identified using rep-PCR was verified through the use of DNA extracted from water samples and amplified for the genetic marker, Bacteroides thetaiotaomicron, because of its high specificity in human fecal matter (Teng and others, 2004; Carson and others, 2005) and the presence of 3β-coprostanol, a human-fecal biomarker, in stream samples.

Biological

The Invertebrate Data Analysis Program (IDAS) was used to calculate measures of community diversity and to resolve taxonomic ambiguities in the data (Cuffney, 2003). Taxonomic ambiguities were resolved by data combination for all sites and then assignment of ambiguous parents to children. This approach is appropriate when sites were expected to have similar assemblages in the absence of anthropogenic effects, as is the case in this study area. Once individual site metrics were determined, data from selected stream reaches were averaged with nearby sites to aid and simplify data interpretation. These groupings were assigned in accordance with a human disturbance gradient grouping developed by Poulton and others (2007) and knowledge of basin land-use patterns.

Missouri Stream Condition Index (SCI) values were determined according to procedures outlined in Sarver and others (2002). Individual metric values for total taxa richness; Ephemeroptera, Plecoptera, Trichoptera (EPT) richness; Missouri Biotic Index; and the Shannon Diversity Index at each site are scored and then normalized by comparison to the range of reference site values for the ecoregion, in this case the Plains/Missouri Tributaries between the Blue and Lamine Rivers. The four normalized values then are summed to achieve the final SCI value. Based on the SCI scores, an aquatic life use status (ALUS) was determined to be either non-supportive, partially supportive, or fully supportive of biota (Sarver and others, 2002).

Stream physical habitat was assessed using standards outlined for Missouri by Sarver (2003b). Ten physical attributes of the instream and riparian areas adjacent to the sampling site that could be expected to affect biotic habitat were measured or rated on a scale of 0 to 20. Attributes were summed to provide an overall assessment; higher scores indicated habitat better suited for aquatic organisms.

Toxicity evaluations included the responses of primary producers (algae), consumers (crustaceans), and decomposers (bacteria) to surface-water samples. Samples were considered toxic when sample response was greater than a prescribed difference (10 to 50 percent) of the control samples (Canna-Michealidou and others, 2000; Johnson, 2005).

A chronic toxicity test, using the unicellular freshwater algae *Pseudokirchneriella subcapitata*, (formerly *Selenastrum capricornutum*), was performed under controlled conditions of light and temperature [21–25 °Celsius (C)]. Algae concentrations of five serial dilutions of samples (three replicates each) were determined every 24 hours over a 3-day growth period by optical density measurement at 670 nanometers. Toxicity was measured as percent growth inhibition in samples relative to the exponential growth rate of the control.

Toxicity tests, using the crustacean *Daphnia magna*, were determined by exposing recently hatched neonates (less than 24-hours old) to surface-water and bottom sediment samples.

Five replicates per sample and one control, each of which contained five daphnids, were measured for each sample. Exposures were 24-hour and 48-hour at 20 °C in darkness. The percentage of deceased or immobilized daphnids at the end of each time was compared against the control to determine toxicity.

The response of the bioluminescent bacteria, *Vibrio fischeri*, exposed to samples was measured under standard conditions and compared to that measured in controls at 5- and 20-minute intervals. The percent reduction in the light output of the luminescent bacteria between the samples and the control was used to determine toxicity. All samples were measured in duplicate and at a minimum of two concentrations, full strength and at 50 percent dilution. Samples that exhibited light inhibition greater than 25 percent compared to the control were resampled for toxicity confirmation.

Statistical Analyses

Statistical analyses were conducted comparing water-quality characteristics between sites. Nonparametric statistical methods were used to analyze the data because water-quality data are not normally distributed, the data frequently contain values less than the method detection limit (censored data), and because these methods are not unduly influenced by extreme data values (outliers) since ranks of the data are used instead of constituent concentrations. A significance level (α) of 0.05 was used for the statistical tests. However, the attained significance level or probability of error (p-value) from the test was frequently much lower and was reported to provide a qualitative indication of the degree of similarity or difference between data sets.

The nonparametric methods included the Kruskal-Wallis test and multiple comparison t-tests on the ranks (Helsel and Hirsch, 1992). The Kruskal-Wallis test is an analysis of variance test on the ranks of the data to evaluate for differences in the central tendency, medians, of two or more groups. When the the Kruskal-Wallis tests indicated a significant difference at the 0.05-level, a t-test on the ranks (Mann-Whitney) was performed on each pair group to evaluate which groups were statistically different from one another.

Water-Quality Character and Trends in the Blue River Basin

Trends are the average increases or decreases in measurements over a specific time or through space that are unlikely to have occurred by chance (Helsel and Hirsch, 1992). The time frame for trends can vary from short (hours or days), long (months or seasons), to long term (year or decade) depending upon the type of constituent or property being evaluated and the amount or type of change being examined. Spatial trends can include changes that occur on small scales within streams or between sites or within the water column—such as those changes that occur between the overlying water column and underlying bottom sediments. They also may include changes that occur between tributaries or those that occur along various stream reaches.

Water-quality trends in the Blue River Basin from 1998 through 2007 were assessed using a multidisciplinary approach that included temporal and spatial dimensions. Previous studies examined how concentrations, loads, and yields of constituents varied at sites within the basin and the role of hydrology and various point and nonpoint sources in receiving water concentrations and loads (Wilkison and others, 2002; 2006). For this study, measurements of streamflow, physical properties, nutrients, fecal-indicator bacteria, suspended sediment, organic wastewater and pharmaceutical compounds in base-flow and stormflow samples from basin streams collected October 2004 through December 2007 (tables 7–13, at the back of this report) were incorporated with similar measurements from earlier studies (Wilkison and others, 2002; 2005; 2006) to evaluate temporal and spatial trends over a 10-year period. A combination of benthic macroinvertebrate assessments, stream physical habitat assessments, and toxicity evaluations was used to assess the biological integrity of basin streams.

Continuous Water-Quality Data

Continuous (every 15 minute) water-quality data were collected at two sites (sites 7 and 16; fig. 1; table 1) from April through early to mid-December 1998 through 2007. Data included water temperature, specific conductance, dissolved oxygen, pH, and turbidity. Values for continuous water-quality variables and the range of values observed each month are shown in figure 3. Water-temperature data at site 16 (Brush Creek at Rockhill Road) for the months December through March were measured only from 1998 through 2002.

Water temperature is strongly affected by the ambient air temperature. Maximum temperatures in the Kansas City area occur in July and these are reflected in the water temperatures for that month. Stream temperature is important because it mediates biogeochemical processes. Warmer water temperatures support aquatic growth, which can contribute to stream eutrophication. Warmer temperatures, coupled with increased solar radiation, also can lead to increased degradation of contaminants, just as cooler temperatures can increase the half-life of chemicals and produce longer residence times. Additionally, because many wastewater-treatment processes are biologically mediated, these facilities operate more efficiently in warmer temperatures. Although the median temperatures between the two sites are similar, Brush Creek temperatures typically were higher by as much as 1 °C during July and September. Instantaneous temperature values sometimes exceeded the State of Missouri warm-water standard of 32.2 °C (Missouri Department of Natural Resources, 2007), but the daily mean value

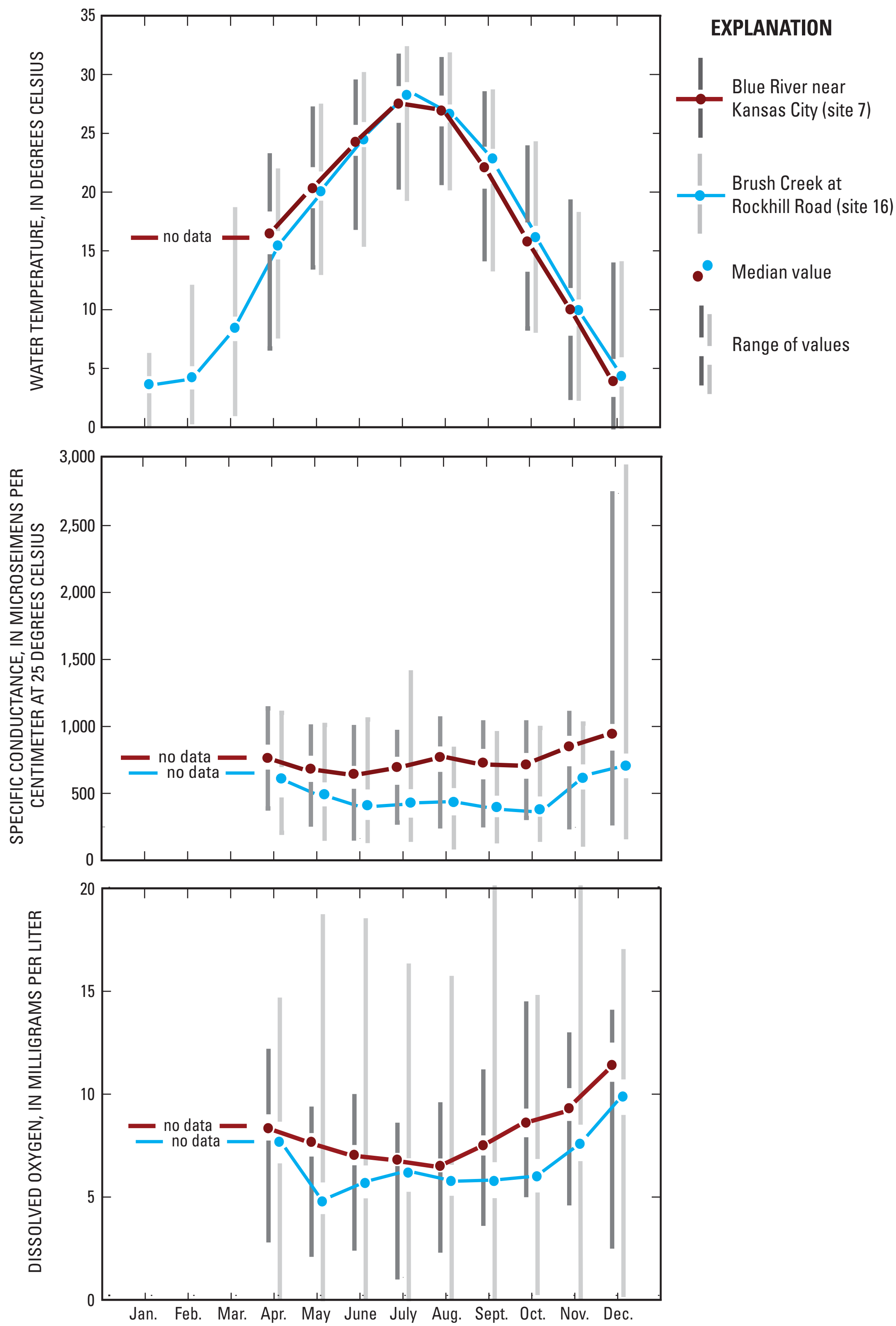


Figure 3. Continuous water-quality and streamflow data by month from 1998 through 2007.

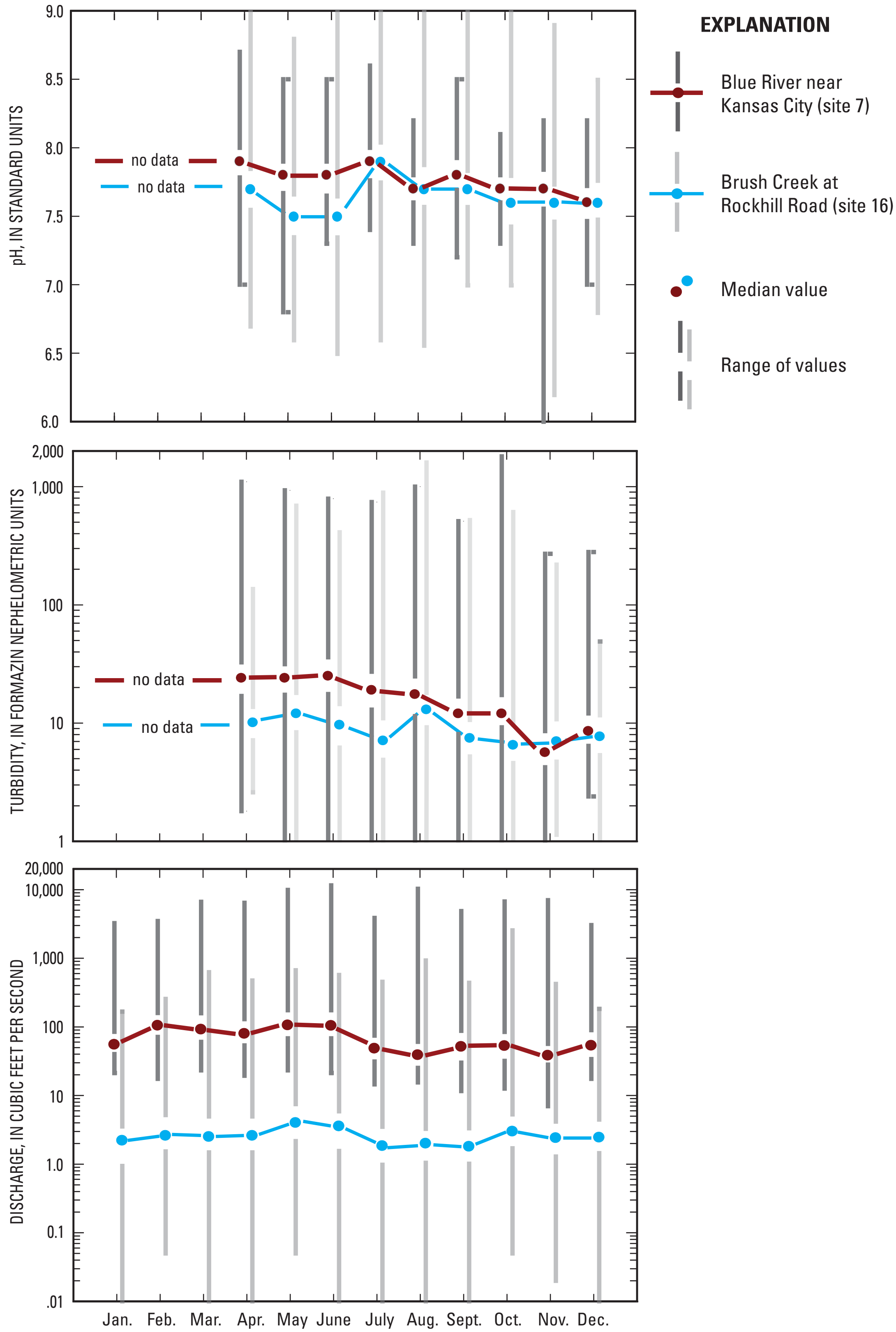


Figure 3. Continuous water-quality and streamflow data by month from 1998 through 2007.—Continued

rarely did. Two instances of daily mean water temperature exceeding 32.2 °C occurred only at site 16.

Specific conductance values on Blue River near Kansas City (site 7) typically were larger than the values on Brush Creek at Rockhill Road (site 16). There are several factors that likely are responsible for this. In many instances, a large percentage of the flow at site 7 consists of treated wastewater effluent. Sewage generally has larger concentrations of common dissolved ions, many of which are not substantially removed during treatment. Although the water has been treated prior to its discharge into the river in accordance with applicable standards, it does contain concentrations of a variety of substances that can elevate the specific conductance. The percentage of impervious cover upstream from site 16 is 2.5 times greater than at site 7 (Wilkison and others, 2006), thus a larger amount of runoff in this area does not infiltrate into the ground and migrate through the unsaturated zone before entering the stream as groundwater recharge. Consequently, runoff from impervious surfaces has fewer opportunities to pick up dissolved constituents or buffering capacity, although exceptions to these phenomena can sometimes occur.

Large spikes in specific conductance values seen in December (figs. 3–4) were associated with deicing and road salt applications that occurred in anticipation of winter storms at sites 7 and 16 as well as at adjacent sites (06893100 and 06893390) operated as part of concurrent studies in the basin (Rasmussen and others, 2008). Specific conductance values two to five times the background levels occurred following a series of small winter storms in parts of the basin where road deicers were applied and subsequently rapidly moved into basin streams during snowmelt (fig. 4). USGS site 06893100 is located approximately midway between sites 1 and 2 (fig. 1) and USGS site 06893390 is approximately 0.8 kilometer upstream from site 6 (fig.1). Sites in areas with the highest population density (site 16) or kilometers of road surfaces (site 06893390) (Wilkison and others, 2006) typically showed the sharpest increase and most pronounced effects. These data indicate there are few mechanisms to slow or limit the

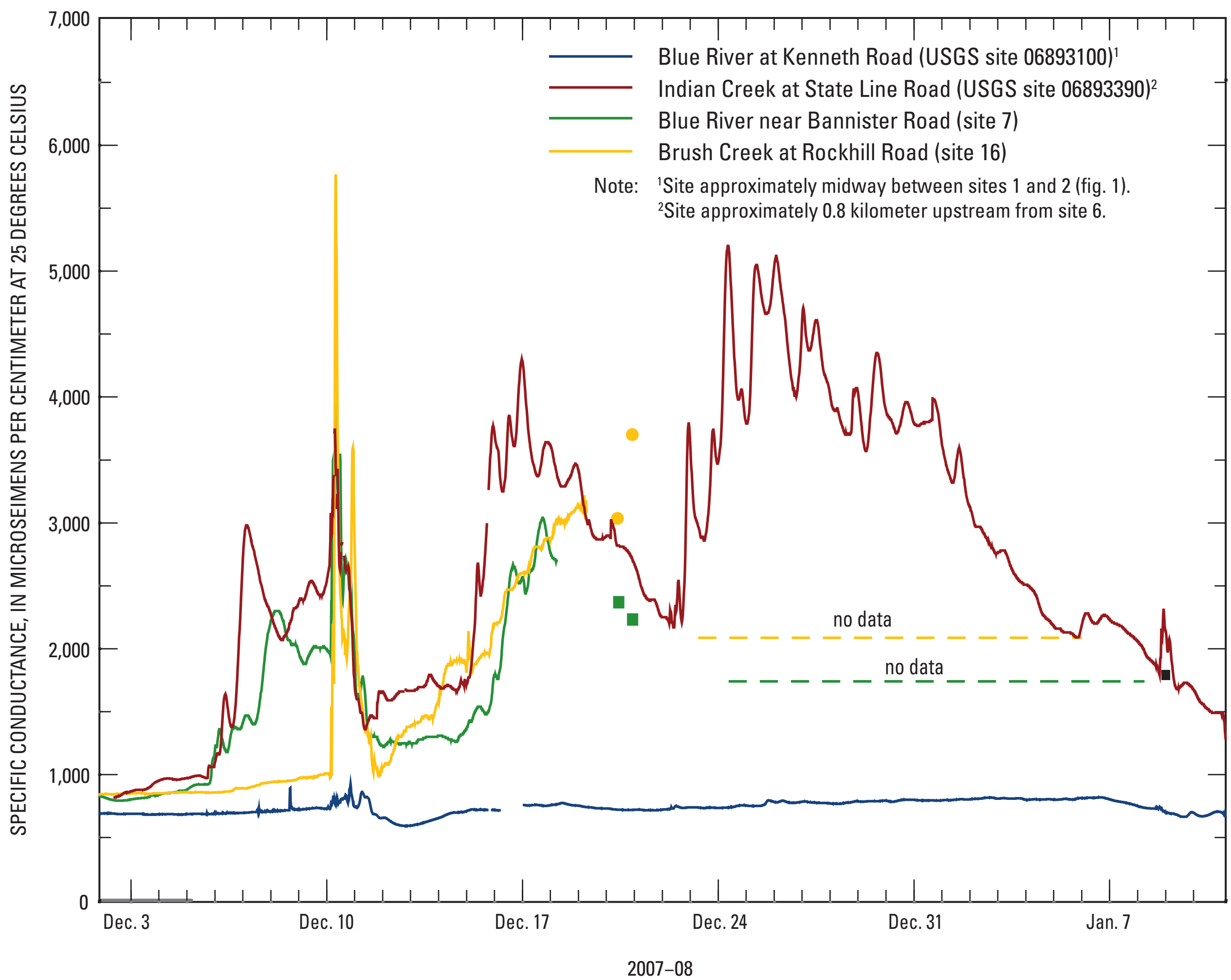


Figure 4. Hourly specific-conductance values for four streams in the Blue River Basin from December 2, 2007 to January 11, 2008.

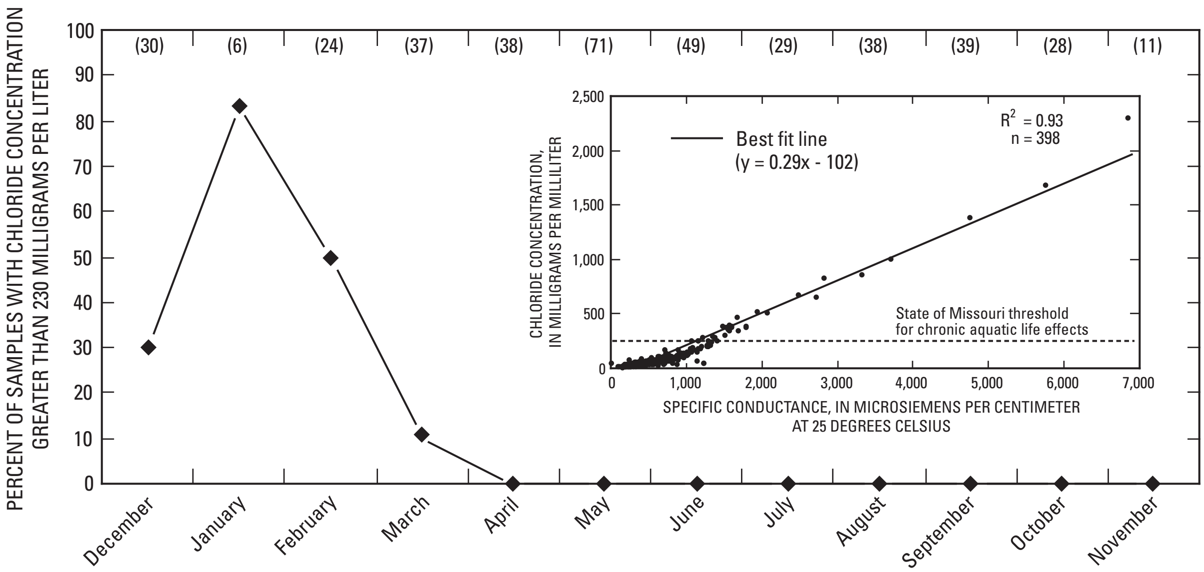


Figure 5. Percentage of stream samples collected in the Blue River Basin from July 1998 through December 2007 with dissolved choride values greater than the State of Missouri threshold of 230 milligrams per liter and relation between specific conductance values and chloride concentration in stream samples.

movement of highly soluble road salts into streams. In some winters, such as occurred in 2007, winter storms occur at a frequency of about once every 7 to 10 days for a month or more with each storm contributing successive pulses of road salt to streams (fig. 4). When this is the case, deicing and road salts can linger in the environment for extended periods and prolong elevated specific conductance values above background concentrations.

Specific-conductance values were strongly correlated with chloride concentrations in stream samples (fig. 5; coefficient of determination, 0.93) and specific conductance values in excess of 1,400 microsiemens per centimeter at 25 °C (µS/cm) are representative of stream chloride concentrations greater than the State of Missouri threshold of 230 milligrams per liter (mg/L) for chronic effects on aquatic life (Missouri Department of Natural Resources, 2007). Based upon the relation between specific conductance values and dissolved chloride concentrations (fig. 5), stream segments in Indian Creek, the Blue River downstream from its junction with Indian Creek, and Brush Creek likely would have had chloride concentrations in excess of this threshold for more than a month. Samples collected from December to March had chloride concentrations greater than the chronic threshold for full support of aquatic life, with the coldest months, January and February, having the largest percentage (more than 50 percent) of samples greater than the chloride chronic standard (fig. 5). Four samples from December to March had chloride concentrations greater than 860 mg/L, the State of Missouri acute threshold for support of aquatic life (Missouri Department of Natural Resources, 2007). No samples collected April through November had chloride concentrations in excess of State acute or chronic thresholds (fig. 5). These data indicated that stream chloride concentrations in excess of 230 mg/L resulted primarily from road deicers entering streams in winter months, which likely coincided with periods of decreased benthic invertebrate activity. The determination of potential deleterious effects on stream biota from individual compounds was beyond the scope of this study. However, because of the seasonality of this phenomenon, elevated chloride concentrations from road salt applications may be less important to overall stream health than other factors, such as urbanization and habitat loss.

At both sites, monthly median dissolved-oxygen concentrations increased in the fall, late September through early December, (fig.3) as water temperatures declined and solubility increased. As water temperatures increased from April to July, the solubility of dissolved oxygen in streams declined, and median values decreased. However, monthly median dissolved-oxygen concentrations at site 7 (Blue River near Kansas City) were significantly greater than values at site 16 (Brush Creek at Rockhill Road) for all months between April and November of each year (Mann-Whitney tests; $p < 0.001$). Dissolved-oxygen concentrations at site 16 also fluctuated two to three times more than at site 7, in part because of the varied nature of inputs into Brush Creek in concert with stream hydrologic alterations. Numerous reaches on Brush Creek have low-head dams that impound water and concrete-lined channel beds and sides. Except during storm events, flows through these reaches are limited, but nutrients typically are not. This can lead to frequent and rapid algal blooms. During these periods, photosynthesis during daylight hours tends to induce super-saturated dissolved-oxygen concentrations, whereas at night, respiration causes dissolved-oxygen concentrations to drop sharply. As previously reported (Wilkison and others, 2006), storms can induce rapid reductions in dissolved-oxygen concentrations as organic matter during wet weather enters these reaches, collects in the impoundments, and then begins to degrade, which depletes dissolved-oxygen concentrations. Dissolved-oxygen declines were more frequent during months with the highest average precipitation (May, June, and September) and more frequent discharges from combined sewers. The largest decrease in median monthly dissolved-oxygen concentrations occurred at site 16 during May (fig. 3)—the month with the highest average precipitation.

Processes such as eutrophication and storm inputs have substantial effects on stream dissolved-oxygen concentrations. Daily mean dissolved-oxygen concentrations at site 16 were below the State of Missouri standard of 5 mg/L for full support of aquatic life (Missouri Department of Natural Resources, 2007) 27 percent of the time compared to only 3 percent of the time at site 7 (fig. 6).

Values for pH at sites 7 and 16 frequently ranged over several units but were usually in the range of 6 to 9 standard units (fig. 3). A substantial part of the pH fluctuation has to do with nutrient saturation that occurs in these streams. Excess nutrients foster algal blooms. As these blooms progress, stream pH tends to peak near the time of daily maximum photosynthesis, while respiration reduces the pH during the night as excess carbon dioxide is released into the water column (Wetzel, 2001). The pH of the Blue River near Kansas City (site 7) is buffered some by treated effluent being discharged upstream from this site, so the Blue River does not have the same degree of fluctuation as does Brush Creek at Rockhill Road (site 16). There is a drop in pH in the months of May and June at both sites because of increased runoff; however, the Brush Creek pH decline is more evident because of the relatively large amount of impervious area in Brush Creek, which generates runoff from lower pH, lightly buffered precipitation that undergoes minimal soil contact. Additionally, CSO events, which tend to have lower pH values than receiving streams in part because of the large percentage of rainfall in the overflow, would be more frequent during May and June, a factor that may also have reduced pH values.

Stream pH values are most commonly in the range between 7 and 8, which is consistent with the range where many organic wastewater and pharmaceutical compounds would be expected to be persistent in the aqueous phase (Wells, 2006). This, coupled with the daily inputs from WWTPs and the less frequent, but still common, inputs from CSOs, helps to explain the persistent nature of some of these compounds in many stream reaches (Wilkison and others, 2002; 2005; 2006).

Turbidity values often correlate with the concentration of suspended particles in streams, which can be organic matter (for example, algal matter or leaf debris) or inorganic particles. Median turbidity values at site 7 were about twice that at site 16. Algal matter in streams is largely a function of available light, nutrients, and temperature, although zooplankton grazing also can be an important limiting control (Wetzel, 2001). Because dissolved inorganic nitrogen and phosphorus are available, stream reaches in the basin are not nutrient limited. Therefore, algal populations likely are limited by light, temperature, or heterotrophy, which all peak in midsummer. Higher turbidity values also correlate with storm events that contribute large amounts of sediment into streams. The majority of instream sediment is mobilized by the largest storms, which occur in the months with the highest median turbidity values. Monthly median turbidity values in the Blue River were about twice those in Brush Creek during the spring and summer, an indication of the much higher sediment load transported in the main stem of the Blue River than in Brush Creek. Impounded reaches on Brush Creek trap sediments and minimize downstream transport.

Longitudinal Trends

Synoptic samples, samples collected in a short timeframe under near-uniform base flow hydrologic conditions, were collected from 19 sites in the Blue River Basin during base flow in August through September 2004 and again in May and August 2005. Sample-site locations were focused in the CSS area. Eight sites on the main stem of the Blue River (sites 2, 7–9, and 21–24), eight sites on Brush Creek (sites 11, 13–18, and 20), and one site each on Indian Creek (site 6), Town Fork Creek (site 19), and an unnamed tributary in Penn Valley Park (site 25) were sampled.

Average fecal-indicator bacteria densities and loads for these three sampling events are shown in figure 7. Although bacteria densities fluctuated somewhat between sites, densities generally increased downstream in the basin. This increase corresponds with increased amounts of urbanization that occurred progressively downstream in the basin. Rasmussen and others (2008) showed that bacteria densities increased as the percent of urban land increased in Johnson County, Kansas. Because these downstream increases occurred during base-flow conditions, they are an indication of nonpoint-source contributions to basin streams during dry weather. One potential source of these contributions would be the interaction of groundwater and water migrating through the unsaturated zone with compromised sewer lines and its ultimate discharge into surface waters. Some of these interactions would be expected to occur along preferential flow paths that would allow limited opportunities for the adsorption and degradation of bacteria. This potential is additionally underscored by previous work (Wilkison and others, 2002; 2005) where typically at least one-third of *E. coli* bacteria were attributable to human sources during base-flow conditions. The age of many system pipes coupled with historical construction techniques employed to join pipe segments are believed to provide an opportunity for inflow and infiltration processes to occur in many parts of the system (City of Kansas City, Missouri, 2009).

Instantaneous *E. coli* loads during base-flow conditions were large in streams even before they entered the CSS area. Lower Blue River sites (sites 21–24) generally had increased densities of bacteria, but inputs from Brush Creek only accounted for approximately 10 percent of the total downstream loads because of its much smaller discharge.

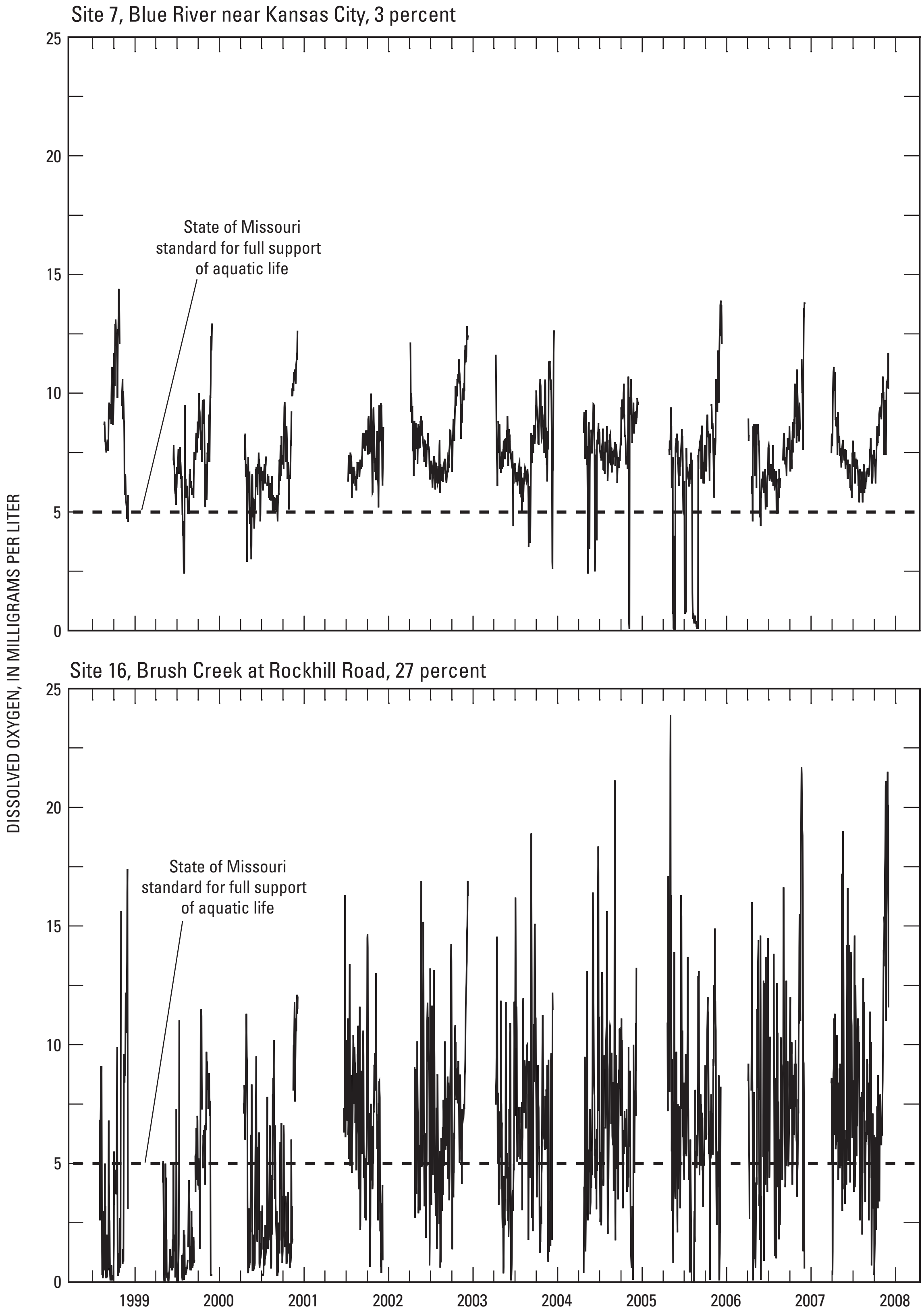


Figure 6. Daily mean dissolved-oxygen concentrations at sites 7 and 16 from July 1998 through December 2007 and percentage of days where mean concentration was below the standard for full support of aquatic life.

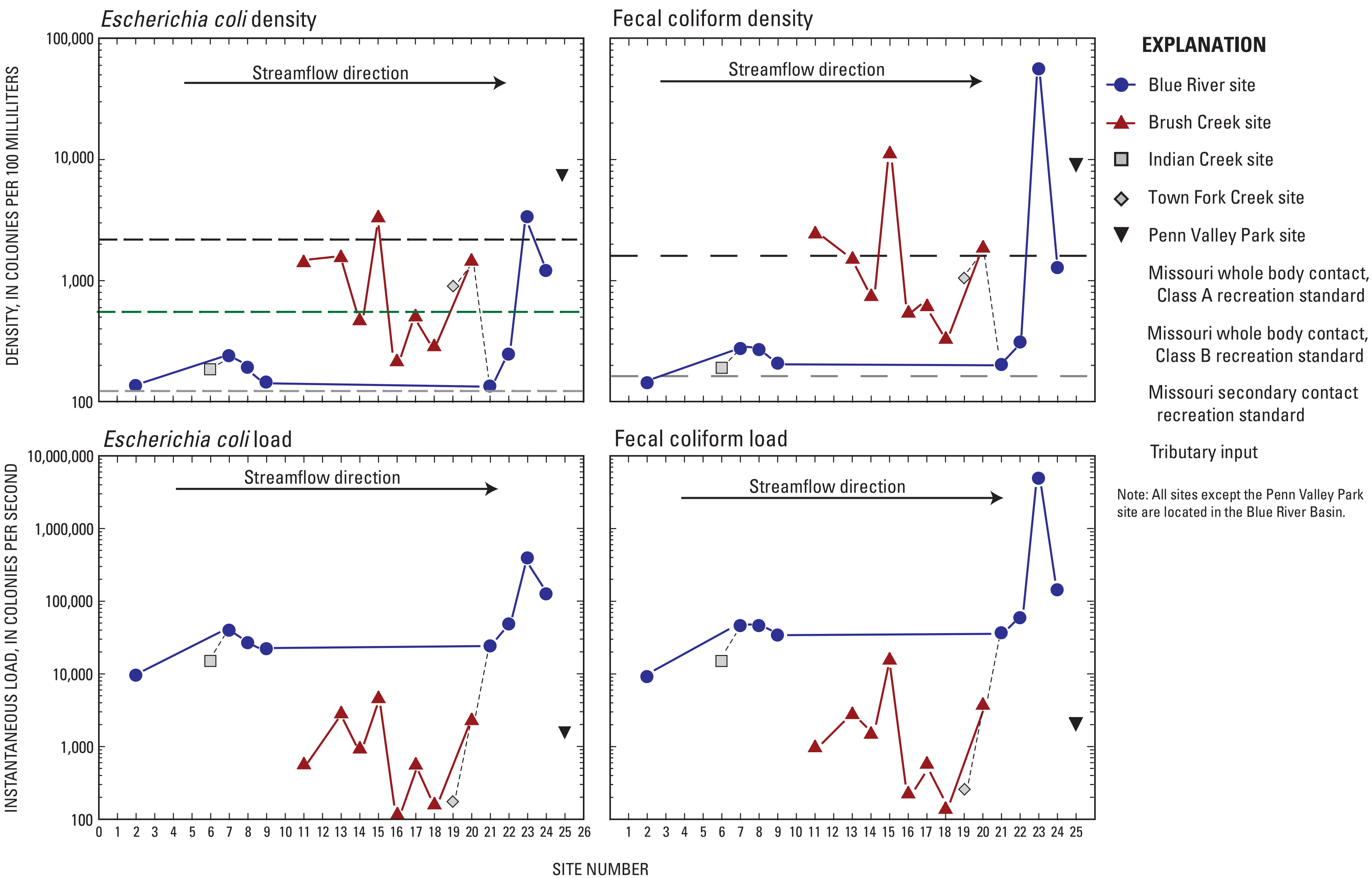


Figure 7. Average fecal-indicator bacteria densities and loads at study sites for samples collected during three synoptic base-flow sampling events between August 2004 and August 2005.

As previously reported (Wilkison and others, 2006; Rasmussen and others, 2008), a large percentage of the nutrients, total nitrogen and total phosphorus, in the Blue River downstream from the confluence of Indian Creek to the mouth, originate from WWTP effluents. There are three WWTPs that discharge into the basin—one that discharges into upper Blue River, one into upper Indian Creek, and one into Tomahawk Creek near its confluence with Indian Creek (fig. 1). A fourth plant, located near the confluence of the Blue and Missouri Rivers, discharges into the Missouri River. The plants vary in size and treatment technologies so effluent character varies between the plants. The smallest plant is located upstream from site 2, and discharges, on average, about 16 percent of the total effluent discharged into the basin (U.S. Environmental Protection Agency, 2008). Site 6 (fig. 1) downstream from the other two plants receives the bulk of the treated effluent in the basin. Previous work (Wilkison and others, 2006) indicated that at site 7, downstream from all three discharge points, treated effluent comprised over 90 percent of the flow about 85 percent of the time. As of 2009, population increases and planned increases in treatment capacity likely will raise these percentages.

Average nutrient concentrations and loads for the three synoptic base-flow sampling events (fig. 8) illustrate the role of these plants on downstream nutrient levels. During base flow, most nutrients in the middle and lower Blue River originate from the two WWTPs that ultimately discharge into Indian Creek upstream from site 6. Smaller amounts originate from the WWTP that discharges into the upper Blue River, and even smaller amounts originate from the basin tributaries Brush and Town Fork Creeks. Nutrient contributions to Brush Creek increased downstream in the basin, likely the result of increased nonpoint-source contributions in the middle and lower reaches of Brush Creek.

Previous work (Wilkison and others, 2006) estimated WWTPs contributions to stream reaches in the Blue River Basin for a 20-month period (July 2002 through September 2004). WWTPs contributions were compared to all the sources, including nonpoint-source runoff. This work compared median WWTPs loads to median downstream loads, which includes the combination of the point and nonpoint sources. Because of the difficulty of accurately characterizing contributions from WWTP bypasses that occurred during storm events, these loads were not included in these estimates. The percentage of the total nutrient load estimated to originate from treated effluent ranged from 28 to 61 for total nitrogen and 16 to 56 for total phosphorus loads in the Blue River Basin stream reaches. The upper Blue River reaches had the lowest nutrient contributions from WWTP effluents and Indian Creek had the largest. Differences in WWTPs contributions were related to the number of discharges upstream from sites, the volume of discharges, the proximity of sites to discharge points, and the treatment processes employed.

Rasmussen and others (2008) quantified treated effluent from WWTPs for 2005 and 2006 and determined that 40 to 90 percent of the total nitrogen and 25 to greater than 90 percent of the total phosphorus load in selected Blue River Basin stream reaches originated from WWTP effluent. As with a previous study (Wilkison and others, 2006), WWTP contributions were lowest in the upper reaches of the Blue River and greatest in the lower reaches of Indian Creek. During dry years, the relative contribution from WWTPs to basin streams generally increases because WWTP contributions remain relatively stable throughout the year, and nonpoint-source runoff contributions effectively diminish.

As nutrients are added to the Blue River Basin, important instream biogeochemical pathways and processes transform, remove, or add to concentrations. Biogeochemical pathways and processes include sediment deposition and resuspension, denitrification, microbial degradation, plant senescence, and assimilation into plant and animal matter. From the synoptic sampling events conducted between August through September 2004 and August 2005, there is evidence of nutrient loss in the approximately 20-km reach of the Blue River downstream from Indian Creek during this period. Between sites 7 and 9 and sites 21 and 24, there was a 13 percent decrease in total nitrogen and a 26 percent decrease in total phosphorus loads. Sedimentation may account for some of these losses; however, there were even more substantial losses of dissolved nutrients (33 percent for dissolved nitrate and 52 percent for dissolved orthophosphate) in this reach (fig. 8). These data indicate that assimilation by benthic plants and denitrification can sometimes play a role in dissolved nutrient decreases. Nutrient assimilation and denitrification would likely be greatly decreased in the winter at water temperatures below 10 ºC, so these data, which were collected during warmer periods, likely represent a period of maximum nutrient removal. Previous data collected between May 1999 and June 2004 indicated that, although there were slight decreases in loads along this 20-km reach, the differences were not statistically significant (Wilkison and others, 2006), another indication that assimilation and denitrification processes are likely limited to selected periods during any given year.

Base flow nutrient sources are only part of the nutrient sources in the basin because during wet-weather events other sources, such as nonpoint-source runoff and CSOs, contribute nutrients to streams. During intense, or prolonged storms, sanitary sewer overflows and WWTP bypasses also contribute nutrients to streams. In some stream reaches, stormflow nonpoint-nutrient contributions are the principal component (Wilkison and others, 2006). These contributions are addressed in a later section (Annual Contribution of Constituents) of this report.

Metals are described in this report as the sum of the dissolved concentrations of cadmium, chromium, copper, lead, nickel, and zinc and loads at stream sites. Metals concentrations and loads are shown in figure 9 along with the concentration and load of dissolved zinc in stream samples. Wastewater effluent and nonpoint-source runoff would be expected sources of metals in an urban environment. The largest dissolved-metals concentration was observed at Indian Creek, site 6, the stream reach with the highest percentage of treated effluent.

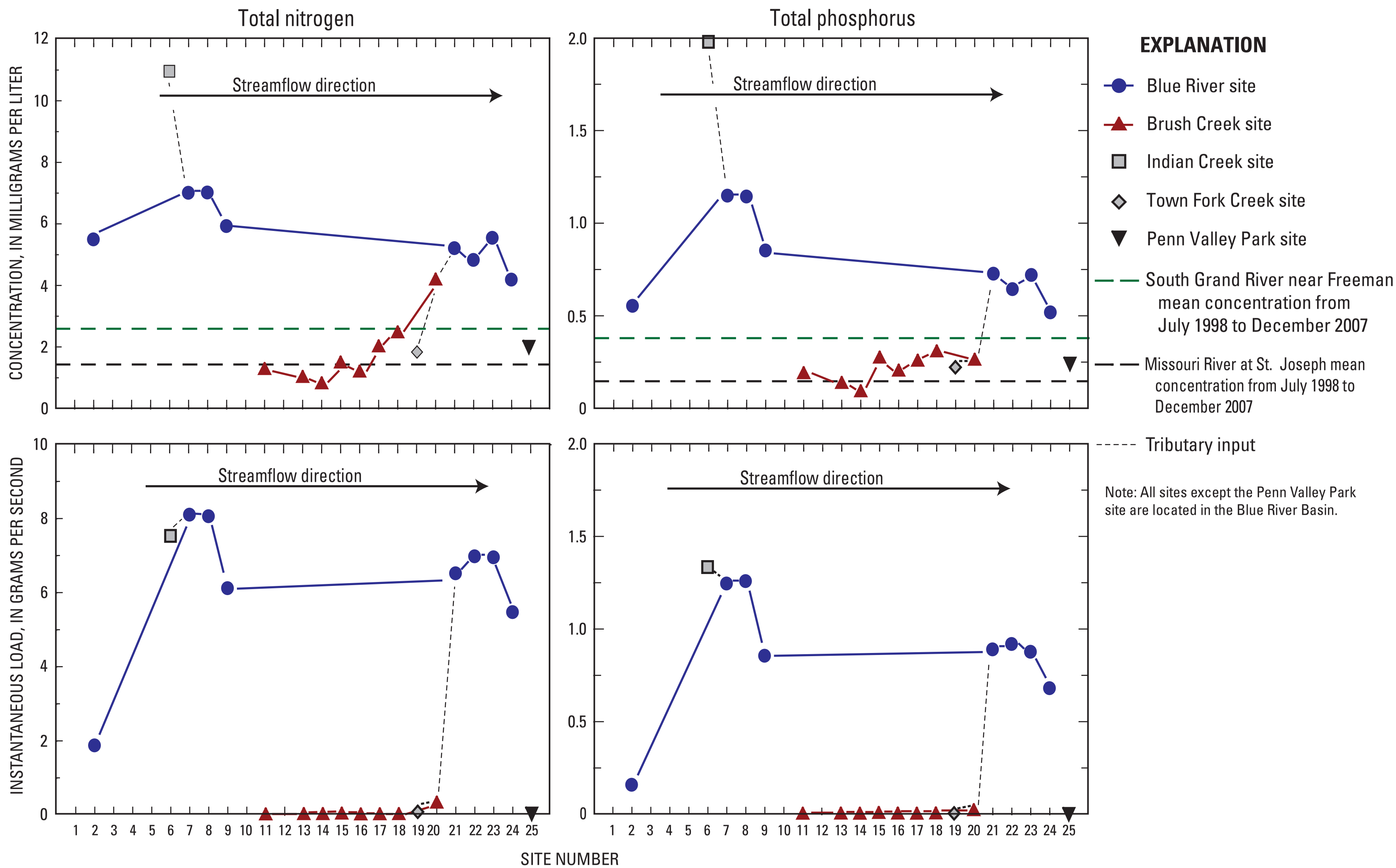


Figure 8. Average total nitrogen and total phosphorus concentrations and loads at study sites for samples collected during three synoptic base-flow sampling events between August 2004 and August 2005.

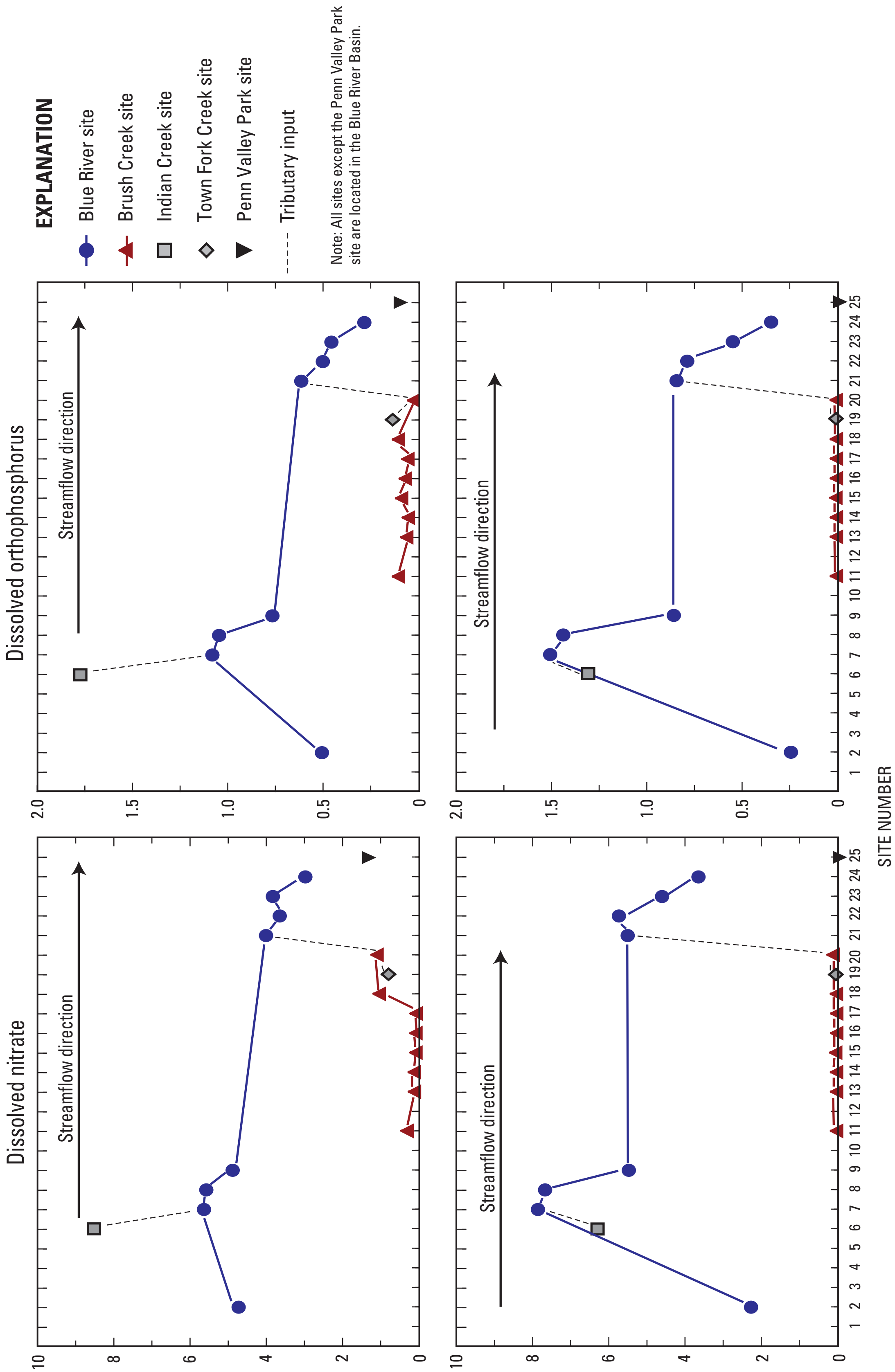


Figure 8. Average total nitrogen and total phosphorus concentrations and loads at study sites for samples collected during three synoptic base-flow sampling events between August 2004 and August 2005.—Continued

Zinc concentrations at site 6 also constituted the largest percentage of the total metals measured (71 percent) as compared to other sites. Concentrations of individual metals in base-flow synoptic samples were well below the standard for acute and chronic aquatic life protection (Missouri Department of Natural Resources, 2007). The solubility of metals is strongly linked to the source of the metals. Metals derived from the weathering of alumno-silicate materials, such as loess, have extremely limited solubility in streams; typically, only copper and zinc have solubilities that would provide concentrations above detection limits at the pH range of most surface waters (Desboeufs and others, 2005). By contrast, metals originating in urban areas are more likely to be adsorbed impurities or salts that are extremely soluble in the range of pH values observed in stream samples. Therefore, dissolved metals in stream samples in the Blue River Basin are likely to originate from anthropogenic sources during base-flow conditions.

In Brush Creek, there were general increases in dissolved metals and zinc concentrations from the most upstream (site 11) to the downstream site (site 20). These data are another indication of a shift toward nonpoint-source contributions in the middle and lower reaches of Brush Creek. The upstream Brush Creek site also had the lowest percent of zinc (17 percent) as compared to the total dissolved-metals concentration measured at all other sites in the basin.

Bacteria Densities and Sources

Bacteria densities are strongly linked to stormwater runoff in the basin. *E. coli* densities in stream samples collected from 1998 to 2007 are shown in figure 10. *E. coli*, a species of fecal coliform bacteria specific to human and other warm-blooded animals, is considered to be an important indicator of health risk from contact with recreational waters. *E. coli* densities measured in stream samples ranged over five orders of magnitude. Median *E. coli* density in base-flow samples was 185 colonies per 100 milliliter (col/mL) compared to median values of 100 times that amount in stormflow samples (18,200 col/mL). The range and variability of *E. coli* measured in base-flow samples was much greater than in stormflow samples, primarily because *E. coli* in stormflow samples largely are attached to sediment in the stream, which is largely a function of the discharge, whereas the bacteria density in base-flow samples is often related to a greater number of factors than discharge and sediment concentration. These include temperature, length of time since the last rainfall event, algal density, intensity and duration of sunlight, and bacteria regrowth. The median *E. coli* density for all samples, base-flow and stormflow combined, was 415 col/100 mL, which is near the median estimated value determined by Rasmussen and others (2008) for Indian Creek near the Kansas-Missouri State line (385 col/100 mL), the most urbanized site sampled as part of that study.

One site, Town Fork Creek (site 19), a tributary to Brush Creek, consistently had higher base-flow and stormflow fecal-indicator bacteria densities than the overall median densities measured at other stream sites. The median *E. coli* density in base-flow samples from Town Fork Creek (825 col/100 mL) was nearly twice the median base-flow sample density in other parts of the basin. Stormflow samples collected at Town Fork Creek had *E. coli* densities (median value of 170,000 col/100 mL) about 10 times greater than the median value for all stormflow samples (18,200 col/100 mL). During a typical year, the CSO volume is estimated to be approximately 23 percent of the total storm runoff volume in Town Fork Creek (City of Kansas City, Missouri, written comm., 2008), a likely factor in the high fecal-indicator bacteria densities measured in this stream. In fact, median *E. coli* densities in Town Fork Creek stormflow samples were above the median density of samples collected from CSOs (fig. 10). By contrast, three samples collected at Brush Creek at Belinder Avenue, site 12, located upstream from the CSS area had median *E. coli* densities slightly less than the densities measured in stormwater outfall samples collected in the basin.

Town Fork Creek flows into an impounded reach near the lower end of Brush Creek. During runoff events, suspended sediments from Town Fork Creek and upstream Brush Creek reaches (Wilkison and others, 2006) and, therefore, bacteria–because bacteria are strongly associated with particulate matter–settle out in the lower reaches of Brush Creek. Previous bottom sediment samples from Brush Creek were enriched with organic wastewater compounds as compared to other stream reaches in the basin; however, fecal-indicator bacteria densities in bottom sediments were quite low–less than 50 colonies per 100 gram (g) of sediment (Wilkison and others, 2006).

The city of Kansas City, Missouri, maintained a sampling program at 10 sites in the CSS area over the period 2005 to 2006. These included sites sampled as part of this study (sites 8, 9, 13, 16, 18–20, and 25), as well as the outflow to Penn Valley Lake (site 26), and also included one site on the Missouri River. As part of this program, grab samples generally were collected weekly from April through November without regard to hydrologic condition. Samples were not collected at every site each week and fewer samples were collected in December and January of each year. These data generally fit the range of values seen in the base-flow and stormflow samples collected as part of this study. However, because weekly values were censored at 100 col/100 mL, the lower end of the data range is not clearly expressed in a boxplot (fig. 10). In reality, the lowest values from the weekly sampling would likely follow a random distribution pattern in the range from 1 to 100 col/100 mL similar to that observed in the base-flow samples collected as part of this study. Additionally, 60 percent of samples were collected during base-flow conditions compared to 40 percent collected during stormflow runoff. It is unknown how many of the weekly event samples were collected during or immediately following runoff events. Together these data are an indication of typical *E. coli* densities that occur not just in streams in the CSS area, but also in the most urban parts of the city.

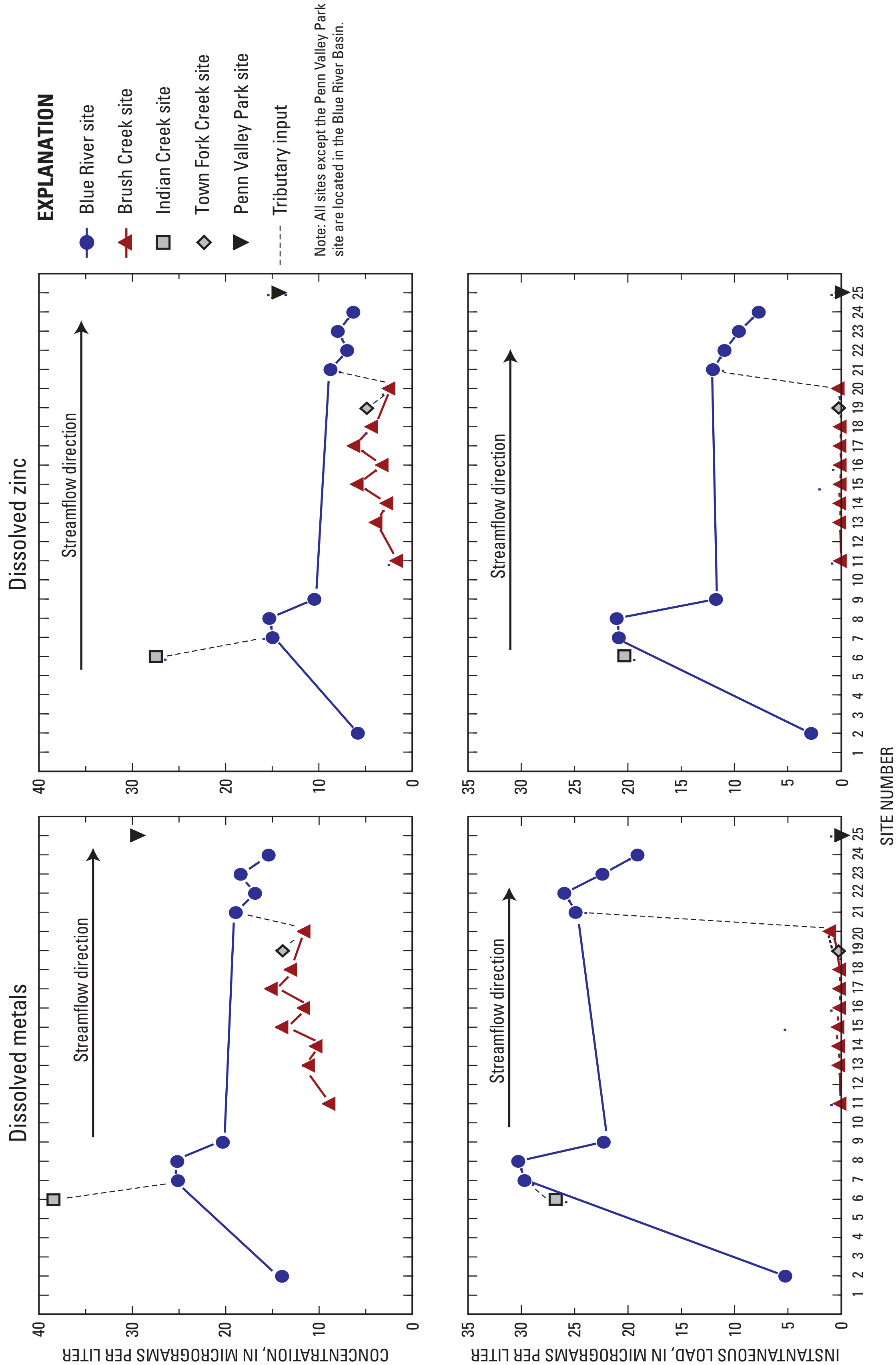


Figure 9. Average dissolved metal (sum of cadmium, chromium, copper, lead, nickel, and zinc) concentrations and instantaneous metal loads and average dissolved zinc and instantaneous zinc loads at study sites for samples collected during three synoptic base-flow sampling events between August 2004 and August 2005.

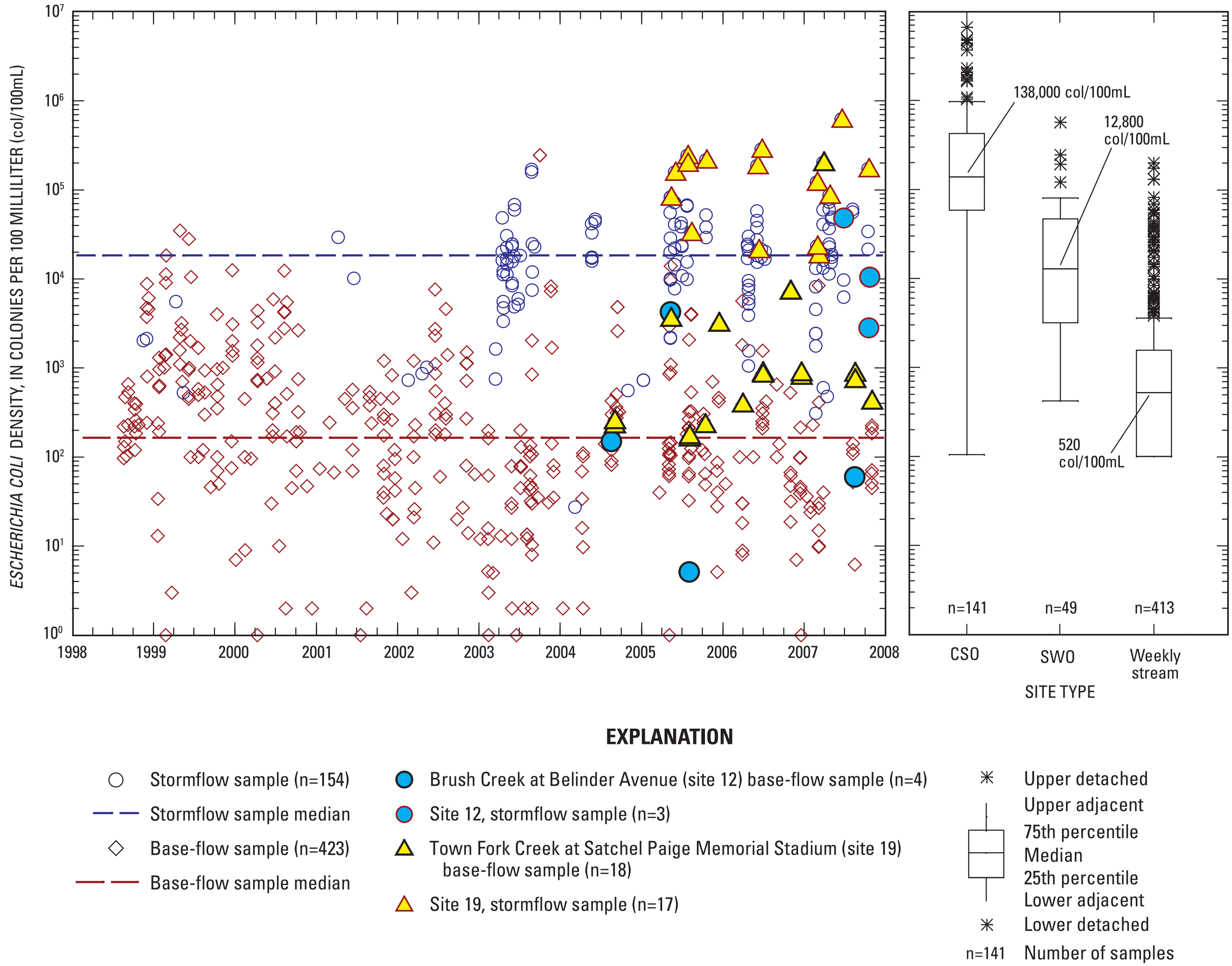


Figure 10. *Escherichia coli* densities in stream samples collected from 1998 through 2007 as part of this study compared to densities measured in combined sewer overflows (CSO), stormwater outfalls (SWO), and stream samples collected as part of the City of Kansas City, Missouri weekly sampling program in 2005 and 2006.

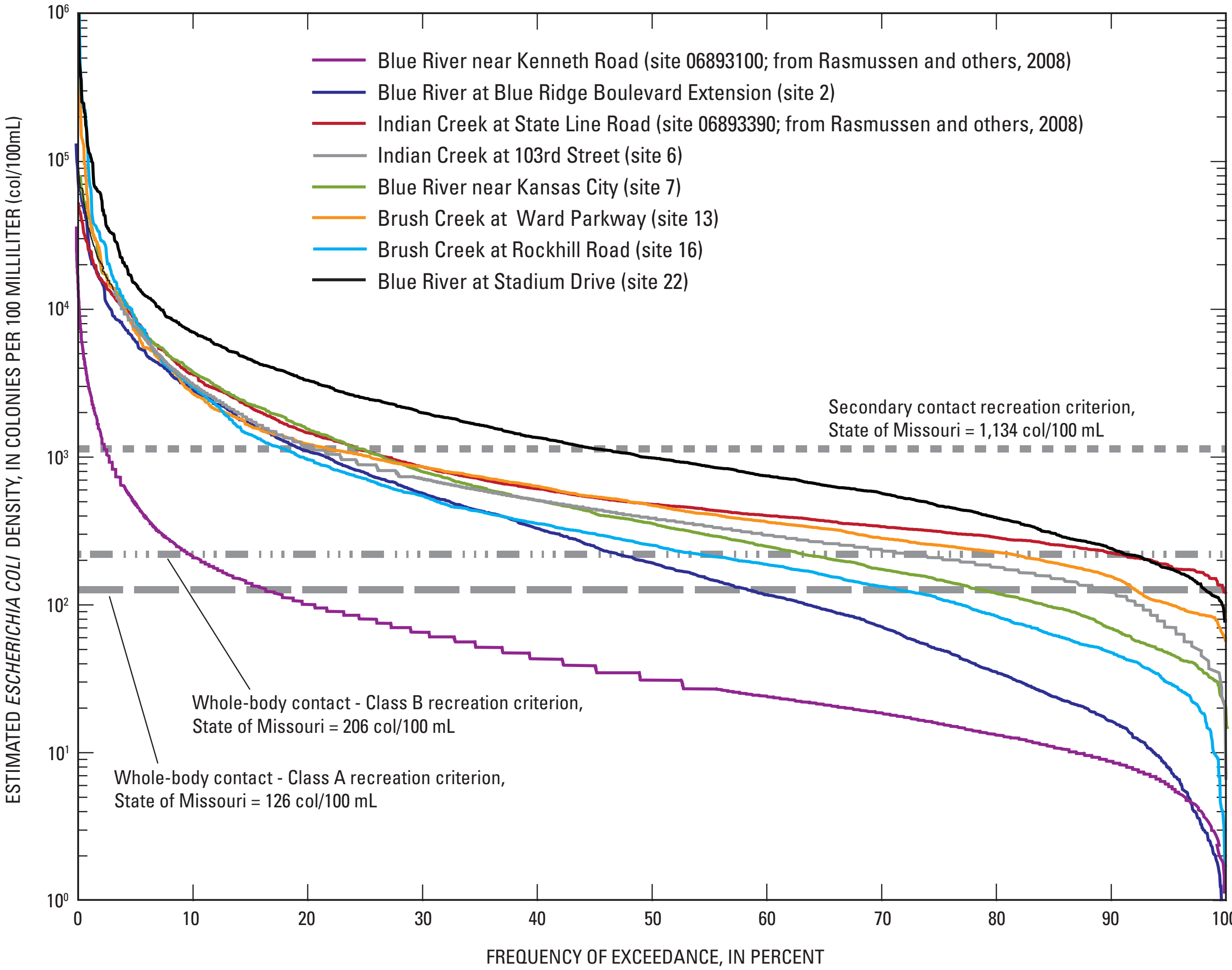


Figure 11. Estimated daily mean *Escherichia coli* density duration curves at water-quality sites in the Blue River Basin, October 2002 through September 2007.

In 2005, the city of Kansas City, Missouri, collected samples for *E. coli* determination (fig. 10) from nine CSOs or diversion structures and six stormwater outfalls. Stormwater outfall samples were collected during runoff events that drained predominantly commercial, industrial, or residential land use areas. Median *E. coli* densities from CSOs were 138,000 col/100 mL, more than 10 times the median value measured in stormwater outfall samples and about 7.5 times the median value measured in USGS stormflow samples from all sites in the Blue River Basin (18,200 col/100 mL). Median *E. coli* densities from stormwater outfalls located in residential land-use areas were 5 times higher than those in industrial areas and 15 times higher than those from areas where commercial land use predominated. These data indicate that large amounts of fecal-indicator bacteria in receiving waters originate as nonpoint-source pollution in residential areas. Additionally, these data indicate that leaks or compromised sewer lines may affect elevated instream fecal-indicator bacteria densities enumerated in more densely populated parts of the city. Sewer leaks would not likely be observed in the field directly discharging into receiving waters—especially because in many reaches of Brush Creek impoundment, water levels are higher than the surrounding sewer grade—unless the leaks were major or connected to a force main. Instead, because of sewer lines construction, small leaks would likely gravitate to the underlying gravel pack and from there, potentially migrate through the gravel pack and then downgradient to receiving waters. Backfilled trenches for placement and relocation of other infrastructure such as telephone, computer, and cable lines also likely have created numerous preferential pathways, many of which likely intersect zones where sewer lines have been placed. Although some biotransformation along these short-circuited, preferential flow paths likely would occur, it would probably amount to less biotransformation than possible when water migrates through unsaturated zone soils. Estimates of the percentage of annual contributions of

Table 14. *Escherichia coli* bacteria standards applicable to stream reaches of the Blue River, Missouri and Kansas, 2009.

[col/100 ml, colonies per 100 milliliters of water]

Criterion	Applies to	Description	Designated use and (applicable standard)
2,358 col/100 mL	Headwaters to State line	Geometric mean of at least five samples in 30-day period from November to March	Primary contact recreation in public waters (Kansas Department of Health and Environment, 2005)
2,358 col/100 mL	Headwaters to State line	Single sample at any time during the year	Secondary contact recreation in public waters (Kansas Department of Health and Environment, 2005)
262 col/100 mL	Headwaters to State line	Geometric mean of at least five samples in 30-day period from April to October	Primary contact recreation in public waters (Kansas Department of Health and Environment, 2005)
206 col/100 mL[1]	State line to Bannister Road (site 7)	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact—Class B[1] (State of Missouri, 2008)
126 col/100 mL	Bannister Road (site 7) to 59th Street (approximately 2.1 kilometers north of site 9)	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact—Class A (Missouri Department of Natural Resources, 2007)
206 col/100 mL[1]	59th Street (approximately 1.3 miles north of site 9) to confluence with Missouri River	Geometric mean during the recreational season from April 1 to October 31 in waters designated for recreation or at any time in losing streams	Whole body contact—Class B[1] (State of Missouri, 2008)

[1]Emergency rule adopted December 15, 2008. Prior standard was 528 colonies per 100 milliters.

fecal-indicator bacteria originating from point and nonpoint sources in the basin are discussed in the Annual Contribution of Constituents section of this report.

Cumulative duration curves for estimated daily mean *E. coli* densities at eight water-quality sites in the Blue River Basin from October 2002 to September 2007 are shown in figure 11. Estimates were determined by dividing the daily load estimates by the daily mean discharge at a given site. These curves show the amount of time estimated fecal-indicator bacteria densities were exceeded at eight sites in the basin. Thus, a frequency of 100 percent exceedance would indicate the lowest estimated density, and a frequency near zero would indicate the highest estimated density.

There are currently (2009) six separate *E. coli* bacteria standards that apply to the main stem of the Blue River (table 14), in part, because of the interjurisdictional nature of the basin, but also because designated uses for the stream change once it crosses into Missouri (Kansas Department of Health and Environment, 2005; Missouri Department of Natural Resources, 2007; State of Missouri, 2008). With the exception of the Kansas secondary contact recreation criterion, standard compliance is determined by comparison with the geometric mean of samples collected during specific timeframes throughout the year (table 14). In Missouri, standard compliance for fecal-indicator bacteria is assessed from the geometric mean of at least five samples collected during the recreational season (defined from April 1 to October 31) over a period of 3 years. If the geometric mean for any year exceeds the applicable standard, the stream is deemed impaired. However, to illustrate and provide an understanding of the frequency at which

Table 15. Percentage of days, by month, from October 2002 through September 2007 where estimated daily mean *Escherichia coli* densities in Blue River Basin streams would have met three levels of State of Missouri fecal-indicator bacteria criteria.

[<, less than]

Stream	Sites included	State of Missouri secondary contact recreation criterion: 1,134 colonies per 100 milliliters												Average	
		January	February	March	April	May	June	July	August	September	October	November	December	Yearly	April–October
Blue River	2, 7, and 22	91	85	86	73	58	42	57	60	55	70	82	83	69	59
Indian Creek	6	85	74	75	73	70	62	74	75	79	77	83	81	75	73
Brush Creek	13 and 16	93	93	91	86	80	67	72	66	68	73	84	89	79	73
Stream	**Sites included**	**State of Missouri whole-body contact-Class B recreation: 206[1] colonies per 100 milliliters**													
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Yearly**	**April–October**
Blue River	2, 7, and 22	57	51	35	29	17	5	21	26	14	27	46	37	30	20
Indian Creek	6	19	9	2	3	4	2	17	15	1	2	1	14	8	6
Brush Creek	13 and 16	50	59	48	40	26	20	22	16	23	12	17	30	30	23
Stream	**Sites included**	**State of Missouri whole-body contact-Class A recreation criterion: 126 colonies per 100 milliliters**												**Average**	
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Yearly**	**April–October**
Blue River	2, 7, and 22	39	40	22	17	9	2	15	18	9	19	36	28	18	15
Indian Creek	6	<1	<1	<1	<1	<1	<1	1	1	<1	<1	<1	<1	<1	<1
Brush Creek	13 and 16	29	43	35	30	14	10	10	10	11	3	6	19	17	12

[1]Standard adopted by emergency rulemaking December 15, 2008. Prior standard was 528 colonies per 100 milliters.

bacteria densities might have been expected to fall above or below a particular threshold from September 2004 through October 2007, whole-body and secondary contact criterion are plotted in relation to the estimated density duration curves on figure 11.

Estimated *E. coli* density graphs (fig. 11) illustrate a number of different things. *E. coli* densities are lowest throughout the entire range of densities at the least urban site [Blue River near Kenneth Road (site 06893100); Rasmussen and others, 2008.] A similar trend was seen with other Johnson County, Kansas, sites in that the lowest *E. coli* densities were observed at the most rural sites (Rasmussen and others, 2008). Slightly more than 80 percent of the time, *E. coli* densities at the Kenneth Road site were below the Missouri whole-body contact Class A recreation criterion of 126 col/100 mL; however, because the site lies immediately upstream from the Kansas-Missouri State line, State of Kansas standards apply (Kansas Department of Health and Environment, 2005). Under Kansas standards (262 col/100 mL), the estimated *E. coli* density would be below the standard approximately 90 percent of the time; both the State of Missouri and State of Kansas secondary contact criteria would be met more than 95 percent of the time at this site.

Applicable *E. coli* standards for the Blue River vary by stream reach based upon the designated use (table 14). Class A stream reaches are those reaches where free and open access by the public for swimming is allowed; Class B stream reaches are those reaches where other forms of whole-body-contact recreational use other than public swimming are allowed (Missouri Department of Natural Resources, 2007). Secondary contact recreation uses include fishing, wading, recreational boating, and incidental contact with the water. At site 2, for example, the estimated *E. coli* densities were less than the Missouri secondary contact recreation criterion (1,134 col/100 mL) about 85 percent of the time in October 2002 to September 2007 (fig. 11), with higher densities occurring primarily during stormflow runoff. However, during that same time, the whole-body contact B criteria would have been exceeded slightly more than one-half the time at site 2.

Stream segments of the Blue River downstream from the Kansas-Missouri State line are currently (2009) listed (table 14) for whole body contact—Class A (geometric mean of 126 col/100 mL) or whole body contact—Class B (geometric mean of 206 col/100 mL). Before December 15, 2008, the Missouri Class B standard was 528 col/100 mL. For the Class A reach of the Blue River from Bannister Road (site 7) to 59th Street (approximately midway between sites 9 and 10; fig. 1), estimated daily *E. coli* densities were below the Class A standard from 2002 to 2007 approximately 20 percent of the time, based on site 7 data (fig. 11). From 59th Street to the mouth at the Missouri River, where the less rigorous Class B standard is in place, estimated daily *E. coli* densities exceeded the Class B threshold value approximately 90 percent of the time from October 2002 through September 2007, based on site 22 data (fig. 11; table 15). If the Missouri secondary contact recreation criterion for *E. coli* of 1,134 col/100 mL were to be adopted for all Missouri reaches of the Blue River Basin, this standard would be exceeded approximately 30 percent of the time, primarily during wet weather events (table 15).

Instream fecal-indicator bacteria were evaluated to determine presumptive *E. coli* sources through the use of genotypic microbial source-tracking methods. These methods compared the similarity of genetic markers from host species *E. coli* to those from instream *E. coli* to identify presumptive sources of *E. coli* at stream sites in the basin. Base-flow and stormflow-runoff samples from nine sites in the basin were analyzed for host sources. The amount of bacteria in a sample assigned to a presumptive host source was determined from the percentage that each host class represented of the total *E. coli* density enumerated from the sample. Because bacteria densities in stormwater runoff are much greater than in base-flow samples, sources that contribute most heavily during storms would constitute a much higher percentage of the total number identified. From the density weighted mean percent of all 56 samples collected from February 2000 to August 2007, 30 percent were assigned to presumptive dog sources, 5 percent were assigned to geese, 58 percent to human, and 7 percent were from unknown, or unclassifiable, sources (table 16). The overall percentages of human-derived bacteria are higher than those previously reported for base-flow samples (Wilkison and others, 2006).

Almost one-half (45 percent) of the human *E. coli* bacteria measured in stream samples originated from two storm events on Town Fork Creek (site 19). This was, in part, because site 19 had large densities of human-sourced bacteria and because stormflow densities were so much greater than base-flow densities (tables 7 and 8). When samples are viewed from the hydrologic event perspective, a higher percentage of the *E. coli* is derived from human sources during storm events than during base-flow events (table 16). This was expected because several human-source pathways are confined to storm runoff. During large storms, CSO and WWTP bypasses contribute large amounts of untreated wastewater bacteria to streams, although some bypass discharges are treated to remove bacteria.

Stormwater runoff also can mobilize previously deposited sediments, which may harbor fecal-indicator bacteria for extended periods (Van Kessel and others, 2007; Donovan and others, 2008). As evidenced by the high percentage of human bacteria in base-flow samples (43 percent), the environmental persistence of *E. coli* may be a concern in the basin. Infiltration and the subsequent migration of water through the unsaturated and saturated zones in areas with compromised sewer lines also may affect the high percentages of presumptive human *E. coli* observed in base-flow stream samples. The role of such phenomena, essentially a short-circuiting of the sewer system, likely represents a substantial, though as yet unquantified contribution to instream fecal-indicator bacteria.

Only a very small percentage of the total *E. coli* bacteria in basin streams in any given year was characterized using microbial source tracking methods. Consequently, the percentage of each host class can vary substantially from year to year

Table 16. Percentage of *Escherichia coli* measured in stream samples collected between February 2000 and August 2007 assigned to presumptive host sources.

[Numbers in bold are basin averages weighted by sample bacterial densities; <, less than]

Hydrologic condition	Stream name	Site(s) included (fig. 1)	Number of samples	Number of isolates	Presumptive host source			
					Dog	Goose	Human	Unknown or unclassified
	Brush Creek	13, 15, 16, 20	23	304	24	16	43	17
	Blue River	2, 7, 22	22	296	42	16	40	3
	Indian Creek	6	7	123	31	25	38	6
	Town Fork Creek	19	4	57	29	< 1	65	6
Base-flow		2, 6, 7, 13, 15, 16, 19, 20, 22	49	652	37	16	43	4
Stormflow		2, 6, 7, 13, 16, 19, 20, 22	7	128	30	5	58	7
	All samples (weighted by densities)	**2, 6, 7, 13, 15, 16, 19, 20, 22**	**56**	**780**	**30**	**5**	**58**	**7**

and, thus, caution should be exercised in assuming that these percentages are entirely representative of basin streams. Single storm events, because of their ability to mobilize large *E. coli* densities, can account for almost all the *E. coli* bacteria in any given year (Rasmussen and others, 2008). Host-source data indicate that while other animal sources can at times contribute the bulk of *E. coli* to streams, human bacteria frequently constitute a substantial part of the stream *E. coli* load.

Trends with Time

Trends are the changes, either increases or decreases, in measurements over a specific time period. Determination of whether or not significant changes are occurring in water chemistry with time is especially important if substantial changes are happening, or projected to happen, within the basin. The CSO control plan has components designed to alter selected stream reach hydrology and reduce contaminant inputs. Therefore, the plan has the potential to substantially alter stream water chemistry. Thus, an understanding of trends is important to providing a basis for understanding the effectiveness of mitigation strategies.

Flow-adjusted concentration trends were calculated because concentration trends are often strongly affected by streamflow trends. By removing streamflow trends that may be present, flow-adjusted trends reflect changes that have occurred in the basin over time, such as land-use changes or implementation of best-management strategies designed to reduce either point or nonpoint-source contributions.

Discrete water samples collected over a range of hydrologic conditions were used to develop load-estimation models for selected constituents (table 17, at the back of this report). These load-estimation models then were used to determine daily, monthly, seasonal, and annual load estimates and to determine flow-adjusted trends with time. The monthly, seasonal, and annual loads were sums of daily loads over the appropriate time span. Flow-adjusted trends in water-quality data were determined for the period of 1998 through 2007 at four sites (sites 7, 13, 16, and 22) in the basin and for the period 2002 through 2007 at two sites (sites 2 and 6) in the basin. The time span was chosen based upon the length of data collection at each site and for each constituent modeled. Flow-adjusted trends were determined by use of fitted linear regression models that compared concentration to flow, time, and in some cases yearly or seasonal terms.

Table 18 (at the back of this report) lists flow-adjusted trend data determined at sites and model parameters used to fit the trend models. Where possible, monotonic (changing in one direction only) flow-adjusted trends were determined at stream sites for 22 constituents by fitting a model that met previously defined model-selection criteria. Constituents for flow-

Table 19. Summary of flow-adjusted concentration trends at sites in the Blue River Basin, 1998 through 2007.

[FAC, flow-adjusted concentration; n, number; p, significance level; --, not applicable; >, greater than; <, less than or equal to]

Site number (fig.1)	Period of analysis	Fitted FAC models	FAC models with no significant trend (p>0.05)		FAC models with significant trends (p< 0.05)		FAC models with significant and downward trends			FAC models with significant and upward trends		
		n	n	Percentage of total fitted	n	Percentage of total fitted	n	Percentage of total fitted	Average annual decrease	n	Percentage of total fitted	Average annual increase
2	June 2002–Sept. 2007	18	14	78	4	22	4	22	- 15	0	0	--
6	April 2002–Sept. 2007	20	13	65	7	35	6	30	-6.5	1	5	2.0
7	Oct. 1998 – Sept. 2007	20	11	55	9	45	6	30	-5.9	3	15	4.5
13	Oct. 1998–Sept. 2007	19	13	68	6	32	6	32	-7.1	0	0	--
16	Oct. 1998–Sept. 2007	19	15	79	4	21	4	21	-6.4	0	0	--
22	Oct. 1998–Sept. 2007	21	9	43	12	57	11	52	-6.7	1	5	7.0
Total or **average**		117	75	**64**	42	**36**	37	**32**	**-8**	5	**4**	**5**

adjusted trend analysis included total and dissolved nutrients, chloride, suspended sediment, fecal-indicator bacteria, and selected organic wastewater indicator compounds including caffeine, DEET, sterol, and triclosan. In this method, trends can rise and fall with time; however, the average flow-adjusted trend over the entire time period is reported (table 18). Flow-adjusted trends were considered significant only if the significance level of the time term was less than or equal to 0.05 ($p < 0.05$). Fitted models with time terms that have significance levels greater than 0.05 ($p > 0.05$) indicate that conditions in the basin have not significantly changed over time with respect to that particular constituent.

Approximately two-thirds (64 percent) of the fitted flow-adjusted models did not have a significant time trend. These data indicate that conditions generally remained stable with time in the basin over the period October 1998 through September 2007 (table 19). However, where significant flow-adjusted concentration trends were determined, most (88 percent) were declines and these were primarily associated with constituents strongly associated with suspended sediment.

Significant flow-adjusted declines in suspended-sediment concentration occurred at five of the six sites in the basin (table 18). Declines in flow-adjusted suspended-sediment concentrations from October 1998 through September 2007 were significant ($p<0.001$) at sites 7, 13, and 22 and at sites 2 and 6 from October 2002 through September 2007. Flow-adjusted suspended-sediment concentrations also declined at site 16, Brush Creek at Rockhill Road, but the trend was not statistically significant. Flow-adjusted suspended-sediment concentrations declined at sites 7, 13, and 22 by an average 8 percent per year over the 9-year period from October 1998 through September 2007. These data indicate that limiting sediment supply to streams reduce many other constituent concentrations in basin streams. Declines in suspended-sediment concentration are important because many constituents, such as bacteria, some nutrients, and a number of wastewater-derived compounds, have a strong affinity for sediment particles.

Although flow-adjusted declines in fecal-indicator bacteria were observed at five of the six sites, the declines were only significant at site 2 (table 18) for the period October 2002 to September 2007. Significant declines also were observed at some sites for a number of other constituents (DEET, sterol, plastic compounds, and the sum of organic wastewater compounds) that have a strong affinity for sediment.

Observed declines in flow-adjusted suspended-sediment concentrations may be the result of several initiatives that began around the year 2000 in the basin. The city of Kansas City, Missouri, began several initiatives, such as more rigorous street sweeping and catch basin cleaning programs, around this time. Between 1999 and 2007, approximately 17,000 catch basins were cleaned annually as part of this program and more than 5,000 older ones replaced (Richard Gaskin, Kansas City, Missouri, Water Services Department, written commun., 2008). New design criteria for sediment erosion and control were adopted in the metropolitan area beginning in 2003 (American Public Works Association, written commun., 2008). In the several years prior to that time, a number of watershed groups as well as governmental and nongovernmental agencies began concerted efforts to educate the public about methods to reduce runoff, erosion, and protect basin water quality. Although exact numbers are not available, these presentations have numbered in the thousands over the last 10 years and have reached an audience expected to number in the hundreds of thousands (Larry O'Donnell, Little Blue River Watershed Coalition, oral commun., 2008; Wendy Sangster, Missouri Department of Conservation, oral commun., 2008). Additionally, parts of the upper Blue River Basin (primarily upstream from site 2) experienced substantial suburban growth and development over the last 10 years resulting in the transformation of some agricultural land to developed land, which may be less vulnerable to erosion.

Significant increases in flow-adjusted concentrations were observed for dissolved chloride at two sites on the main stem of the Blue River (sites 7 and 22, table 18). These increases likely were related to increased, or more frequent, use of road deicers in the basin during, and in anticipation of, severe winter weather. As previously discussed, chloride concentrations in streams can remain elevated for weeks following such applications. A small, but significant, increase in flow-adjusted dissolved nitrite plus nitrate and total nitrogen was observed at site 7. Generally, more than 80 percent of the total nitrogen at this site is in the form of dissolved nitrate; therefore, an increase in dissolved nitrate likely would be reflected in the total nitrogen trend. Increases in total and dissolved nitrogen at this site may reflect upstream population increases (22 percent; U.S. Census Bureau, 2008) in the period 1998 to 2007 and the resultant increases in WWTP discharges, changes in land-use practices as land use becomes more urbanized or suburbanized, or a combination of both.

Table 18 also lists the reference concentrations over the modeled time frame. The reference concentration represents a central tendency (median) of the modeled data over the range of hydrologic conditions during the modeled period. The reference concentration is similar to the median value of all discrete water-quality samples (which includes base-flow and stormflow samples) and provides another means of comparing central tendencies between sites or a benchmark for comparison to future concentrations or densities. The reference value integrates many more values than does the median value of discrete base-flow and stormflow samples because the model output includes daily values over a minimum 5-year timeframe (water years 2003–2007), but in most cases the timeframe was 9 years (water years 1999–2007). Water years are the 12-month period, October of one year through September of the next year.

A flow-adjusted model attempts to factor out the effect of trends in flow from trends in concentration. It is important to note that the flow-adjusted trends in concentrations or densities does not necessarily equate to the trend in actual observed loads. This would only be the case if streamflow remained constant with time, which it does not. Instead, the flow-adjusted concentration trend reflects the average change that has occurred in the basin, whereas trends in basin loads reflect the trend in concentration plus the variability in flow conditions that occurred over the same time interval (fig. 12). In some years, especially those with large storms, increased sediment loads occur because flow is such a large component of loads.

Flows in the Blue River Basin were much greater than average during the first year of data collection (July 1998–June 1999) when compared to the long-term average; flows in some months were more than 700 percent of the long-term average (fig. 13). For example, on the Blue River (site 7), 30 percent of all the daily mean flows greater than 2,500 cubic feet per second (ft^3/s) between July 1998 and December 2007 occurred during the first year. Based upon the long-term record at this site, flows of this magnitude would have an expected annual probability of occurrence of 0.02 percent (fig. 14) in any given year. There were 12 occurrences of daily mean streamflow in excess of 2,500 ft^3/s at site 7 between July 1998 and June 1999, an indication of just how wet the initial year of observations was with regards to normal streamflow.

Streamflow greatly affects constituent concentrations in the basin (Wilkison and others, 2006). This is partly because most sediment in the basin is transported in extremely large storms (Rasmussen and others, 2008). Large storms also trigger more CSOs, and extended periods of wet weather would be expected to raise groundwater levels in the basin and increase the likelihood and magnitude of any issues associated with sewer leaks. Conversely, drought periods also have a pronounced effect on constituent concentrations. This is because, in part, as the number or intensity of storm events decrease, opportunities for nonpoint-source transport also diminish. However, in effluent-dominated reaches, the percent of streamflow composed of treated effluent frequently increases to more than 95 percent during droughts. The number and length of CSO events likely will decline during drought periods.

The wetter than average period July 1998 through June 1999 was immediately followed by several years, July 1999 through July 2003, of below normal streamflow. This large decrease in streamflow over a relatively short timeframe also may have contributed to flow-adjusted concentration trend declines observed between 1998 through 2007.

The effect of increased streamflow in the early part of the study also is reflected in the monthly total nitrogen, total phosphorus, caffeine, DEET, triclosan, and sterol (defined in this report as the sum of coprostanol plus cholesterol) loads (table 20, at the back of this report). For these constituents, an average of 23 percent of the total Blue River load (site 7) over the period 1998 to 2007 was contributed during the first water year (October 1998 to September 1999). For Brush Creek, the average percent contribution during the first year was even higher, 27 percent at site 13 (Brush Creek at Ward Parkway) and 32 percent at site 16 (Brush Creek at Rockhill Road). These data indicate that extremely wet periods contribute increasingly larger amounts of constituents, in part, because many sources in the basin are triggered by rainfall. These sources include increased CSOs and more frequent WWTP bypasses as well as increased contributions from nonpoint sources during large rain events.

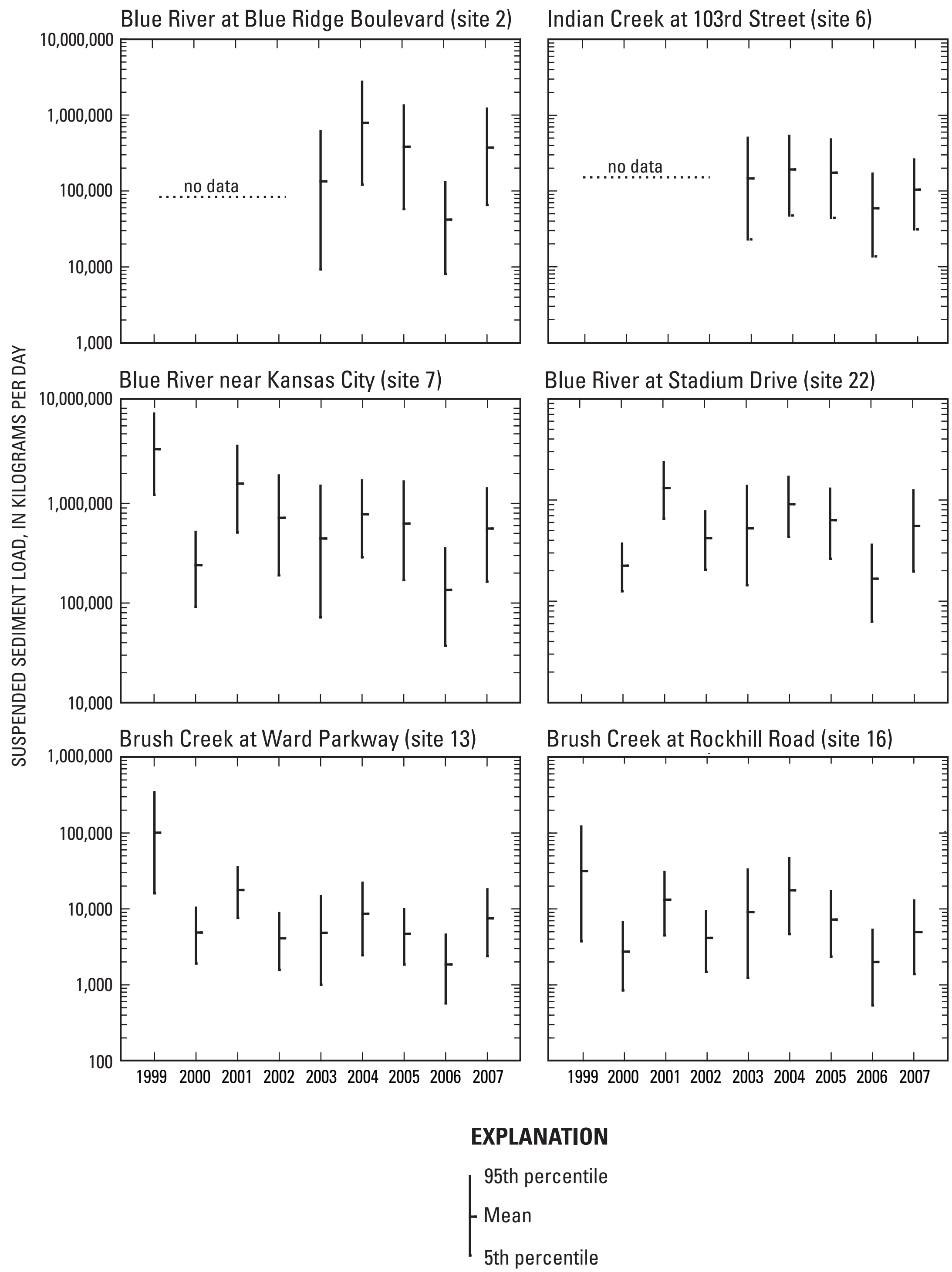


Figure 12. Daily mean load of suspended sediment at sites in the Blue River Basin for water years 1999 through 2007.

Estimated daily mean concentrations (or densities) for selected constituents at basin sites from the modeled data are shown in figure 15. Estimates are provided only for the period of record for sites where models met the previously defined model-selection criteria. Thus, for sites that began in 1998, data are shown for the period October 1998 to September 2007. At sites 2 and 6, where data collection began later, data are shown from the spring of 2002 to September 2007. Estimated daily mean concentrations were determined by dividing the estimated daily load by the daily mean discharge; therefore, these estimates included the effects of flow on concentration and densities. Because plots (fig. 15) included daily estimates of values over many years, patterns that might not

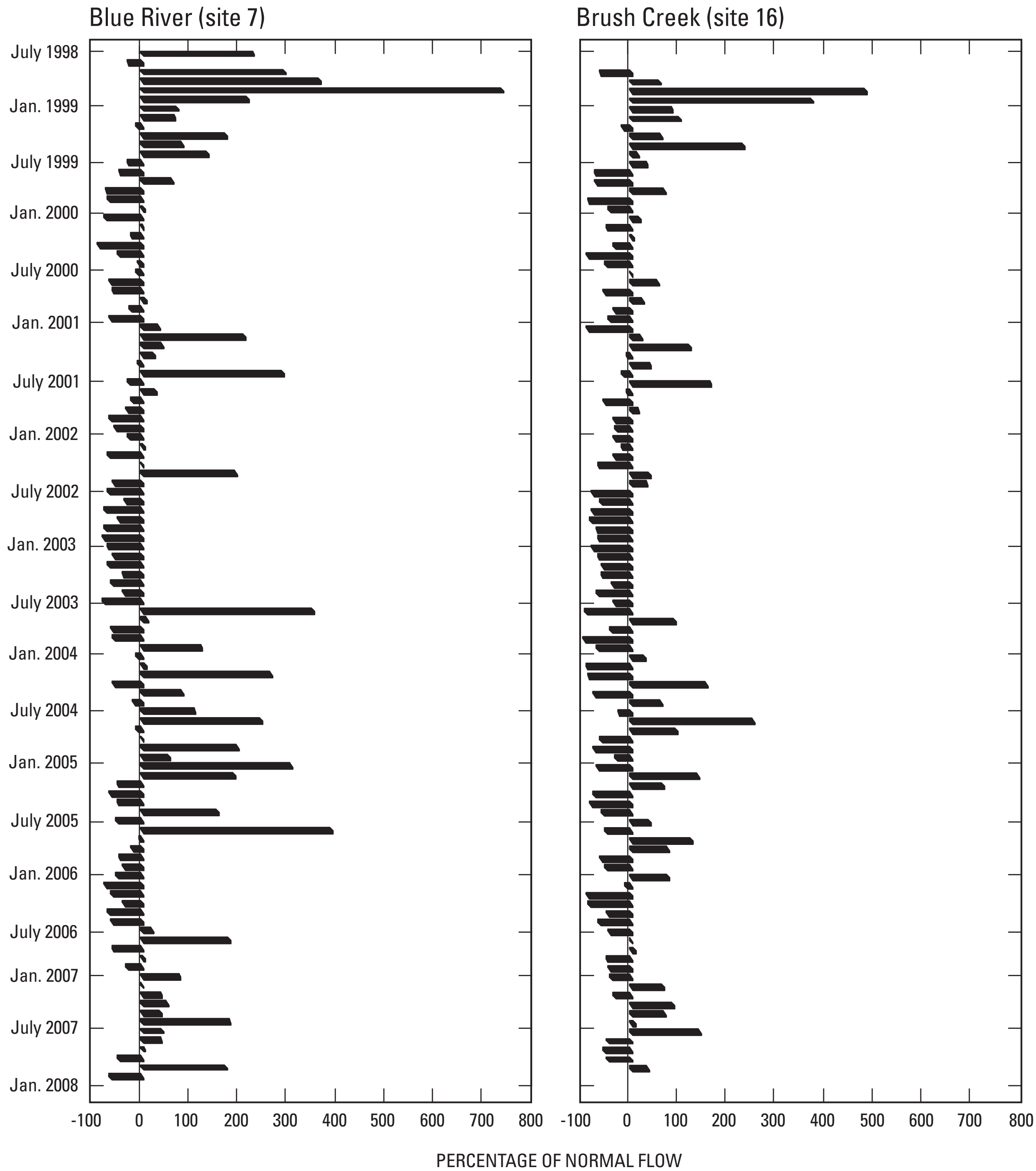


Figure 13. Monthly mean streamflow deviation from the long-term average on the Blue River (1939–2007) and deviation from the 10-year average (1998–2007) on Brush Creek from July 1998 through December 2007.

have been visible based solely upon examination of discrete values with time plots can be more readily observed.

There was considerable variation in the estimated daily mean concentration of constituents at any given site (fig. 15). Constituent concentration variations were affected by a variety of factors including streamflow, time of year, sources, the type of constituent, and combinations of these factors. For some constituents, the interannual concentration pattern changed in response to source differences. For example, at sites on the Blue River (sites 2, 7, and 22) and Indian Creek (site 6) a part of the in-stream total nitrogen concentration resulted from WWTP inputs. These inputs occurred primarily in the dissolved phase (as dissolved nitrate) and resulted in increased total nitrogen concentrations during periods with the lowest streamflow (Wilkison and others, 2005). WWTP discharge permits for plants in the basin also allowed for increased concentrations of nutrients to be discharged during winter periods (U.S. Environmental Protection Agency, 2008) when

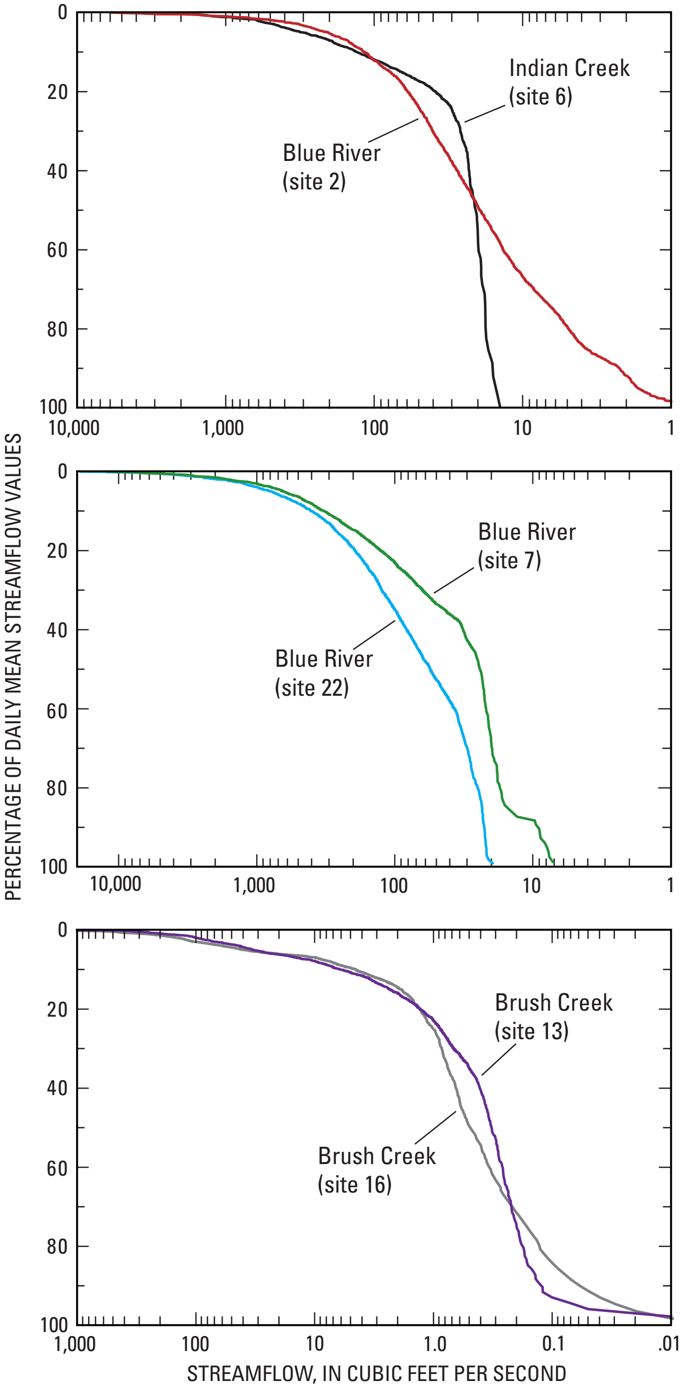


Figure 14. Flow duration curves for sites in the Blue River Basin from July 1998 through December 2007.

biogeochemical processes, which would be expected to help assimilate instream nutrients, are reduced by colder winter temperatures. Thus the greatest total nitrogen concentrations at sites 2, 6, 7, and 22 tended to occur during periods with the lowest flow and the coldest temperatures. This is most easily observed when values are graphed by month (fig. 16). For example, at Indian Creek (site 16; fig. 16), the median daily total nitrogen concentrations exceeded 10 mg/L for the months November through March and the lowest median concentration (7.5 mg/L) occurred during June.

Total nitrogen concentration patterns in Brush Creek (site 16; fig. 16) were shifted slightly from the Indian Creek pattern and concentrations were lower in Brush Creek than in Indian Creek. The peak monthly median total nitrogen concentration at site 16 occurred in February and March (average of 2.96 mg/L) and the lowest median concentration occurred in August and September (average of 1.60 mg/L). The cycle of total nitrogen monthly values observed at site 16, with declining values throughout the summer months, indicated that changes in nutrient assimilation rates throughout the year also may have affected in-stream concentrations. Fertilizer applications to lawns and golf courses during the early part of the year (February through March) also may have contributed to increased median total nitrogen concentrations. Because of colder temperatures and less available solar energy, late winter periods also tended to coincide with periods of more limited nutrient assimilation by plants.

Daily plots of estimated daily mean concentrations also illustrate how the range and minimum value of concentrations differed between sites. For example, the estimated total phosphorus concentration in Indian Creek (site 6; fig. 15) from October 2002 through September 2007 ranged from 0.90 mg/L to 4.8 mg/L, but were below 1 mg/L only 6 percent of the time.

The minimum total phosphorus concentration at site 6 on Indian Creek (0.71 mg/L; fig. 15) was approximately double the average minimum concentration for site 2 on the Blue River (0.34 mg/L; fig.15) and approximately 5 times the concentration at site 16 on Brush Creek site (0.17 mg/L; fig. 15). The increases were largely attributable to the effect of WWTP effluents on stream total phosphorus concentrations as well as the size of the drainage area upstream from a site. Two WWTPs discharge in the 168-km^2 drainage area upstream from site 6, as opposed to one plant discharging in the 241-km^2 drainage area upstream from site 2 (Wilkison and others, 2005). Additionally, the two WWTPs upstream from site 6 had an average annual effluent discharge of more than four times that of the WWTP upstream from site 2 (U.S. Environmental Protection Agency, 2005; 2008).

Estimated daily mean suspended-sediment concentrations (fig. 15) show similar patterns as do the plots of estimated *E.coli* densities, partly because both constituents largely were determined by streamflow. The bulk of suspended sediment and bacteria originated during runoff events. Thus, increased *E. coli* densities for 2004 to 2005 largely were attributable to the larger than average streamflow that occurred during this period (fig. 13). Daily mean E.coli densities spiked during storms and remained elevated during runoff periods and increased streamflow; however, densities typically decreased substantially within a few days to prestorm levels. Because bacteria densities are responsive to storm runoff, the range of *E. coli* densities at sites typically covered a large span. For example, bacteria densities at several sites (sites 2 and 22)

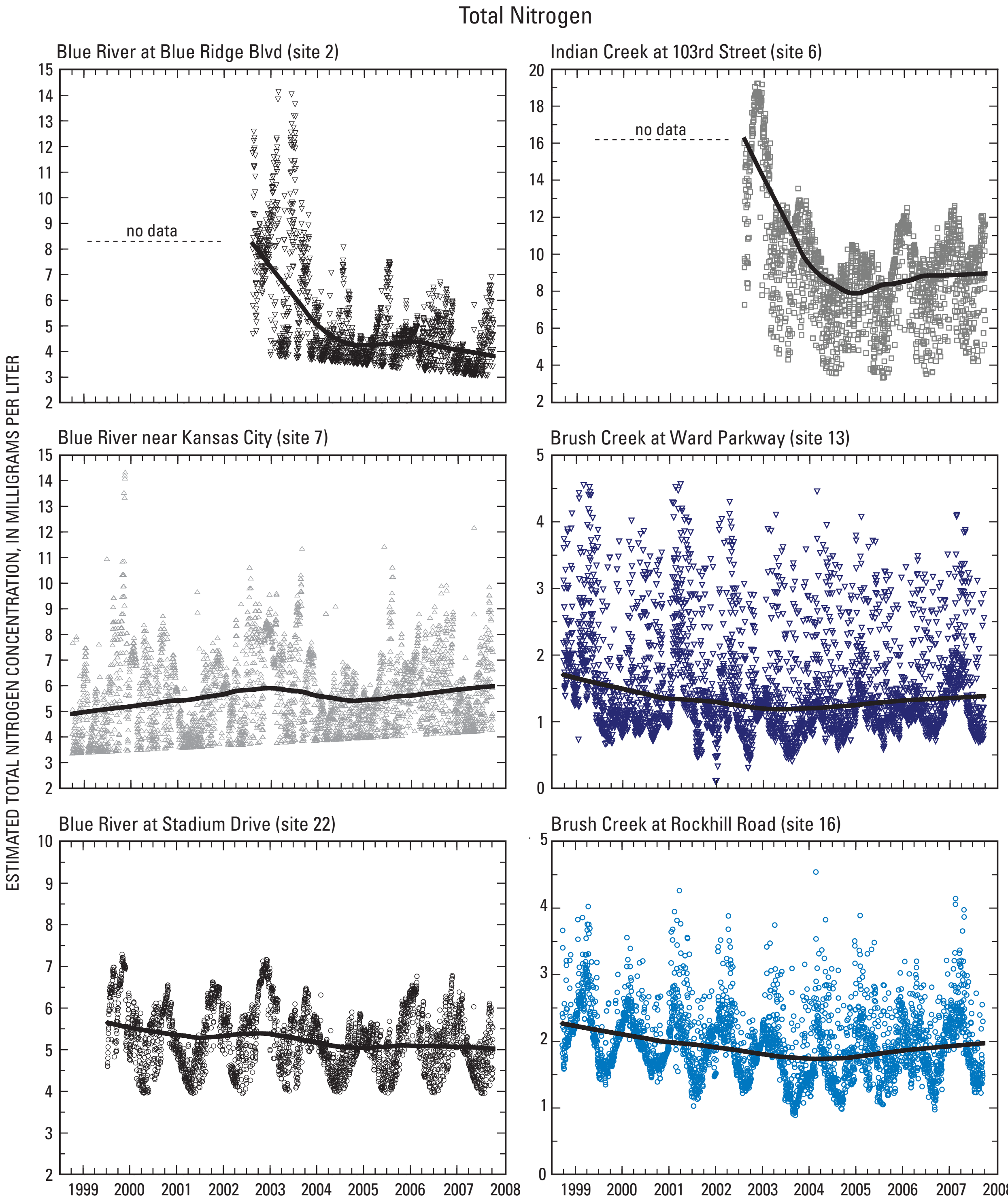


Figure 15. Estimated daily mean concentrations from October 1998 through September 2007 at sites in the Blue River Basin. Solid lines are locally weighted linear regression (LOWESS) curves through the data points. (Note scale change between plots)

frequently spanned four to five orders of magnitude during any given year (fig.15).

At all sites, daily mean *E.coli* densities followed a cyclical pattern throughout the year, with the lowest median densities occurring during the midwinter months and the peak median densities occurring during late spring to summer months (fig. 16; table 20). As previously noted, fecal-indicator bacteria standards are not uniform for stream segments in the basin (table 14) and stream *E. coli* densities in excess of the various State of Missouri fecal-indicator criteria occurred in every month (table 15). June, the month with the greatest average precipitation, had the highest median *E.coli* densities and

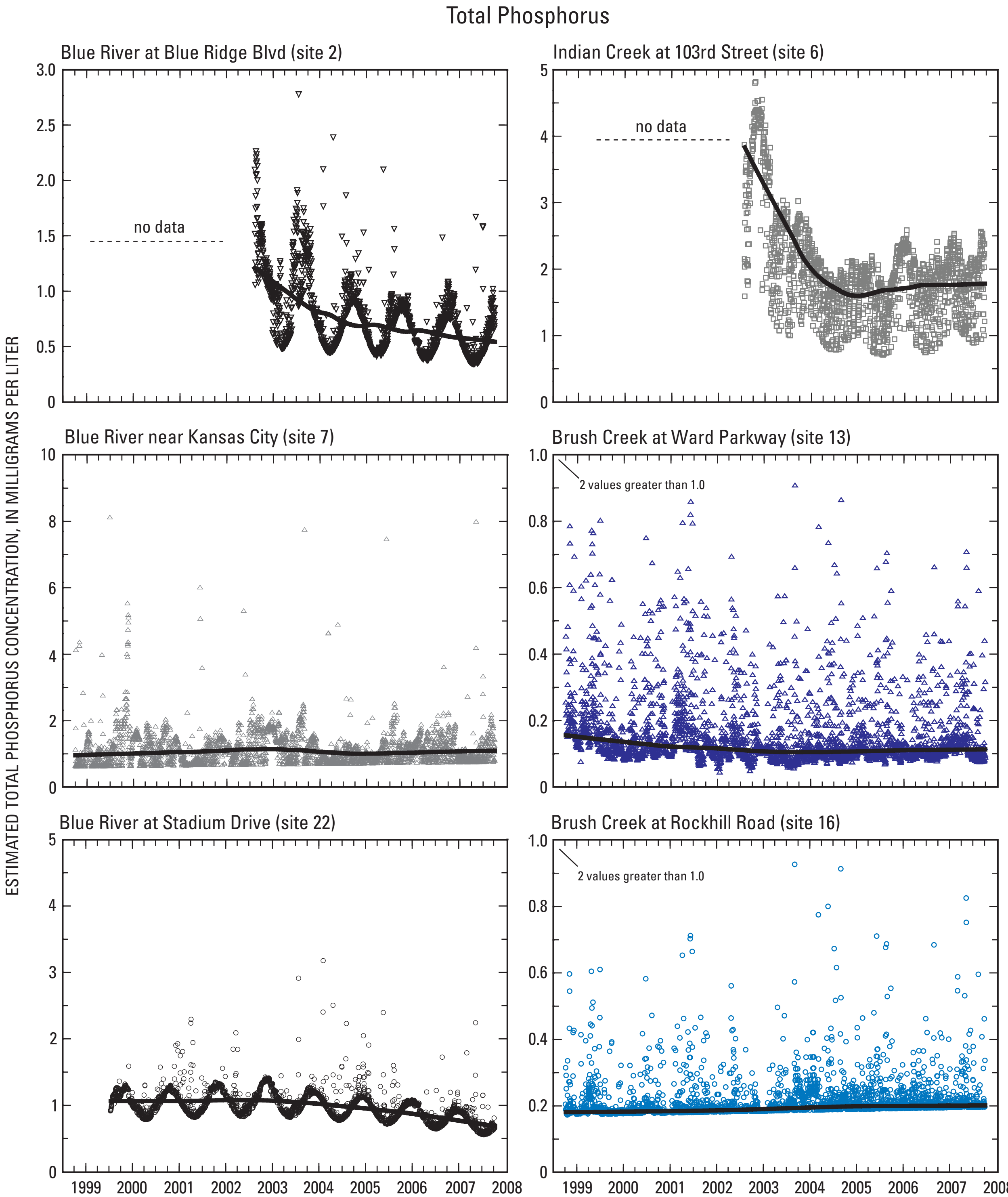


Figure 15. Estimated daily mean concentrations from October 1998 through September 2007 at sites in the Blue River Basin. Solid lines are locally weighted linear regression (LOWESS) curves through the data points. (Note scale change between plots)—Continued

the fewest number of days in which bacteria criteria would have been met (fig. 16; table 15).

Daily mean caffeine concentration patterns reflected the primary differences in sources at sites as well as the effects of temperature on instream concentrations. For example, sites 7 and 22 on the Blue River are located downstream from three WWTPs. The monthly median caffeine concentration in the Blue River peaked during December and January (average of 1.13 µg/L; fig. 16) when temperatures were the coldest and the percentage of streamflow consisting of effluent was the largest. Monthly median caffeine concentrations then declined to their lowest levels during June and July (average of 0.37

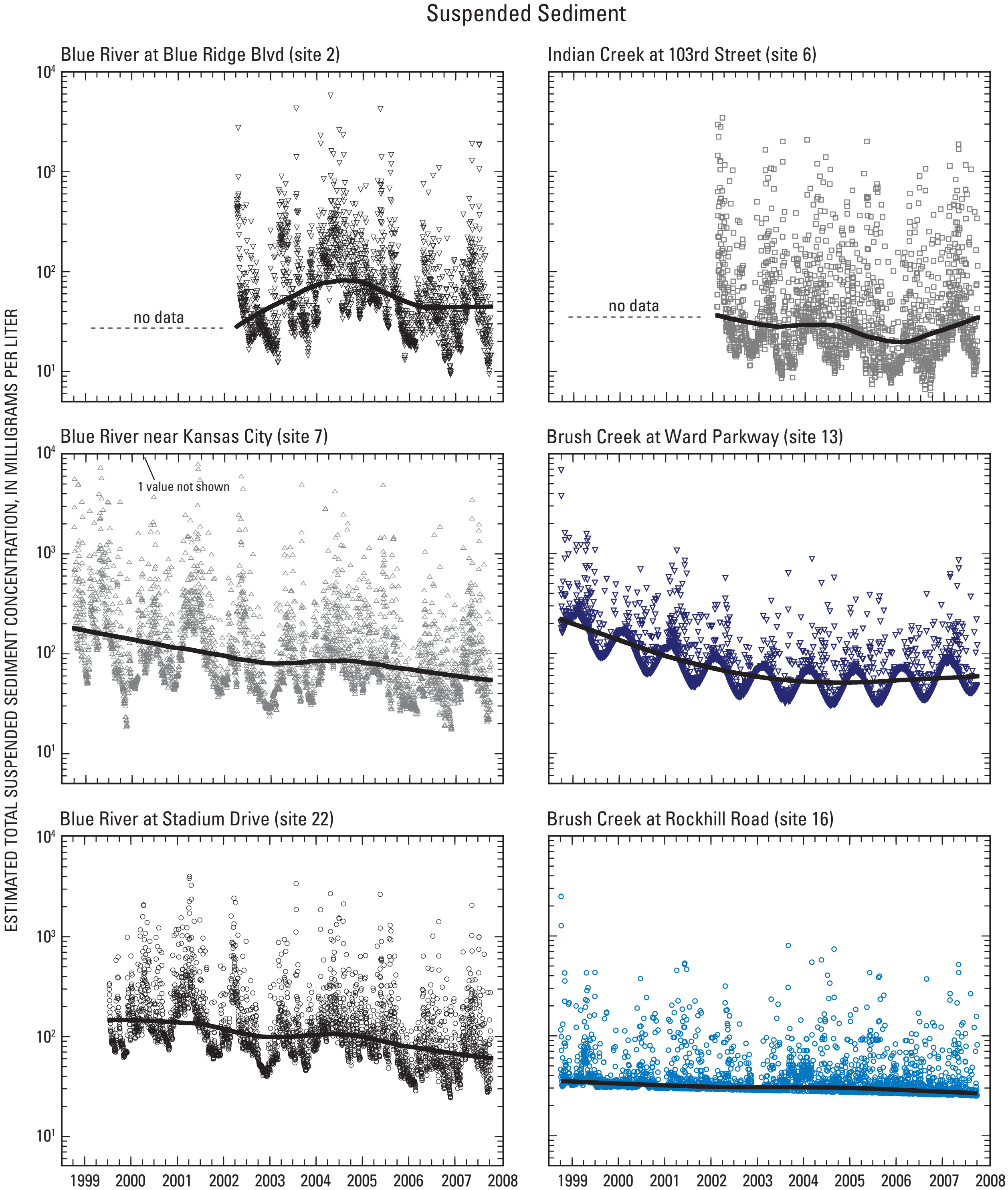


Figure 15. Estimated daily mean concentrations from October 1998 through September 2007 at sites in the Blue River Basin. Solid lines are locally weighted linear regression (LOWESS) curves through the data points. (Note scale change between plots)—Continued

µg/L; fig. 16), which was probably because of the effects of increased WWTPs removal efficiencies during the summer. Once released to the environment, biodegradation and photolysis would remove additional caffeine from streams; these processes would be expected to peak in midsummer (Buerge and others, 2003). By contrast, the monthly median concentrations on Brush Creek (site 16) peaked from March to May (average concentration, 1.14 µg/L), and the lowest monthly median concentration occurred in August and September (average concentration, 0.56 µg/L).

Concentrations of the insect repellant DEET would be expected to peak during early to mid-summer when targeted

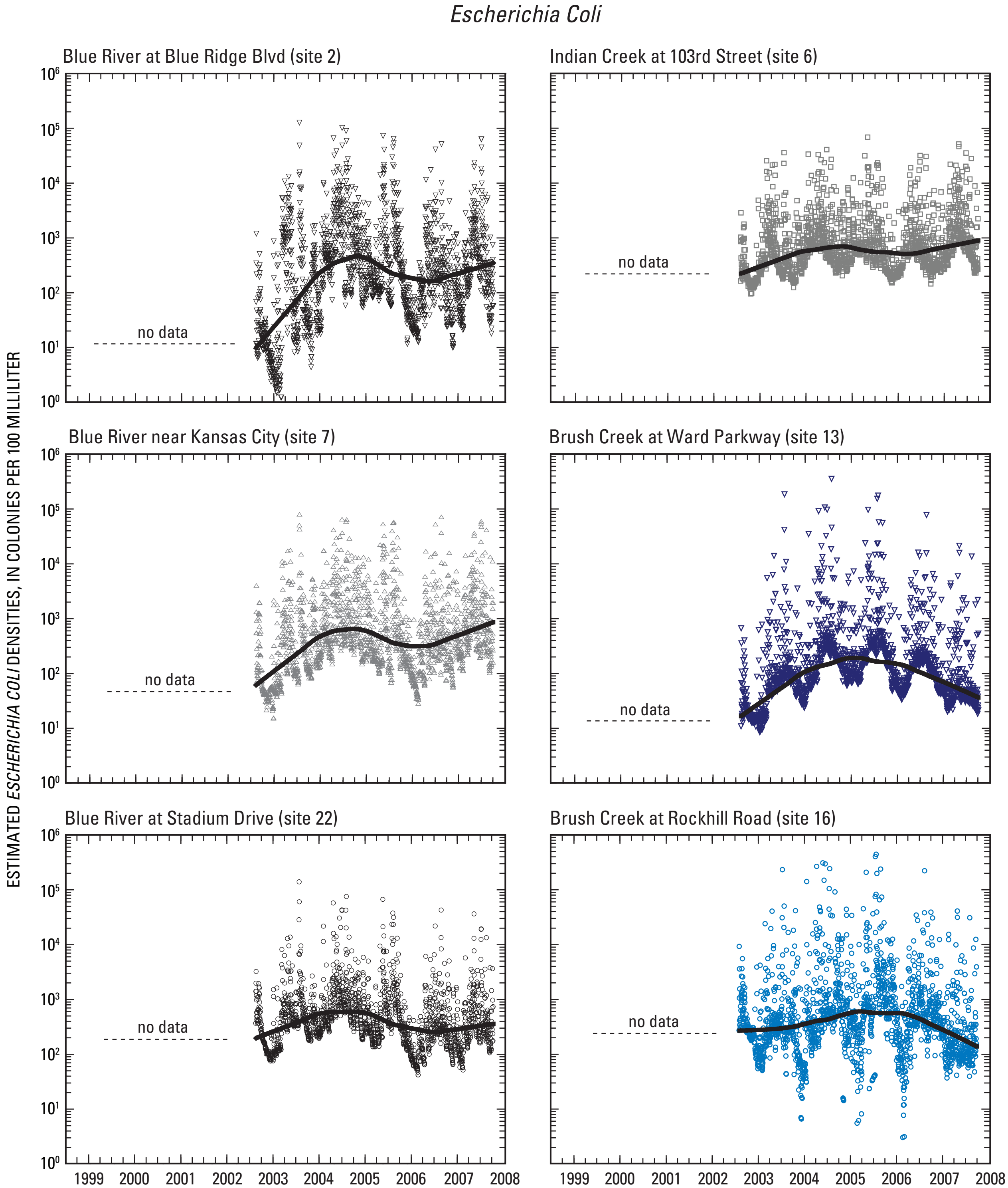


Figure 15. Estimated daily mean concentrations from October 1998 through September 2007 at sites in the Blue River Basin. Solid lines are locally weighted linear regression (LOWESS) curves through the data points. (Note scale change between plots)—Continued

nuisance insect populations—such as ticks and mosquitoes—hatch. Monthly plots of DEET concentrations indicate that peak DEET concentration occurred in the months of May and June or June and July (fig.16). For Indian Creek (site 6), the largest median monthly concentrations of DEET occurred in June and July with the average concentration (0.704 µg/L), approximately double the largest median concentration for the Blue River (sites 2, 7, and 22; average concentration, 0.296 µg/L) and Brush Creek (sites 13 and 16; average concentration, 0.36 µg/L), which occurred in May and June (fig. 16). The lowest concentrations of DEET occurred during January. Monthly median DEET concentrations in January ranged from

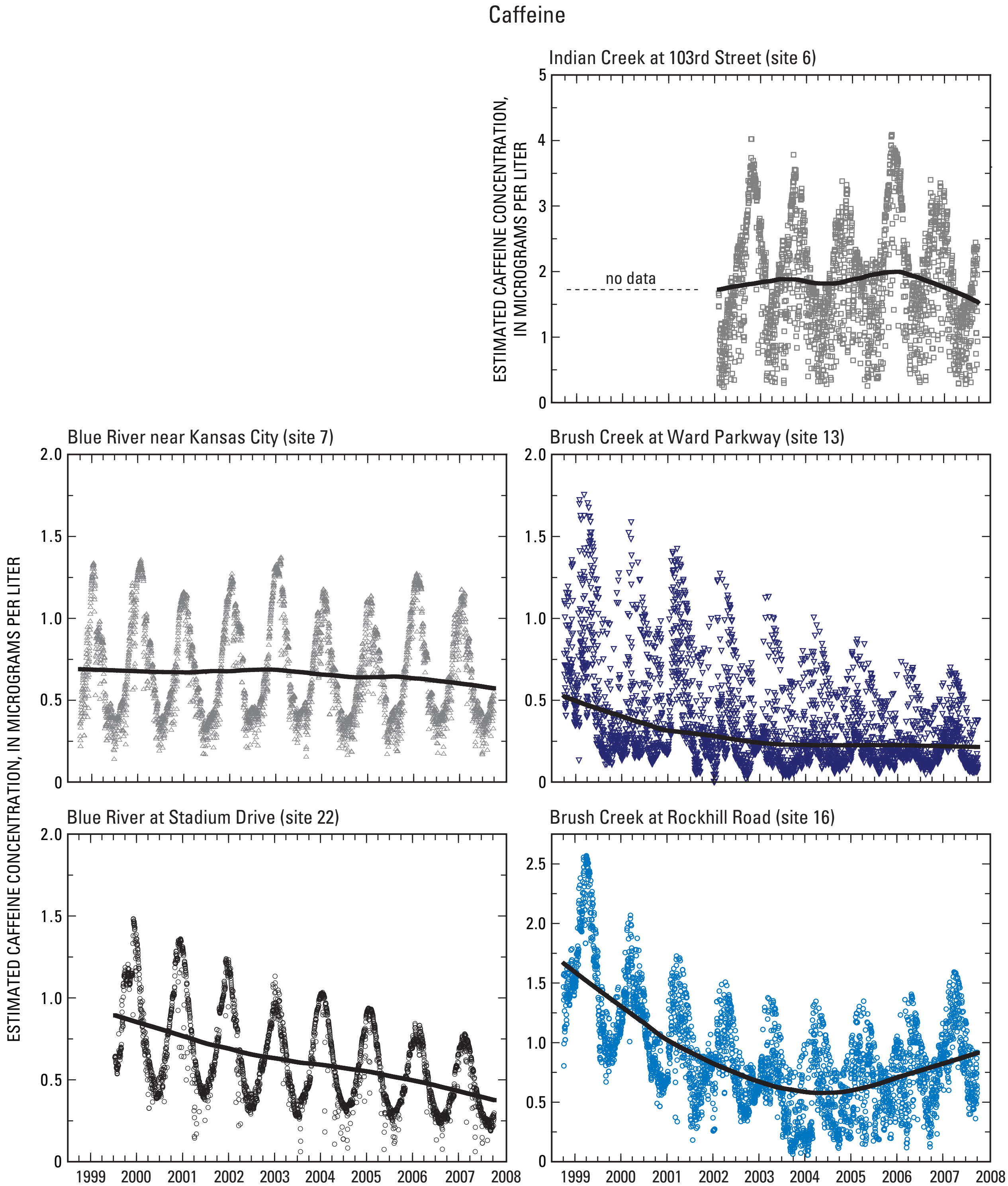


Figure 15. Estimated daily mean concentrations from October 1998 through September 2007 at sites in the Blue River Basin. Solid lines are locally weighted linear regression (LOWESS) curves through the data points. (Note scale change between plots)—Continued

0.115 µg/L at Indian Creek (site 6) to 0.202 µg/L for the Blue River (sites 2, 7, and 22) to 0.117 µg/L for Brush Creek (sites 13 and 16).

For the antimicrobial triclosan, the strongest cyclic variation in concentration with time was observed at site 7, downstream from 3 WWTPs (fig. 15). Triclosan concentrations at all sites typically varied over a narrow of values—less than 1 microgram—throughout the year. When viewed by month (fig. 16), monthly median triclosan concentration on the Blue River (sites 7 and 22; fig.16) peaked during the winter months and declined to the lowest values of the year during the summer. On Brush Creek (site 16), monthly median triclosan values

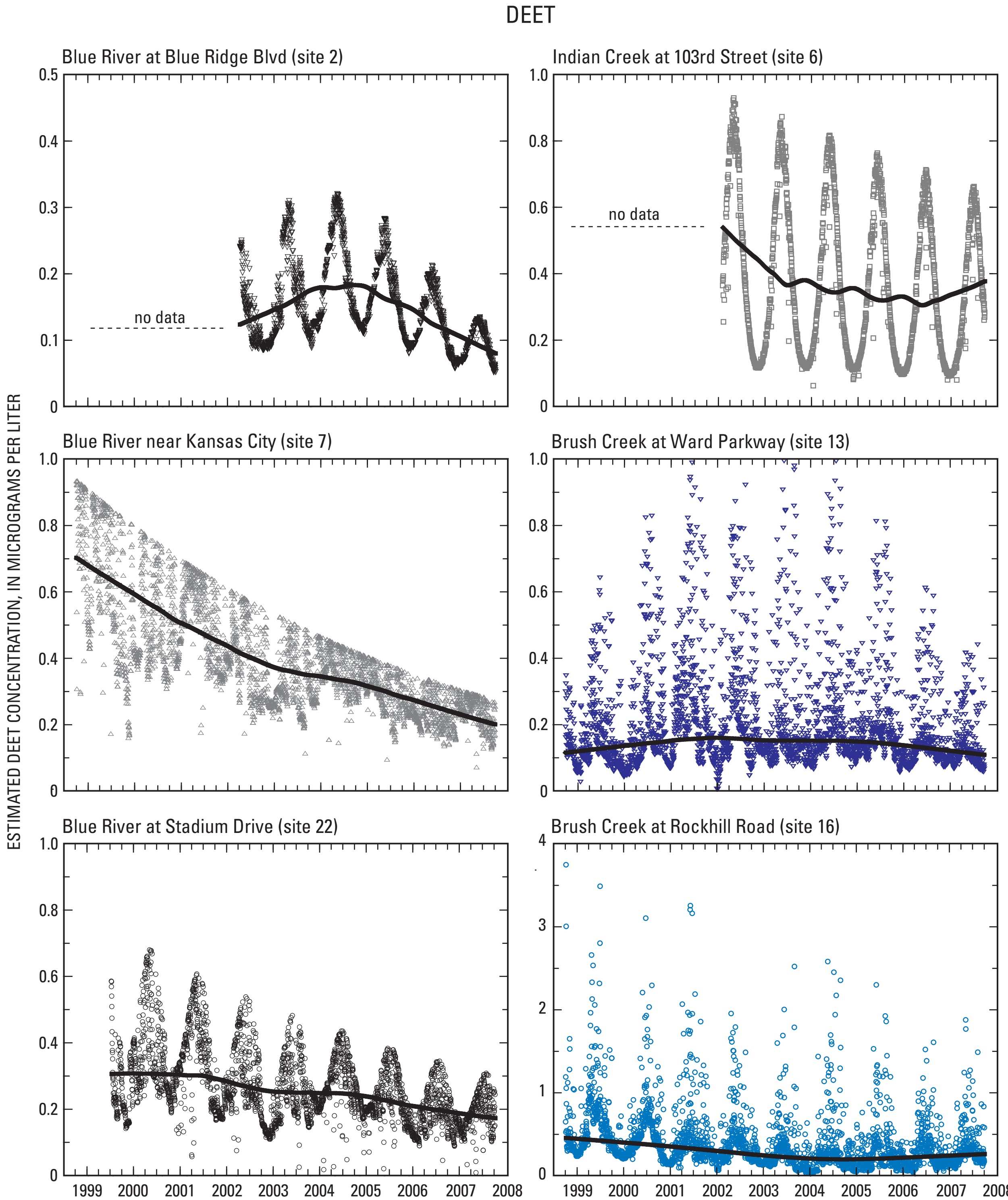


Figure 15. Estimated daily mean concentrations from October 1998 through September 2007 at sites in the Blue River Basin. Solid lines are locally weighted linear regression (LOWESS) curves through the data points. (Note scale change between plots)—Continued

peaked in March through May with an average concentration of 0.158 µg/L, and then declined to approximately one-half that value in August and September (average concentration, 0.086 µg/L).

Concentrations of sterol followed a strong seasonal pattern at sites on Indian Creek and the Blue River (fig. 15). Monthly median concentrations on Indian Creek (site 6; fig. 16) peaked in January and December (average concentration, 13.7 µg/L) and fell to approximately one-third that level in June (average concentration, 4.28 µg/L). Although the monthly median concentrations on the Blue River (sites 2, 7, and 22) typically were only about 30 percent of the concen-

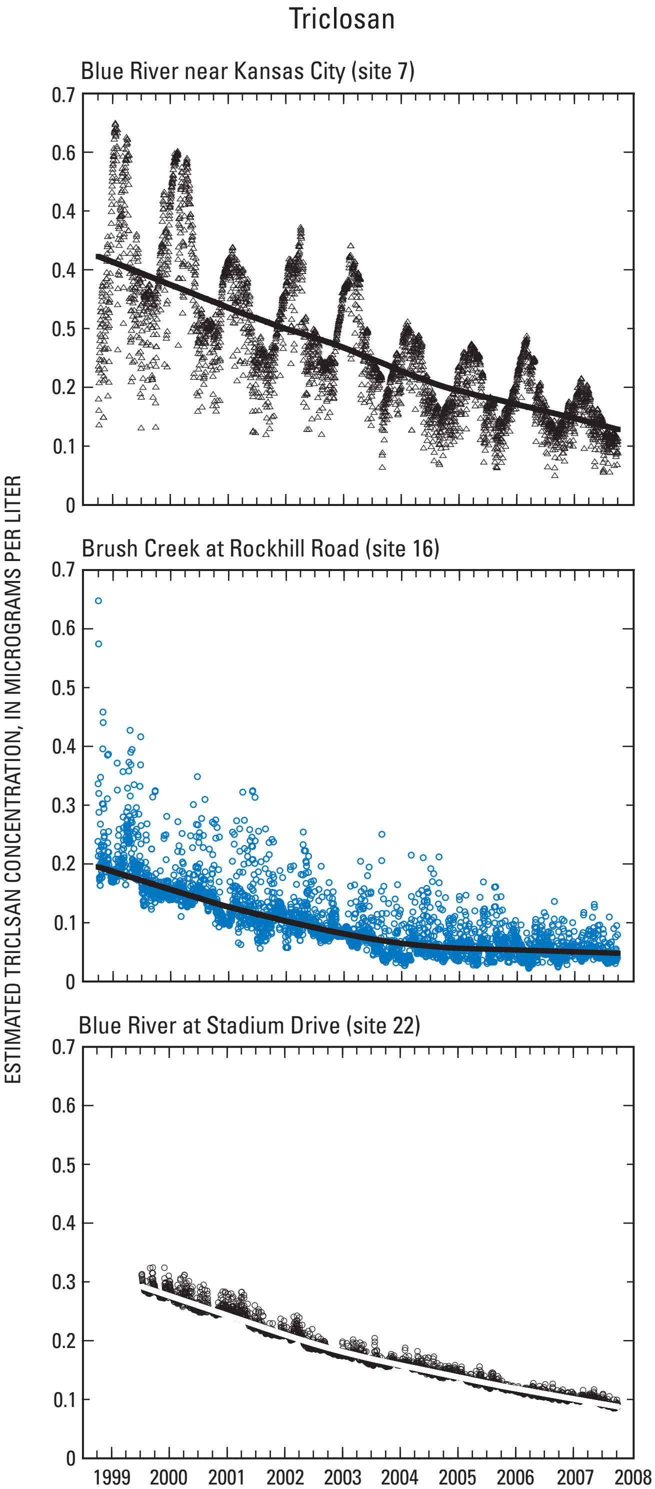


Figure 15. Estimated daily mean concentrations from October 1998 through September 2007 at sites in the Blue River Basin. Solid lines are locally weighted linear regression (LOWESS) curves through the data points. (Note scale change between plots)—Continued

trations in Indian Creek, the pattern–peaks in the winter and lower values in the summer–was similar. Monthly median sterol concentrations at Brush Creek sites (sites 13 and 16; fig. 16) were greatest from April through May (average concentration, 1.78 µg/L) and declined to their lowest values in August and September (average concentration, 1.57 µg/L).

Modeled estimates of daily mean concentrations were used to develop concentration duration curves for a number of selected constituents (fig. 17). The curves show the frequency at which estimated concentrations occurred at any given site from 1998 through 2007. For example, at the Indian Creek site (site 6), the estimated total nitrogen concentration exceeded 10 mg/L about 50 percent of the time. At sites on the Blue River (sites 7 and 22) the estimated total nitrogen concentration exceeded 10 mg/L only a few days from 1998 through 2007. This corresponded to days in which flows were almost exclusively from treated effluent. For Brush Creek sites (sites 13 and 16), the range of total nitrogen concentrations was much narrower and never exceeded 5 mg/L. All sites in the basin were affected by nonpoint source runoff; however, these data indicate that sites affected by WWTP effluent had a greater range of nutrients supplied to them. The estimated total nitrogen concentration at most sites almost always exceeded the U.S. Environmental Protection Agency (USEPA) ecoregional total nitrogen criterion of 0.69 mg/L (Code of Federal Regulations, 2003). The nutrient criteria are not regulatory criteria but instead reflect representative levels whereby human activities would be expected to have minimal effect on surface waters as well as the baseline levels needed to prevent surface-water eutrophication and subsequent water-quality degradation (U.S. Environmental Protection Agency, 2000).

Estimated total phosphorus concentration duration curves show a pattern similar to total nitrogen curves, primarily because the principal sources and mechanisms behind the occurrence of phosphorus is the same as for total nitrogen delivery (fig. 17). Sites on Indian Creek and the Blue River under the dominant affect of WWTP effluent had greater ranges and median concentrations than Brush Creek sites. When compared to the USEPA ecoregional total phosphorus criterion of 0.037 mg/L (Code of Federal Regulations, 2003), concentrations at sites on Indian Creek and the Blue River were greater than the criterion 100 percent of the time. For Brush Creek sites, estimated concentrations were greater than the criterion less than 10 percent of the time and occurred specifically during storm runoff.

With the exception of site 16, Brush Creek at Rockhill Road, estimated suspended-sediment concentrations from 1998 through 2007 ranged more than three orders of magnitude. The greatest concentrations in suspended sediment occurred during the largest flows. Because large concentrations occurred during extremely large flows, almost all of the total annual sediment transport occurred in a few storms. At site 16, because of trapping in upstream impounded reaches, suspended-sediment concentrations varied little between lower and medium range flows.

Where enough data are available, estimated daily concentrations for four wastewater organic compounds also are shown in figure 17. Where model fits are determined primarily by seasonal components, such as for total nitrogen at sites 16

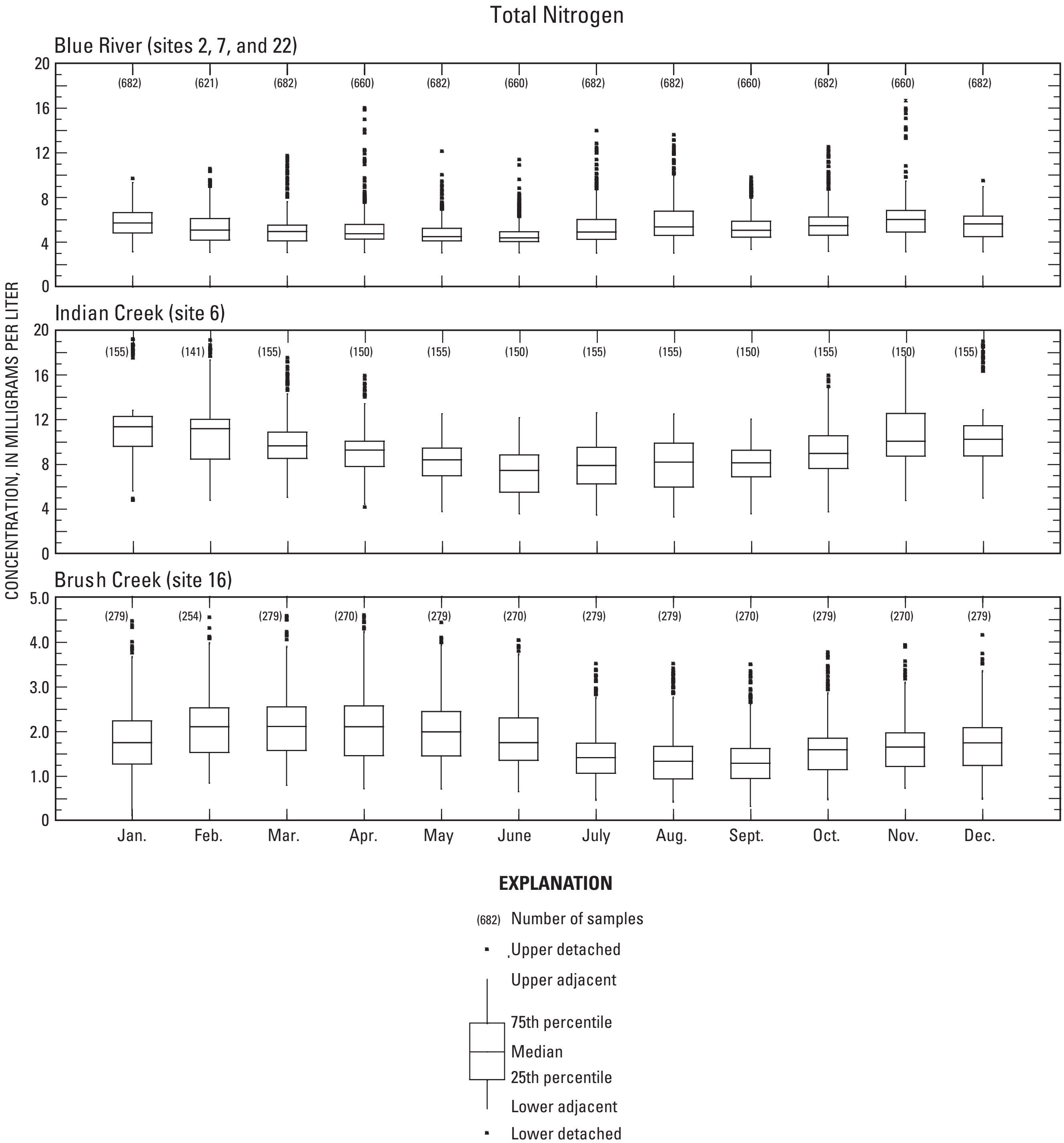


Figure 16. Estimated daily mean concentration, by month, in stream samples from October 1998 through September 2007.

and 22, the estimated concentrations follow a clear sinusoidal pattern (fig. 15). At other sites, such as 6 and 13, the sinusoidal pattern is still visible, but masked to some extent because concentrations, although still determined, in part, by seasonality in the fitted model, respond more to flow. Caffeine is one compound where the fitted model included a strong seasonal component at every site. For some compounds, such as DEET and triclosan (fig. 15), the maximum estimated concentrations gradually declined with time partly because the levels of contaminants detected in streams tended to decline, but also because discharges in the early part of the study were greater than average (fig. 13).

In general, the concentration duration curves for these constituents followed a pattern similar to those seen for

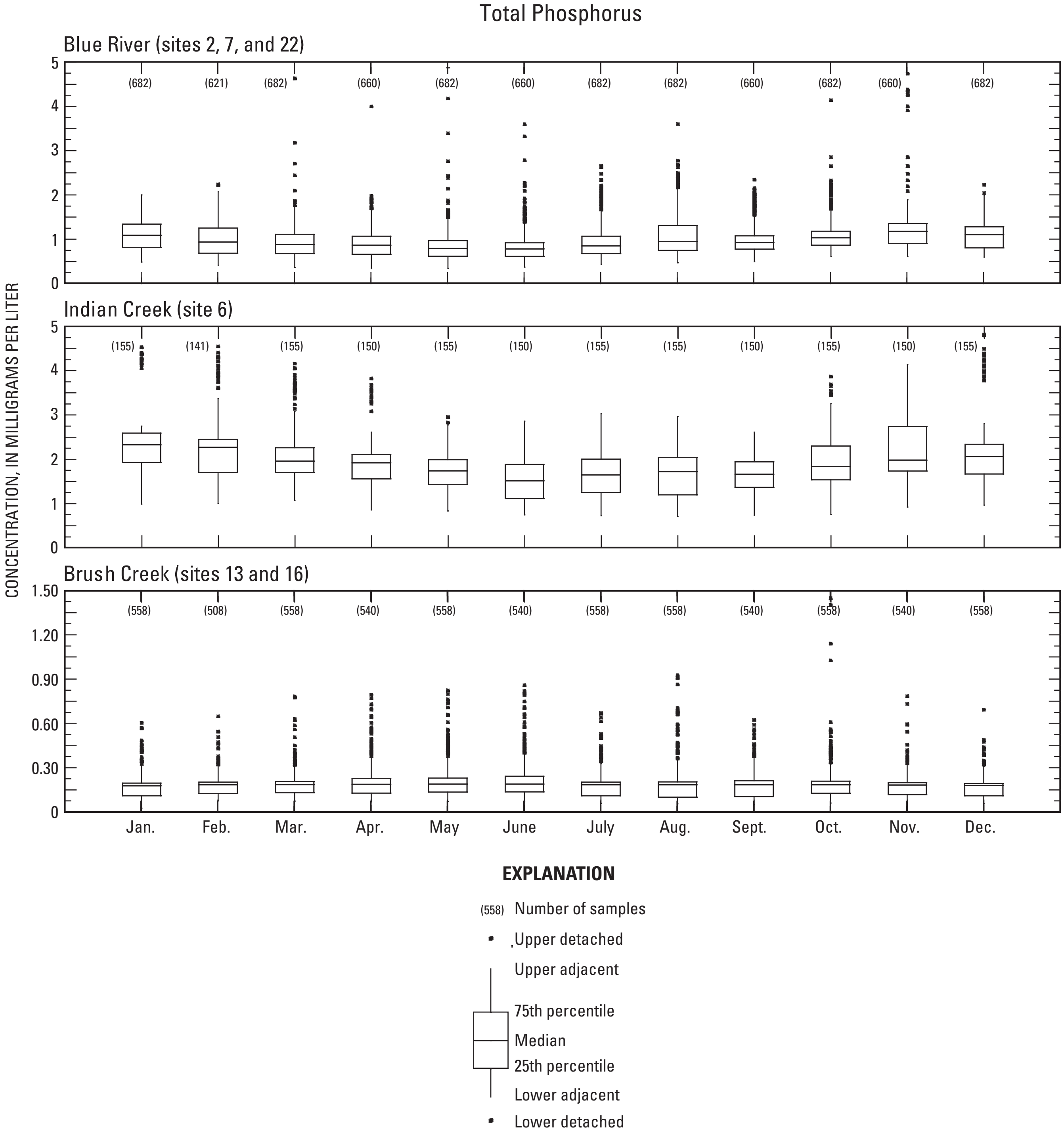


Figure 16. Estimated daily mean concentration, by month, in stream samples from October 1998 through September 2007.—Continued

estimated nutrient concentrations, although there are a couple of exceptions. The range of estimated caffeine and DEET concentrations was greatest at site 16, Brush Creek at Rockhill Road. The largest concentrations corresponded with larger flow periods in the spring and summer. Also, the Blue River and Indian Creek sites had larger concentrations during winter months when flows were lowest. A similar pattern was seen in the estimated concentrations of triclosan and sterol. At site 16, which receives CSOs, the largest concentrations were observed during storm events in the spring and summer. At sites on Indian Creek and the Blue River, the largest concentrations were observed during winter low flows. These data

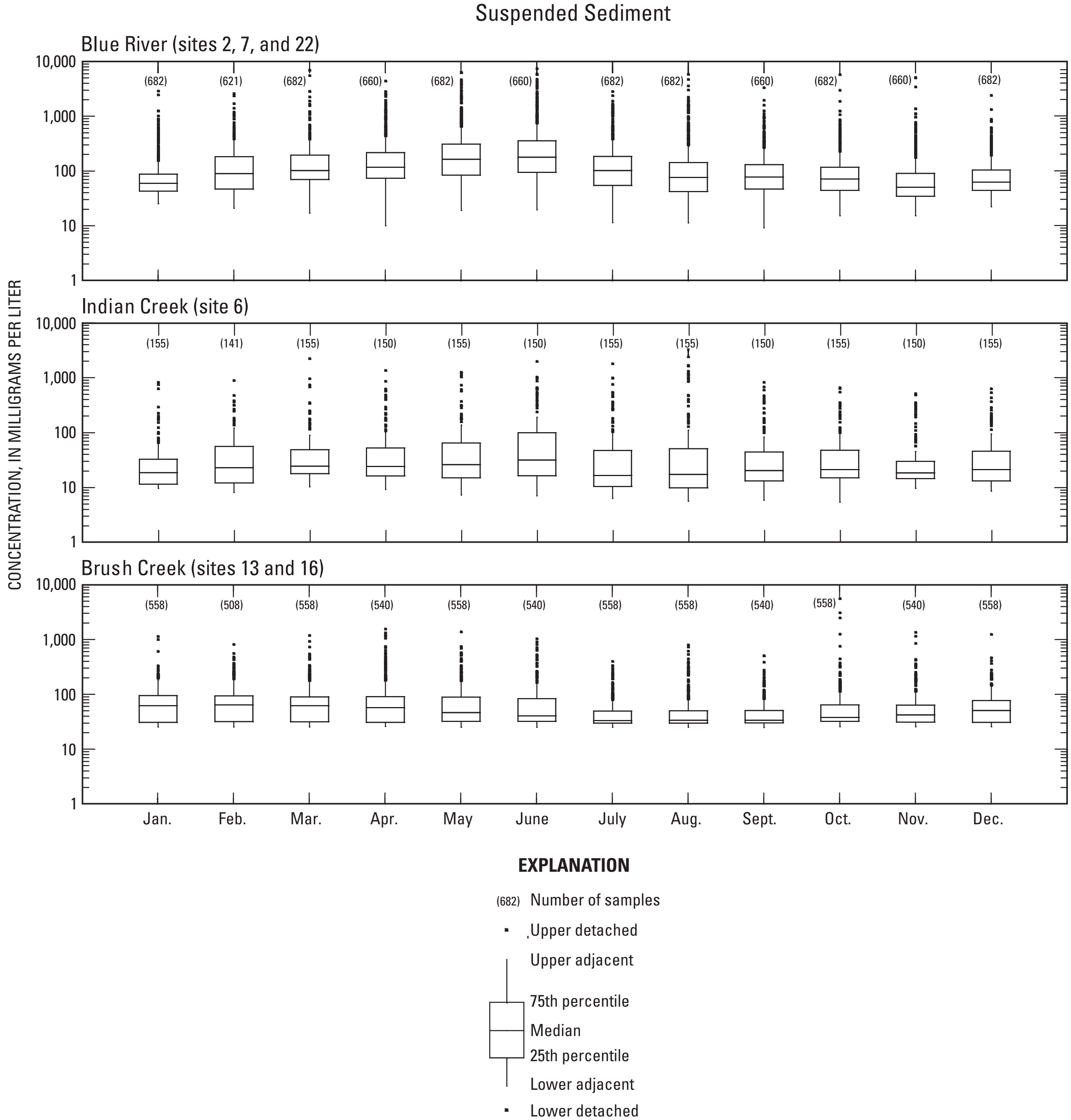


Figure 16. Estimated daily mean concentration, by month, in stream samples from October 1998 through September 2007.—Continued

underscore that the primary mechanism for transport of many constituents in Brush Creek is stormwater runoff. While these same processes occur in other reaches in the Blue River Basin, the highest concentrations frequently are related to the percent of streamflow attributable to WWTP effluent and the time of year.

Seasonal Contribution of Constituents

Constituent concentrations and pollutant loadings change during any given year in response to a number of factors including seasonality. Season affects water temperature, which can mediate biogeochemical processes, use rates (for example, applications of fertilizers and insect repellants), precipita-

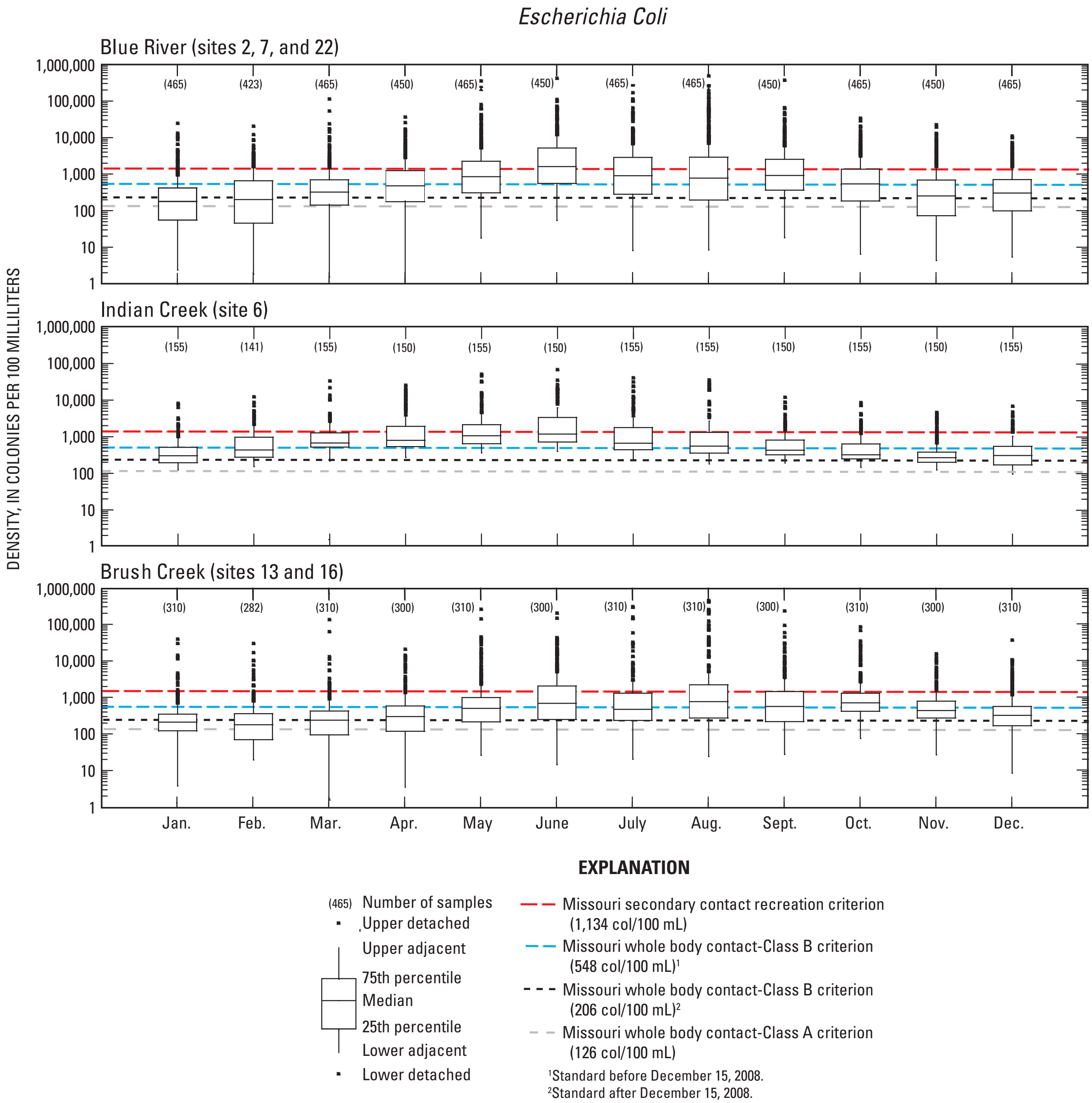


Figure 16. Estimated daily mean concentration, by month, in stream samples from October 1998 through September 2007.—Continued

tion, and streamflow. Constituent loads (concentration times discharge) frequently are affected more by streamflow than concentration because the discharge usually spans a larger range than does concentration. These data provide information and insight about when to implement management practices designed to reduce instream contaminants, and how some processes and factors may affect constituent concentrations and loads observed in streams.

Seasonal (sum of the daily loads for a 3-month timeframe) loads of total nitrogen, total phosphorus, caffeine, DEET, sterol, and triclosan for the Blue River near Kansas City (site 7) and Brush Creek at Rockhill Road (site 16) are shown in figure 18. Seasonal loads of total nitrogen typically

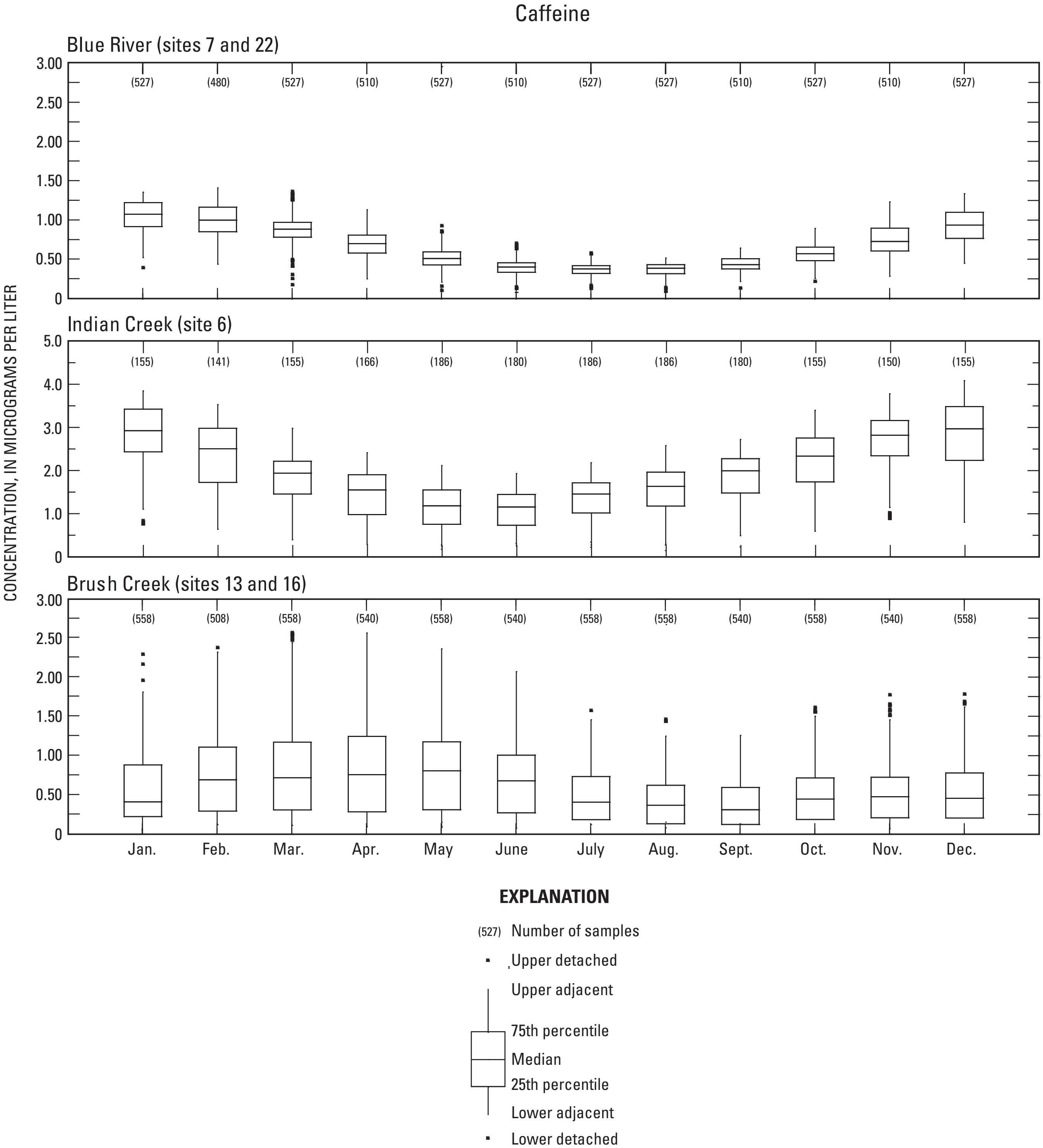


Figure 16. Estimated daily mean concentration, by month, in stream samples from period October 1998 through September 2007.—Continued

were about 10 times greater than total phosphorus loads at both sites. Loads of caffeine, DEET, and triclosan at site 7 typically were about 10,000 times less than those for total nitrogen and 1,000 times less than that for total phosphorus at both sites as a result of the much smaller concentrations of these constituents when compared to nutrient concentrations. Seasonal loads of sterol generally were about 10 times greater than those for triclosan, another organic wastewater compound, primarily because of concentration differences between the two. In general, concentrations of caffeine, DEET,

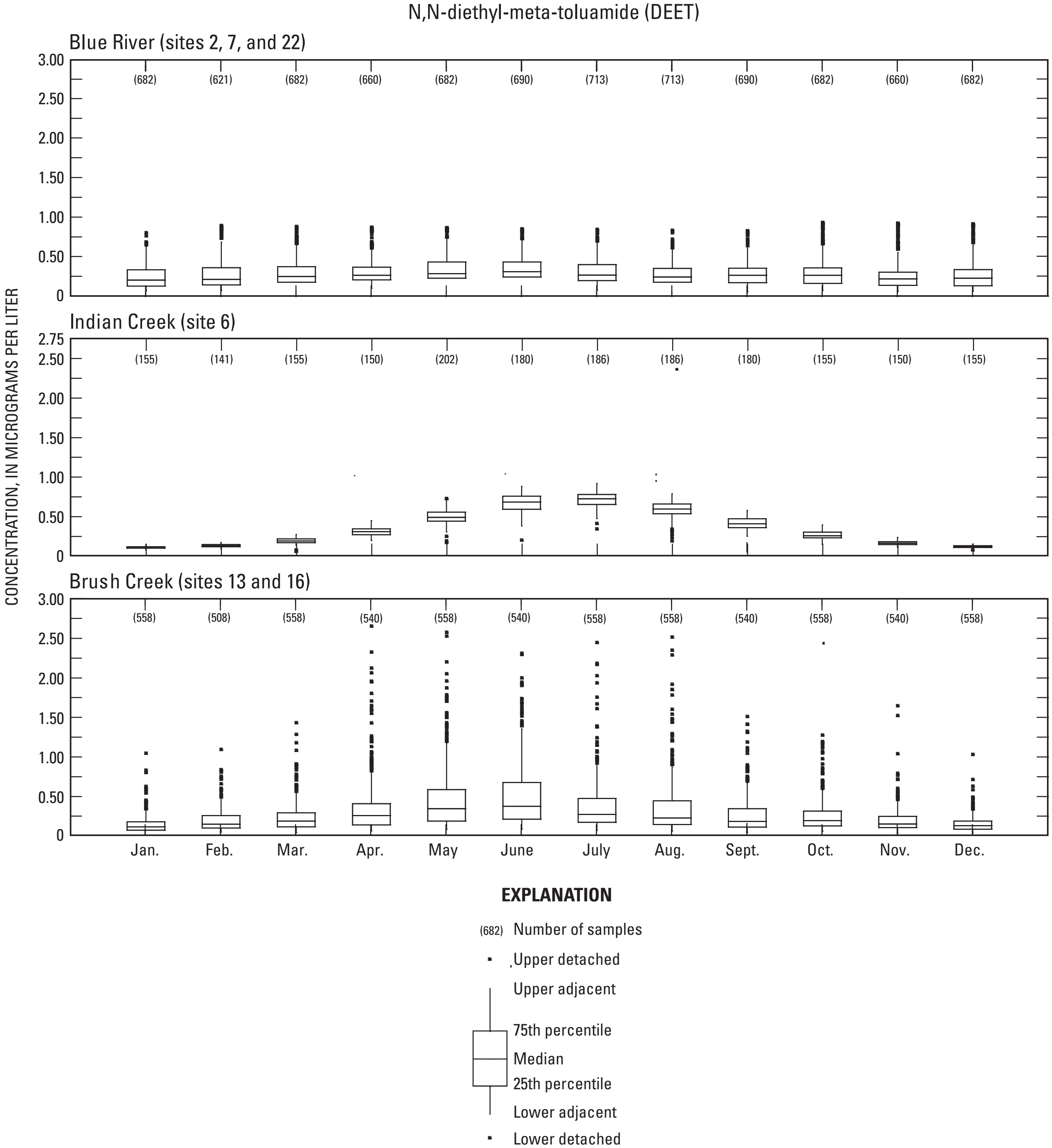


Figure 16. Estimated daily mean concentration, by month, in stream samples from October 1998 through September 2007.—Continued

sterol, and triclosan in streams are much less than those for total nitrogen and total phosphorus because the sources for these compounds are more limited than for nutrients. In many stream reaches, a significant part of nutrients originates from nonpoint source runoff, whereas the bulk of caffeine, DEET, and triclosan are contributed by point sources, such as treated effluent or CSOs. Although data are sparse, average removal rates measured at WWTP plants in the basin for caffeine (94 percent), sterol—cholesterol (80 percent) and coprostanol (83 percent), DEET (76 percent), and triclosan (68 percent)

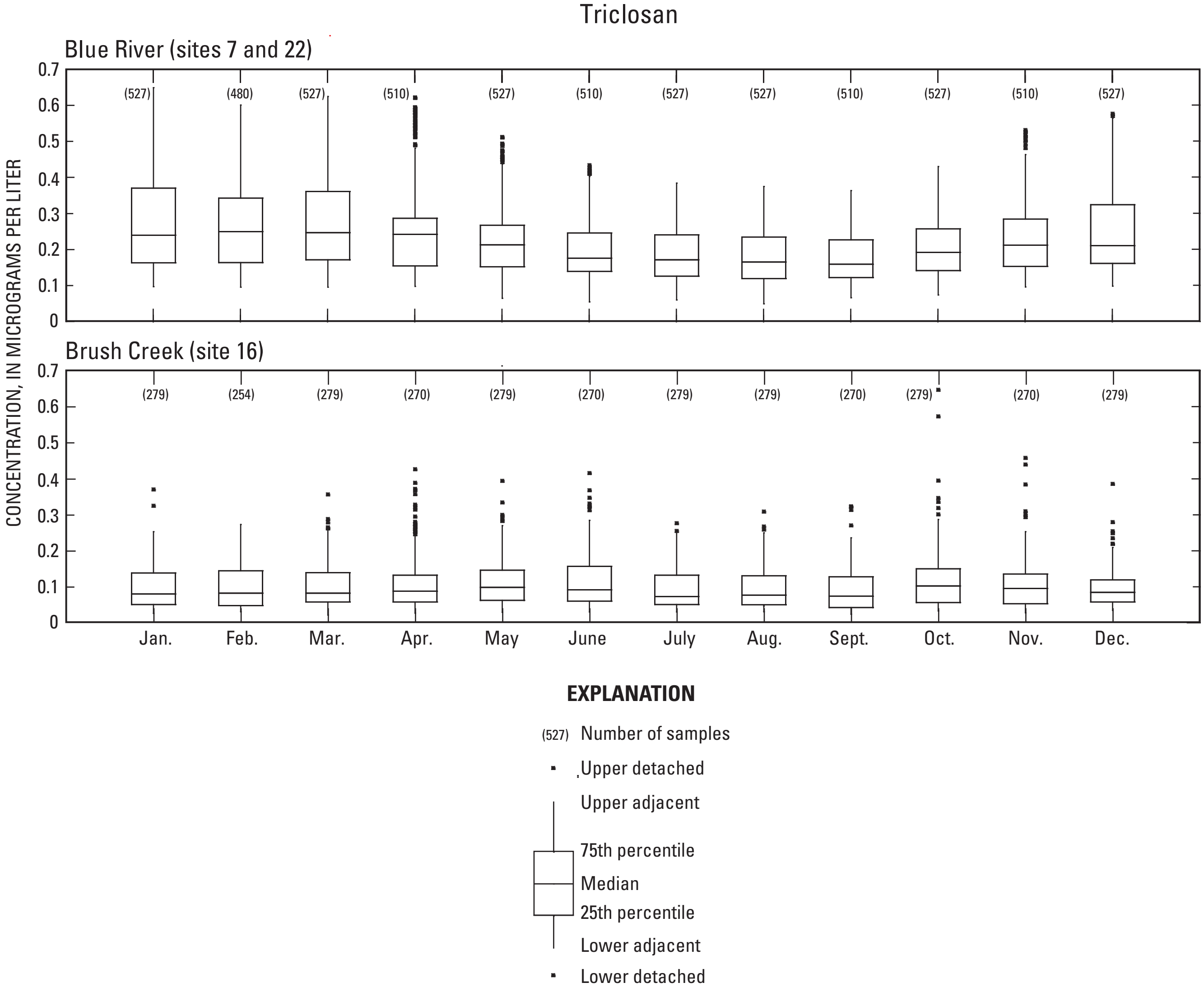


Figure 16. Estimated daily mean concentration, by month, in stream samples from October 1998 through September 2007.—Continued

indicate that substantial amounts of these constituents are removed during treatment (Wilkison and others, 2002). Nutrient removal rates for WWTPs in the basin are unknown, but even the most advanced biological treatment processes are not designed to remove all nutrients. Nutrients passing through WWTPs primarily are soluble and more bioavailable forms of nitrogen and phosphorus, which are discharged to receiving streams (Wells, 2006; Wilkison and others, 2006). Also, influent nutrient concentrations are several orders of magnitude greater than organic wastewater compound concentrations; therefore, even if nutrient removal rates approached 90 percent, nutrient effluent concentrations would still be expected to be much greater than caffeine, DEET, sterol, and triclosan concentrations. On average, the loads of nutrients, caffeine, DEET, sterol, and triclosan on the effluent-dominated Blue River were 20 times greater than those on CSO-dominated Brush Creek, although flows were only 10 times greater (fig. 18).

When grouped by season, the largest contributions of nutrients to the Blue River Basin occurred from March through August of each year (fig.19) primarily because this period corresponded with the highest flows and a substantial part of nutrient concentrations occurred during storm runoff. Additionally, storm-runoff loads include point- and nonpoint-source contributions. There were some slight differences between seasonal load patterns on the Blue River and Brush Creek as nutrient loads from March through August accounted for 70 percent of the total annual contributions on the Blue River and 77 percent of the total annual contributions on Brush Creek from 1998 through 2007 (fig. 19). Increased loads during the spring and summer corresponded with a period of prolonged and more intense precipitation that would

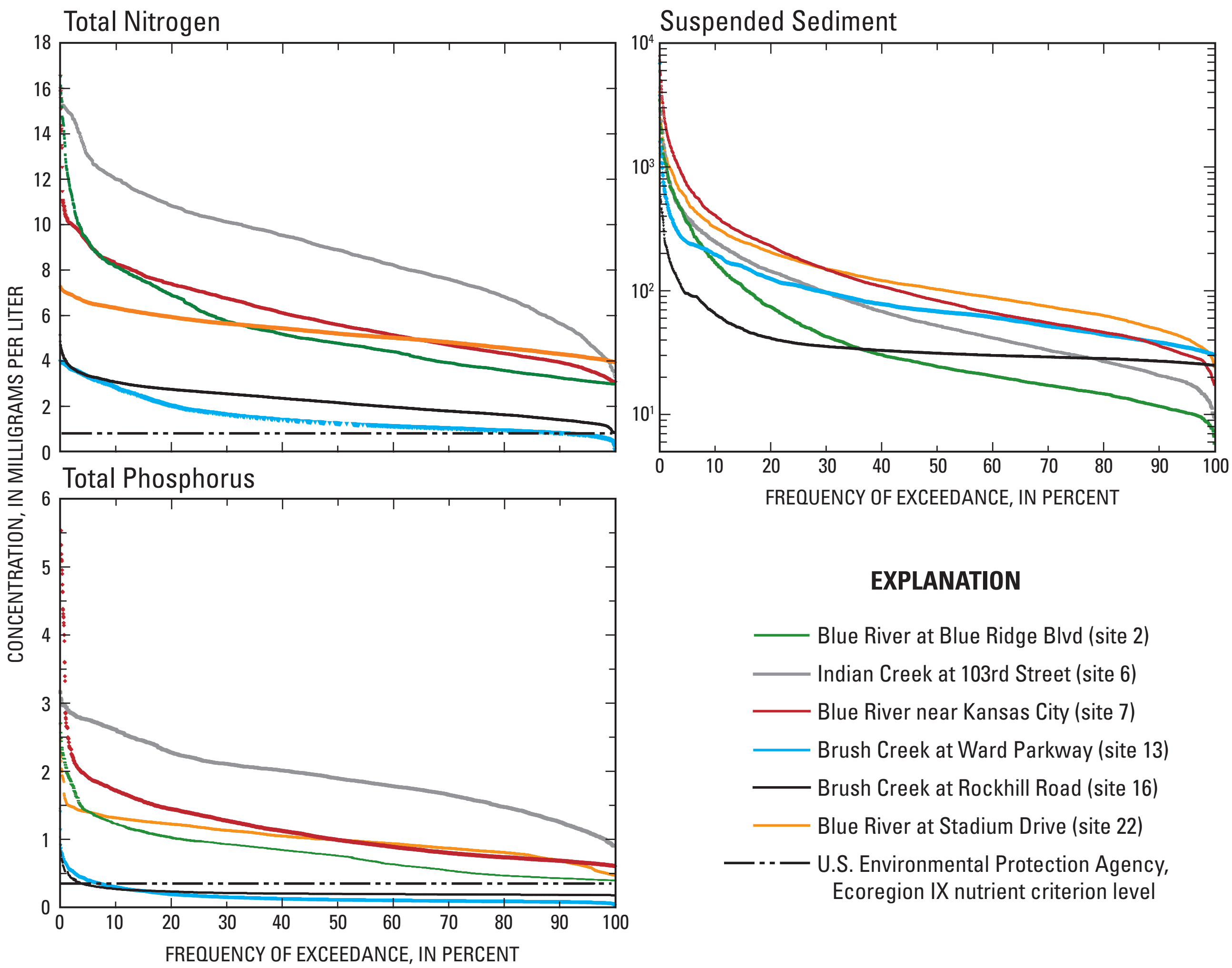


Figure 17. Estimated daily mean concentration duration curves for selected water-quality consitutents in the Blue River Basin, October 1998 through September 2007.

be expected to produce large runoff events as well as more frequent CSOs.

With a couple of exceptions, seasonal loads followed the precipitation patterns in the basin (fig. 19). These differences are largely the result of the effluent-dominated nature of the Blue River during low-flow periods compared to the effects of CSOs on constituent loads in Brush Creek, which occur during storm runoff events.

Flows throughout the year on the Blue River and Indian Creek are augmented by effluents from three upstream WWTPs; each effluent stream provides part of the total downstream flow and load. During low-flow periods, such as December through February, the ratio of treated wastewater effluent compared to the total streamflow increase, which contribute to larger relative loads in streams when compared to the precipitation patterns (fig. 19). Also, because most wastewater-treatment processes are biological, the removal rates for many compounds decline during the colder periods and increase during the warm periods (Wells, 2006). This may account for the relatively increased caffeine (30 percent of annual load) and sterol (25 percent of annual load) loads in the Blue River during the December to February periods and declining loads during the summer (June to August) and early fall (September to November). Caffeine consumption rates also may vary throughout the year with the greatest intake occurring during the winter and the lowest during the hotter summer months. However, any naturally occurring component of cholesterol, such as from plants, that may have contributed to the overall sterol load would have been expected to be greatest during midsummer, which is not the case. The greatest percentage of DEET loads in the Blue River (site 7) and Brush Creek (site 16) occurred from June to August, the period expected to coincide with the greatest use of insect repellant. These data also indicate that caffeine, DEET, and triclosan are persistent compounds in streams throughout the year, and that sources other than the discharge of treated wastewater effluent into receiving waters likely contribute to some of the observed loads, especially during storm runoff. Other potential sources

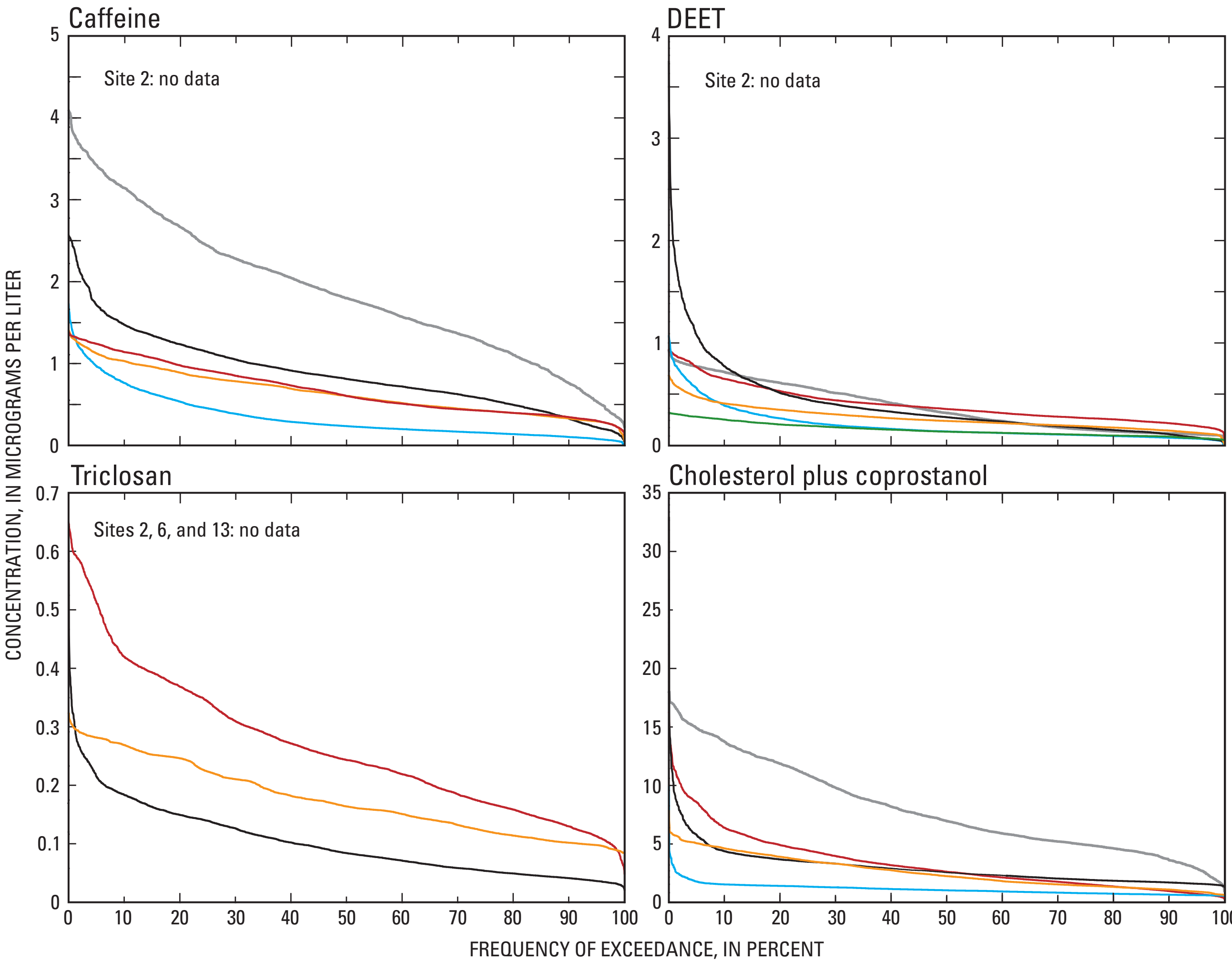


Figure 17. Estimated daily mean concentration duration curves for selected water-quality consitutents in the Blue River Basin, October 1998 through September 2007.—Continued

of these compounds include leaks from sewer lines and WWTP bypasses triggered during large or prolonged storm events. Atmospheric deposition also may contribute some DEET to streams during runoff events, although this pathway is thought to be a minor component (Weigel and others, 2002; Costanzo and others, 2007).

On Brush Creek (site 16), loads of nutrients, caffeine, DEET, sterol, and triclosan were approximately 10 percent of the average annual loads during the winter, which is consistent with the decreased winter precipitation. Precipitation during the fall period is 25 percent of the annual total but constituent loads were approximately 10 percent of the annual total. A decline in loads also was observed in the Blue River (site 7), which likely indicates the effects of greater biological activity in the fall as compared to the winter months. Higher temperatures in the fall would be expected to increase the biological breakdown, transformation, and assimilation of constituents in streams and, thereby, reduce their concentrations.

Annual Contribution of Constituents

Understanding the relative annual contribution of point and nonpoint sources in the basin is important to understanding the efficacy of strategies designed to reduce inputs. The principal point-source contributions in the basin are discharges from CSOs and WWTPs. Nonpoint-source contributions include a wide variety of sources including runoff from sidewalks, streets, roofs, lawns, parks, golf courses, and agricultural lands. The annual loads from all sources at selected basin sites, along with loads originating from CSOs and upstream WWTPs, and estimates of nonpoint-source contributions from 1999 to 2007 are listed in table 21 at the back of this report. From 2002 through 2007, annual total nitrogen and total phosphorus loads originating from three WWTPs that discharge in the upper basin were determined by summing the average monthly loads of each constituent as reported by the plant (Wilkison and others, 2006; U.S. Environmental Protection Agency, 2008). Data before 2002 were unavailable. Extremely

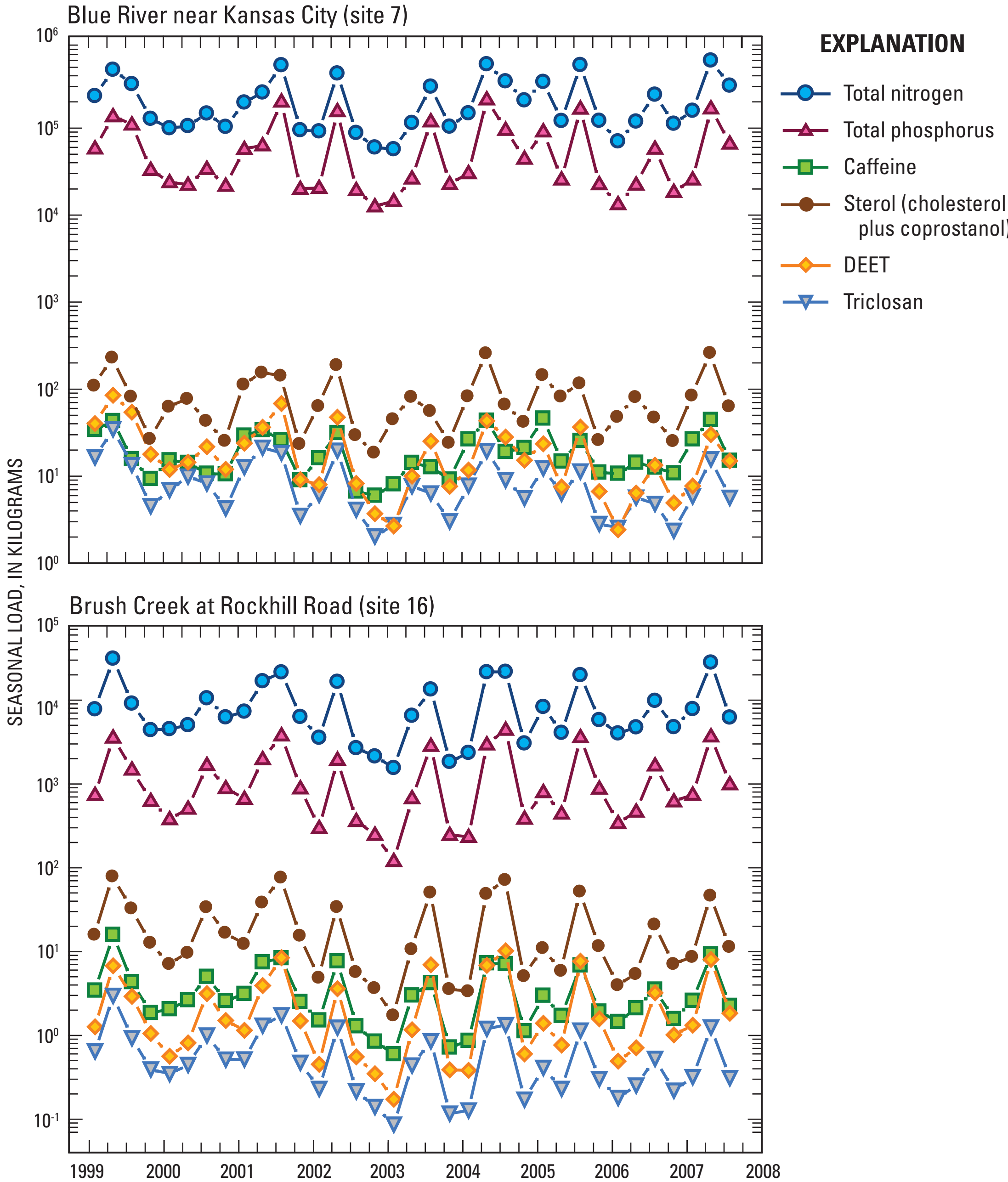


Figure 18. Seasonal total nitrogen, total phosphorus, caffeine, sterol (cholesterol plus coprostanol), DEET (n,n-diethyl-meta-toluamide), and triclosan loads at two stream sites from 1999 through 2007.

intense or prolonged storms can cause some wastewater to bypass all, or part, of the WWTP processes. These bypasses result in the discharge of untreated or partially treated sewage to streams. However, the total nitrogen and total phosphorus load estimates reported for 2002–07 and fecal coliform load estimates for 2002–04 and 2006 do not account for WWTP bypass contributions; therefore, amounts from WWTPs listed in table 19 for those years would be considered minimums. Fecal coliform load estimates from WWTPs for 2005 and 2006 were reported previously by Rasmussen and others (2008). These data included bypass contributions as part of the total. Estimates of *E. coli* contributions from WWTPs were not available but would be expected to be less than those derived for fecal coliform. Upstream nonpoint source contributions were determined by subtracting known point source loads (from WWTPs and CSOs) from the total annual load at a site for a given year. For years in which WWTP bypasses were not calculated as part of the total WWTP contribution, a part of the nonpoint-source load allocation listed in table 21 originated from bypasses.

Water-quality data from CSOs were available only for 2005. Total nitrogen, total phosphorus, *E. coli*, and fecal

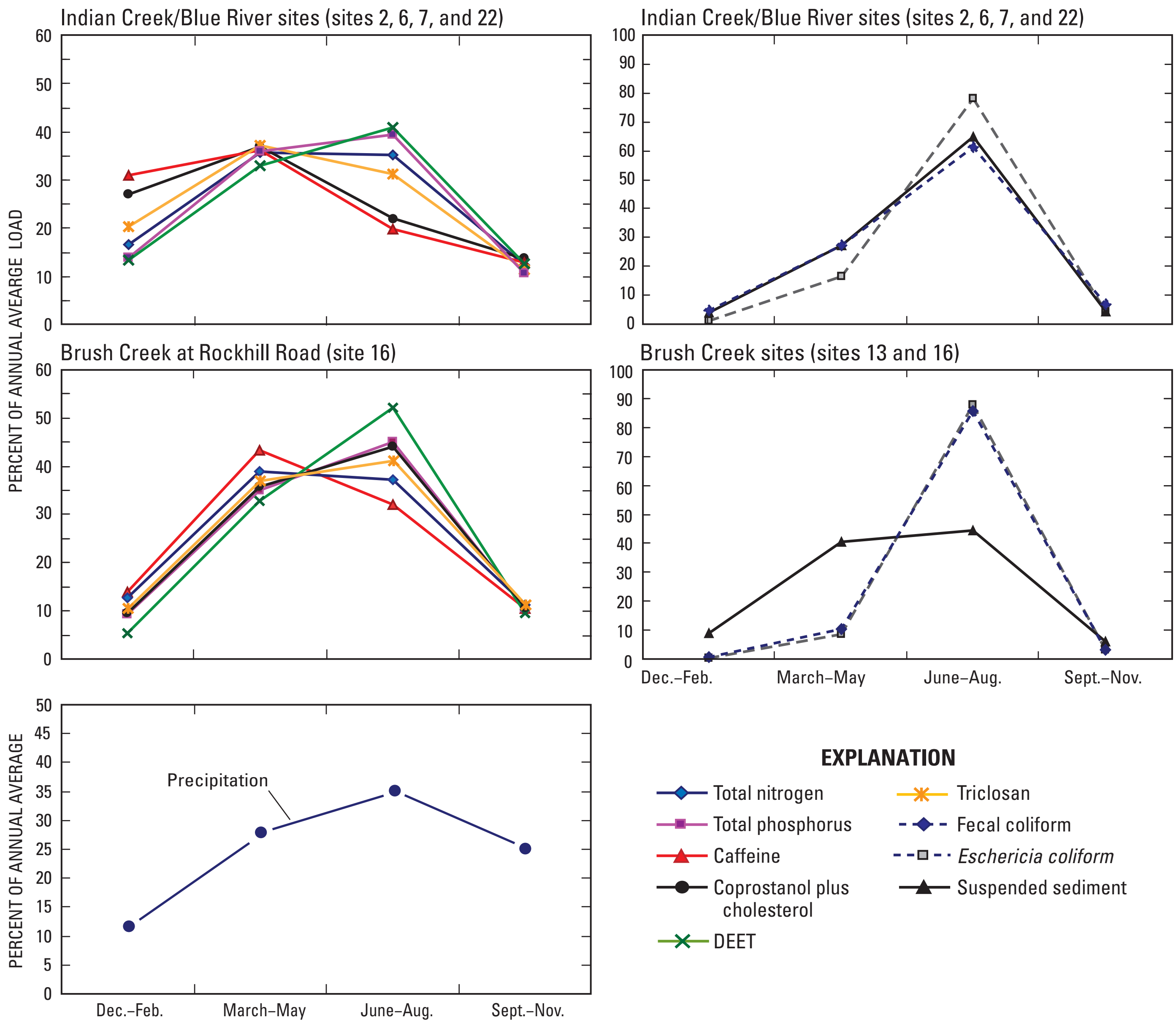


Figure 19. Seasonal contributions of nutrients, selected organic wastewater compounds, fecal-indicator bacteria, suspended sediment, and precipitation from 1998 through 2007 in the Blue River Basin.

coliform loads originating from CSOs were estimated from the median concentration or density measured in overflow samples and the estimated annual CSO volume for a given stream reach (City of Kansas City, Missouri, 2007).

Nonpoint-source estimates were calculated by subtracting the sum of the point sources discharging upstream from a site from the total estimated load from all sources for a given. Attributions to Kansas and Missouri sources were based solely on the relative drainage areas upstream from site 2 and site 6 in each respective State, assuming that runoff conditions remained constant throughout these reaches and that in-stream biotransformation and removal were negligible. At site 2, 84 percent of the upstream drainage lies in Kansas and 16 percent in Missouri. At site 6, 99 percent of the upstream drainage area lies in Kansas and only 1 percent in Missouri.

Source allocations vary year-to-year, primarily in response to annual variations in precipitation and hydrology. Average contributions from sources based upon the available period of data for a given source category are listed in table 21. However, because of unequal periods of data and rounding errors, the average sum of nonpoint sources, WTTP, and CSO contributions may not equal the total estimated load from all sources, and the sum of the average percent contributions from individual sources, may not equal 100.

Nutrients and Source Allocations

Nutrient contributions at a given site on the main stem of the Blue River or the tributary Indian Creek are in large part driven by nonpoint source runoff, the proximity of the site to WWTPs, and the number of facilities upstream from the sites. The bulk (on average 69 percent of the total nitrogen and 82 percent of the total phosphorus from 2003 through 2007) in the upper Blue River (site 2) originated from nonpoint source runoff (table 21). Conversely, on average, 31 percent of the total nitrogen and 18 percent of the total phosphorus in the upper Blue River (site 2) originated from the upstream WWTPs.

At site 6 on lower Indian Creek, nonpoint-source runoff contributed only 38 percent of the total nitrogen and 42 percent of the total phosphorus to lower Indian Creek. An estimated 63 percent of the total nitrogen and two-thirds of the total phosphorus at site 6 originated from upstream WWTPs (table 21). There are no CSOs upstream from site 2 or site 6.

Site 7, located on the middle Blue River and downstream from three WWTPs, has a drainage area (477 km^2) approximately four times that of site 2 (118 km^2) and about three times greater than site 6 (168 km^2). Because of this, the relative contributions from nonpoint sources and WWTPs are between the values at sites 2 and 6. At site 7, more total nitrogen (an average of 59 percent) originated from nonpoint sources than from WWTPs (average of 41 percent). Average total phosphorus contributions from nonpoint sources at site 7 were slightly larger (73 percent; table 21), with 29 percent originating from WWTPs. Although there are no CSOs upstream from site 7, there are CSOs along the Blue River reach downstream from site 7 to the confluence with Brush Creek. Estimated contributions from these CSOs are included with site 7 for comparison purposes and indicate, that given the magnitude of nonpoint and point sources in that reach, nutrient contributions from CSOs in the middle Blue River likely are only a small part (1 percent or less) of the average total load.

Further downstream on the main stem of the Blue River (site 22), nutrient contributions from nonpoint sources become more substantial relative to those from upstream WWTPs because the drainage area (671 km^2) at site 22 increases by 41 percent from that at site 7 (Wilkison and others, 2006). Additionally, there may be base-flow periods, especially during the summer months when a part of the WWTPs load is removed through biogeochemical processes in downstream reaches. In addition to the WWTPs that discharge upstream from this site, numerous CSOs, most of which are located along the tributaries Town Fork Creek and Brush Creek, also contribute to the nutrient load in the lower Blue River (site 22). However, in 2005, CSOs from all sources that ultimately discharge into the Blue River contributed just 1 percent of the total nutrient load to the lower Blue River. Approximately three-fourths of the nutrient contributions in the lower Blue River originated from nonpoint sources (74 percent of the total nitrogen and 82 percent of the total phosphorus) with the remainder having originated from WWTPs.

These data indicate that on the main stem of the Blue River and the tributary Indian Creek, the primary sources of nutrients were nonpoint-source runoff and WWTPs effluent discharges. The relative contribution of these two sources varied somewhat from year to year based upon annual precipitation and the number of upstream WWTPs. Load fluctuations occurred between years, primarily in response to hydrologic changes, but other factors also may have contributed to these differences. Wet years increase the volume (and loads) from WWTPs because increased infiltration results in increased flows to plants and ultimately to higher discharges. However, increases from infiltration were not as pronounced as the increases that resulted from increased runoff into streams, so during wet years the percent contribution from WWTPs to streams typically declines. Conversely, during dry years, although streamflow may have declined dramatically, WWTPs contributions remained fairly stable; therefore, the percent contribution from WWTPs to streams typically increased during drier periods. Nutrient contributions from CSOs to the Blue River are minor when compared to those from nonpoint sources and from WWTPs.

The two principal sources of nutrients on Brush Creek (site 16) in 2005 were nonpoint source contributions and CSOs, with approximately two-thirds of the nutrient contributions originating from nonpoint sources and the remaining one-third from CSOs (table 21). There are no WWTPs that discharge into Brush Creek, but on occasion—during heavy or prolonged storm events—three WWTP bypasses discharge partially treated wastewater into upper Brush Creek (upstream from site 13). Bypass contributions were not individually measured in this study; any contribution from them are included in the nonpoint source estimates. However, bypass contributions are believed to constitute only a small part of the overall nonpoint-source contribution.

Fecal-Indicator Bacteria and Source Allocations

Annual contributions of fecal-indicator bacteria in the basin follow a much different pattern than nutrients. WWTPs remove, by design, substantial amounts of nutrients and bacteria by settling the particulate matter from the waste stream. A number of different processes and techniques then are used to reduce or transform concentrations. In the case of nutrients, a substantial part of the nutrients are oxidized into more soluble forms of nitrogen and phosphorus, which are discharged into receiving waters. Although these discharges and amounts are regulated under State and Federal permits, the result is that large amounts of nutrients are discharged into streams, especially where multiple plants operate in the same basin. However, because of potential human health risks associated with the discharge of bacteria to streams, WWTPs are required to greatly reduce the level of bacteria in treated effluent. This is done by a number of different techniques including solids removal (to which the bacteria are largely attached), chlorination, and ultraviolet radiation. Consequently, fecal-indicator bacteria levels in treated effluent typically are extremely low, and in many cases, lower than the receiving waters into which they are discharged (Lee and others, 2005).

CSOs currently (2009) do not receive any treatment. Although the annual volume of CSO water discharged into streams compared to treated effluent may be small, the amount of bacteria in CSOs can be large. This is because CSOs contain a mixture of untreated sewage and storm runoff each of which can contain large bacteria densities.

On the main stem of the Blue River and Indian Creek, almost all of the bacteria contributions originated from nonpoint sources (table 21). Nonpoint-source contributions to these stream reaches were 96 percent or greater of the total annual contributions in the years 2003 through 2007 (table 21). During that same time period, bacteria contributions from WWTPs were estimated to be 4 percent or less of the total annual load. Although CSO contributions to Blue River reaches in 2005 were sometimes more than 100 times the WWTP fecal coliform contributions, CSO contributions were still only 2 percent or less of the average total annual fecal coliform and *E. coli* load measured at Blue River sites 7 and 22.

On Brush Creek (site 16), fecal-indicator bacteria contributions from CSOs accounted for 39 percent of the total fecal coliform load and 24 percent of the total *E. coli* load in 2005 (table 21). The remainder, approximately two-thirds, of fecal-indicator bacteria contributions to Brush Creek originated from nonpoint sources—61 percent of the fecal coliform bacteria load and 76 percent of the *E. coli* load. An unknown part of the estimate attributed to nonpoint sources comes from partially treated wastewater discharged into upper Brush Creek by occasional WWTPs bypasses. However, beginning in 2002, high-rate disinfection treatment was installed to reduce the bacteria concentration in these bypasses (John Metzler, Johnson County Wastewater, 2007, oral commun.). Because of that and their infrequent nature, bacteria loadings from WWTP bypasses are expected to comprise only a small part of the total load. The average annual *E. coli* load measured in Brush Creek compared to downstream reaches of the Blue River was 7 percent (table 21). This estimate of the percent contribution from the tributary Brush Creek to the Blue River was similar to previous determinations (10 percent) during base-flow conditions (Wilkison and others, 2006).

Taken together, these data indicate that water quality in the basin could be improved by incorporating multiple strategies in order to reduce stream loads. Nonpoint-source reductions in the basin have the potential to decrease nutrient quantities and bacteria densities in area streams. Strategies designed to reduce or eliminate CSOs would substantially decrease the annual loads of nutrients and bacteria to Brush Creek but have minimal effect on total Blue River loadings. However, annual loads of nonpoint nutrients and fecal-indicator bacteria to Brush Creek (site 16) were about twice the CSO loadings; therefore, nonpoint-source reduction potentially could have an equivalent, if not greater, effect on water quality. Methods designed to reduce nutrient loads from WWTPs that discharge into the basin could substantially reduce the overall nutrient load in Indian Creek and the Blue River.

Biological Assessments

Biological assessments included sampling of benthic macroinvertebrate communities for diversity and abundance, habitat assessments, and toxicity screenings. Macroinvertebrate samples were collected from 11 stream sites in 2002 through 2004 and from 7 stream sites in 2006 and 2007. Habitat assessments were conducted at 11 sites in 2006. Toxicity evaluations were conducted at 14 sites in 2007.

Previous work (Wilkison and others, 2006; Poulton and others, 2007) has shown that biological communities within the Blue River Basin follow an urban gradient with the greatest diversity and highest abundance of aquatic organisms occurring in headwater reaches. Similar studies in nearby basins (Poulton and others, 2007) also have demonstrated that as human disturbance and urban land-use factors increase, macroinvertebrate diversity and abundance decline.

Macroinvertebrate Community Assessments

Macroinvertebrate community assessments were conducted annually from 2002 through 2007 with the exception of 2005. In 2002, one assessment was conducted in the spring and another one in the fall. In the remaining years all assessments were conducted in either the last week of February or the first week of March to avoid spring runoff events that might render sites inaccessible, and to collect samples before the significant emergence of hatching organisms occurred that might bias sample results.

During the 5 years of sampling for this study, 155 different macroinvertebrate taxa were collected. A similar study in adjacent Johnson County, Kansas, detected 188 taxa at 16 sites in the years 2003 and 2004 (Poulton and others, 2007). The reasons for the increased number of taxa present at the Johnson County sites likely are related to a combination of factors including increased number of sample sites, less urbanization, and slightly different sampling approaches between the studies.

Five calculated metrics and the Missouri Stream Condition Index Score (SCI) for Blue River Basin stream reaches from 2002 through 2007 are shown in figure 20. The SCI score is determined from four core metrics: total taxa richness; Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa richness; Shannon Diversity Index; and the Missouri Biotic Index (MOBI). A value for each metric is assigned on the basis of how the core metric scores relate to the range of values at reference sites. The sum of these scores is the SCI, and this value is used to determine the aquatic life use support status

(ALUS). SCI scores in the range of 4 to 8 are considered biologically nonsupportive of aquatic life, those with scores in the range of 10 to 14 are considered partially supportive, and SCI scores between 16 and 20 are considered fully supportive (Sarver and others, 2002). Poulton and others (2007) developed a human disturbance index for Johnson County, Kansas, and classified sites as having either a low, moderate, or high degree of human disturbance. The average value for each Johnson County, Kansas, human disturbance category for the years 2003 and 2004 are plotted on the graphs (fig. 20) to allow comparisons between the two data sets. Metrics calculated at individual sites for years 2002 to 2005 previously were reported (Wilkison and others; 2005; 2006). Data for sites sampled in 2006 and 2007 are reported in table 22.

Total taxa richness, the number of distinct taxa in a sample, was greatest at sites 1 and 2 in the upper Blue River (fig. 20). Total taxa richness at the outside control, South Grand River near Freeman (site 27), was less every year than at the upper Blue River sites, although values from the South Grand River site and the upper Blue River sites generally were in the same range as the Johnson County sites with a low degree of human disturbance. Total taxa richness declined in downstream reaches, with the lowest values typically associated with the lower Brush Creek and lower Blue River reaches (sites 20 and 22). Total taxa richness at these sites tended to be slightly less than values for sites in Johnson County that have experienced a high degree of human disturbance.

The metric EPT taxa richness can be useful in biological assessments because this metric is believed to be more stable than total taxa richness and many EPT genera are considered to be pollution intolerant (Lenat, 1983; 1988). ETP taxa richness generally followed the same pattern as total taxa richness with greatest values in the upper stream reaches and declining values in downstream reaches. EPT taxa richness values in the upper Blue River and at the South Grand River were similar to those observed at the least disturbed Johnson County, Kansas, sites. The South Grand River site had a greater percentage of grassland, forests, and cropland and a lower percentage of urban land than the Blue River Basin sites (Wilkison and others, 2006). Values at other stream reaches were below the range of Johnson County, Kansas, sites with a high degree of human disturbance.

The Shannon Diversity Index provides a measure of the diversity and evenness of population distributions at a site. Thus, the greater number of organisms and the more evenly they are distributed across all taxa, the greater the Shannon Diversity Index. As with the two previous metrics, the greatest scores occurred in the upper Blue River and the control site (sites 1, 2, and 27), and the lowest scores occurred at downstream sites (sites 20 and 22; fig. 20). Shannon Diversity Indices in the upper Blue River and South Grand River were in the range of scores of the Johnson County, Kansas, sites with a low degree of human disturbance. Scores in the lower reaches were even lower than those for the Johnson County, Kansas, streams with a increased degree of human disturbance.

The MOBI is a measurement of the average pollution tolerance of organisms at a site. Higher MOBI scores at a site indicate an overall composition of organisms that are more pollution tolerant; therefore, a lower score indicates better water quality or habitat. In general, sites sampled in this study largely consisted of organisms that were at least moderately pollution tolerant. Sites in the lower part of the Blue River Basin had the highest MOBI scores (fig. 20), which reflected a preponderance of organisms at these sites that were capable of surviving higher pollution levels than organisms at upstream sites and the outside control site.

Sites in the lower part of the Blue River Basin with the highest MOBI scores tended to have aquatic communities primarily composed of only a few organisms. For example, more than 95 percent of the organisms at sites 20 and 22 consisted of only five taxa in 2002 (fig.20). These taxa also tended to be dominated by the more pollution tolerant oligochaeta, chironomidae, and diptera taxa. At sites 1 and 2 in the upper part of the basin, the five most dominant taxa composed a smaller percentage of the total aquatic community than at downstream basin sites. In the years when these tended to account for a fairly substantial part of the total taxa (greater than 70 percent), it was largely because of the preponderance of moderately pollution tolerant trichoptera (net-spinning caddisflies) together with more pollution sensitive coleopteran (riffle beetle) and mayfly taxa (Wilkison and others, 2006; U.S. Geological Survey, Lee’s Summit, Missouri, unpub. data, 2008).

Based upon the SCI scores, no stream segments met the criteria for fully supporting aquatic life. The upper Blue River and the South Grand River control sites were classed as partially biologically supportive. Stream reaches of Indian and Tomahawk Creek and the lower Brush Creek and Blue River were between partially supporting and nonsupporting or in the nonsupporting category. Values for the Johnson County, Kansas, sites are included for comparison purposes only and indicate that even stream reaches considered to have minimal human disturbances would have been considered, at best, to be partially supportive of aquatic life as determined by the SCI score. The Johnson County sites were determined to be partially supportive when evaluated using the State of Kansas criteria for aquatic life support (Poulton and others, 2007). These data indicate that even in the least disturbed parts of the basin, the aquatic community structure has developed in response to some degree of water-quality and habitat degradation.

Habitat Assessments

Stream physical habitat assessments were conducted in 2006 at all 11 sites sampled for benthic macroinvertebrates in 2002 through 2004 (table 23). The assessments evaluate 10 different measures of the physical stream aquatic habitat expected to affect the condition of stream biota. Such measures incorporate information about the riparian vegetation, flow and channel characteristics, sedimentation, and substrate.

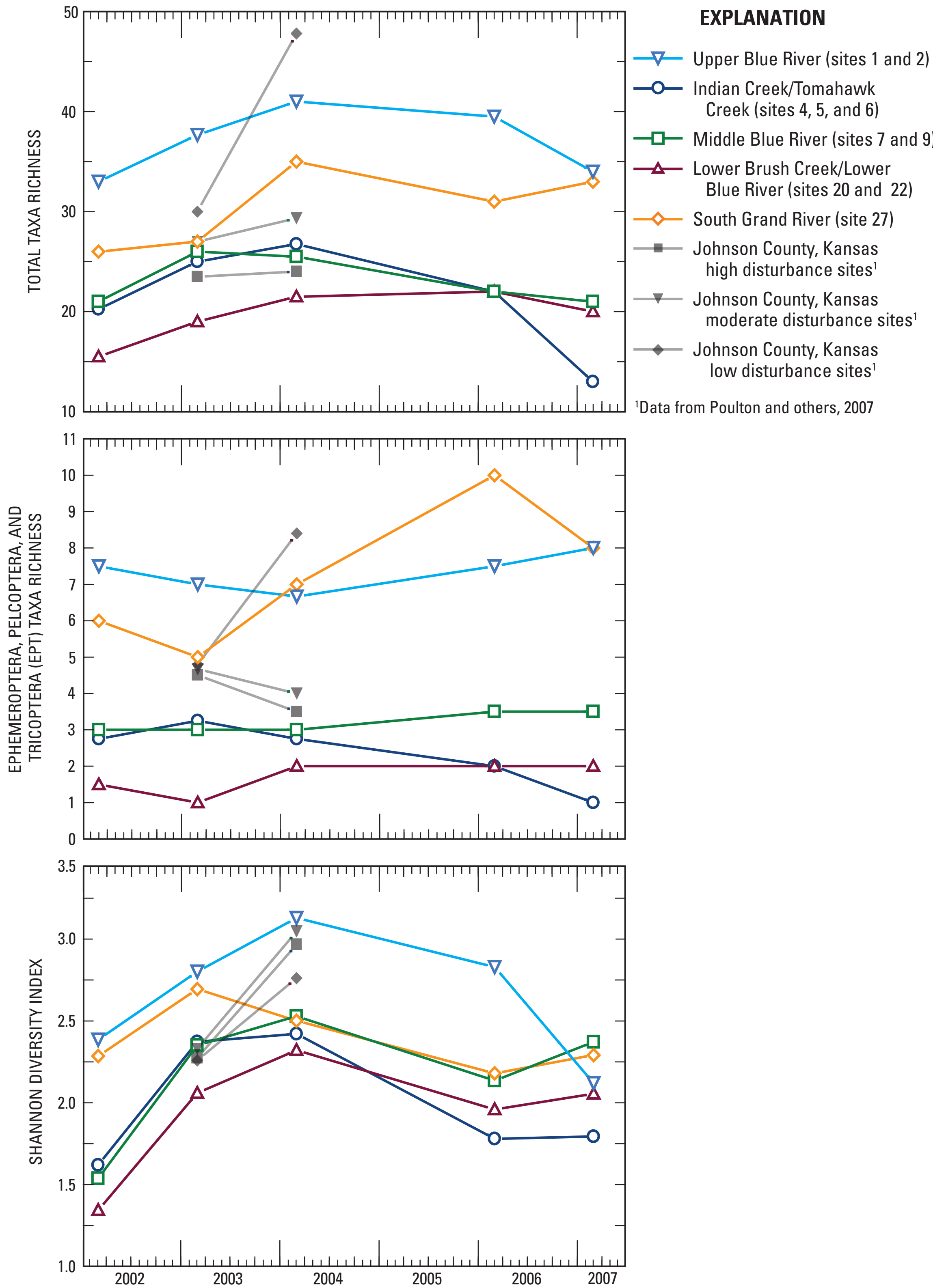


Figure 20. Selected biological metrics, including Missouri Department of Natural Resources core-metrics, Stream Condition Index (SCI) scores, and Aquatic Life Use Support Status (ALUS) for sites sampled in the Blue River Basin from 2002 through 2007.

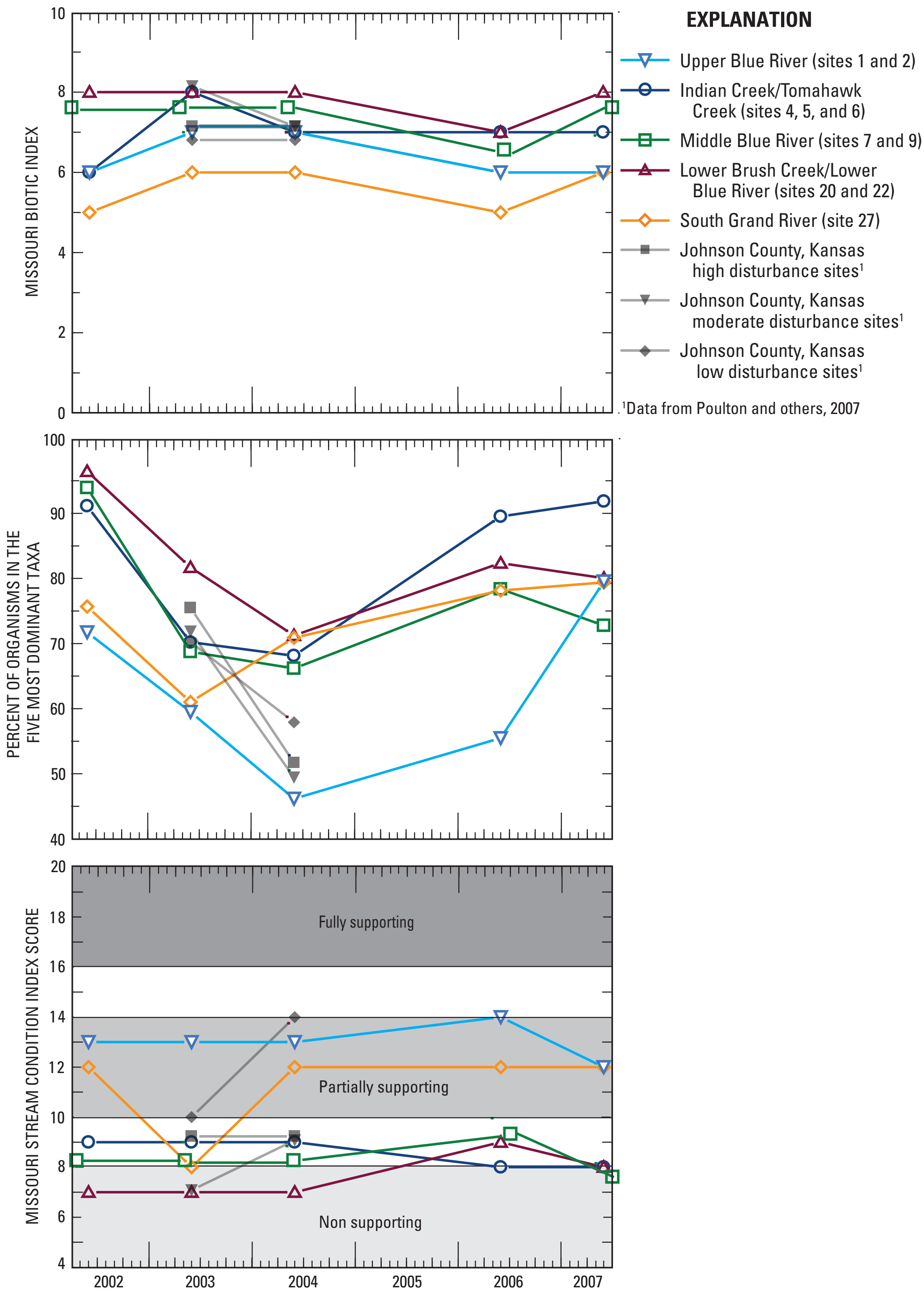


Figure 20. Selected biological metrics, including Missouri Department of Natural Resources core-metrics, Stream Condition Index (SCI) scores, and Aquatic Life Use Support Status (ALUS) for sites sampled in the Blue River Basin from 2002 through 2007.—Continued

Table 22. Benthic macroinvertebrate metric values, stream condition index scores (SCI) for Missouri Department of Natural Resources core metrics, and aquatic life use support (ALUS) status for sites sampled in 2006 and 2007 in the Blue River Basin.

[EPT, Ephemeroptera-Plecoptera-Trichoptera; MO-BI, Missouri Biotic Index; SDI, Shannon Diversity Index; ≥, greater than or equal to; M, March; >, equal to or greater than; PBS, partially biologically supporting; NBS, non-biologically supporting]

Site number (table 1)	Sample period	Total Taxa Richness		EPT Taxa Richness		MO-BI		SDI		Percent scrapers	Percent chironomidae	Percent tanytarsini midges	Percent MO-BI ≥ 6.5	EPT to Oligicheata Ratio	Percent dominant intolerant taxa	Total SCI score	ALUS status
		Metric value	SCI score	Metric value	SCI score	Metric value	SCI score	Metric value	SCI score								
								2006									
2	M	25	1	6	3	5.8	5	2.16	3	4.9	46.9	4.2	37.4	1.3	92	12	PBS
6	M	22	1	2	1	7.3	3	1.78	3	1.6	26.9	0	92.7	0	63	8	NBS
7	M	22	1	3	1	6.4	5	2.23	3	5.1	42.0	2.1	73.1	0	80	10	PBS
9	M	22	1	4	1	6.3	5	2.05	3	5.5	26.7	1.1	71.4	.14	85	10	PBS
20	M	15	1	1	1	7.6	3	1.73	3	2.0	69.0	0	81.8	0	32	8	NBS
22	M	29	1	3	1	6.4	5	2.19	3	2.5	32.7	.47	73.5	0	81	10	PBS
27	M	31	1	10	3	4.7	5	2.18	3	3.4	19.0	.52	7.2	25	93	12	PBS
								2007									
2	M	34	1	8	3	5.6	5	2.12	3	36	41.5	2.0	17.6	3.29	89	12	PBS
6	M	13	1	1	1	7.2	3	1.79	3	.3	25.4	0	88.5	0	42	8	NBS
7	M	21	1	4	1	7.0	3	2.40	3	14	33.6	0	70.4	.19	43	8	NBS
9	M	21	1	3	1	6.8	3	2.35	3	3.1	39.7	.20	69.3	.04	50	8	NBS
20	M	16	1	0	1	7.7	3	2.18	3	.8	30.9	.11	89.3	0	26	8	NBS
22	M	24	1	4	1	7.5	3	1.93	3	1.5	18.1	.14	85.5	0	35	8	NBS
27	M	33	1	8	3	6.0	5	2.29	3	15	52.3	.27	38.0	2.5	73	12	PBS

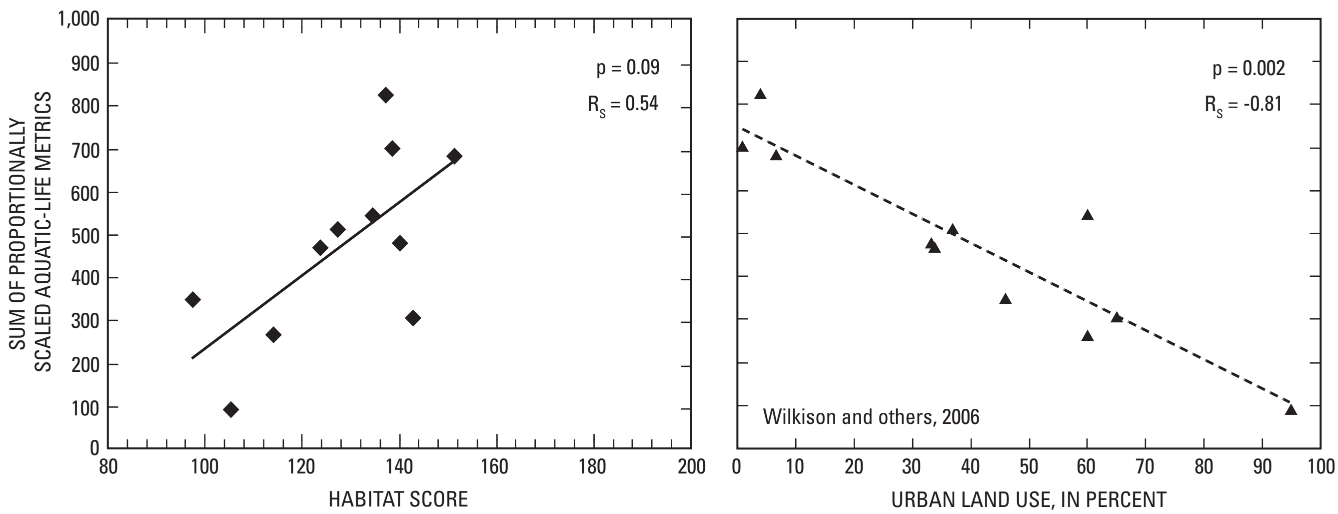


Figure 21. Relation between aquatic life metric scores and stream habitat assessment scores and urban land use at stream sites.

Scores for each measure then are summed to provide the habitat assessment score.

Habitat scores ranged from a high of 151 at site 2 to a low of 97 at site 22 with an average score of 128 for all sites sampled (fig. 1). Total scores typically were higher at stream sites in the upper part of the basin and lower in downstream reaches and, in general, the overall scores were reflective of the increased levels of channel disturbance in downstream reaches. Differences between higher habitat scores observed at sites in the upper, least disturbed parts of the basin and lower habitat scores observed at downstream, more disturbed sites primarily were attributed to channel alteration, loss of riparian vegetation, and sedimentation (table 23). Channel alteration and loss of riparian vegetation accounted for almost two-thirds of the difference in these scores. Factors related to instream habitat (embeddedness, epifuanal substrate, riffle quality, and sediment deposition) were secondary determinants for the lower scores at downstream sites.

These data indicate that channel alterations, which affect numerous stream reaches in the basin but more so in downstream reaches (Wilkison and others, 2005), result in reduced stream physical habitats. This partly is because of the loss of much of the native stream vegetation, loss of many natural pool and riffle sequences, and replacement of lotic (free-flowing) reaches with lentic (impounded) reaches. In some cases, altered flow regimes have resulted in channel scouring, which has reduced the amount and quality of riffles and, therefore, available habitat for benthic organisms. In other cases, in-stream habitat has been lost as sediment deposition has embedded or covered coarse-grained materials that would serve as substrate for bottom-dwelling organisms.

The relation between habitat scores and proportional multimetric macroinvertebrate scores at sites (Wilkison and others, 2006) is shown in figure 21. The habitat scores are a sum of 10 measures of a site's habitat (table 22) and the multimetric macroinvertebrate aquatic life scores are a sum of 10 measures of the diversity, composition, tolerance, and feeding characteristics of the macroinvertebrate communities at each site (Wilkison and others, 2006; Poulton and others, 2007). Spearman's Rho correlation coefficients between habitat scores and proportional macroinvertebrate scores (Rho = 0.54) were only marginally significant (p=0.09), indicating that habitat assessment scores were not robust indicators of macroinvertebrate communities at urban sites in the Blue River Basin and that other factors, such as basin land use/land cover and water quality, may impose stronger limitations on invertebrates.

By contrast, there was a statistically significant relation between aquatic-life metric scores and percent urbanization—defined as the roadway surface area plus the commercial, industrial, and residential land use—at sites (Rho = -0.81; p = 0.002; fig. 21). Several factors likely contribute to the difference between the relations between aquatic-life metrics and urban land use compared to aquatic-life metrics and habitat scores. These data indicate aquatic community health and diversity declined as the percent of urbanization increased, and site water quality is affected by the upstream land use and land cover. These factors may be more important than stream-channel habitat in determining the health of aquatic communities.

Habitat scores are designed to measure the nearby habitat and not the overall land use upstream from sites. Most sites sampled in this study were located in parklands; therefore, habitat scores may not accurately reflect the overall land use upstream from a site. Although the stream physical habitat at a site affects the quality of stream biota, larger scale land-use patterns, such as the amount of vegetation and impervious cover upstream from a site, may play a more substantial role in the health of aquatic communities. As previously noted (Wilkison and others, 2006), urbanization patterns result in increased point- and nonpoint-source inputs in downstream

Table 23. Stream habitat assessment scores for sites sampled in 2006 in the Blue River Basin.

Site number	Site name	Bank stability	Channel alteration	Channel flow status	Embed-dedness	Epifaunal substrate	Riffle quality	Riparian vegetation	Sediment deposition	Vegetative protection	Velocity-depth regime	Total score
1	Blue River near Stanley, Kansas	13.0	20	11.8	16	17	7.8	18.2	11	12.4	10.0	137
2	Blue River at Blue Ridge Boulevard Extension	14.6	20	13.2	18	19	15.0	18.2	14	9.4	10.0	151
3	Indian Creek near 69 Highway	12.8	20	10.	14	16	12.2	19.4	10	13.0	4.4	132
4	Indian Creek at Farley Boulevard	17.2	17.2	11.8	15	17	15.0	15.4	13	11.6	9.6	143
5	Tomahawk Creek at Tomahawk Creek Greenway	14.0	20	6.2	13	10	15.0	18.8	6	9.8	10.0	123
6	Indian Creek at 103 Street	15.4	8.4	13.2	14	17	15.0	5.6	12	3.2	10.0	114
7	Blue River near Kansas City, Missouri	11.2	18.2	11.2	16	17	15.8	20	11	9.0	10.8	140
9	Blue River near Gregory Boulevard, Kansas City Missouri[1]	7.2	18.2	13.2	16	10	6.2	20	14	16.0	6.6	127
20	Brush Creek at Elmwood Avenue	8.8	12.6	9.4	11	13	9.8	19.4	6	5.2	10.2	105
22	Blue River at Stadium Drive	20	0.0	10.6	12	11	9.4	0.0	10	15.8	8.6	97
27	South Grand River near Freeman, Missouri	14.0	16.8	10.2	18	16	15.0	20	13	5.6	10.0	139
Average of all sites		**13.5**	**15.6**	**11.0**	**15**	**15**	**12.4**	**15.9**	**11**	**10.1**	**9.1**	**128**

[1]Sampled at 63rd Street

basin reaches and additionally affect the health and diversity of aquatic communities.

Toxicity Screenings

Water and bottom-sediment samples were screened for acute and short-term acute toxicity using a tiered approach to evaluate the response of the three major trophic levels – primary producers, consumers, and decomposers. Samples were evaluated using a standard series of tests that included Daphnia magna, unicellular green algae, and bioluminescent bacteria. In general, organisms were exposed to test waters or sediments, and growth or mortality was measured against that of controls for each test. Base-flow samples from 13 sites, stormflow samples from 8 sites, and bottom-sediment samples from 12 sites were evaluated (table 24). The tiered approach was used to better capture the full range of responses that might be expected to be seen in the environment and because singular approaches sometimes fail to capture these responses.

Primary Producers

None of the algal toxicity samples tested using the green algae Psuedokirchneriella subcapitata indicated decreased growth when measured against the controls. In fact, about one-half of the algal toxicity samples indicated increased growth rates when compared to the control samples. These data indicate that water samples from the basin acted to stimulate plant growth, which would be expected given that most stream reaches in the basin receive excessive amounts of nutrients. In many samples, nutrient concentrations were several orders of magnitude greater than what might be expected from background conditions (Wilkison and others, 2006).

Consumers

No sample data indicated any evidence of toxicity using *Daphnia magna*. Other studies have shown *Daphnia magna* to be less sensitive than other methods for evaluating toxicity. Expressions of toxicity in higher trophic-level organisms may not have acute but rather chronic expressions in organisms. Long-term chronic effects were not measured in any of these tests.

Decomposers

Bioluminescent bacteria, *Vibrio fischeri*, were used to evaluate the toxicity of stream samples and bottom sediments to decomposers. Aliquots of *Vibrio fischeri* were exposed to samples, and the response was compared to that measured in controls. Luminescence declines (inhibition) of greater than 50 percent in stream samples compared to the control were considered toxic responses. No sample data indicated toxic responses for the 5-minute test, although three stormflow samples from Brush Creek and one from Town Fork Creek did exhibit toxicity in the 20-minute tests. Four snowmelt samples with large specific-conductance values, two from the Blue River (site 7) and two from Brush Creek (site 16), did not exhibit toxicity for either test. Based on specific-conductance values, these samples had estimated dissolved-chloride concentrations from 450 to 650 mg/L (fig. 5), which are below the 860 mg/L acute threshold for support of aquatic life, but above the chronic threshold of 230 mg/L (Missouri Department of Natural Resources, 2007) indicating that chronic, rather than acute, effects of road salt would be expected at these concentrations. Bottom sediment samples collected from two sites (site 13, Brush Creek at Ward Parkway and site 26, Penn Valley Park Lake) exhibited toxicity in the 20-minute test but not in the 5-minute test. All together, approximately one-fourth (24 percent) of the stormflow and bottom sediment samples exhibited some level of chronic toxicity in the *Vibrio fischeri* test (table 24). These data indicate that in some instances, storm runoff and bottom sediments may contain constituents that can potentially harm lower trophic-level organisms. Total polycyclic aromatic hydrocarbons (PAH) concentration in the Penn Valley Lake bottom sediment sample (11,900 μg/kg) was less than the consensus-based probable effects concentration of 22,800 μg/kg (MacDonald and others, 2000). However, previous studies (Wilkison and others, 2006) indicated that bottom sediment PAH concentrations in Brush Creek impoundments exceeded the consensus-based probable effects concentration about 40 percent of the time with an average concentration of 30,000 μg/kg. Other studies (Parvez and others, 2005) have shown that bioluminescent bacteria tests tend to be more sensitive than tests that rely on higher trophic-level organisms. In particular, lower-weight PAHs, those common in stormwater runoff from roads and impervious surfaces in urban areas, have been demonstrated to be more toxic to aquatic organisms than are higher weight PAHs of more limited solubility (Black and others, 1983).

Acute toxicity screenings that were performed using a series of tests that included primary producers, consumers, and decomposers indicated that although water and sediments in the basin typically do not pose an acutely toxic threat to biota, runoff events occasionally may pose such a threat, primarily to decomposers. These data indicate that any acutely toxic effects from exposure to stream waters or sediments are more likely to be expressed at the cellular, rather than at the organismal, level. However, screenings conducted during this study were not designed to determine the potential of long-term chronic effects on aquatic organisms. Such effects are possible given the high concentrations of dissolved chloride in streams during winter periods and the concentrations of PAHs measured in bottom sediments, both measured at levels expected to be harmful to aquatic life. The possibility still exists that concentrations of some constituents may pose chronic effects to organisms over longer exposures.

Table 24. Toxicity screening results for water and sediment samples collected in the Blue River Basin, October to December 2007.

[=, sample response within 10 percent of control response; >10, sample response stimulated greater than 10 percent of control ; <25–50, sample response inhibited between 25 and 50 percent of control; <50, sample response inhibited by more than 50 percent of control; KS, Kansas; Blvd, Boulevard; min, minutes,--, no data]

Site number (fig. 1)	Station name	Test (duration)				
		Psuedokirchneriella subcapitata (72 hours)	*Daphnia magna* (24 hours)	*Daphnia magna* (48 hours)	*Vibrio fischeri* (5 min)	*Vibrio fischeri* (20 min)
	Base flow samples					
1	Blue River near Stanley, Kansas	=	=	=	=	=
2	Blue River at Blue Ridge Boulevard Extension	=	=	=	=	=
5	Tomahawk Creek near 111th Street	=	=	=	=	=
6	Indian Creek at 103rd Street	=	=	=	=	=
7	Blue River near Kansas City, Missouri	>10	=	=	=	=
8	Blue River near Gregory Blvd	>10	=	=	=	=
12	Brush Creek at Belinder Ave.	=	=	=	=	=
13	Brush Creek at Ward Parkway	>10	=	=	=	=
16	Brush Creek at Rockhill Road	>10	=	=	=	=
19	Town Fork Creek	>10	=	=	=	<25–50
20	Brush Creek at Elmwood Ave.	>10	=	=	=	=
22	Blue River at Stadium Drive	>10	=	=	=	<25–50
27	South Grand River near Freeman	>10	=	=	=	=
	Stormflow samples					
2	Blue River at Blue Ridge Blvd Extension	=	=	=	=	=
6	Indian Creek at 103rd Street	=	=	=	=	=
7	Blue River near KCMO	=	=	=	=	=
7	Blue River near KCMO (snowmelt)	--	--	--	=	=
7	Blue River near KCMO (snowmelt)	--	--	--	=	=
8	Blue River at 63rd Street	=	=	=	=	=
12	Brush Creek at Belinder Ave.	>10	=	=	<25–50	<50
13	Brush Creek at Ward Parkway	=	=	=	<25–50	<50
16	Brush Creek at Rockhill Road	>10	=	=	<25–50	<50
16	Brush Creek at Rockhill Road (snowmelt)	--	--	--	=	=
16	Brush Creek at Rockhill Road (snowmelt)	--	--	--	=	=
19	Town Fork Creek	=	=	=	<25–50	<50
22	Blue River at Stadium Drive	>10	=	=	=	=
	Sediment samples					
2	Blue River at Blue Ridge Blvd Extension	--	=	=	=	=
5	Tomahawk Creek near 111th Street	--	=	=	=	=
6	Indian Creek at 103rd Street	--	=	=	=	=
7	Blue River near KCMO	--	=	=	=	=
8	Blue River near Gregory Blvd	--	=	=	=	=
12	Brush Creek at Belinder Ave.	--	=	=	=	=
13	Brush Creek at Ward Parkway	--	=	=	<25–50	<50
16	Brush Creek at Rockhill Road	--	=	=	=	=
20	Brush Creek at Elmwood Ave.	--	=	=	=	=
22	Blue River at Stadium Drive	--	=	=	=	=
26	Penn Valley Lake	--	=	=	<25–50	<50
27	South Grand River near Freeman	--	=	=	=	=

Impounded Sediments

Previous work (Wilkison and others, 2002; 2006) indicates that as sediment is transported downstream from the upper reaches of Brush Creek, it encounters lower stream gradients and reduced stream velocities in impoundments. Lower stream velocities limit the stream's carrying capacity for suspended sediment, which results in bottom sediment accumulation in impoundments. This phenomenon is most pronounced in the lower reach of Brush Creek adjacent to site 20, known locally as Lake of the Enshriners, which has the largest impounded area. As particulates settle from the water column, they carry attached constituents that can accumulate with time. Although a number of biogeochemical processes may act to degrade a part of these constituents, data have shown that the streambed sediments frequently are enriched in a number of organic wastewater compounds including detergents, fragrance compounds, plasticizers, and sterols as well as PAHs and pesticides (Wilkison and others, 2006). Over-the-counter and prescription medications also have been detected in these bottom sediments (Wilkison and others, 2006).

Some of the smaller upstream impoundments (such as adjacent to site 16) were designed to scour sediment during large runoff events, and these reaches tend to remain relatively free of accumulated sediment. Additionally, sediment supply is limited in this reach as the upstream impoundment (adjacent to site 15) traps a part of the suspended sediment, which acts to starve downstream reaches (Wilkison and others, 2002). Sediment also is removed every couple of years from the impoundment just upstream from site 15, which further limits the potential for downstream transport. The shallow upstream impoundments allow sunlight to penetrate throughout the entire water column, which can degrade compounds. Concentrations measured in the upper impoundments were less than those measured in Lake of the Enshriners sediments (Wilkison and others, 2006).

An estimate of the sediment accumulation in Lake of the Enshriners was conducted by comparing the lake bathymetry against the elevation profile of the lake bottom at the time of construction. The net difference between these two elevation profiles constituted the accumulated sediment volume that had occurred from 1996 to 2006. Based upon these data, approximately 1.5 million cubic feet (34 acre-feet) of sediment accumulated in Lake of the Enshriners during this time. However, the mean net sediment yield (the average annual lake sedimentation volume divided by the drainage area over the lifespan of the lake) for Lake of the Enshriners was quite small (0.12 acre-feet per square mile per year) when compared to other lakes in the region (values ranged from 0.03 to 2.04 acre-feet per square mile per year; Kyle Juracek, U.S.Geological Survey, written commun., 2008). Sediment inputs have displaced approximately 16 percent of the original lake volume in 10 years.

Bottom sediments in Penn Valley Park Lake (site 26) were collected in August 2006 and analyzed for 62 organic wastewater compounds (OWCs; table 10). Concentrations of PAHs accounted for 75 percent of the total OWCs measured in this sample. The total PAH concentration (11,900 µg/kg)—determined by the sum of the 1-methylnaphthalene, 2-methylnaphthalene, anthracene, benzo (α) pyrene, fluoranthene, naphthalene, para-cresol, phenanthrene, and pyrene concentrations—was near the lower range of values previously observed in bottom sediments at Brush Creek sites 15, 16, and 20 where values ranged from 11,300 to 68,000 µg/kg (Wilkison and others, 2006). The total PAH concentration measured in Penn Valley Park Lake was about one-half the consensus-based probable effects concentration (PEC) for total PAHs in freshwater sediments (MacDonald and others, 2000). However, fluoranthene, phenanthrene, and pyrene concentrations exceeded the PEC guidelines as they have in previous samplings of other sites (sites 4–6, 15–16, and 20) in the Blue River Basin (Lee and others, 2005; Wilkison and others, 2006). Total PAH concentrations determined from sediments collected near the mouth of the Blue River near site 24 (Echols and others, 2007) were three times less than concentrations determined in Penn Valley Park Lake, and concentrations in bottom sediments collected in Blue River headwater reaches upstream from site 2 generally were 50 to 200 times less than those observed in Penn Valley Park Lake.

There are numerous sources of PAHs in the environment, including atmospheric deposition, sewage, and runoff. However, studies have demonstrated that PAH concentrations are strongly linked to the level of nearby automobile traffic (Van Metre and others, 2000). Concentrations of PAHs measured in bottom sediments throughout the course of this study were similar to those reported elsewhere for urban lakes (Van Metre and others, 2002). PAHs bind to particles on road surfaces, which are rapidly transported to receiving waters during runoff events. Renewed accumulation on surfaces begins almost immediately once precipitation ends (Krein and Schorer, 2000), resulting in a nearly continuous source of materials ready for available transport to receiving waters.

As with PAHs, concentrations of detergent metabolites, pesticides, plastics, and solvents in Penn Valley Park Lake sediments (table 10) were near the lower range of concentrations previously measured in Brush Creek impoundments (Wilkison and others, 2006). Two classes of compounds, disinfectants and sterols, which are thought to be strong indicators of wastewater contamination, were not detected in the Penn Valley Park Lake sample. Bottom sediment OWCs concentrations tended to decrease with the size of the impoundment. Penn Valley Park Lake's surface area is approximately one-tenth as large as the smallest impoundment on Brush Creek, which may have affected detection levels as well as the fact that there is only one CSO discharge point upstream from Penn Valley Park Lake. The predominate source of OWCs affecting the quality of bottom sediments in Penn Valley Park Lake likely are runoff from impervious surfaces.

Summary and Conclusions

A study was conducted in the Blue River Basin, Kansas City Metropolitan area, in cooperation with the City of Kansas City, Missouri Water Services Department to characterize water quality from a basin perspective, identify constituent sources, and evaluate spatial and temporal trends from 1998 through 2007. The water quality of streams in the Blue River Basin have been affected by CSOs, other point and nonpoint source pollution, physical stream conditions, and complex water-quality processes; an understanding of the myriad of sources, conditions, and processes was critical for a complete evaluation of stream-water quality. These data were needed to provide a baseline for evaluating the effectiveness of long-term combined sewer overflow control and basin management plans to meet water-quality standards and protect designated stream uses.

A network of 27 streamflow and water-quality sites was established and sampled from 1998 through 2007. Discrete and continuous measurements of streamflow and water-quality properties combined with nutrient, fecal-indicator bacteria, suspended sediment, organic wastewater, and pharmaceutical compound data from base-flow and stormflow samples were used to examine spatial and temporal trends occurring in the basin, develop load estimation models at selected sites for seasonal and annual trend analysis, and evaluate contaminant sources. The biological integrity at stream sites was assessed using measurements of benthic aquatic macroinvertebrates, stream physical habitats, and toxicity screenings.

Hydrologic alterations, primarily low-head dams and concrete-lined channels, to the Brush Creek stream channel resulted in statistically significant differences between Brush Creek and the Blue River for several water-quality properties and constituents. Monthly median specific-conductance values of the Blue River were larger than the values of Brush Creek partly because a substantial part of flows in the Blue River downstream from Indian Creek sewage effluent that, although treated to meet applicable water-quality standards, has increased concentrations of a number of dissolved ions that increase specific conductance. Additionally, the Brush Creek Basin has a higher percentage of impervious cover than does the upper Blue River, which directs substantial amounts of low-conductance precipitation directly to Brush Creek. Turbidity values in the Blue River were approximately twice that in Brush Creek, reflective of the greater sediment load the Blue River carried during large runoff events. Additionally, sediment trapping within impounded reaches of Brush Creek lessened sediment concentrations in Brush Creek compared to the Blue River.

From April through November of each year, Blue River dissolved-oxygen concentrations rarely were (3 percent of days) below the 5 mg/L standard for full support of aquatic life, unlike Brush Creek where dissolved-oxygen concentrations were below the standard approximately 27 percent of time. These differences partly were because storms deliver suspended sediment, organic matter, and nutrients to impounded Brush Creek reaches where biogeochemical processes frequently acted to reduce dissolved-oxygen levels. Nutrient-enriched waters also resulted in periodic algal blooms and eutrophication in impounded reaches of Brush Creek. Instream nutrient assimilation processes acted to remove part of the nutrient load (13 percent of the total nitrogen and 26 percent of the total phosphorus) in a 20-km reach of the Blue River. However, these processes appeared to be limited to warmer and drier periods and are insufficient to eliminate nutrient saturation of basin streams.

Large fecal coliform densities were strongly linked to stormflow runoff; the median *Escherichia coli (E. coli)* density in stormflow samples was 100 times the median base-flow density. During three base-flow synoptic samplings of 19 basin sites focused in the combined sewer system area, fecal-indicator bacteria densities (*E. coli* and fecal coliform) generally increased downstream and, correspondingly, as urbanization increased. Brush Creek, the tributary with the greatest number of CSO discharge points, contributed, on average, approximately 10 percent of the annual *E. coli* to downstream reaches of the Blue River. The tributary Town Fork Creek had median base-flow *E. coli* densities double that of other sites in the basin and median stormflow densities that were about 10 times greater than other stormflow samples primarily because approximately one-fourth of the runoff in Town Fork Creek Basin was thought to originate in combined sewers.

Cumulative duration curves of estimated daily mean *E. coli* densities in the Blue River Basin indicated that sites on the upper reaches of the main stem of the Blue River would meet the State of Missouri secondary contact criterion (1,134 col/100 mL) for *E. coli* approximately 85 percent of the time from October 2002 through September 2007 with exceptions occurring during runoff events. For stream segments of the Blue River where the current (2009) whole body contact, Class A criterion apply (126 col/100 mL), estimated *E. coli* densities rarely were below the standard. In reaches where the current (2009) whole body contact, Class B criterion (206 col/100 mL) apply, estimated *E. coli* densities were below the standard approximately 10 percent of the time.

Microbial-source tracking indicated that a substantial part of instream bacteria for wet weather and base-flow events was of human origin. Stormwater runoff generated the largest *E. coli* densities and *E. coli* loads and the largest amount of human *E. coli* to streams. Almost one-half (45 percent) of the human-sourced bacteria measured in the basin originated from two stormwater events on the Town Fork Creek tributary (site 19) because of large *E. coli* densities in this stream and the high percentage of these samples typed as human. The percent of human-sourced bacteria in basin base-flow samples (average of 43 percent) indicated that the persistence and adaptability of *E. coli* may be a concern.

Flow-adjusted concentration trends were determined for two sites on the main stem of the Blue River (sites 7 and 22) and for two sites on Brush Creek (sites 13 and 16) from October 1998 through September 2007. For two other basin sites, one on the upper Blue River (site 2) and one on Indian Creek (site 6), which had shorter timeframes of data collection, flow-adjusted concentration trends were determined from October 2002 through September 2007. Monotonic trends were determined for 22 constituents using fitted linear regression models that included concentration, flow, time, and in some cases, yearly or seasonal terms. Constituents for flow-adjusted concentration trend analysis included total and dissolved nutrients, fecal-indicator bacteria, suspended sediment, chloride, and selected organic wastewater indicator compounds including caffeine, the sterols—cholesterol plus coprostanol, the insect repellant DEET, and the antimicrobial compound triclosan. In approximately two-thirds (64 percent) of the cases where models met the fit-selection criteria, trends were not significant, indicating that, in general, basin conditions remained relatively stable during the study period and did not affect constituent concentrations. Where statistically significant flow-adjusted trends were detected, most (88 percent) were declines. Declines in flow-adjusted concentration were associated with suspended sediment or constituents that have a strong affinity for suspended sediment.

A number of policies and efforts designed to reduce or control sediment in the basin began near the inception of this study and flow-adjusted sediment concentrations declined significantly at five of six sites in the basin. Declines in sediment concentrations are important because many water-quality contaminants have an affinity for suspended sediment, and limiting sediment supply to streams can reduce their concentration in streams. *E. coli* densities also declined at basin sites, although only one site (site 2) had a statistically significant decline.

Daily mean concentration duration curves for total nitrogen, total phosphorus, *E. coli*, suspended sediment, and the frequently detected wastewater indicator compounds – caffeine, DEET, sterol, and triclosan – were developed from fitted models that included concentration, flow, time, and in some cases, yearly or seasonal terms. Total nitrogen concentrations on Indian Creek (site 6) exceeded 10 milligrams per liter (mg/L) about 50 percent of the time from 2000 through 2007 and to a much lesser extent on sites in the Blue River (sites 2, 7, and 22) from 1998 through 2007 with the largest concentrations corresponding to the days in which treated effluent was the largest percent of streamflow.

Total nitrogen concentrations never exceeded 5 mg/L at Brush Creek sites from 1998 through 2007 and concentrations were greatest during runoff events rather than during base-flow events. At all sites in the basin, total nitrogen concentrations almost always exceeded the recommended U.S. Environmental Protection Agency ecoregional total nitrogen criterion of 0.69 mg/L.

Estimated total phosphorus concentration duration curves at stream sites followed similar patterns to estimated total nitrogen curves because sources largely are the same for both constituents. At stream sites dominated by treated sewage effluent (Blue River and Indian Creek), the median and range of concentrations were greater than at Brush Creek sites. Estimated total phosphorus concentrations on the Blue River and Indian Creek also exceeded the U.S. Environmental Protection Agency ecoregional criterion of 0.037 mg/L 100 percent of the time from 1998 through 2007, with the largest concentrations occurring when effluent comprised the largest percentage of streamflow. The median and range of total phosphorus concentrations at Brush Creek sites also were less than at Blue River and Indian Creek sites. Estimated total phosphorus concentrations exceeded the U.S. Environmental Protection Agency ecoregional criterion less than 10 percent of the time on Brush Creek, and these periods corresponded with stormwater runoff.

Concentration ranges for caffeine were greater on Brush Creek (site 16) and the largest concentrations occurred during runoff in the spring and summer as opposed to sites on Indian Creek and the Blue River, where the highest concentrations occurred during the winter months when streamflows were largely comprised of effluent and biological removal processes were slowed by lower water temperatures. Concentrations of DEET, sterol, and triclosan generally were greater at wastewater-dominated sites than at CSO-dominated sites. DEET concentrations tended to peak during summer months at all sites; however, at wastewater-dominated sites, increased sterol and triclosan concentrations corresponded with winter base flows.

Loads of nutrients and organic wastewater compounds were, on average, about 20 times greater in the effluent-dominated Blue River than for the CSO-dominated Brush Creek. Seasonally, the largest contribution of nutrients to basin streams occurred from March through August of each year, partly because this corresponded with the greatest flows, and a substantial part of nutrient inputs originated during storm runoff. These events provide nonpoint and point-source contributions. An even larger percentage of nutrients was contributed to Brush Creek from March through August because precipitation events triggered more frequent CSO discharges. Seasonal patterns for caffeine, DEET, sterol, and triclosan were slightly different between the effluent-dominated Blue River and the CSO-dominated Brush Creek. On the Blue River, with flows augmented by discharges from three upstream WWTPs, colder winter temperatures reduced treatment plant removal efficiencies which, coupled with winter low-flow periods, resulted in an increased percentage of these constituents being delivered to the Blue River compared to Brush Creek, where the dominant source is CSO discharges, which occur much less frequently during the winter. DEET contributions to area streams were greatest during the summer, the expected period of greatest use. Declining percentages of caffeine and sterol in the Blue River throughout the summer and early fall indicate biogeochemical processes increase and act to decrease instream concentrations.

Total annual contributions of nutrients and fecal-indicator bacteria to stream reaches in the basin, and annual contributions from the two primary basin point sources, CSOs and WWTPs, as well as contributions from nonpoint sources were determined. For the main stem of the Blue River and Indian Creek, the primary sources of nutrients were nonpoint-source runoff and WWTPs effluent discharges. The relative contribution of these two sources varied from year to year based upon annual precipitation and the number of upstream WWTPs. Nutrient contributions from CSOs to the Blue River were minor (1 percent or less of the annual total) when compared to those from nonpoint sources and from WWTPs. Nonpoint-source contributions of fecal-indicator bacteria contributions on the main stem of the Blue River and Indian Creek accounted for more than 96 percent of the annual total, whereas those from WWTPs accounted for 4 percent or less. In 2005, even though CSO contributions to Blue River reaches were sometimes more than 100 times larger than WWTP contributions, CSOs still contributed only 2 percent or less of the total fecal-indicator load to the Blue River.

On Brush Creek, approximately two-thirds of the annual nutrient load originated from nonpoint-source contributions, with the remaining one-third from CSOs. Annual contributions from CSOs accounted for 39 percent of the total fecal coliform load in 2005 and 24 percent of the total *E. coli* load. The bulk of the annual fecal coliform load in Brush Creek originated from nonpoint sources.

Biological assessments were conducted at basin sites using the sampling of benthic macroinvertebrate communities for diversity and abundance, habitat assessments, and toxicity evaluations. Macroinvertebrate communities that were the most diverse, the most evenly distributed among taxa, and the least tolerant of pollution occurred at sites in the upper Blue River and the outside control site. Downstream basin reaches contained the least diverse populations and the largest percentage of pollution-tolerant organisms of basin sites. Based upon Missouri Stream Condition Index Scores, no sites in the basin met the criteria for fully supporting aquatic life from 2000 through 2007. Sites in the upper Blue River fell into the range of partially biologically supportive, whereas sites in lower reaches were near the lower limit of partially supporting, or the upper limit of nonsupporting of aquatic life.

Channel alteration and loss of riparian vegetation accounted for almost two-thirds of the difference in stream physical habitat assessment scores observed at sites in the upper, least disturbed parts of the basin, and lower habitat scores observed at downstream, more disturbed sites. However, local stream habitat features were not as robust measures of the quality of macroinvertebrate communities as were the larger-scale landuse/land cover upstream from sites.

Toxicity screenings, using a tiered-approach to assess the major trophic levels – primary producers, consumers, and decomposers–were used to evaluate the acute and short-term acute toxicity of water and bottom sediments. Water and bottom sediments were not acutely toxic to the unicellar green algae *(Pseudokirchneriella subcapitata)* or consumers *(Daphna magna)*. In fact, the growth rate of green algae exposed to stream water increased compared to that of control samples likely because of the nutrient-rich quality of basin streams. Although acute toxicity was not observed in the bioluminescent bacteria, *Vibrio fischeri*, when exposed to base-flow samples, approximately one-fourth of stormflow and bottom-sediment samples exhibited some degree of short-term acute toxicity. These data indicate that deleterious effects associated with contaminants present in the Blue River Basin are more likely to be expressed as chronic, rather than as acute toxicity, and that responses are more likely to be observed at the cellular, rather than organismal level.

Polycyclic aromatic hydrocarbons (PAHs) accounted for approximately 75 percent of the organic wastewater compounds measured in lake-bottom sediments of Penn Valley Park Lake, an indication that the predominant source of PAHs entering the lake was likely to be runoff from impervious surfaces. Bottom-sediment concentrations of fluoranthrene, phenanthrene, and pyrene exceeded the consensus-based probable effects concentration for freshwater sediments.

Analysis of a wide variety of constituents in streamwater samples coupled with biological assessments from 1998 through 2007 provide the basis for assessing the efficacy of long-term combined sewer control and basin management plans in the Blue River Basin. These data provide spatial and temporal resolution to factors that affect the quality of water and biota in the basin and indicate that water quality in the basin could be improved by incorporating multiple strategies in order to reduce constituent loads in streams. Strategies designed to reduce or eliminate CSOs substantially would reduce the annual loads of nutrients and fecal-indicator bacteria in Brush Creek, but have little effect on Blue River loadings. Nonpoint-source reductions to Brush Creek potentially could have an equivalent, if not greater, effect on water quality than CSO reductions. Although WWTPs account for a small part (less than 1 percent) of the total annual bacteria loads to the Blue River and Indian Creek, reduction of WWTPs nutrient loads could substantially reduce Indian Creek and the Blue River nutrient loads. Nonpoint-source reductions could substantially reduce annual nutrient and bacteria loadings to the Blue River and Indian Creek.

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