Prepared in cooperation with Johnson County Wastewater

Effects of Wastewater Effluent Discharge and Treatment Facility Upgrades on Environmental and Biological Conditions of the Upper Blue River, Johnson County, Kansas and Jackson County, Missouri, January 2003 through March 2009

Scientific Investigations Report 2010–5248

U.S. Department of the Interior
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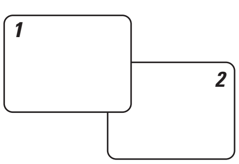
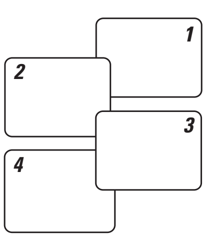


Front cover.

1. Upper Blue River near Blue Ridge Boulevard in Jackson County, Missouri, July, 2008.
2. Upper Blue River near Kenneth Road in Johnson County, Kansas, June, 2008.



Back cover.

1. Sediment sample collection,
2. habitat assessment,
3. invertebrate sample collection, and
4. monitor installation at upper Blue River study sites in Johnson County, Kansas and Jackson County, Missouri.

Effects of Wastewater Effluent Discharge and Treatment Facility Upgrades on Environmental and Biological Conditions of the Upper Blue River, Johnson County, Kansas and Jackson County, Missouri, January 2003 through March 2009

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Barry C. Poulton

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
meter (m)	3.2808	foot (ft)
mile (mi)	1.609	kilometer (km)
centimeter (cm)	0.3937	inch (in)
millimeter (mm)	0.03937	inch (in)
micrometer (µm)	0.001	millimeter (mm)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
square meter (m^2)	10.76	square feet (ft^2)
	Volume	
milliliter (mL)	0.0338	ounce, fluid (oz)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
milligrams per liter (mg/L)	1	parts per million (ppm)
milligrams per square meter (mg/m^2)	0.000001	kilogram per square meter (kg/m^2)
microgram per kilogram (µg/kg)	1	parts per billion (ppb)
microgram per liter (µg/L)	1	parts per billion (ppb)
	Mass	
kilogram (kg)	2.204	pounds (lb)
milligram (mg)	0.001	gram (g)
microgram (µg)	0.000001	gram (g)
ton per year (ton/yr)	0.9072	metric ton per year

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

$$°F=(1.8\times°C)+32$$

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

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

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

Effects of Wastewater Effluent Discharge and Treatment Facility Upgrades on Environmental and Biological Conditions of the Upper Blue River, Johnson County, Kansas and Jackson County, Missouri, January 2003 through March 2009

By Jennifer L. Graham[1], Mandy L. Stone[1], Teresa J. Rasmussen[1], and Barry C. Poulton[2]

Abstract

The Johnson County Blue River Main Wastewater Treatment Facility discharges into the upper Blue River near the border between Johnson County, Kansas and Jackson County, Missouri. During 2005 through 2007 the wastewater treatment facility underwent upgrades to increase capacity and include biological nutrient removal. The effects of wastewater effluent on environmental and biological conditions of the upper Blue River were assessed by comparing an upstream site to two sites located downstream from the wastewater treatment facility. Environmental conditions were evaluated using previously and newly collected discrete and continuous data, and were compared with an assessment of biological community composition and ecosystem function along the upstream-downstream gradient. This evaluation is useful for understanding the potential effects of wastewater effluent on water quality, biological community structure, and ecosystem function. In addition, this information can be used to help achieve National Pollution Discharge Elimination System (NPDES) wastewater effluent permit requirements after additional studies are conducted.

The effects of wastewater effluent on the water-quality conditions of the upper Blue River were most evident during below-normal and normal streamflows (about 75 percent of the time), when wastewater effluent contributed more than 20 percent to total streamflow. The largest difference in water-quality conditions between the upstream and downstream sites was in nutrient concentrations. Total and inorganic nutrient concentrations at the downstream sites during below-normal and normal streamflows were 4 to 15 times larger than at the upstream site, even after upgrades to the wastewater treatment facility were completed. However, total nitrogen concentrations decreased in wastewater effluent and at the downstream site following wastewater treatment facility upgrades. Similar decreases in total phosphorus were not observed, likely because the biological phosphorus removal process was not optimized until after the study was completed.

Total nitrogen and phosphorus from the wastewater treatment facility contributed a relatively small percentage (14 to 15 percent) to the annual nutrient load in the upper Blue River, but contributed substantially (as much as 75 percent) to monthly loads during seasonal low-flows in winter and summer. During 2007 and 2008, annual discharge from the wastewater treatment facility was about one-half maximum capacity, and estimated potential maximum annual loads were 1.6 to 2.4 times greater than annual loads before capacity upgrades. Even when target nutrient concentrations are met, annual nutrient loads will increase when the wastewater treatment facility is operated at full capacity. Regardless of changes in annual nutrient loads, the reduction of nutrient concentrations in the Blue River Main wastewater effluent will help prevent further degradation of the upper Blue River.

The Blue River Main Wastewater Treatment Facility wastewater effluent caused changes in concentrations of several water-quality constituents that may affect biological community structure and function including larger concentrations of bioavailable nutrients (nitrate and orthophosphorus) and smaller turbidities. Streambed-sediment conditions were similar along the upstream-downstream gradient and measured constituents did not exceed probable effect concentrations. Habitat conditions declined along the upstream-downstream gradient, largely because of decreased canopy cover and riparian buffer width and increased riffle-substrate fouling. Algal biomass, primary production, and the abundance of nutrient-tolerant diatoms substantially increased downstream from the wastewater treatment facility. Likewise, the abundance of intolerant macroinvertebrate taxa and Kansas Department of

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Health and Environment aquatic-life-support scores, derived from macroinvertebrate data, significantly decreased downstream from the wastewater treatment facility. Ecosystem functional health, evaluated using a preliminary framework based on primary production and community respiration, downstream from the wastewater treatment facility was mildly impaired relative to the upstream site during summer 2008 but not during other times of the year.

Upgrades to the Blue River Main Wastewater Treatment Facility improved wastewater effluent quality, but the wastewater effluent discharge still had negative effects on the water quality and biological conditions at the downstream sites. Wastewater effluent discharge into the upper Blue River likely contributed to changes in measures of ecosystem structure (streamflow, water chemistry, algal biomass, algal periphyton and macroinvertebrate community composition) and primary production, a measure of ecosystem function, along the upstream-downstream gradient. Because the Blue River Main Wastewater Treatment Facility is located in a rapidly urbanizing area, urbanization effects also may play a role in the decline in environmental and biological conditions along the upstream-downstream gradient. Despite these differences in environmental and biological conditions, ecosystem functional health was not impaired downstream from the WWTF during most times of the year, indicating the declines in environmental and biological conditions along the upstream-downstream gradient were not substantial enough to cause persistent changes in ecosystem function.

Introduction

Johnson County is the fastest growing county in Kansas, with a current (2010) population of about 543,000 people. The population in Johnson County has increased by approximately 20 percent every decade, a growth trajectory that is expected to continue for at least the next 20 years (U.S. Census Bureau, 2010). Infrastructure needs will continue to increase with ongoing population growth and urban development. Urban growth and development can have substantial effects on water quality (Walsh and others, 2005), and streams in Johnson County are affected by nonpoint-source pollutants from stormwater runoff and point-source discharges such as municipal wastewater effluent (Lee and others, 2005). Understanding of current (2010) water-quality conditions and the effects of urbanization is critical for the protection and remediation of aquatic resources in Johnson County, Kansas and downstream reaches located elsewhere.

Nutrients, particularly nitrogen and phosphorus, are considered one of the leading causes of water-quality impairment in Kansas and the nation (Kansas Department of Health and Environment, 2004; U.S. Environmental Protection Agency, 2009). Nutrients are essential for the growth of all organisms; however, excessive concentrations in aquatic environments may cause nuisance algal growth. Overly abundant algal growth causes aesthetic concerns, degrades habitats, and decreases dissolved oxygen stability. There are point and nonpoint sources of nutrient pollution, but point sources, such as wastewater effluent discharges, are easily identified and provide targeted opportunities to reduce nutrient loads in the environment (Kansas Department of Health and Environment, 2004).

The Johnson County Blue River Main Wastewater Treatment Facility (WWTF) is a point-source wastewater effluent discharge on the Blue River in Johnson County, Kansas (fig. 1). In April 2007, upgrades to increase capacity and include biological nutrient removal at the Blue River Main WWTF were completed (Johnson County Wastewater, written commun., 2010). Biological nutrient removal is a modification of traditional biological treatment processes that enhances the removal of nitrogen and phosphorus by selecting for specific microorganisms within the wastewater (Tchobanoglous and others, 2003). Wastewater treatment is subject to local, State, and Federal regulations to help protect water quality and aquatic life, though regulations only apply to limited jurisdictional areas. The National Pollutant Discharge Elimination System (NPDES) permit for the expansion and upgrades to the Blue River Main WWTF defines target wastewater effluent concentrations for total nitrogen and phosphorus (TN and TP, respectively) of less than 8.0 and 1.5 milligrams per liter (mg/L), respectively, as an annual mean (NPDES permit number KS0092738; Kansas permit number M-MO26-0006). These targets were established by the Kansas Department of Health and Environment (KDHE) based on typical removal efficiencies for nutrients by biological nutrient removal processes as part of the Kansas Surface Water Nutrient Reduction Plan (Kansas Department of Health and Environment, 2004). The NPDES permit also requires an evaluation of wastewater effluent effects on the receiving stream after upgrades are complete (NPDES permit number KS0092738).

The U.S. Geological Survey (USGS), in cooperation with Johnson County Wastewater, conducted a study to assess the effects of post-expansion wastewater effluent discharges on the upper Blue River. Water-quality and biological data were collected to allow assessment of chemical and resulting ecological effects of the wastewater effluent discharge before and after WWTF upgrades. This study improves the understanding of the effects of wastewater effluent on stream quality, biological community composition, and ecosystem function. In addition, this information can be used to help achieve NPDES wastewater effluent permit requirements after additional studies are conducted.

Purpose and Scope

The purpose of this report is to describe the effects of wastewater effluent discharge and treatment facility upgrades on environmental and biological conditions in the upper Blue River, downstream from the Blue River Main WWTF. Data

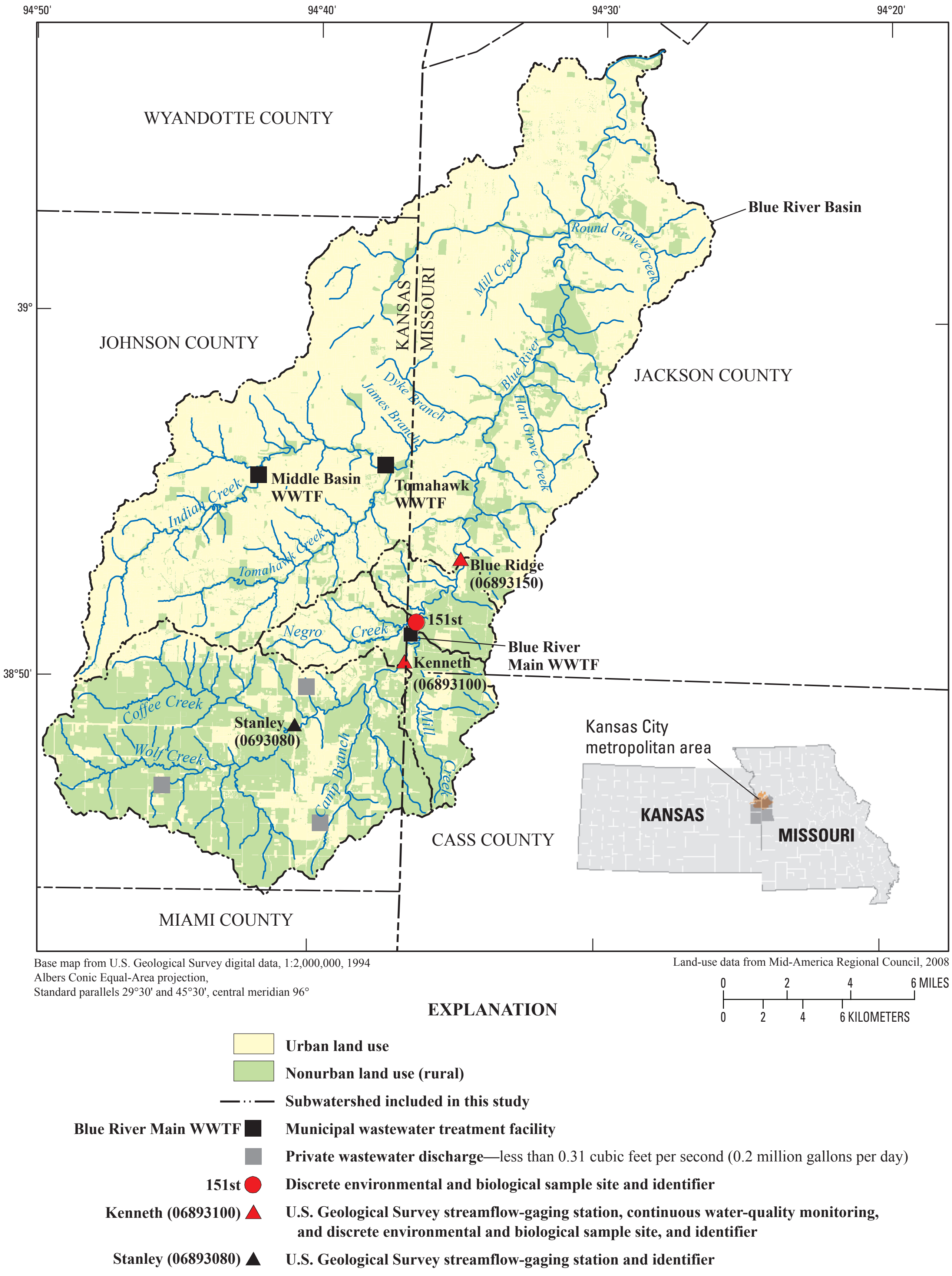

Figure 1. Location of municipal wastewater treatment facilities and rural and urban land use in the Blue River basin, and sample sites, the Blue River Main Wastewater Treatment Facility, and privately owned wastewater treatment facilities located in the upper Blue River basin.

collected by the USGS from the upper Blue River during January 2003 through March 2009, including data from before and after the upgrade, were used to evaluate environmental and biological conditions. Streamflow, discrete and continuously measured stream-water chemistry, streambed-sediment chemistry, and habitat data were used to: evaluate differences in environmental conditions upstream and downstream from the wastewater effluent discharge; develop relations between continuously measured water-quality variables and discrete water-quality samples to define mean annual concentrations and loads of total and dissolved nitrogen and phosphorus in the upper Blue River; and determine the percent contribution of nutrients in wastewater effluent discharge to total annual nutrient loads in the upper Blue River. Periphyton, macroinvertebrate, and stream metabolism (primary productivity and respiration of biological communities) data were used to evaluate differences in biological conditions upstream and downstream from the wastewater effluent discharge. Evaluation of environmental and biological data allow assessment of the physical, chemical, and resulting ecological effects of wastewater effluent discharge in the upper Blue River.

Acknowledgments

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Description of Study Area

The Blue River Basin is 280 square miles (mi^2) and includes portions of Johnson and Wyandotte Counties in Kansas and Jackson and Cass Counties in Missouri. The headwaters of the Blue River are located in Johnson County, Kansas (fig. 1) and flow northeast into the Missouri River (not shown). Land use in the headwaters of the Blue River is predominantly rural and includes a combination of agricultural land uses and forested areas; however, urban land use increases in the downstream direction as the river flows through the Kansas City metropolitan area. For the purposes of this report, the upper Blue River is defined as the area above the confluence with Indian Creek (fig. 1). There are three WWTFs, all located in Johnson County, Kansas, in the Blue River basin: the Blue River Main WWTF discharges into the upper reaches of the Blue River, and the Middle Basin and Tomahawk WWTFs discharge into Indian Creek, which discharges to the middle reaches of the river (fig. 1).

The Blue River Main WWTF, the only municipal treatment facility in the upper Blue River basin, discharges into Negro Creek, which discharges to the upper Blue River (fig. 1). The WWTF underwent upgrades during 2005–2007 to increase treatment capacity and implement biological nutrient removal. Upgrades increased average daily design flow from 5.1 cubic feet per second (ft^3/s) to 16.2 ft^3/s (3 to 10.5 million gallons per day) and extended aeration activated sludge was replaced with a biological nutrient removal activated sludge system (NPDES permit number KS0092738). Expansion and upgrades were officially completed in April 2007, but the WWTF began using biological nutrient removal in October 2006. Before capacity upgrades, Blue River Main was the smallest municipal WWTF in Johnson County, contributing about 16 percent of the total wastewater effluent discharged (Wilkison and others, 2009). Blue River Main is currently (2010) the second largest WWTF in Johnson County and contributed about 25 percent of the total wastewater effluent discharged during 2007 and 2008 (Johnson County Wastewater, 2007, 2008).

To characterize environmental and biological responses to wastewater effluent discharge, three sites along a 6.4-mile reach of the upper Blue River were sampled: Blue River at Kenneth Road (Kenneth) in Johnson County, Kansas (approximately 2.0 miles upstream from the WWTF wastewater effluent discharge); Blue River at 151st Street (151st) in Jackson County, Missouri (approximately 0.25 miles downstream from the wastewater effluent discharge); and Blue River at Blue Ridge Boulevard (Blue Ridge) in Jackson County, Missouri (approximately 4.1 miles downstream; table 1, fig. 1). There are three small private wastewater effluent discharges (less than 0.31 ft^3/s or 0.2 million gallons per day) upstream from the Kenneth site (fig. 1) and several thousand septic systems throughout the basin (Johnson County Automated Information Mapping System, written commun., 2009).

The Kenneth site basin drains approximately 65.4 mi^2 (23 percent of the entire Blue River Basin), the 151st site approximately 84.0 mi^2 (30 percent), and the Blue Ridge site approximately 92.5 mi^2 (33 percent; table 1). For consistency across county and state boundaries, 2008 regional land use data from the Mid-America Regional Council (MARC) (MARC, written commun., 2009) were used to characterize

Table 1. Location and description of upper Blue River sampling sites in Johnson County, Kansas and Jackson County, Missouri, including drainage area, land cover, and distance from the Blue River Main Wastewater Treatment Facility wastewater effluent discharge.

[--, not applicable]

Site identifier (fig. 1)	Site description					Approximate land cover (percent)	
	Site name	U.S. Geological Survey streamflow-gaging station number	County	Drainage area (miles^2)	Distance from Blue River main wastewater discharge (miles)	Urban	Impervious surface
Kenneth	Blue River at Kenneth Road	6893100	Johnson	65.4	2.0 above	20.7	5.8
--	Intervening Area	--	Johnson/ Jackson	18.6	--	39.8	11.4
151st	Blue River at 151st Street	385137094362200	Jackson	84.0	.25 below	24.9	7.1
--	Intervening Area	--	Jackson	8.5	--	34.3	13.7
Blue Ridge	Blue River and Blue Ridge Boulevard	6893150	Jackson	92.5	4.1 below	25.8	7.7

basin land use in the study reach. Urban land use (defined as commercial, industrial, residential, right of way, or public/semi-public land uses) and impervious surface area (defined as right of ways, parking lots, and buildings) increase along the study reach (table 1, fig. 1). Differences in overall basin land use are relatively minimal among sites (table 1) and all three sites are classified as rural based on the criteria used by Poulton and others (2007) (urban sites have greater than 32 percent urban land use and greater than 10 percent impervious surface). Among-site differences along this upstream-downstream urbanization gradient are more evident when only land use in the intervening basin area between sites (land use in the area most proximate to the sample sites) is described. Using this approach, the 151st and Blue Ridge sites are classified as urban, with urban land use and impervious surface area nearly double that of the Kenneth site (table 1, fig. 1).

KDHE and the Missouri Department of Natural Resources have listed several Johnson County, Kansas and Jackson County, Missouri streams as impaired waterways under section 303(d) of the 1972 Clean Water Act (Kansas Department of Health and Environment, 2010; Missouri Department of Natural Resources, 2010). KDHE has listed five pollutants impairing designated uses for the upper Blue River in Johnson County, starting at the State line and traveling upstream to the headwaters. Dissolved oxygen, biology, and diazinon are listed as impairments for aquatic life, mercury is listed as an impairment for food procurement, and fecal coliform bacteria (including the Camp Branch, Coffee Creek, and Wolf Creek tributaries, fig. 1) is listed as an impairment for contact recreation (Kansas Department of Health and Environment, 2010). In Jackson County, bacteria is listed as an impairment for whole body contact recreation in the Blue River from the State line to the confluence with the Missouri River (Missouri Department of Natural Resources, 2010).

Previous Investigations

The Kenneth and Blue Ridge sites on the upper Blue River have been included in several studies of water quality in Johnson County streams or large-scale assessments of water quality in the Blue River Basin (Lee and others 2005; Wilkison and others 2002, 2006, 2009; Poulton and others, 2007; Rasmussen and others, 2008, 2009a). Continuous streamflow and water-quality data have been collected at the Kenneth site since 2004 and streamflow data have been collected at the Blue Ridge site since 2001. Current and previously collected streamflow and continuous water-quality data are available online at: *http://waterdata.usgs.gov/nwis*.

Studies in Johnson County and the Blue River Basin indicate that most streamflow at sites located downstream from wastewater effluent discharges is composed of wastewater effluent during base-flow conditions. During below-normal streamflows, wastewater effluent may represent more than 99 percent of streamflow (Wilkison and others, 2002; Lee and others, 2005). During below-normal and normal streamflows, nutrient concentrations are commonly an order of magnitude larger at sites located immediately downstream from wastewater effluent discharges than at sites unaffected by wastewater effluent discharge. Concentrations of dissolved solids, pharmaceuticals, and organic wastewater effluent compounds also are larger downstream from wastewater effluent discharges. Because of the diluting effect of wastewater effluent, sediment and bacteria concentrations typically are lower downstream from wastewater effluent discharges (Lee and others, 2005; Wilkison and others, 2006, 2009; Rasmussen and others, 2008).

Wilkison and others (2006) estimated wastewater effluent contributions to total nutrient loads in the Blue River Basin during July 2002 through September 2004 by comparing median instantaneous WWTF loads to median instantaneous downstream loads (composed of point and nonpoint sources). More than 70 percent of the TN and TP loads in the upper Blue River Basin were contributed by nonpoint sources during runoff events; the Blue River Main WWTF contributed about 28 percent and 16 percent to TN and TP loads, respectively (Wilkison and others, 2006). By comparison, in some stream reaches located in the lower portions of the Blue River Basin where there are two additional WWTF discharges (fig. 1), wastewater effluent discharges contributed as much as 90 percent of total annual nutrient loads (Wilkison and others, 2006, 2009; Rasmussen and others, 2008). Previous studies indicate that the majority (more than 90 percent) of sediment, bacterial, and biochemical oxygen demand loads in the Blue River Basin are contributed from nonpoint sources (Wilkison and others, 2006, 2009; Rasmussen and others, 2008).

To determine acutely toxic effects of water and bottom sediment on aquatic organisms, Wilkison and others (2009) conducted toxicity tests on samples collected from several sites throughout the Blue River Basin during October through December 2007. Acute toxicity was not observed in samples from upper Blue River Basin sites, and few responses were observed elsewhere in the basin. In general, toxicity test results indicated that negative effects on aquatic organism health through exposure to contaminants are more likely because of chronic long-term exposure, rather than short-term acute toxicity.

Sites located in the upper Blue River Basin, including the Kenneth and Blue Ridge sites, consistently have among the greatest habitat assessment scores in Johnson County and the Blue River Basin (Rasmussen and others, 2009a; Wilkison and others, 2009), indicating habitat at these sites has been affected to a lesser extent by human activities. In the Blue River Basin, habitat scores decline in the downstream direction as the basin becomes increasingly urban. Declines in habitat quality were associated with increased channel disturbance and alteration, loss of riparian vegetation, and increased sedimentation, which are factors that tend to increase with urbanization (Wilkison and others, 2009).

Rasmussen and others (2009a) included algal periphyton as part of an overall assessment of water-quality conditions in Johnson County streams. Periphyton taxa in Johnson County streams generally were indicative of somewhat degraded conditions with small to moderate amounts of organic enrichment. Chlorophyll concentrations, an estimate of algal biomass, exceeded the nuisance threshold of 100 milligrams per meter squared (mg/m^2) at about one-half of the sites in Johnson County during spring, including the Kenneth site; the Blue Ridge site was not included in this study because it is located in Jackson County, Missouri. Nuisance chlorophyll concentrations occurred at rural and urban sites and there were no statistically significant associations with physical or chemical conditions.

Bioassessments using macroinvertebrates have been regularly conducted in the Blue River Basin since 2002 (Wilkison and others, 2006, 2009) and in Johnson County streams since 2003 (Poulton and others, 2007; Rasmussen and others, 2009a). These studies indicate that the biological condition of streams is negatively related to several urbanization factors including percent urban land use, percent impervious cover, and wastewater effluent discharges from domestic and industrial sources. Sites located in the upper Blue River Basin above the Blue River Main WWTF, including the Kenneth site, consistently have among the greatest bioassessment scores in Johnson County and the Blue River Basin. However, macroinvertebrate communities at almost all sampling sites are indicative of some level of impairment and none consistently meet the KDHE fully supporting criteria. The Blue Ridge site typically has lower bioassessment scores than sites located above the WWTF wastewater effluent discharge, but scores are larger than at sites located further downstream in the increasingly urban portions of the basin (Poulton and others, 2007; Rasmussen and others, 2009a).

Methods

Environmental and biological conditions were assessed at one upstream site (Kenneth) and two sites located downstream (151st and Blue Ridge) from the Blue River Main WWTF wastewater effluent discharge into the Blue River (fig. 1). Two downstream sites were assessed to evaluate the differences in conditions immediately downstream from the discharge (151st), and further downstream (Blue Ridge), where there has been more time for dilution, sedimentation, degradation, and assimilation of nutrients and other contaminants characteristic of wastewater effluent. Data collected by the USGS from the upper Blue River during the period January 2003 through March 2009 were used to evaluate environmental and biological conditions upstream and downstream from the wastewater effluent discharge.

Data Collection

Blue River Main Wastewater Treatment Facility Wastewater Effluent Data

The Blue River Main WWTF keeps a daily record of wastewater effluent discharge volume. In addition, wastewater effluent is monitored for several water-quality variables, including nutrients, once per week. All wastewater effluent samples are analyzed by the Johnson County Environmental Laboratory, Olathe, Kansas. Daily wastewater effluent volume and weekly water-quality data were obtained from

Johnson County Wastewater for the years 2003 through 2008. These data were used to describe annual wastewater effluent discharge volume, average annual TN and TP concentrations in wastewater effluent, and TN and TP loads contributed by the WWTF. The period 2003 through 2008 was selected for analysis because it allowed an evaluation of changes in wastewater effluent discharge volume, nutrient concentrations, and nutrient loads after capacity and biological nutrient removal upgrades were completed. In addition, previously collected water-quality data for the upper Blue River are available during the period 2003 through 2008.

Previously Collected Data

Streamflow data from the Blue River near Stanley, Kansas site (fig. 1), continuously operated since 1974, were used to compare streamflow conditions during the January 2003 through March 2009 study period to historical streamflow conditions. Streamflow gages have been operated at the Blue Ridge and Kenneth sites since October 2001 and April 2003, respectively. Continuous water-quality monitors have been operated at the Kenneth site since March 2004. Discrete water-quality data have been collected at the Blue Ridge site since 2000 and the Kenneth site since 2003. These data facilitated comparison of water-quality conditions in the upper Blue River before and after upgrades to the Blue River Main WWTF. For parity, Blue Ridge data collected before 2003 were not used in this report. Previously collected samples were analyzed for a variety of water-quality constituents; analyses were most commonly conducted by the USGS National Water Quality Laboratory (NWQL), Lakewood, Colorado, and the Johnson County Environmental Laboratory (Lee and others, 2005; Wilkison and others, 2006; Rasmussen and others, 2008, 2009a). Samples were collected by several methods, including equal-width-increment (EWI) methods, grab samples, and autosampler-collected samples. Streamflow and water-chemistry data were downloaded from the USGS National Water Information System website (*http://waterdata.usgs.gov/nwis*).

Streambed-sediment, habitat, algal periphyton, and macroinvertebrate data have been collected less frequently than water-quality data at the Kenneth and Blue Ridge sites. These data are used for descriptive comparisons and are not used in statistical analyses in this report. Streambed-sediment, habitat, and algal periphyton and macroinvertebrate community data were compiled from report tables and appendixes (Lee and others, 2005; Wilkison and others, 2006; Poulton and others, 2007; Rasmussen and others, 2008, 2009a).

Discrete Water-Quality Samples

Stream-water samples were collected from the Kenneth and Blue Ridge sites in a range of streamflow conditions during April 2008 through March 2009 (appendix 1). In addition, samples were collected concurrent with biological samples from all three study sites (Kenneth, 151st, and Blue Ridge; fig. 1) during April 1–2, 2008 and August 26, 2008. Water samples were collected following USGS EWI methods (U.S. Geological Survey, 2006). All water samples were analyzed for suspended sediment, dissolved solids, major ions, nutrients (nitrogen and phosphorus), organic carbon, biochemical oxygen demand (BOD), and indicator bacteria. Samples collected during April 1–2, 2008 also were analyzed for organic wastewater-effluent and pharmaceutical compounds.

Suspended-sediment concentration was analyzed at the USGS Iowa Sediment Laboratory, Iowa City, Iowa, according to methods described in Guy (1969). Dissolved solids, major ions, nutrients, organic carbon, biological oxygen demand, and indicator bacteria were analyzed by the Johnson County Environmental Laboratory according to standard methods (American Public Health Association and others, 1995); selected replicate samples were sent to the NWQL and analyzed according to methods presented in Fishman and Friedman (1989). Chemical oxygen demand was analyzed at the NWQL according to methods presented in Fishman and Friedman (1989).

Organic wastewater effluent and pharmaceutical compounds were analyzed at the NWQL using methods described by Zaugg and others (2002) and Furlong and others (2008), respectively. These methods are sensitive and detect compounds at minimal concentrations, often less than the microgram per liter (µg/L) level. Reported values may be denoted as estimated (E) for some constituents when values are reported outside of instrument calibration range, performance of the analyte does not meet acceptable method-specific criteria, or matrix interference conditions occurred. Values reported as estimated are considered detections, although the precision of the value is frequently less than for values without this qualifier (Childress and others, 1999).

Continuous Water-Quality Monitoring

Continuous water-quality data were collected from the Kenneth and Blue Ridge sites (fig. 1). Streamflow was measured using methods presented in Buchanan and Somers (1969) and Oberg and others (2005). Continuous water-quality monitors have been operated at the Kenneth site since March 2004; monitors were installed at the Blue Ridge site in March 2008. The continuously monitored sites were equipped with YSI 6600EDS water-quality monitors that measured specific conductance, pH, water temperature, turbidity (YSI 6136 optical turbidity sensor), and dissolved oxygen (YSI optical dissolved oxygen sensor).

Monitors were installed near the centroid of the stream cross-section to best represent conditions across the width of the stream and were maintained in accordance with standard USGS procedures (Wagner and others, 2006; Rasmussen and others, 2008). Continuous water-quality data were recorded at 15-minute intervals. The 15-minute interval data were used to compute stream metabolism; hourly values were used for all other data analyses in this report. Continuous streamflow and water-quality data are available on the USGS website at *http://waterdata.usgs.gov/ks/nwis*. In this report, results are presented for both sites for the period April 1, 2008 through March 31, 2009.

Streambed-Sediment Samples

Streambed-sediment samples were collected concurrent with biological sampling at all three sample sites (fig. 1) during April 1–2, 2008. Streambed-sediment samples were collected from the upper 2 centimeters (cm) of deposition using stainless-steel spoons. Only the most recently deposited fine material was removed from several depositional zones along the streambed at each site. Samples were collected in a large glass container, homogenized, and field-sieved using a 2 millimeter (mm) stainless steel sieve into glass sample bottles (Shelton and Capel, 1994; Radtke, 2005). Streambed-sediment samples were analyzed for total organic carbon, total carbon, major ions, nutrients, trace elements, and organic wastewater effluent compounds.

Sediment carbon, nutrient, and trace element analyses were performed at the USGS Sediment Chemistry Laboratory, Atlanta, Georgia using digestion after homogenization and passage through a 63-micrometer (µm) sieve (Horowitz and others, 2001). Analysis was done only on the fraction of the sediment sample with particles less than 63 µm in diameter (silt and clay size) to minimize sediment-size effects on chemical concentrations. Organic wastewater effluent compounds were analyzed at the NWQL using methods described by Burkhardt and others (2006). These methods are sensitive and detect compounds at minimal concentrations in the environment, often less than the microgram per kilogram (µg/kg) level. Reported values may be denoted as estimated (E) for some constituents when values are reported outside of instrument calibration range, performance of the analyte does not meet acceptable method-specific criteria, or matrix interference conditions occurred. Values reported as estimated are considered detections, although the precision of the value is frequently less than for values without this qualifier (Childress and others, 1999).

Habitat Assessment

Physical-habitat characteristics were evaluated at all three sample sites (fig. 1) during June 2008 using the methods described in Rasmussen and others (2009a). A total of 17 habitat variables in three categories (channel conditions and characteristics, bank and riparian conditions, and aquatic habitat availability) were evaluated. Data collection was completed using a combination of field measurements and surveys, and available aerial photography and topographic maps.

Each habitat variable was assigned a score on a scale of 1 to 12 (Rasmussen and others, 2009a); all habitat data were integrated into one total site score by summing each of the scores from individual variables. To simplify comparisons and graphic presentations, all scores were normalized to a scale of 0 to 100 by dividing each score by the total possible score and then multiplying by 100. Four rating categories (based on those described by Rasmussen and others, 2009a) of relative quality were used to evaluate habitat conditions at each site (score 80 to 100 is optimal; 55 to 79 is suboptimal; 30 to 64 is marginal; less than 30 is poor). Normalized scores of individual habitat variables and normalized total habitat scores were used to describe among-site differences in habitat conditions.

Periphyton

Periphyton Communities

Periphyton community samples were collected from all three sample sites (fig. 1) during April 1–2, 2008 (spring) and August 27, 2008 (summer), after a period of at least 2 weeks without any substantial streamflow events. The streambed along the study reach is dominated by coarse-grained substrates (gravel and cobbles); therefore, cobble substrate in riffles and runs were sampled for periphyton at each site. This single habitat sampling approach for periphyton helps to minimize variability among sites because of differences in habitat (Stevenson and Bahls, 1999; Moulton and others, 2002). Triplicate samples were collected at each site to more accurately compare differences among sites while accounting for within-site variability.

Periphyton samples were collected from a composite of cobbles collected from three adjacent riffles at each site. Four cobbles were collected randomly from each of the three riffles (a total of 12 cobbles per sample), placed in a plastic dishpan, and transported to an onsite processing station. Using a scouring sampler (Davies and Gee, 1993), periphyton samples were scraped from a known area on each cobble and rinsed into a beaker using 0.7-µm filtered stream water. This process was repeated several times until all of the visible periphyton was removed from the known area. After all cobbles were scraped, periphyton material was rinsed from the beaker into a graduated cylinder. Sample volume was recorded and the sample was poured into a 1-liter high density polyethylene (HDPE) bottle. After vigorous shaking, the sample was split into three aliquots. Two aliquots were processed for chlorophyll and one for taxonomic identification and enumeration. Chlorophyll samples were processed as described in Hambrook-Berkman and Canova (2007). Samples for taxonomic identification and enumeration were preserved with a 9:1 Lugol's iodine:acetic acid solution. The known areas for all 12 cobbles in a sample were summed to determine total surface area sampled.

Chlorophyll was analyzed at the USGS Kansas Water Science Center. Total chlorophyll (uncorrected for degradation products) was extracted in heated ethanol (Sartory and Grobbelar, 1986) and analyzed fluorometrically using EPA Method 445.0 (Knowlton, 1984; Arar and Collins, 1997). Samples were analyzed in duplicate and the results reported as an average of the two.

Periphyton samples were analyzed for taxonomic identification, enumeration, and biovolume of soft algae and diatoms by BSA Environmental Services, Inc., Beachwood, Ohio. The soft algae in the periphyton samples were first enumerated to the lowest possible taxonomic level using membrane-filtered slides (McNabb, 1960). A minimum of 400 natural units were counted. Diatoms were counted by natural unit as a general category, and then examined more closely in permanent diatom mounts. Diatom slides were made using the traditional nitric acid digestion method (Patrick Center for Environmental Research, 1988). A minimum of 400 valves were identified to the lowest possible taxonomic level. Biovolume, calculated using mean measured cell dimensions, is an estimate of algal biomass. Biovolume factors for soft algae and diatoms were calculated using the methods described in Hillebrand and others (1999). Diatom biovolumes were calculated from the permanent slides. A mean biovolume measurement per cell was calculated for each sample, and that value was used as the biovolume measurement in the general diatom category.

Summer Periphyton Biomass

Periphyton biomass may change rapidly because of changing environmental conditions, such as scouring during high flow events, and repeated sampling is necessary to evaluate among-site differences. Periphyton samples were collected at least weekly during June through September 2008 at the Kenneth and Blue Ridge sites (fig. 1) and analyzed for chlorophyll, an indicator of algal biomass. Periphyton samples for chlorophyll analysis were a composite of three cobbles collected from one riffle. Cobbles were processed and chlorophyll was analyzed in the same manner as described for periphyton communities.

Macroinvertebrates

Macroinvertebrate community samples were collected from all three sample sites (fig. 1) during April 1-2, 2008 (spring) and August 26-28, 2008 (summer), after a period of at least 2 weeks without any substantial streamflow events. Triplicate samples were collected at each site to more accurately compare differences among sites while accounting for within site variability. Triplicates corresponded with three separate riffle-pool sequences, except at the Blue Ridge site where one of the two available riffles was separated by a gravel island with a riffle on each side. In this case, the area was divided into two separate riffles, with associated pool and shoreline habitats upstream and downstream, one on each side of the island.

A semi-quantitative method using timed sampling from multiple habitat types (Kansas Department of Health and Environment, 2000) was followed for sample collection. Two independent 100-organism samples were collected and counted in the field by two scientists for approximately one hour each. Sampling ended if 100 organisms were not obtained in that hour. All of the 100-organism samples were field preserved in 125-milliliter (mL) polyethylene bottles containing 80-percent ethanol. Macroinvertebrate samples were analyzed for taxonomic identification and relative abundance at the NWQL using the methods described in Moulton and others (2000). Data from the two independent samples collected within the same riffle were combined into one 200-organism sample after laboratory enumeration and identification were completed.

Macroinvertebrate samples were collected with standard rectangular frame kicknets (500-micron mesh) by physical disturbance of the substrate upstream from the net. In standing-water habitats, the net was used with a sweeping or scooping motion. A streamside white sorting tray was used to enhance the visibility of the organisms during sorting. As organisms were removed from the tray with forceps, a hand counter was used to count the organisms. Any organisms appearing different (size, shape, color) compared to those previously sorted were included in the sample to maximize diversity of organisms. Generally, no more than 25 percent of the organisms sorted came from any one of the available habitats, which included coarse gravel and cobble in riffles, fine gravel and sand/silt substrates near the margins or in runs, leaf packs or organic matter accumulations, vegetation and undercut banks around snags and pool margins, and large moveable objects such as logs or rocks.

Data Analysis

Stream-Water Chemistry Data

Water-quality conditions were compared between the Kenneth and Blue Ridge sites and before (January 2003 through October 2006) and after (November 2006 through March 2009) the WWTF upgrade at the Blue Ridge (downstream) site with respect to below-normal, normal, and above-normal streamflows. Below-normal, normal, and above-normal streamflows were defined using streamflow duration curves for each site and percentile classes. Streamflow conditions were classified using the percentile classes defined on the USGS WaterWatch website (*http://waterwatch.usgs.gov*); below-normal streamflows are less than the 25th percentile, normal streamflows are between the 25th and 75th percentiles, and above-normal streamflows are greater than the 75th percentile.

Duration curves were used to compare streamflows between the Kenneth and Blue Ridge sites during January 2003 through March 2009 and water-quality conditions for continuously measured variables during April 2008 through March 2009, when monitors at both sites were operating simultaneously. Duration curves are cumulative distribution functions and were constructed using hourly values to evaluate and compare frequency and magnitude characteristics at the two sites (Rasmussen and Ziegler, 2003; Rasmussen and others, 2005). The curves indicate the percentage of time that specified conditions were equaled or exceeded, or the frequency of exceedance (Maidment, 1993). Although several similar formulas exist for calculating plotting position, the Weibull formula (Helsel and Hirsch, 2002) was used in this study. Streamflow and water-quality condition duration curves for both sites are available for the period of record on the USGS website at: *http://nrtwq.usgs.gov/ks/*.

Ordinary least squares analysis was used to develop regression models for the Kenneth and Blue Ridge sites using continuous water-quality data and concurrent discrete sample data (Helsel and Hirsch, 2002; Christensen and others, 2000; Rasmussen and others, 2008). Models for the Kenneth site, previously published by Rasmussen and others (2008), were updated to include sample data through March 2009; a total of 32 samples collected from July 2003 through March 2009 were included (appendix 1). All available data were used for models at the Kenneth site because continuous data were available and no substantial changes in water quality occurred that would affect relations between explanatory and response variables. The dataset used to develop regression models for the Blue Ridge site included 20 samples collected between April 2008 and March 2009 (appendix 1). Two of the samples were collected as part of a different study by the USGS Missouri Water Science Center using sampling methods consistent with those used in this study. Although other discrete samples were collected during previous studies (Wilkison and others, 2009), data from those samples were not included in model development because continuous water-quality data were not available and upgrades to the WWTF may have affected relations between explanatory and response variables.

For each response variable, all continuously measured variables and seasonal components (sine and cosine variables) were tested for significance. Continuous data used in regression models were obtained from the monitor deployed at the site (after applying appropriate data corrections, computations, and review) and expressed as time-weighted averages (average of the start, middle, and end time) during discrete sample collection. Models were evaluated based on diagnostic statistics (R^2, coefficient of determination; *RMSE*, root mean square error; *PRESS*, prediction error sum of squares), patterns in residual plots, and the range and distribution of discrete and continuous data. The best model for each constituent was selected to maximize variability in the response variable that is explained by the model (R^2) and to minimize heteroscedasticity (irregular scatter) in the residual plots and uncertainty associated with computed values (*RMSE* and *PRESS*). Regression methods used in this study are described in detail in Cohn and others (1989), Helsel and Hirsch (2002), and Rasmussen and others (2008, 2009b). A bias correction factor (Duan, 1983) was used to correct for log-transformation bias in load estimation.

Regression models were used to calculate hourly concentrations of TN and TP at the Kenneth and Blue Ridge sites for the period April 1, 2008 through March 31, 2009. Continuous (hourly) loads were calculated using hourly concentration (in mg/L), hourly streamflow (in ft^3/s), and a unit conversion factor (0.22427). Monthly and total loads were calculated by summing hourly calculations. Yields were calculated for each site by dividing total loads by the corresponding drainage area. No documented wastewater effluent overflow events occurred during the study period.

Periphyton Data

A total of 277 periphyton community metrics were calculated using the Algal Data Analysis System v. 2.4.8a (ADAS) developed for the USGS National Water-Quality Assessment (NAWQA) Program (Cuffney, 2003). During analysis with ADAS, rare taxa were not deleted, and lowest taxonomic levels were used. Abundance was selected for these calculations rather than biovolume because abundance is used in the calculation of most published bioassessment metrics for periphyton and interpretation of biovolume results can be ambiguous (Stevenson and Bahls, 1999). The ADAS program uses a common logarithm ($\log_{10}$) base to calculate the Shannon Diversity Index; however, previous studies in Johnson County and the Blue River Basin used a natural logarithm base (ln) for Index calculation. To allow direct comparison among studies, ADAS calculated Index values were converted to a natural logarithm base by multiplying by 2.3026 (Brower and others, 1990). A subset of 24 metrics in five categories (oxygen tolerance, saprobity, trophic condition, nitrogen-uptake metabolism, and other indices) was selected for additional analyses to determine among-site differences. These metrics were chosen to minimize redundancy and represent water-quality variables of particular interest. Some, such as TN, TP, specific conductance, and chloride tolerances, were excluded because less than 50 percent of the taxa present had autecological classifications in ADAS with respect to these variables.

An analysis of variance (ANOVA) was used to test for statistical differences in periphyton chlorophyll, abundance, biovolume, and community metrics among sites. ANOVA tests indicate whether two or more means are significantly different from each other and the *F*-value represents the test statistic. The *F*-value, also called the sample variance ratio, is calculated as the ratio of the variance between means to the error variance. When comparing more than two means ANOVA does not identify which means are significantly different. Least-squares means and simultaneous confidence intervals were used to make pairwise comparisons among site means to determine which were significantly different (Sokal and Rohlf, 1995). Analyses were performed independently for the April and August 2008 sampling periods. Significance for these analyses was set at a probability value (*p*-value) of less than 0.05. Analyses were conducted using SAS® 9.2 (SAS Institute, Inc., 2009).

Macroinvertebrate Data

A total of 34 metrics were initially chosen to represent the macroinvertebrate data. These included the 4 KDHE aquatic-life-support status metrics (Kansas Department of Health and

Environment, 2008a), 7 metrics that were used for multimetric site scoring in Poulton and others (2007) and Rasmussen and others (2009a), and an additional 23 metrics selected from the Rapid Bioassessment Protocols (RBP; Barbour and others, 1999). These metrics represent core metrics used in many State evaluation programs, those known to be sensitive and reliable for measuring degradation of stream assemblages, and those that allow determination of stream impairment status and comparisons with data from previous Blue River studies. Twenty-eight metrics were generated by the Invertebrate Data Analysis System v. 4.2.19 (IDAS) developed for NAWQA (Cuffney, 2003). During analysis with IDAS, rare taxa were not deleted, lowest taxonomic levels were used, and taxonomic ambiguities were resolved by retaining ambiguous taxa. Shannon Diversity Index values were converted as described for periphyton. The six metrics not included in the IDAS program (Macroinvertebrate Biotic Index, Kansas Biotic Index, Percentage of Intolerant Organisms, Clinger Richness, and Percentage of Clingers) were calculated as described in Barbour and others (1999) or Poulton and others (2007). Statistical differences in macroinvertebrate community composition among sites were determined as described for periphyton.

To determine the aquatic-life-support status and relative degree of impairment for the sampling sites, scores were determined using the 4 KDHE aquatic-life-support status metrics used by the State of Kansas. The State metrics include the Macroinvertebrate Biotic Index (MBI; Davenport and Kelly, 1983), the Kansas Biotic Index (KBI-NO; Huggins and Moffet, 1988), Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness, and relative abundance of EPT taxa. Each metric was scored on a three-point system that was based on State criteria (Kansas Department of Health and Environment, 2008a). Impairment status for each site was determined by combining these metric scores into an overall site score representing the mean across all of the metrics included.

Stream Metabolism Data

Stream metabolism at the Kenneth and Blue Ridge sites was determined using the whole stream metabolism program developed for the USGS NAWQA Nutrient Enrichment Effects Team (NEET; Bales and Nardi, 2007). The calculations and assumptions in the stream metabolism program are described in detail in Bales and Nardi (2007) and are based on standard approaches (Odum, 1956; Marzolf and others, 1994; Mulholland and others, 2001). Stream metabolism was calculated using the diurnal oxygen curve method. Using this method, oxygen changes in a 24-hour period are indicative of the dissolved oxygen additions by photosynthesis and reaeration, and dissolved oxygen losses by community respiration. Estimates of community respiration are based on nighttime measurements (when there is no light and hence, no photosynthesis) and are assumed to be equal to daytime respiration. Each site had one continuous water-quality monitor; however, the stream metabolism program has an increased amount of output information for estimates based on the two-monitor method. The one-monitor method output calculates only gross primary production, whereas the two-monitor method output calculates gross primary production, community respiration, and net ecosystem metabolism. The one-monitor method was modified to simulate a two-monitor method by entering the continuous data from each site into the program twice, with the second entry offset by 15 minutes (Bales and Nardi, 2007; J.D. Bales, written commun., 2009).

Daily estimates of gross primary production (GPP), community respiration (CR), net ecosystem production (NEP), and the production to respiration ratio (P/R) were calculated for the period April 1, 2008 through March 31, 2009. Because stream metabolism variables should only be calculated during stable flow conditions, 24-hour periods having flow that varied by more than 10 ft^3/s were excluded from the analysis. Mean daily discharge and 15-minute dissolved oxygen, specific conductance, and temperature data were used in stream metabolism calculations. The program also required estimates of several physical variables including velocity, wetted width, depth, area, reach length, channel slope, and a reaeration coefficient. Velocity, wetted width, depth, and area were determined using the rating curves developed for each site to determine streamflow. Reach length was estimated based on how far a parcel of water would travel during a 15-minute time interval (J.D. Bales, written commun., 2009). Channel slope was estimated from USGS 7.5-minute, 1:24,000-scale topographical maps (U.S. Geological Survey, 1975a, b) by measuring the stream distance where the contour lines cross the stream channel and dividing that distance into the contour interval. The reaeration coefficient was estimated by the Energy Dissipation Model (EDM; Tsivoglou and Neal, 1976). Conditions for each of these variables during the study period are presented in appendix 2.

Statistical differences in stream metabolism variables among sites were determined for the entire study period (April 2008 through March 2009) and seasonally. Seasons were defined as spring (April through June), summer (July through September), fall (October through December), and winter (January through March). A two-sided nonparametric Wilcoxon signed-rank analysis was used to determine statistical differences among sites (Sokal and Rohlf, 1995). The analysis tests whether median differences between ranks of paired values is 0 (the null hypothesis). Significance for this analysis was set at a *p*-value of less than 0.05 and was conducted using SAS® 9.2 (SAS Institute, Inc., 2009).

Quality-Assurance and Quality-Control

Stream-Water Chemistry Data

Quality-assurance and quality-control samples were collected within a range of streamflow conditions. Six sequential replicate samples were analyzed for suspended sediment, dissolved solids, major ions, nutrients, carbon, biochemical oxygen demand, and indicator bacteria. One sequential replicate sample was analyzed for organic wastewater effluent compounds and pharmaceutical compounds. Relative percentage difference (RPD) was used to evaluate differences in analyte concentrations detected in replicate water samples. The RPD was calculated using the following equation:

$$RPD = \left[\left| A - B \right| / \left(\frac{A + B}{2} \right) \right] \times 100 \qquad (1)$$

where *A* and *B* are concentrations in each replicate pair. The median RPD between replicate pairs was less than 10 percent for all constituents except ammonia plus organic nitrogen (12 percent), *Escherichia coli* (*E. coli)* bacteria (12 percent), and the wastewater effluent compound isophorone (12 percent). Generally, larger RPDs occurred when values were near the reporting level.

Comparison with cross-section measurements provided verification that minimum bias occurred as a result of sonde location within the stream cross-section. The median RPD between cross-section and continuous monitor measurements at the Kenneth site was previously determined to be about 1 percent for all measurements (Rasmussen and others, 2008). At the Blue Ridge site, the largest median RPD of 7 percent occurred for turbidity measurements. The larger differences between cross-section and continuous monitor measurements occurred during stormwater runoff when conditions were changing rapidly.

Continuous data during the study period generally required corrections of less than 10 percent which classifies the data quality as good according to established guidelines (Wagner and others, 2006). Time-series measurements occasionally were missing or deleted from the dataset because of equipment malfunction or excessive fouling caused by environmental conditions. Poor turbidity data at the Blue Ridge site during October 2008 was deleted during a 5-day period (representing about 1.5 percent of the total record); streamflow was returning to normal conditions during this 5-day period and turbidity values decreased from about 20 formazin nephelometric units (FNU) to about 4 FNUs. In addition, hourly streamflow data at the Blue Ridge site were missing during a 3-day below-normal streamflow period in December 2008. Data during those periods were interpolated between measured values to minimize bias in load calculations. Three hourly turbidity values at the Kenneth and the Blue Ridge sites may have exceeded the maximum values the sensors are capable of measuring during the study period. No adjustments were made to those values.

Streambed-Sediment Chemistry Data

One sequential replicate streambed-sediment sample was analyzed for carbon, major ions, nutrients, trace elements, and organic wastewater effluent compounds. RPD values for carbon, major ions, nutrients, and most trace elements were less than 10 percent; antimony, vanadium, and mercury had RPD values of about 12, 13, and 67 percent, respectively. Most organic wastewater effluent compound data were either below the laboratory reporting level or estimated concentrations. Where concentrations were measured or estimated, the RPD between replicate pairs ranged from about 3 percent to 164 percent (median: 25 percent). Poor replication and large RPD values are likely because of the low detection levels for these compounds and matrix interference conditions.

Periphyton Data

Samples for periphyton community and chlorophyll analyses were collected in triplicate. Because of the patchy nature of periphyton communities within streams (Stevenson, 1997), the variability among replicate samples may be much greater than for water-chemistry data. Concurrent field-replicate samples for periphyton abundance and chlorophyll had smaller coefficients of variation (CVs) (37 and 23 percent, respectively; both number of pairs=6) (Sokal and Rohlf, 1995) than biovolume (median: 66 percent; number of pairs=6). The CVs for the 24 individual periphyton community metrics ranged from 0 to 173 percent (median: 26 percent); however 65 percent of metric comparisons (number of pairs=144) had CVs less than 40 percent. Those metric comparisons with CVs greater than 75 percent (11 percent of metric comparisons) were strongly affected by rare taxa that composed less than 10 percent of the overall community and occurred in some replicates but not others. Metrics affected by rare taxa included those indicative of very low dissolved oxygen, polysaprobic conditions, and oligo-mesotrophic, mesotrophic, and meso-eutrophic conditions. Large CVs are likely because of the natural variation of periphyton communities and the effect of relatively rare taxa that did not occur in all samples. The large variance in some metrics because of the natural spatial variation in periphyton communities precludes the statistical detection of small differences among sites (Morin and Cattaneo, 1992).

Field-split replicate samples for chlorophyll analysis were collected from all samples. Most field-split replicate chlorophyll samples (90 percent, number of pairs=50) had CVs less than 10 percent, although CVs ranged from 0 to 26 percent (median: 4 percent). Field-split replicate samples with large CVs likely were caused by clumps of periphytic material that could not be homogenized by vigorous shaking.

Macroinvertebrate Data

The CVs for the 34 individual macroinvertebrate community metrics ranged from 0 to 173 percent (median 11 percent; number of pairs=204); however, 91 percent of metric comparisons had CVs less than 40 percent. Those metric comparisons with CVs greater than 75 percent (4 percent of metric comparisons) were strongly affected by rare taxa that composed less than 10 percent of the overall community and occurred in some replicates but not others. Metrics affected by rare taxa included percent Tanytarsini midges, percent Plecoptera,

Plecoptera richness, percent Oligochaeta, and percent *Corbicula*. An additional source of variability was likely differences in habitat among the three riffle-pool sampling locations at each site. The large variance in some metrics because of the natural spatial variation in macroinvertebrate communities precludes the statistical detection of small differences among sites (Miller and others, 2008).

Quality-assurance and quality-control measures for macroinvertebrate identification, enumeration, and data entry followed those outlined in Moulton and others (2000) and included within-laboratory cross checking of specimen identification. Updated taxonomic keys and voucher specimens are kept on file at the NWQL. Other quality-assurance measures included repeats of identification and enumeration procedures on the same sample by different laboratory technicians and a full comparison of bench sheets for a minimum of 10 percent of the samples.

Environmental Conditions of the Upper Blue River

The environmental conditions evaluated include streamflow, stream-water chemistry, streambed-sediment chemistry, and habitat. Conditions were evaluated at one site located upstream and two sites located downstream from the Blue River Main WWTF. Data collected from the upper Blue River during January 2003 through March 2009, a period that includes data from before and after the WWTF upgrade, were used to evaluate environmental conditions.

Streamflow

Streamflow is one of the key variables that shape the structure and function of stream ecosystems. Alterations to the natural streamflow regime may affect water quality, physical habitat, biological communities, and ecosystem function (Poff and others, 1997, 2010). Wastewater effluent discharge may substantially alter natural streamflow regimes, especially during periods when streamflow is naturally low.

Streamflows at the Stanley site (fig. 1) were lowest during 2003, with annual median streamflow about one-third of the period of record (September 1974 through March 2009) median, and highest during 2008, with annual median streamflows about 3 times greater than the period-of-record median (table 2). Median streamflow during 2008 was the third highest on record. The highest streamflows typically occur during May and June and the lowest in August. Similar patterns in streamflow were observed at the Kenneth and Blue Ridge sites, with the lowest annual median streamflows occurring in 2003 and the highest in 2008 (table 2). Median streamflow at the Blue Ridge site (29.0 cubic feet per second, ft^3/s) was about 2 times larger than the median streamflow at the Kenneth site (15.0 ft^3/s) during the study period (January 2003 through March 2009; table 2). Based on streamflow duration curves for the study period, normal streamflows ranged from 5.5 to 36 ft^3/s at the Kenneth site and 12 to 62 ft^3/s at the Blue Ridge site (fig. 2).

Upgrades increased the capacity of the Blue River Main WWTF by about 220 percent (from 5.1 to 16.2 ft^3/s). On average, the volume of wastewater effluent discharge increased by 26 percent during 2007 and by 71 percent during 2008 relative to 2003 through 2006. Despite these increases, annual wastewater effluent discharge from the Blue River Main WWTF during 2008 was about one-half of the maximum capacity of the upgraded facility (table 2). Continued increases in wastewater effluent discharge approaching maximum capacity will substantially change the contribution of wastewater effluent to streamflow in the upper Blue River. Potential wastewater effluent contributions to streamflow at maximum capacity were estimated using mean daily streamflows at the Blue Ridge site during January 2003 through March 2009 and the mean daily design flow (16.2 ft^3/s) of the upgraded WWTF. This approach assumes that the WWTF is always discharging at maximum capacity and represents maximum potential contributions of wastewater effluent to streamflow.

Wastewater effluent contribution to total annual streamflow volume at the Blue Ridge site below the Blue River Main WWTF ranged from 4.6 percent during relatively wet years to 14 percent during relatively dry years. Overall, wastewater effluent contributed about 6.6 percent to total streamflow volume during the study period. By comparison, based on potential wastewater effluent contributions at maximum capacity, wastewater effluent contribution to total annual streamflow volume may range from 11 to 49 percent (table 2).

The contribution of wastewater effluent to streamflow at the Blue Ridge site ranged from negligible (less than 1 percent) during large runoff events to nearly 100 percent during the lowest streamflows (fig. 3). Wastewater effluent contributed more than 20 percent to total streamflow during below-normal and normal streamflows (75 percent of the time) during the study period. More than 90 percent of total streamflow was contributed by wastewater effluent about 6 percent of the time. Before capacity upgrades (January 2003 through March 2007) wastewater effluent contributed between 6.4 and 51 percent (median: 16 percent) to total streamflow during normal streamflows (fig. 3). After capacity upgrades (April 2007 through March 2009), the wastewater effluent contribution to streamflow during normal flow conditions increased by about 30 percent (range: 8.3 to 68 percent, median: 23 percent; fig. 3). By comparison, based on potential wastewater effluent contributions at maximum capacity, wastewater effluent may contribute between 26 and nearly 100 percent (median: 56 percent) to total streamflow during normal flow conditions (fig. 3).

Table 2. Streamflow statistics for the Stanley, Kenneth, and Blue Ridge sites on the upper Blue River, flow statistics for the Blue River Main Wastewater Treatment Facility, and the percent contribution of wastewater effluent to annual streamflow at the Blue Ridge site during January 2003 through March 2009 and for the period of record at each site.

[Streamflow and flow statistics are based on mean daily values for each site; Blue River streamflow data are available on the USGS National Water Information website (*http://waterdata.usgs.gov/nwis*); ft³/s, cubic feet per second; min, minimum; max, maximum; --, not applicable]

Time period	Upper Blue River sites (fig. 1)												Blue River Main Wastewater Treatment Facility					
	Stanley streamflow (ft³/s)				Kenneth streamflow (ft³/s)				Blue Ridge streamflow (ft³/s)				Flow (ft³/s)				Percent contribution of wastewater	
	median	mean	min	max	median	mean	min	max	median	mean	min	max	median	mean	min	max[4]	Contribution of wastewater effluent to annual streamflow[1]	Potential maximum design flow contribution of wastewater effluent to annual streamflow[2]
2003	2.00	10.3	0.00	1,000	6.20	20.6	0.00	1,340	6.10	33.3	1.10	2,880	4.18	4.54	2.13	8.70	14	49
2004	13.0	64.6	.80	4,450	22.0	81.8	2.20	4,830	41.0	118	4.00	5,800	5.11	5.48	3.38	9.56	4.6	14
2005	7.60	42.3	.10	2,810	12.0	64.8	.40	3,770	25.0	89.8	4.20	5,030	4.97	5.48	2.73	9.57	6.1	18
2006	4.10	16.8	.20	1,200	6.60	20.7	.03	1,270	17.0	43.0	4.80	1,470	4.48	4.82	2.56	14.1	11	38
2007	10.0	48.8	.10	2,170	17.0	69.8	.40	3,600	31.0	114	3.40	5,240	3.71	6.38	3.15	23.6	5.6	14
2008	16.0	70.8	.40	4,030	27.0	91.3	1.10	4,160	49.0	145	8.30	5,350	8.04	8.74	5.68	20.9	6.0	11
January 2003 to March 2009	8.10	42.4	.00	4,450	15.0	60.1	.00	4,830	29.0	91.2	1.10	5,800	5.37	5.99	2.13	23.6	6.6	18
Period of record[3]	5.50	36.5	.00	5,520	15.0	61.0	.00	4,830	27.0	87.4	.70	5,800	--	--	--	--	--	--

[1]Calculated as the total annual effluent volume divided by the total annual streamflow volume at the Blue Ridge site.

[2]Calculated as the potential total annual effluent volume divided by the total annual streamflow volume at the Blue Ridge site. Potential total annual effluent volume was calcuated using the maximum capacity (16.2 ft³/s) of the upgraded Blue River Main Wastewater Treatment Facility.

[3]The period of record for the Stanley site is September 1974 through March 2009; the period of record for the Kenneth site is April 2003 through March 2009; the period of record for the Blue Ridge site is June 2002 through March 2009.

[4]Maximum flow exceeded mean daily design flow in all years.

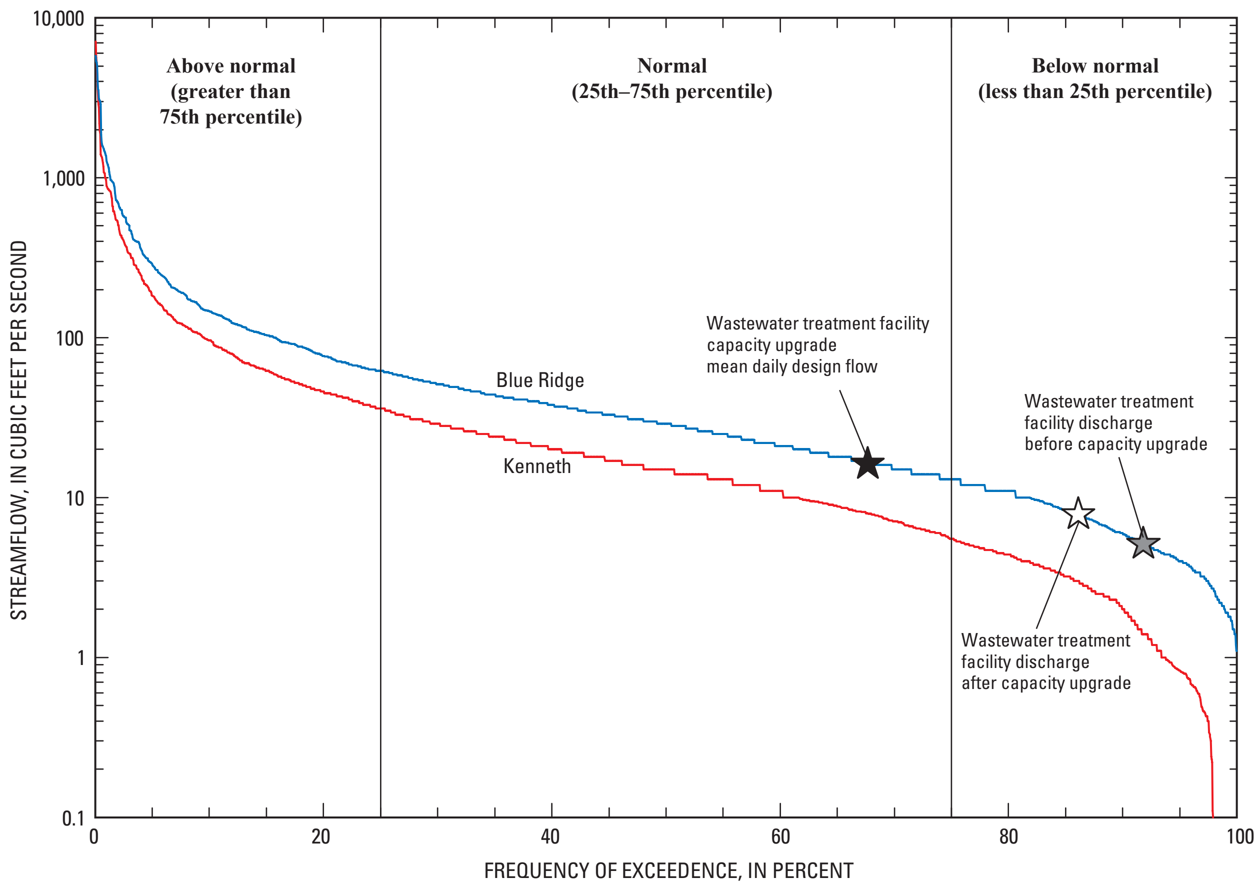

Figure 2. Streamflow duration curves based on mean daily streamflow at the Kenneth (April 2003 through March 2009) and Blue Ridge (January 2003 through March 2009) sites on the upper Blue River; below-normal, normal, and above-normal streamflow conditions as determined by percentiles; and mean Blue River Main Wastewater Treatment Facility wastewater effluent discharge before (January 2003 through March 2007) and after (April 2007 through March 2009) capacity upgrades and capacity upgrade mean daily design flow.

Stream-Water Chemistry

Stream-water chemistry at the Kenneth and Blue Ridge sites was evaluated using discrete water-quality data collected during January 2003 through March 2009 and continuous water-quality data collected during April 2008 through March 2009. Water samples also were collected at the Kenneth, 151st, and Blue Ridge sites during April and August 2008 when periphyton and macroinvertebrate samples were collected. Discrete samples were analyzed for physical properties, nutrients, suspended solids and sediment, biochemical oxygen demand, indicator bacteria, dissolved solids, major ions, and organic carbon. Samples collected during April 2008 also were analyzed for wastewater-effluent and pharmaceutical compounds. Continuous water-quality data included specific conductance, pH, water temperature, turbidity, and dissolved oxygen.

Specific Conductance, pH, Temperature, and Dissolved Oxygen

Specific conductance, pH, temperature, and dissolved oxygen are described using the continuous data collected at the Kenneth and Blue Ridge sites during April 2008 through March 2009 (table 3). Data for these properties in discrete water-quality samples are presented in table 4 and appendix 3.

Specific conductance is an indirect measure of dissolved solids in water (Hem, 1992). Some dissolved solids, such as chloride and some nutrients, may have elevated concentrations in wastewater effluent. Thus, wastewater effluent generally has larger specific conductance values than receiving stream water (Cheremisinoff, 1995). Specific conductance was consistently greater at the Blue Ridge site, downstream from the WWTF, than at the Kenneth site (fig. 4*A*). The difference between sites was most pronounced during below-normal streamflows,

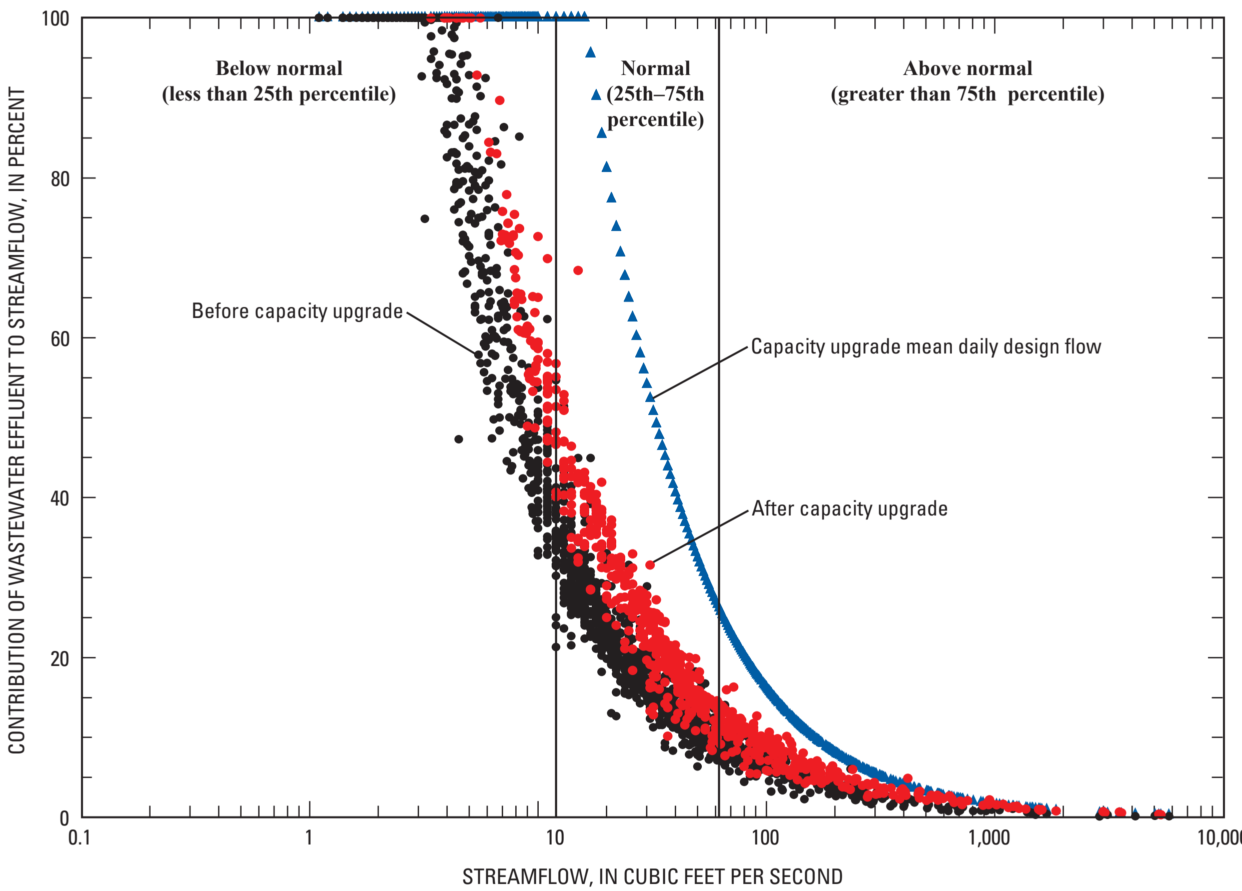

Figure 3. The percent contribution of wastewater effluent to streamflow during below normal, normal, and above normal streamflows at the Blue Ridge site on the upper Blue River before (January 2003 through March 2007) and after (April 2007 through March 2009) capacity upgrades and potential maximum contribution based on capacity upgrade mean daily design flow.

with the median value at the Blue Ridge site (706 µS/cm) about 20 percent larger than at the Kenneth site (567 µS/cm). However, during normal and above-normal streamflows, maximum specific conductance values at the Blue Ridge site were approximately twice as large as maximum values at the Kenneth site (table 3). Road salt may substantially affect specific conductance in streams during winter months, particularly in more urban locations (Rasmussen and others, 2008). The Blue Ridge site is more urban than the Kenneth site with substantially more impervious surface cover (table 1, fig. 1). The largest specific conductance values at the Blue Ridge site all occurred during December 2008 and January 2009, indicating road salt likely affected specific conductance. Winter increases in specific conductance were not observed at the Kenneth site.

pH is a measure of the effective hydrogen ion concentration and is often used to evaluate chemical and biological reactions in water (Hem, 1992). Kansas aquatic-life-support criteria require that pH in streams not measure less than 6.5 or more than 8.5 standard units (Kansas Department of Health and Environment, 2008b). pH was consistently larger at the Blue Ridge site than at the Kenneth site (fig. 4*B*). The difference between sites ranged from 0.1 to 1 standard units (median: 0.2). Measured pH was never lower than 6.5 at either site, but exceeded the maximum aquatic-life-support criterion of 8.5 standard units about 5 percent of the time at the Blue Ridge site (fig. 4*B*). Exceedances primarily occurred during normal streamflows in April and May 2008 and likely are caused by increased algal photosynthesis.

Water temperature affects biological activity and the solubility of chemicals in water. Kansas water-quality criteria require that discharges to streams not raise the water temperature more than 3 degrees Celsius (°C) or raise the temperature above 32°C (Kansas Department of Health and Environment, 2008b). Water temperatures at both sites ranged from about zero to 31°C, with the coldest temperatures occurring in December 2008 and January 2009 and the warmest in July and August 2008. Water temperature at the Blue Ridge site tended to exceed temperature at the Kenneth site during colder months, when temperatures were in the lower one-half

Table 3. Summary statistics for water-quality constituents measured continuously (hourly) at the Kenneth and Blue Ridge sites on the upper Blue River during below-normal, normal, and above-normal streamflow conditions, April 2008 through March 2009.

[Continuous real-time water-quality data are available on the USGS National Real-Time Water-Quality website (*http://nrtwq.usgs.gov/ks*); *n*, number of measurements; min, minimum; max, maximum; med, median; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; FNU, formazin nephelometric units; mg/L, milligrams per liter]

Water-quality property	Kenneth					Blue Ridge				
	n	min	max	mean	med	*n*	min	max	mean	med
Below-normal streamflow conditions[1]										
Specific conductance (µS/cm)	1,159	495	644	571	567	358	540	827	706	706
pH	1,159	7.8	8.5	8.1	8.0	358	7.8	8.6	8.3	8.3
Water temperature (°C)	1,159	15.0	30.9	23.2	24.2	358	15.6	30.8	24.0	24.0
Turbidity (FNU)	1,159	6.60	44	14	14	358	.60	12	2.7	2.0
Dissolved oxygen (mg/L)	1,159	3.8	12	7.6	7.5	358	5.4	12	8.0	7.6
Normal streamflow conditions[2]										
Specific conductance (µS/cm)	4,876	355	813	593	601	5,338	446	1,820	699	682
pH	4,876	7.5	8.5	7.9	7.9	5,338	7.8	9.0	8.3	8.2
Water temperature (°C)	4,876	-.10	29.7	11.4	10.1	5,338	-.10	31.0	13.4	13.3
Turbidity (FNU)	4,876	.80	86.0	11.7	9.4	5,266	.40	190	6.0	3.9
Dissolved oxygen (mg/L)	4,876	4.8	16	11	11	5,338	5.0	18	11	10
Above-normal streamflow conditions[3]										
Specific conductance (µS/cm)	2,516	114	771	474	492	3,000	181	1,270	526	537
pH	2,725	7.0	8.3	7.9	7.9	3,000	7.6	8.5	8.0	8.0
Water temperature (°C)	2,725	0	20.2	13.6	13.6	3,000	-.10	28.9	14.1	14.2
Turbidity (FNU)	2,725	1.50	1,290	89	35	2,938	2.40	1,660	91	31
Dissolved oxygen (mg/L)	2,725	5.5	13.7	9.6	9.6	3,000	5.4	17	9.6	9.5

[1]Below-normal streamflow conditions were defined as streamflows less than the 25th percentile using streamflow duration curves for the period January 2003 through March 2009. Below-normal streamflows were less than 5.5 and less than 12 cubic feet per second for the Kenneth and Blue Ridge sites, respectively.

[2]Normal streamflow conditions were defined as streamflows between the 25th and 75th percentiles using streamflow duration curves for the period January 2003 through March 2009. Normal streamflows were between 5.5 and 36 and between 12 and 62 cubic feet per second for the Kenneth and Blue Ridge sites, respectively.

[3]Above-normal streamflow conditions were defined as streamflows greater than the 75th percentile using streamflow duration curves for the period January 2003 through March 2009. Above-normal streamflows were greater than 36 and greater than 62 cubic feet per second for the Kenneth and Blue Ridge sites, respectively.

of the temperature range (about 0 to 15°C; fig. 4*C*). The warmest temperatures at both sites generally occurred during below-normal streamflows, with median values nearly double those observed during normal and above-normal streamflows (table 3); this pattern reflects seasonal low-flows during summer months. Measured temperatures never exceeded 32°C at either site, but water temperatures at the Blue Ridge site exceeded temperatures at the Kenneth site by more than the water-quality criterion of 3°C about 2 percent of the time. Temperature differences of more than 3°C occurred during normal streamflow conditions when temperatures were less than about 10°C (fig. 4*C*) and likely reflect the effect of the wastewater effluent discharge.

Dissolved oxygen is an important factor for the survival of aquatic organisms and concentrations in surface water are related primarily to photosynthesis, respiration, atmospheric reaeration, and water temperature (Lewis, 2006). Dissolved oxygen concentrations were slightly larger at the Blue Ridge site than the Kenneth site most of the time, indicating that the wastewater effluent is not having a negative effect on dissolved oxygen concentrations in the upper Blue River (fig. 4*D*). The lowest dissolved oxygen concentrations at both sites occurred during below-normal streamflows (table 3), reflecting increased water temperatures during seasonal low-flows in summer. Kansas aquatic-life-support criteria require that dissolved oxygen concentrations are not less than 5.0 mg/L (Kansas Department of Health and Environment, 2008b). Dissolved oxygen concentrations were less than the minimum aquatic-life-support criterion less than 1 percent of the time at the Kenneth site, but were never less than 5.0 mg/L

Table 4. Results of analyses in discrete water-quality samples collected at the Kenneth and Blue Ridge sites on the upper Blue River, January 2003 through March 2009.

[*n*, number of samples; ft³/s, cubic feet per second; %, percent; --, not applicable; µS/cm, microsiemens per centimeter at 25 degrees Celsius; FNU, formazin nephelometric units; µg/L, micrograms per liter; mg/L, milligrams per liter; col/100 ml, colonies per 100 milliliters of sample; <, less than]

Water-quality property or chemical (unit of measure)	Below normal and normal flow conditions								
	Kenneth			Blue Ridge before upgrade			Blue Ridge after upgrade		
	n	Range	Median	*n*	Range	Median	*n*	Range	Median
Physical properties, suspended solids, and sediment									
Streamflow (ft³/s)	10	0.2–36	11	12	3.5–44	12	10	6.3–61	25
Wastewater effluent (% streamflow)	--	--	--	12	10.2–158	41.1	10	7.13–89.7	23.6
Dissolved oxygen, field (mg/L)	10	3.1–13.8	7.1	12	6.4–15.2	9.9	10	6.9–14.3	10.7
pH, field (standard units)	10	7.5–8.2	7.9	12	7.6–8.5	8.0	10	8.1–8.4	8.3
Specific conductance, field (µS/cm)	10	434–698	590	12	509–1,150	717	10	564–825	668
Water temperature, field (degrees Celsius)	10	1.4–27.3	17.1	12	1.1–30.3	16.0	10	.4–29.7	10.4
Turbidity, laboratory (FNU)	10	5.3–33	15.0	1	14	14	8	2.5–18	6.0
Total suspended solids (mg/L)	10	<10–28	19.0	3	5–18	5	3	4–11	8
Suspended sediment (mg/L)	10	7.0–91	23.0	12	3.0–57	41	8	4.0–110	16
Dissolved solids and major ions									
Dissolved solids (mg/L)	10	260–440	355	0	--	--	3	397–464	457
Calcium (mg/L)	10	57.6–110	87.8	6	65.5–97.0	79.0	5	76.3–95.9	90.3
Magnesium (mg/L)	10	6.6–13.3	9.5	6	8.7–20.1	14.4	5	10.1–12.9	11.0
Potassium (mg/L)	10	2.2–4.3	3.2	2	7.2–13.2	10.2	3	4.0–9.8	6.1
Sodium (mg/L)	10	12.0–28.9	24.2	3	47.4–113	54.3	5	33.2–63.2	40.7
Chloride (mg/L)	10	22.0–55.0	32.5	11	30.4–144.3	58.6	10	38.3–98.0	59.2
Sulfate (mg/L)	10	24.0–74.0	44.0	3	90.8–154	141	4	56.2–82.0	62.5
Nutrients and carbon									
Ammonia plus organic, total, as nitrogen (mg/L)	9	0.30–0.70	0.50	12	0.52–3.1	0.67	9	0.48–1.0	0.60
Nitrite plus nitrate as nitrogen, dissolved (mg/L)	10	.06–.86	.30	12	1.71–12.3	4.57	10	1.19–4.00	1.86
Ammonia, as nitrogen (mg/L)	10	<.02–.13	.05	12	<.04–1.9	.02	10	<.02–.09	.01
Total nitrogen (mg/L)[1]	10	.43–1.16	.68	12	2.26–15.4	5.25	10	1.29–4.84	2.40
Orthophosphorus, as phosphorus (mg/L)	10	<.01–.19	.03	12	.11–2.42	.49	10	.16–1.06	.41
Dissolved phosphorus (mg/L)	10	<.01–.12	.03	12	.13–2.33	.51	10	.17–1.08	.43
Total phosphorus (mg/L)	10	<.1–.34	.09	12	.17–2.46	.55	10	.21–1.36	.46
Particulate phosphorus (mg/L)[2]	10	.00–.22	.05	12	.00–.13	.04	10	.00–0.28	.02
Dissolved organic carbon (mg/L)	2	2.8–4.6	3.7	11	4.0–8.0	5.6	10	3.1–6.1	4.3
Total organic carbon (mg/L)	2	3.2–7.1	5.2	11	4.4–10.5	6.7	10	4.4–7.1	5.4
Biochemical and bacteria									
Biochemical oxygen demand (mg/L)	2	<2.0–3.0	2.0	11	4.0–8.0	5.6	10	3.1–6.1	4.3
Chemical oxygen demand (mg/L)	2	15–17	16	12	<10–30	16	10	10–21	14
Enterococci (col/100 mL)	10	<4.0–620	21	0	--	--	3	<4.0–10	5.0
Escherichia coli (col/100 mL)	10	<20–790	54	12	5.1–250	44	9	15–98	45
Fecal coliform (col/100 mL)	10	<10–1,900	40	12	<10–1,600	130	9	20–110	70

Table 4. Results of analyses in discrete water-quality samples collected at the Kenneth and Blue Ridge sites on the upper Blue River, January 2003 through March 2009.—Continued

[*n*, number of samples; ft³/s, cubic feet per second; %, percent; --, not applicable; µS/cm, microsiemens per centimeter at 25 degrees Celsius; FNU, formazin nephelometric units; µg/L, micrograms per liter; mg/L, milligrams per liter; col/100 ml, colonies per 100 milliliters of sample; <, less than]

Water-quality property or chemical (unit of measure)	Above normal flow conditions								
	Kenneth			Blue Ridge before upgrade			Blue Ridge after upgrade		
	n	Range	Median	*n*	Range	Median	*n*	Range	Median
Physical properties, suspended solids, and sediment									
Streamflow (ft³/s)	22	47–10,950	848	12	81–1,990	635	19	63–10,100	972
Wastewater effluent (% streamflow)	--	--	--	12	.12–9.79	3.97	19	.30–10.7	2.28
Dissolved oxygen, field (mg/L)	22	6.3–12.7	7.8	0	--	--	15	6.7–10.5	8.0
pH, field (standard units)	22	7.4–8.2	7.8	5	8.0–8.3	8.1	19	7.7–8.2	7.9
Specific conductance, field (µS/cm)	22	170–580	326	6	272–620	366	19	166–900	391
Water temperature, field (degrees Celsius)	21	5.6–24.3	18.2	5	14.1–22.9	19.2	17	9.0–23.1	16.2
Turbidity, laboratory (FNU)	22	46–1,270	320	0	--	--	15	19–1,080	510
Total suspended solids (mg/L)	22	44–4,470	586	0	--	--	15	20–4,100	810
Suspended sediment (mg/L)	22	57–4,170	628	12	101–1,940	1,140	19	60–3,990	817
Dissolved solids and major ions									
Dissolved solids (mg/L)	22	125–350	230	0	--	--	14	159–387	228
Calcium (mg/L)	22	20.8–76.5	40.3	1	47.5	47.5	15	23.1–73.0	46.4
Magnesium (mg/L)	22	2.5–8.6	4.7	1	4.3	4.3	15	2.8–11.8	5.2
Potassium (mg/L)	22	2.6–4.7	3.9	1	4.3	4.3	15	2.7–6.5	3.7
Sodium (mg/L)	22	4.9–35.3	12.6	1	10.9	10.9	15	6.0–40.8	16.9
Chloride (mg/L)	22	6.0–45.0	16.8	12	14.5–65.4	40.1	18	7.0–162	30.0
Sulfate (mg/L)	21	9.0–48.0	24.0	1	19.3	19.3	15	9.0–58.0	24.0
Nutrients and carbon									
Ammonia plus organic, total, as nitrogen (mg/L)	22	0.70–7.60	2.0	12	0.96–4.69	2.84	18	0.74–5.60	2.45
Nitrite plus nitrate as nitrogen, dissolved (mg/L)	22	.44–1.15	.66	12	.51–3.48	1.25	18	.38–3.22	.66
Ammonia, as nitrogen (mg/L)	21	<.02–0.32	.08	12	<.04–.14	.07	18	<.02–.32	.07
Total nitrogen (mg/L)[1]	22	1.47–8.75	2.58	12	2.03–5.64	4.94	18	1.99–6.21	3.31
Orthophosphorus, as phosphorus (mg/L)	22	.01–.12	.06	12	.06–.52	.11	18	.01–.97	.06
Dissolved phosphorus (mg/L)	22	<.05–.19	.09	12	.07–.58	.13	18	.05–.96	.10
Total phosphorus (mg/L)	22	.15–2.45	.54	12	.21–1.54	1.14	18	.18–2.05	.73
Particulate Phosphorus (mg/L)[2]	22	.09–2.37	.45	12	.09–1.38	.93	17	.06–2.00	.54
Dissolved organic carbon (mg/L)	5	3.8–7.2	6.3	12	5.2–7.7	6.3	18	4.5–7.6	5.8
Total organic carbon (mg/L)	5	8.7–55.4	15.3	12	8.9–46.0	19.8	18	6.6–85.9	21.8
Biochemical and bacteria									
Biochemical oxygen demand (mg/L)	4	4.0–9.0	4.5	12	5.2–7.7	6.3	18	4.5–7.6	5.8
Chemical oxygen demand (mg/L)	3	101–240	200	12	21–112	56	17	18–308	101
Enterococci (col/100 mL)	22	200–370,000	14,000	0	--	--	14	1,100–65,000	21,000
Escherichia coli (col/100 mL)	22	250–46,000	10,700	12	1,530–24,400	16,800	18	305–48,400	14,500
Fecal coliform (col/100 mL)	21	500–90,000	20,000	11	3,330–45,000	21,000	18	325–52,000	12,200

[1]Calculated as the sum of nitrite plus nitrate and dissolved and ammonia plus organic, total.

[2]Calculated as the difference between total phosphorus and dissolved phosphorus.

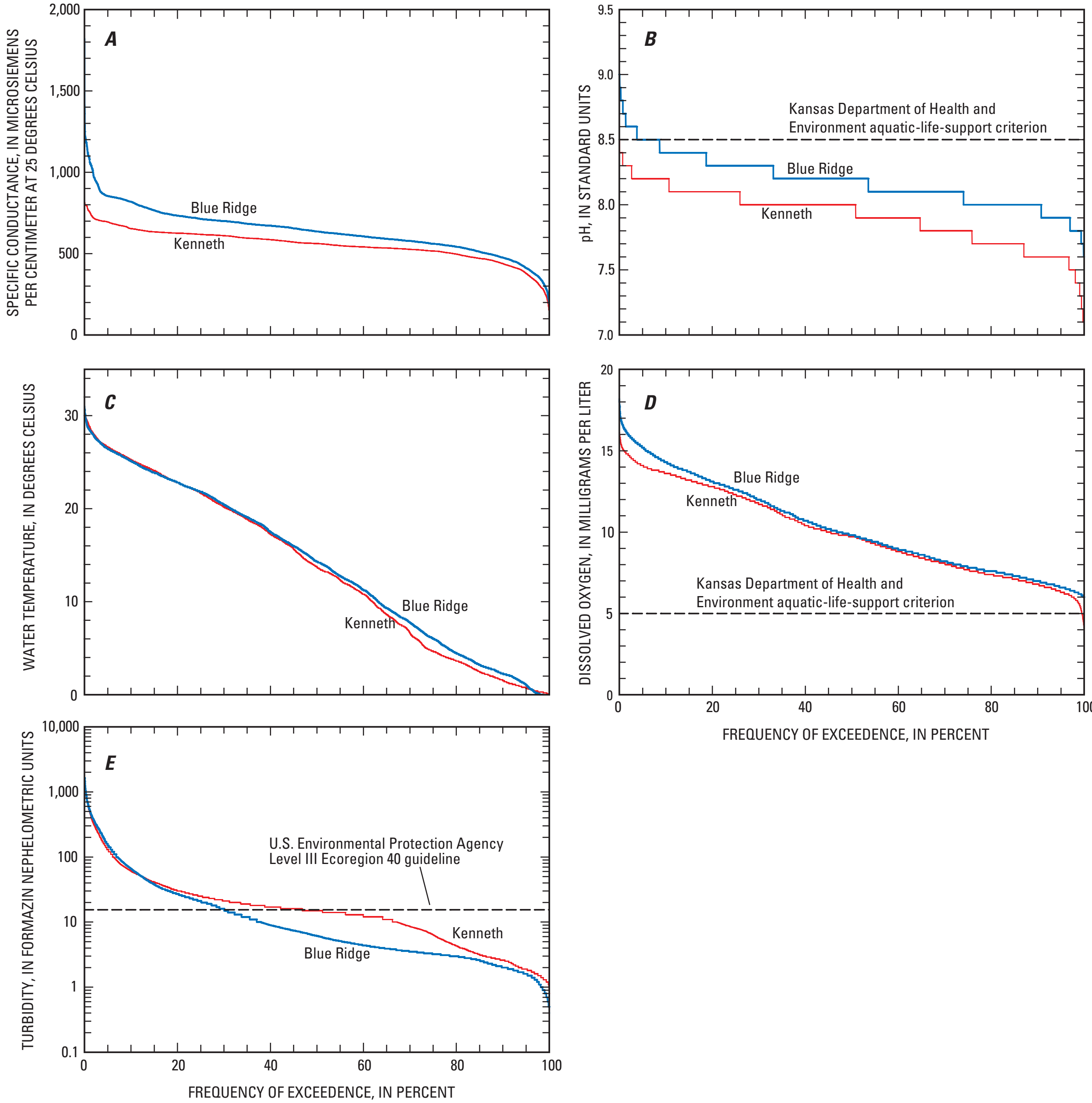

Figure 4. Duration curves for hourly measured specific conductance (*A*), pH (*B*), water temperature (*C*), dissolved oxygen (*D*), and turbidity (*E*) at the Kenneth and Blue Ridge sites on the upper Blue River, April 2008 through March 2009.

at the Blue Ridge site (fig. 4*D*). The larger dissolved oxygen concentrations at the Blue Ridge site are likely because of increased algal photosynthesis and possibly larger streamflows and increased stream reaeration because of better riffle-pool sequences. In addition, low dissolved oxygen concentrations at the Kenneth site may occur during low-flow periods because the monitor is located at the downstream end of a large pool that lacks riffles where atmospheric reaeration can take place.

Turbidity, Suspended Solids, and Suspended Sediment

Suspended solids and sediment in stream water typically are from erosion and subsequent transport of surface and channel bank soils. Suspended solids are effectively removed by most wastewater treatment processes and in the Blue River Basin total suspended solids and sediment concentrations typically are lower downstream from wastewater effluent discharges than upstream during below-normal streamflows (Lee and others, 2005; Wilkison and others, 2006; Rasmussen and others, 2008, 2009a). Increased suspended sediment in streams reduces light penetration and photosynthesis, smothers benthic habitats, and interferes with feeding activities (Wetzel, 2001). In addition, these suspended particulates provide attachment sites for nutrients, organic compounds, and other potential contaminants. Turbidity, caused by suspended and dissolved matter such as clay, silt, fine organic matter, microscopic organisms, organic acids, and dyes (ASTM International, 2003), is often used as a surrogate for suspended solids and sediment.

Turbidity at the Kenneth site was greater than at the Blue Ridge site about 85 percent of the time during April 2008 through March 2009 (fig. 4*E*). U.S. Environmental Protection Agency (USEPA) guidelines for turbidity (based on reference conditions) list 15.5 FNUs for level III ecoregion 40 streams, which includes the Blue River (U.S. Environmental Protection Agency, 2000a). Guidelines are non-enforceable criteria developed for the protection of water quality, aquatic life, and human health. Turbidity at the Kenneth site exceeded the USEPA guideline of 15.5 FNU about 50 percent of the time, compared to about 30 percent of the time at the Blue Ridge site (fig. 4*E*). Exceedances occurred within the range of streamflows at the Kenneth site, but only during normal and above-normal streamflows at the Blue Ridge site (table 3). Differences in turbidity between sites were most pronounced during below-normal streamflows; the median at the Kenneth site (14 FNU) was 7 times larger than at the Blue Ridge site (2.0 FNU). Turbidity downstream from the WWTF is artificially low during below-normal streamflows because of the clarity of wastewater effluent discharge relative to natural conditions in the receiving stream.

Patterns in total suspended solids and suspended sediment upstream and downstream from the WWTF match patterns in turbidity during below-normal and normal streamflows, with median concentrations between 44 and 138 percent larger at the Kenneth site (medians: 19 and 23, respectively) than the Blue Ridge site (medians: 8 and 16, respectively). During above-normal streamflows, total suspended solids and suspended sediment concentrations span similar ranges at both sites (about 20 mg/L to 4,000 mg/L), but median concentrations are about 20 to 30 percent larger at the Blue Ridge site (810 and 817 mg/L, respectively) than the Kenneth site (586 and 628 mg/L, respectively; table 4).

Dissolved Solids and Major Ions

The major constituents of dissolved solids generally are calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, and chloride ions. The amount of dissolved solids in stream water is primarily determined by the amount of groundwater contributing to streamflow, the amount of urbanization, and effluent discharges from wastewater and industrial sites (Hem, 1992; Pope and Putnam, 1997). Water use often results in the addition of dissolved solids to the wastewater effluent stream; for example, when chloride is added through chlorination of drinking water and sodium and chloride are added through water softeners.

Dissolved solids and major ions were consistently larger at the sites located downstream from the WWTF than at the Kenneth site during below-normal and normal streamflows (table 4, appendix 3). The largest difference among sites was in the concentrations of the potassium, sodium, and chloride ions; median concentrations at the Blue Ridge site (40.7, 6.1, and 59.2 mg/L, respectively) were between 40 and 50 percent larger than median concentrations at the Kenneth site (24.2, 3.2, and 32.5, respectively). Increasing streamflow dilutes dissolved solids concentrations because of low concentrations in rainfall and runoff. In general, concentrations of dissolved solids and major ions were about 50 percent lower at both sites during above-normal streamflows, and differences between sites were relatively small (less than 30 percent) for dissolved solids and most major ions. However, median chloride concentration at the Blue Ridge site (30.0 mg/L) was 79 percent larger than the median concentration at the Kenneth site (16.8 mg/L) during above-normal streamflows (table 4). Greater chloride concentrations at the Blue Ridge site during above-normal streamflows are likely the result of runoff from urban areas during winter road de-icing periods. When data from the period of peak road-salt application (late November to early March) are excluded, median chloride concentration at the Blue Ridge site (20.0 mg/L) is about 48 percent larger than at the Kenneth site (13.5 mg/L).

Of the chemicals that make up dissolved solids, chloride is the only one with an established criterion for protection of aquatic life (U.S. Environmental Protection Agency, 1988). The USEPA acute exposure criterion is 860 mg/L and the chronic exposure criterion is 230 mg/L. The chronic exposure criterion is the concentration that may cause effects after exposure throughout an extended period of time. Based on discrete samples (table 4, appendix 3) and continuous data developed from regression models (*http://nrtwq.usgs.gov*), chloride concentrations did not exceed the acute or chronic criteria at any of the upper Blue River study sites, regardless of streamflows.

Nutrients

Data from discrete stream-water and wastewater effluent samples were used to describe nutrient concentrations upstream and downstream from the WWTF and before and after WWTF upgrades. Continuous data, developed from regression models that utilized discrete data, were used to compute total nutrient loads and yields during April 2008 through March 2009.

Nutrient Concentrations Upstream and Downstream from the Wastewater Treatment Facility

In 2000, the USEPA recommended ecoregion-based nutrient criteria for streams. Reference conditions for TN and TP in level III, ecoregion 40 streams are defined as 0.855 and 0.0925 mg/L, respectively (U.S. Environmental Protection Agency, 2000a). These criteria were intended as a preliminary attempt to describe the nutrient concentrations that would protect designated uses and mitigate the effects of nutrient enrichment and are not used for regulatory purposes. Measured total nutrient concentrations at the Blue Ridge site always exceeded reference conditions (TN range: 1.29 to 15.4 mg/L; TP range: 0.17 to 2.46 mg/L). By comparison, total nutrient concentrations at the Kenneth site (TN range: 0.43 to 8.75 mg/L; TP range: less than 0.1 to 2.45 mg/L) were lower than reference conditions in about 60 percent of the samples (number of samples=10) collected during below-normal and normal streamflows, but always exceeded reference conditions during above-normal streamflows (fig. 5*A*, *B*; table 4).

Nutrients in wastewater effluent typically occur in inorganic forms (for example, nitrate and orthophosphorus) and are dissolved. At stream sites influenced by wastewater effluent, concentrations of dissolved constituents typically decrease as streamflow increases because of dilution, and concentrations of suspended constituents increase with streamflow because of transport. At stream sites affected by nonpoint sources, concentrations of all constituents tend to increase with increased streamflow. Changes in nutrient concentrations with streamflow at the upper Blue River sites reflect the effect of dominant sources. At the Kenneth site, nutrient concentrations generally increased with increasing streamflow, indicating the relative contribution of nonpoint sources to overall nutrient loads (fig. 5). In contrast, at the WWTF affected Blue Ridge site, dissolved nutrient concentrations decreased and suspended organic nutrient concentrations increased with increasing streamflow. Total nutrient concentrations initially decreased with streamflow as the nutrient contribution from wastewater effluent was diluted, and then increased as the proportion of nutrients contributed by nonpoint sources during runoff increased (fig. 5).

Total and dissolved nutrient concentrations downstream from the WWTF were 4 to 15 times larger than at the Kenneth site during below-normal and normal streamflows, even after the addition of biological nutrient removal to the treatment process (table 4, appendix 3). At the Blue Ridge site, nitrate plus nitrite (hereinafter referred to as nitrate) and orthophosphorus comprised most (65 to 100 percent) of the total nutrient concentrations during below-normal and normal streamflows. During above-normal streamflows, nutrient concentrations were generally similar between sites, with nitrate and orthophosphorus comprising about 25 and 10 percent of total concentrations, respectively, at both sites (fig. 6).

Nutrients in Wastewater Effluent

Annual mean TN concentration in the Blue River Main WWTF wastewater effluent, calculated from weekly wastewater effluent sample data, decreased by about 50 percent between the periods 2003 through 2006 (15 to 16 mg/L) and 2007 through 2008 (9.1 and 7.7 mg/L, respectively). Annual mean wastewater effluent concentrations were below the NPDES permit target (less than or equal to 8 mg/L) in 2008 (fig. 7*A*). Total phosphorus concentrations decreased by about 30 percent between the periods 2003 through 2006 and 2007 (1.8 to 2.2 mg/L and 1.4 mg/L, respectively) and about 10 percent between the periods 2003 through 2006 and 2008 (1.8 mg/L); however, TP concentrations increased by about 27 percent between 2007 and 2008. Annual mean wastewater effluent TP concentration was below the NPDES permit target (less than or equal to 1.5 mg/L) in 2007, but was about 17 percent larger than the target in 2008 (fig. 7*B*).

The Blue River Main WWTF began using biological nutrient removal in October 2006; however, the WWTF experienced several challenges in achieving phosphorus removal sufficient to meet the annual mean targets established by the NPDES permit. After a year of successful operation, the biological phosphorus removal (BPR) process stopped working during the summer of 2007. It was determined that the level of volatile fatty acids (VFAs) required to drive the BPR process were substantially reduced in the influent wastewater, but the reason for this change could not be identified. A pilot study conducted during April through September 2009 determined that BPR could be achieved with an external carbon source, with mean results less than the 1.5 mg/L target concentration. The pilot study was discontinued during the winter because of freezing and was restarted in spring 2010. Total wastewater effluent phosphorus concentrations during 2010 continue to be below the NPDES permit target of 1.5 mg/L (Johnson County Wastewater, written commun., 2010). Thus, TP concentrations in wastewater effluent during 2008 were anomalous, and wastewater effluent concentrations during 2007 are a more accurate reflection of the BPR process.

Nitrate plus nitrite contributed the largest percentage to TN concentrations in all years; however, the percentage decreased from about 90 percent during 2003 through 2006 to

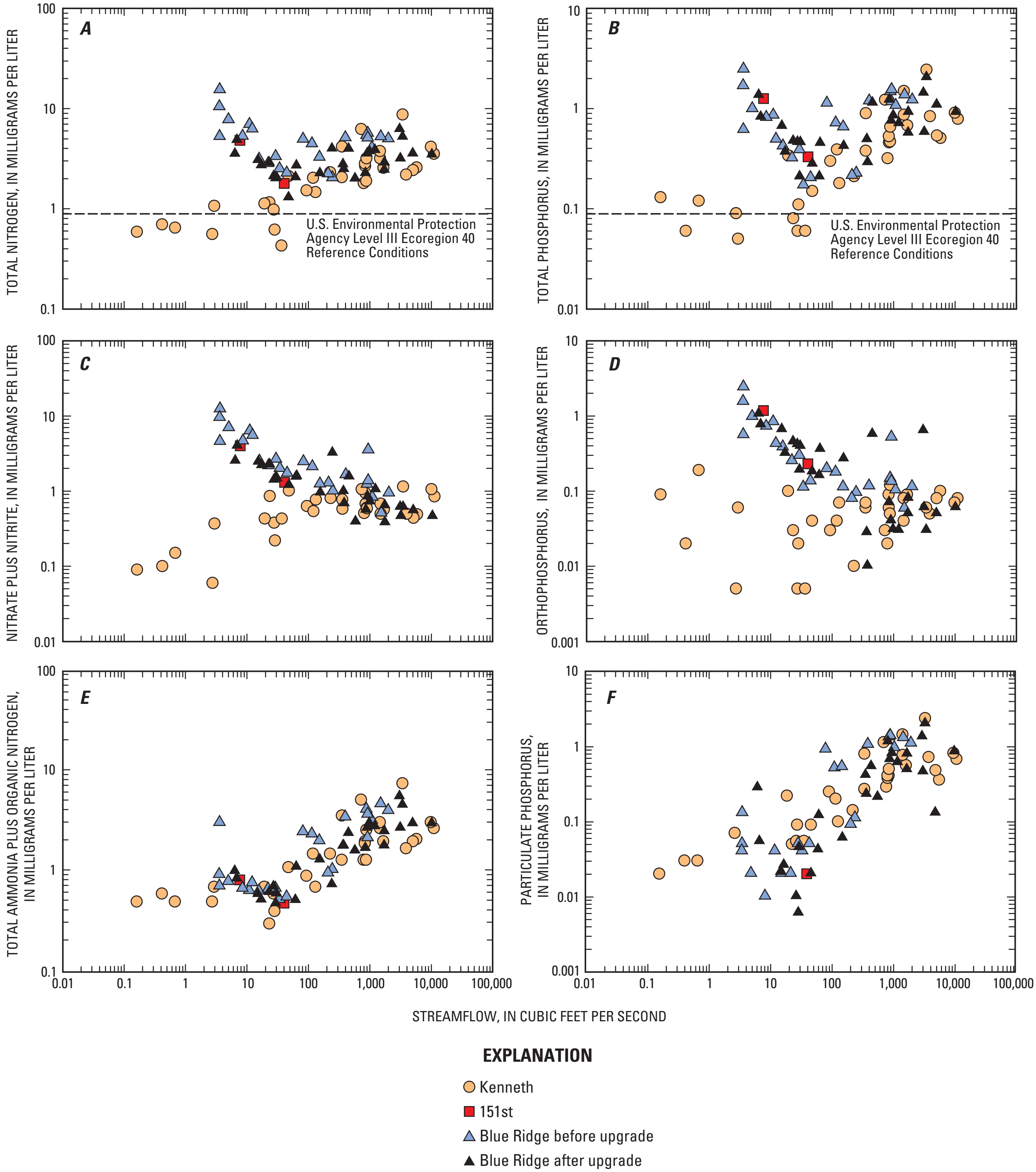

Figure 5. Relations between nutrient concentrations and streamflow at the Kenneth, 151st, and Blue Ridge sites on the upper Blue River during January 2003 through March 2009.

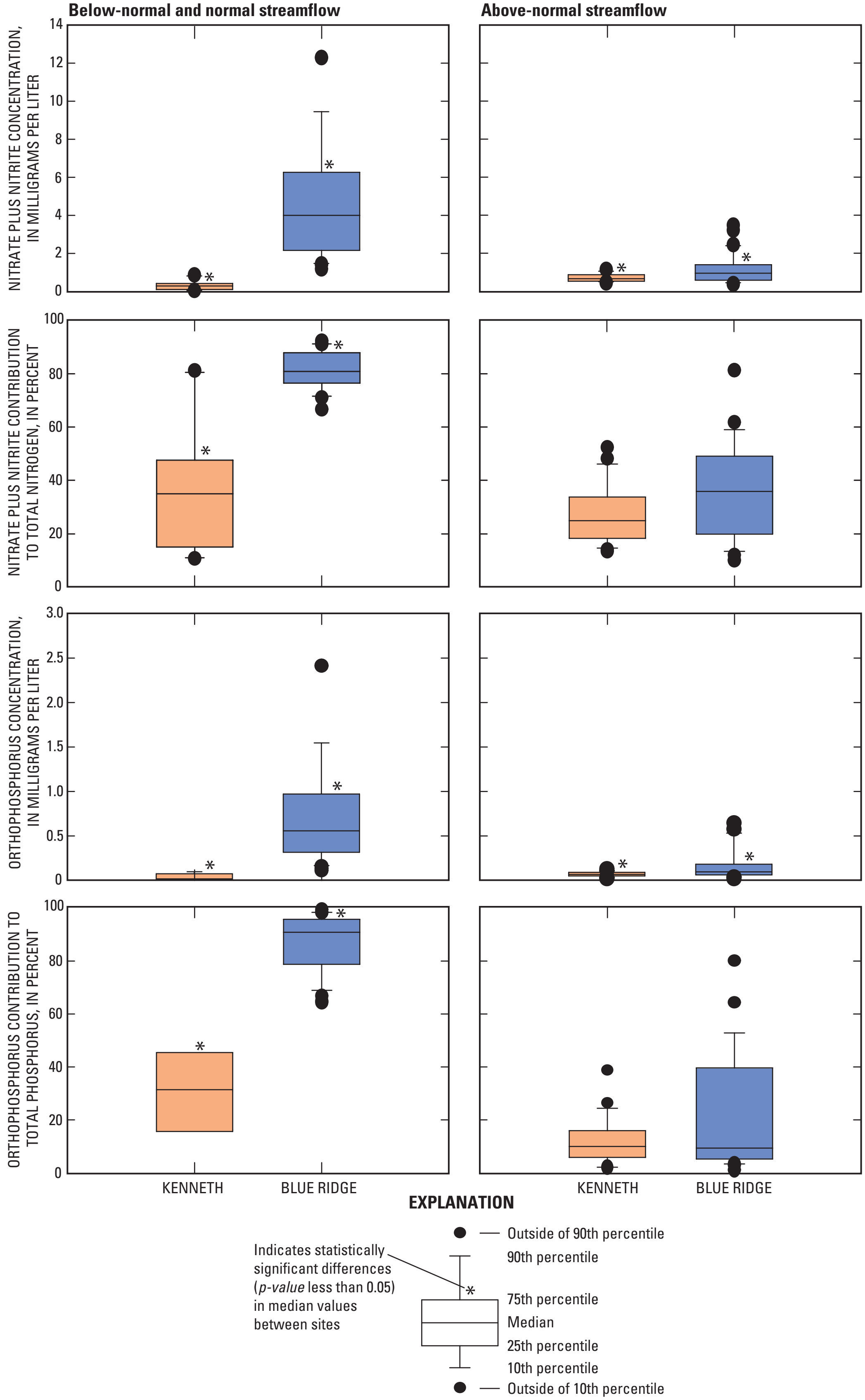

Figure 6. Nitrate and orthophosphorus concentrations and percent contribution to total nitrogen and phosphorus concentrations during below-normal and normal streamflows and above-normal streamflows at the Kenneth and Blue Ridge sites on the upper Blue River during January 2003 through March 2009.

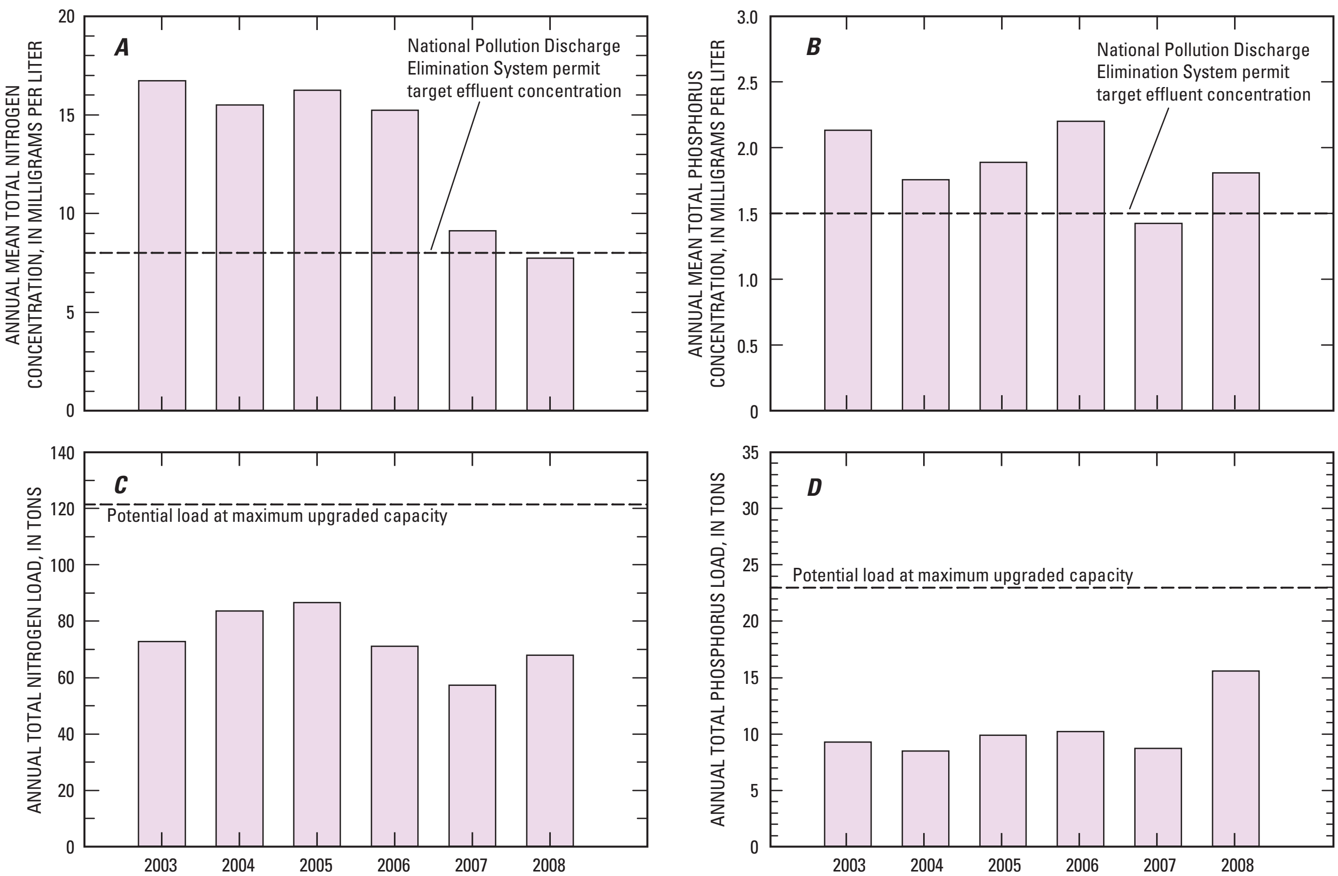

Figure 7. Annual mean wastewater effluent concentrations of total nitrogen and National Pollution Discharge Elimination System (NPDES) permit target wastewater effluent concentration (*A*), annual mean wastewater effluent concentrations of total phosphorus and NPDES permit target wastewater effluent concentration (*B*), annual total nitrogen loads and potential load at maximum upgraded capacity (*C*), and annual total phosphorus loads and potential load at maximum upgraded capacity (*D*) from the Blue River Main Wastewater Treatment Facility during 2003 through 2008.

about 80 percent during 2007 and 2008. The approximately 10 percent decrease in nitrate during 2007 and 2008 was accompanied by a similar increase in the amount of organic nitrogen (table 5). The shift in percent contribution of nitrate plus nitrite to TN is likely a result of the biological nutrient removal process, which may have increased the conversion of inorganic forms of nitrogen to organic forms. Data to allow a similar comparison for phosphorus were not available.

Nitrogen concentrations during below-normal and normal streamflows at the Blue Ridge site reflect decreases in wastewater effluent nitrogen concentration after implementation of biological nutrient removal. The median TN concentration of samples collected after the upgrade (2.40 mg/L) was about 54 percent less than in samples collected before the upgrade (5.25 mg/L) and median nitrate concentration was about 59 percent less (after: 1.86 mg/L; before: 4.57 mg/L). In addition, maximum concentrations of TN and nitrate after the upgrade were between 60 and 70 percent less than before the upgrade (table 4). Differences in TP and orthophosphorus concentrations were not as great, likely due, in part, to issues with the BPR process. Median TP and orthophosphorus concentrations in samples collected after the upgrade (0.46 and 0.41 mg/L, respectively) were about 16 percent less than in samples collected before the upgrade (0.55 and 0.49 mg/L, respectively). Samples collected before and after the upgrades to the WWTF were collected in a similar range of below-normal and normal streamflows, but median streamflow of the before-upgrade samples (12 ft^3/s) was about one-half that of the after-upgrade samples (25 ft^3/s; table 4). This discrepancy is because of increased streamflows during 2007 through 2009 (table 2). Because increased streamflow dilutes wastewater effluent, decreases in nutrient concentrations may not be as great as suggested by direct comparison; however, decreases in TN and nitrate concentrations after the upgrade are evident across the range of below-normal and normal streamflows (fig. 5*A*, *C*).

Annual TN loads from the WWTF reflected patterns in discharge volume and nutrient concentration (table 2, fig. 7). Total nitrogen loads in 2007 and 2008 were about 20 percent less than during 2003 through 2006 (fig. 7*C*). Overall decreases in TN loads despite substantial increases in wastewater effluent discharge volume reflect the addition

Table 5. Nitrogen composition of wastewater effluent in weekly samples from the Blue River Main Wastewater Treatment Facility, 2003 through 2008.

[Values may not add to 100 because of rounding errors; Data courtesy of Johnson County Wastewater; *n*, number of samples]

Year	Percent nitrate plus nitrite				Percent ammonia				Percent organic nitrogen			
	n	Mean	Median	Range	*n*	Mean	Median	Range	*n*	Mean	Median	Range
2003	51	88	90	69–93	48	4.7	0.92	0.26–38	47	8.4	8.0	5.6–15
2004	50	86	87	63–93	48	1.8	.65	.26–18	48	11	11	4.9–19
2005	51	90	90	74–100	46	1.1	.60	.26–6.3	46	8.8	8.8	0.0–25
2006	48	91	91	81–100	44	1.2	.57	.24–7.2	44	8.3	8.2	0.0–19
2007	52	82	83	68–92	47	1.1	.68	.43–5.9	47	17	17	9.3–31
2008	52	80	80	25–100	48	1.1	.71	.49–7.0	46	20	19	10–71

of biological nutrient removal at the facility. Annual TP loads in 2007 were about 10 percent less than the period 2003 through 2006. In contrast, annual TP load in 2008 was about 80 percent larger than in 2007 and 65 percent larger than the period 2003 through 2006 because of increased wastewater effluent discharge volume and issues with the BPR process (table 2, fig. 7*D*). Annual wastewater effluent discharge from the Blue River Main WWTF was about one-half of maximum capacity in 2008 (table 2). Based on annual mean wastewater effluent TN concentrations in 2008, potential maximum annual TN loads are about 1.6 times larger than the annual loads before capacity upgrades. Potential maximum annual TP loads, based on annual mean wastewater effluent TP concentrations in 2007 because of the BPR issues that occurred in 2008, are about 2.4 times larger than the annual loads prior to capacity upgrades (fig. 7*C*, *D*). Thus, while the addition of biological nutrient removal to the WWTF decreased wastewater effluent nutrient concentrations, nitrogen in particular, operation at full capacity would increase nitrogen and phosphorous loads relative to pre-capacity upgrade loads.

Computed Total Nitrogen and Total Phosphorus Concentrations, Loads, and Yields

Regression models and summary statistics for computing nutrient concentrations in the upper Blue River at the Kenneth and Blue Ridge sites are provided in table 6. Models for additional water-quality constituents including suspended sediment, major ions, and bacteria, are provided in appendix 4. Models were included if at least one significant (*p*-value less than 0.05) explanatory variable was determined. Only nutrient models (nitrogen and phosphorus) and calculated data are discussed in detail in this report.

The regression models for TN and TP at both upper Blue River sites included turbidity as the only explanatory variable (table 6). Larger uncertainties are associated with the downstream Blue Ridge models (R^2 of 0.48 for TN and 0.56 for TP, table 6) compared to the upstream Kenneth models (R^2 of 0.79 for TN and 0.94 for TP). The differences between the models can be attributed to increased urbanization and additional nutrient sources, particularly wastewater effluent discharge, at the downstream site. Previous studies in Johnson County have indicated that models developed for less urban sites were less variable than models for more urban sites because of multiple sources and altered pathways in urban areas (Rasmussen and others, 2008).

Both nitrogen and phosphorus models for the Blue Ridge site generally improved when particulate and dissolved forms were considered separately. Turbidity was the single explanatory variable for particulate forms of nitrogen and phosphorus. Streamflow was the single explanatory variable for dissolved nutrient forms, except phosphorus at the Kenneth site, which used specific conductance. The Blue Ridge model for ammonia plus organic nitrogen (TON), which represents particulate nitrogen, had an R^2 of 0.63 (table 6), and the model for nitrate plus nitrite, which represents dissolved nitrogen, had an R^2 of 0.71. The Blue Ridge model for particulate phosphorus (calculated by subtracting dissolved phosphorus from TP) had an R^2 of 0.78, but the dissolved phosphorus model was poor with an R^2 of 0.42. The orthophosphate model for the Blue Ridge site includes streamflow as the explanatory variable and also was poor (R^2 of 0.34). An acceptable orthophosphate model was not determined for the Kenneth site.

The regression models for total and particulate nitrogen and phosphorus at both upper Blue River sites included turbidity as the single explanatory variable because particulate forms of nutrients often attach to sediment particles, which can result in strong relations with turbidity. Regression models in appendix 5 demonstrate the statistical relations between suspended sediment concentration and TN, TP, and other water-quality constituents that often are associated with particulates. At the Kenneth site, where nutrients primarily originate from nonpoint sources, strong relations exist between suspended sediment, and TN (R^2 of 0.82, appendix 5) and TP (R^2 of 0.92). In contrast, at the Blue Ridge site, where nutrients are affected by wastewater effluent as well as more variable urban sources, relations are not as strong between suspended-sediment

Table 6. Regression models and summary statistics for computing total nitrogen and total phosphorus concentrations in water at the Kenneth and Blue Ridge sites on the upper Blue River.

[Discrete sample data for the Kenneth site were collected from July 2003 through March 2009. Discrete sample data for the Blue Ridge site were collected from April 2008 through March 2009; R^2, coefficient of determination; RMSE, root mean square error; MSPE, model standard percentage error; *n*, number of discrete samples; mg/L, milligrams per liter; log, $\log_{10}$; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); TBY, turbidity (YSI model 6136), in formazin nephelometric units (FNUs)]

Site	Regression model	R^2	RMSE	MSPE (upper)	MSPE (lower)	Bias correction factor (Duan, 1983)	Standard error for calculated parameter intercept	Standard error for first dependent variable	Covariance for calculated parameter and first dependent variable	Discrete sample data				
										n	Range of values in variable measurements	Mean	Median	Standard deviation
Nitrogen, total (TN), mg/L														
Kenneth	logTN=0.373logTBY-0.483	0.79	0.1458	40	29	1.06	0.0748	0.0349	-0.9387	32	TN 0.53–8.75	2.36	2.10	1.75
											TBY 3–1,270	270	188	306
Blue Ridge	TN=0.0023TBY+2.32	.48	.9342	88	30	1.00	.2957	.0006	-.7078	20	TN 1.29–6.21	3.16	2.96	1.26
											TBY 2–1,480	364	270	372
Nitrogen, ammonia plus organic (TON), total, mg/L														
Kenneth	TON=0.0047TBY+0.495	0.87	0.5776	74	33	1.00	0.1372	0.0003	-0.6678	32	TON 0.1–7.6	1.8	1.4	1.6
											TBY 3–1,270	270	188	306
Blue Ridge	logTON=0.331logTBY-0.471	.63	.2498	78	44	1.12	.1342	.0596	-.9093	20	TON.1–5.6	2.15	1.80	1.45
											TBY 2–1,480	364	270	372
Nitrogen nitrate plus nitrite, (NO_3), dissolved, mg/L														
Kenneth	logNO_3=0.189logQ-0.747	0.51	0.2266	69	41	1.13	0.0876	0.0339	-0.8895	32	NO_3 0.06–1.15	0.588	0.575	0.292
											Q 1–10,900	1,550	347	2,740
Blue Ridge	logNO_3=-0.238logQ+0.547	.71	.1407	38	28	1.05	.0987	.0357	-.9478	20	NO_3 0.10–5.60	2.150	1.80	1.450
											Q 8–10,000	1,620	670	2,420
Phosphorus, total (TP), mg/L														
Kenneth	TP=0.0016TBY+0.0754	0.94	0.1274	34	25	1.00	0.0303	0.0001	-0.6678	32	TP 0.05–2.45	0.51	0.39	0.51
											TBY 3–1,270	270	188	306
Blue Ridge	TP=0.0009TBY+0.484	.56	.3158	52	39	1.00	.1000	.0002	-.7078	20	TP 0.28–2.05	.82	.71	.46
											TBY 2–1,480	364	270	372
Phosphorus, particulate (P_{part}), mg/L as phosphate														
Kenneth	logP_{part}=0.670logTBY-1.99	0.84	0.2210	66	40	1.12	0.1186	0.0547	-0.9423	32	P_{part} 0.02–2.37	0.45	0.29	0.50
											TBY 3–1,270	270	188	306
Blue Ridge	P_{part}=0.0013TBY+0.0586	.78	.2570	49	45	1.00	.0813	.0002	-.7078	20	P_{part} 0.01–2.00	.52	.37	.53
											TBY 2–1,480	364	270	372
Phosphorus, dissolved (P_{diss}), mg/L as phosphate														
Kenneth	logP_{diss}=-1.01logSC+1.41	0.25	0.3342	116	54	1.26	0.8297	0.3205	-0.9975	32	P_{diss} 0.005–0.19	0.08	0.08	0.05
											SC 175–708	416	421	162
Blue Ridge	logP_{diss}=-0.307logQ+0.0866	.42	.3373	117	54	1.50	.2366	.0856	-.9478	20	P_{diss} 0.05–1.08	.30	.14	.31
											Q 8–10,000	1,620	670	2,420
Orthophosphate, dissolved (OrthoP), mg/L as phosphate														
Kenneth	Poor model													
Blue Ridge	logOrthoP=-0.402 logQ+0.209	0.34	0.4857	206	67	1.80	0.3407	0.1232	-0.9478	20	OrthoP 0.01–1.06	0.30	0.13	0.33
											Q 8–10,000	1,620	670	2,420

concentration and either TN (R^2 of 0.39, appendix 5) or TP (R^2 of 0.54).

TN and TP concentrations and loads in this report were calculated by adding the computed values for particulate and dissolved forms rather than using the TN and TP models directly because the separate models generally explained more variability than the combined models. This was particularly true for the Blue Ridge site, but the same approach was used at the Kenneth site to be consistent. A comparison between measured and computed TP and TN values (fig. 8) provides an indication of model performance, in addition to the individual model statistics located in table 6. Using this approach, upper-range concentrations of TN and TP are likely underestimated at both upper Blue River sites.

Computed TN concentrations during the study period ranged from 0.74 mg/L to 7.6 mg/L at the Kenneth site and 1.4 mg/L to 5.0 mg/L at the Blue Ridge site (table 7). Computed TN at the downstream Blue Ridge site (median: 2.3 mg/L) was nearly always greater than at the Kenneth site (median 0.91 mg/L), except for the largest value (table 7). Computed TP concentrations during the study period ranged from about 0.05 mg/L to 1.5 mg/L at the Kenneth site and 0.33 mg/L to 2.4 mg/L at the Blue Ridge site (table 7). Computed TP at the downstream Blue Ridge site (median 0.66 mg/L) was greater throughout the frequency range than at the Kenneth site (median: 0.12 mg/L, table 7).

Total nitrogen load for the study period was about 1.6 times larger at the downstream Blue Ridge site (409 tons, table 8) than the upstream Kenneth site (251 tons). Generally the largest TN loads originated from nonpoint sources during stormwater runoff rather than from the Blue River Main WWTF. About 63 tons (15 percent) of the nitrogen at the downstream site during the study period originated from the WWTF (table 8, fig. 9). Wilkison and others (2009) estimated that the annual total nitrogen load at the Blue Ridge site originating from the WWTF ranged from 15 to 53 percent during 2003 through 2007, with an average of 16 percent. During 2004, when median streamflow (41.0 ft^3/s, table 2) was most similar to median streamflow during 2008 (49.0 ft^3/s), the estimated contribution from the WWTF was 16 percent (Wilkison and others, 2009), similar to the 2008 contribution of 15 percent estimated by this study. Monthly loads from the WWTF decreased from about 7 tons in April and May 2008 to about 4 tons in March 2009 (fig. 10*A*), in part, as a result of optimization of nutrient removal treatment processes. The largest monthly nitrogen load occurred in June 2008, corresponding with a large rainfall event and streamflow volume originating upstream from the Kenneth site, and accounting for about 25 percent of the total load for the 1-year period (fig. 10*A*). Monthly nitrogen loads originating from the WWTF ranged from about 5 percent during months when streamflow was dominated by stormwater runoff (June 2008) to about 75 percent during drier months (August 2008; fig. 10*A*).

Total nitrogen yield at the downstream Blue Ridge site (4.4 tons per mi^2, table 8) was about 1.2 times greater than the yield at the upstream Kenneth site (3.8 tons per mi^2). Nitrogen yield from the intervening area between Kenneth and Blue Ridge was 5.8 tons per mi^2 when wastewater effluent from the Blue Main WWTF was included in the computation; however, nitrogen yield from the intervening land area without including wastewater effluent (3.5 tons per mi^2) was similar to nitrogen yield from the land area upstream from Kenneth (3.8 tons per mi^2), indicating that increased urbanization has had a negligible effect on yields.

Total phosphorus load for the study period was about 2 times larger at the downstream Blue Ridge site (105 tons, table 8) than the upstream Kenneth site (54 tons). The largest TP loads originated from nonpoint sources during stormwater runoff. About 15 tons (14 percent) of the phosphorus load at the downstream site originated from the WWTF (table 8, fig. 9). Wilkison and others (2009) estimated that the annual total phosphorus load at the Blue Ridge site originating from the WWTF ranged from 7 to 39 percent during 2003 through 2007, with an average of 18 percent. During 2004, when median streamflow (41.0 ft^3/s, table 2) was most similar to median streamflow during 2008 (49.0 ft^3/s), the estimated contribution from the WWTF was 7 percent (Wilkison and others, 2009), about one-half of the 2008 contribution of 14 percent estimated by this study. Monthly loads from the WWTF remained about the same during the study period (fig. 10*B*). Like nitrogen, the largest phosphorus loads occurred in June 2008 (fig. 10*B*), corresponding with the largest rainfall and streamflow volume. Monthly phosphorus loads originating from the WWTF ranged from about 5 percent during months dominated by storm water runoff (June 2008) to about 85 percent during drier months (August 2008; fig. 10*B*).

Total phosphorus yield at the downstream Blue Ridge site (1.1 tons per mi^2, table 8) was about 1.4 times larger than yield at the Kenneth site (0.8 tons per mi^2). The phosphorus yield for the intervening area, including wastewater effluent, was 1.9 tons per mi^2. Phosphorus yield from the intervening land area without including wastewater effluent (1.3 tons/sq mi) was about 1.6 times larger than the phosphorus yield at the Kenneth site. Larger phosphorus yields in the intervening area may be related to urbanization factors such as increased stream channel erosion, stormwater runoff from impervious surface areas, and application of lawn fertilizers. Urbanization may result in substantial increases in phosphorus yield relative to nitrogen yields (Wickham and others, 2008), as seen in the upper Blue River watershed; the mechanisms behind this difference have not been well described but are likely because of the differences in the supply and transport properties of nitrogen and phosphorus (Alexander and others, 2008).

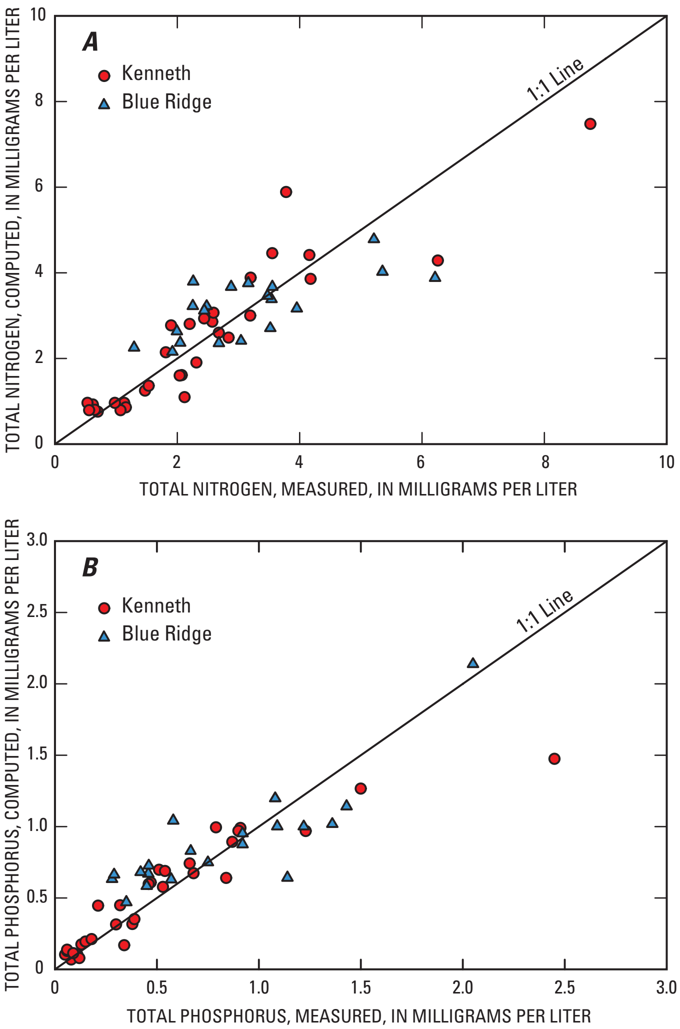

Figure 8. Comparison between measured and computed total nitrogen (*A*) and total phosphorus (*B*) concentrations at the Kenneth and Blue Ridge sites on the upper Blue River.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) measures organic matter which can support the growth of aquatic microorganisms and is commonly used to describe water-quality conditions (Cheremisinoff, 1995). Large concentrations of oxygen demanding substances substantially can reduce oxygen concentrations in streams, thereby adversely affecting aquatic organisms. Relatively pristine streams typically have a low BOD (less than 2.0 mg/L) and streams polluted by organic matter have increased BOD (greater than 13 mg/L; Van Dam and others, 1994; Porter, 2008). BOD never exceeded 13 mg/L at any of the upper Blue River sites (range: less than 2 to 9.0 mg/L), even during above-normal streamflows. BOD was measured in relatively few (number of samples=6) samples from the Kenneth site, but available data indicate concentrations typically are lower than at the sites located downstream from the WWTF (table 4, appendix 3).

Indicator Bacteria

Fecal coliform, *Escherichia coli*, and enterococci are the three most common types of bacteria used as indicators of pathogens in surface water. Indicator bacteria are used to evaluate the sanitary quality of water and its use as a public water supply and for recreational activities such as swimming, wading, boating, and fishing (American Public Health Association and others, 1995). These indicator bacteria and pathogens may cause human diseases ranging from mild diarrhea to respiratory disease, septicemia, meningitis, and polio (Durfour, 1977; Cheremisinoff, 1995). Reducing the number of fecal indicator and other potentially pathogenic bacteria and microorganisms in wastewater effluent requires disinfection. All modern wastewater treatment facilities include disinfection as part of the treatment process. The Blue River Main WWTF uses ultraviolet (UV) radiation for disinfection. UV disinfection is a physical, rather than chemical, process and there is no residual effect that can be harmful to humans or aquatic life (U.S. Environmental Protection Agency, 1999). As a result of the disinfection process, most of the fecal indicator bacteria and other pathogenic microorganisms in streams usually come from nonpoint sources and concentrations are orders of magnitude greater during runoff events than below-normal or normal streamflows (Rasmussen and others, 2008; Wilkison and others, 2009). Nonpoint sources are likely the primary source of fecal indicator bacteria at the upper Blue River sites. Median concentrations of fecal indicator bacteria were 1 to 3 orders of magnitude larger during above-normal streamflows than below-normal and normal streamflows at the Kenneth and Blue Ridge sites (table 4).

Organic Wastewater Effluent and Pharmaceutical Compounds

Organic wastewater effluent compounds are used in commercial, industrial, and residential processes and activities (such as detergents, plasticizers, and fragrances). Pharmaceutical compounds include over-the-counter and prescription medications. Many of these compounds are released into the environment through wastewater treatment processes, albeit in minimal concentrations, and occurrence is prevalent in surface waters throughout the United States (Kolpin and others, 2002). The long-term effects of exposure of natural biota and humans to mixtures of organic wastewater effluent and pharmaceutical compounds currently (2010) are largely unknown, though individual compounds have been determined to negatively affect physiological processes, impair reproductive processes, and increase incidences of cancer (Daughton and Ternes, 1999; Kolpin and others, 2002; Pomati and others, 2008).

Water samples collected from the Kenneth, 151st, and Blue Ridge sites during April 2008 were analyzed for a total of 58 organic wastewater effluent compounds and 13 pharmaceutical compounds. Fourteen organic wastewater effluent compounds and two pharmaceutical compounds

Table 7. Computed concentration percentiles for total nitrogen and total phosphorus at the Kenneth and Blue Ridge sites on the upper Blue River, April 2008 through March 2009.

[mg/L, milligrams per liter]

Site	Number of values	Sample standard deviation	Measurement at indicated frequency of exceedance										
			Minimum	1 percentile	5 percentile	10 percentile	25 percentile	50 percentile (median)	75 percentile	90 percentile	95 percentile	99 percentile	Maximum
Nitrogen, total (TN), mg/L													
Kenneth	8,760	0.54	0.74	0.78	0.80	0.82	0.85	0.91	1.0	1.3	1.7	3.6	7.6
Blue Ridge	8,760	.32	1.4	2.0	2.1	2.1	2.2	2.3	2.5	2.7	2.9	3.7	5.0
Phosphorus, total (TP), mg/L													
Kenneth	8,760	0.14	0.05	0.06	0.06	0.07	0.09	0.12	0.16	0.25	0.38	0.87	1.5
Blue Ridge	8,760	.15	.33	.44	.47	.50	.57	.66	.76	.83	.91	1.1	2.4

were detected. The antibiotic sulfamethoxyzole, detected at the 151st site immediately downstream from the WWTF, was the only compound that was detected at concentrations greater than the laboratory reporting level. Most (75 percent) of the organic wastewater effluent and pharmaceutical compounds detected in the upper Blue River study reach were detected only at sites located downstream from the WWTF (appendix 6).

Streambed-Sediment Chemistry

Some compounds are hydrophobic and have an affinity for sediment. Thus, some compounds occur in greater concentrations in sediment than in the overlying water column (Horowitz, 1991). Contaminated sediment can be toxic to benthic organisms, including periphyton and macroinvertebrates, and contaminants may bioaccumulate in fish and mammals (U.S. Environmental Protection Agency, 2000b). Streambed-sediment samples were collected at the Kenneth, 151st, and Blue Ridge sites during April 2008 and analyzed for carbon, nutrients, trace elements, and organic wastewater effluent compounds (appendixes 7 and 8).

Nutrient concentrations at all upper Blue River sites were below mean background levels in the conterminous United States (Horowitz and Stephens, 2008). Carbon concentrations were approximately one-half of the mean background levels and were relatively similar between sites. Phosphorus concentrations ranged from 18 to 47 percent less than background levels and were smallest at the Kenneth site and largest at the 151st site. Background concentrations for nitrogen are not available for comparison. Concentrations of most trace elements at all upper Blue River sites were similar to (within 25 percent) or below (greater than 25 percent less) mean background levels in the conterminous United States (Horowitz and Stevens, 2008). Barium and titanium were between about 30 to 40 percent above mean background levels at all upper Blue River sites. Arsenic, chromium, lead, and nickel were similar to mean background levels at the Kenneth site, but were generally between 30 to 66 percent above background levels at the sites located downstream from the WWTF. Carbon, nutrient, and trace-element concentrations were within the range observed in previous Johnson County studies (Lee and others, 2005; Rasmussen and others, 2009a). Fifty-eight organic wastewater effluent compounds were analyzed in streambed sediment, and 21 were detected (appendix 8). Concentrations of all detected organic wastewater effluent compounds were an order of magnitude smaller than concentrations at the most urban sites in Johnson County (Lee and others, 2005; Rasmussen and others, 2009a) and the Blue River (Wilkison and others, 2009).

There are no criteria for trace elements or organic wastewater effluent compounds in sediments, but probable effect concentrations (PEC) have been developed for some compounds (U.S. Environmental Protection Agency, 1998; MacDonald and others, 2000). The PEC represents the concentration of a contaminant in streambed sediment that is expected to adversely affect benthic biota. None of the measured compounds exceeded PEC guidelines (appendixes 7 and 8).

Habitat

Habitat-quality evaluations integrate several factors that directly or indirectly affect the water-quality and biological condition of streams, and are a critical part of assessing ecological integrity (Barbour and others, 1996; Barbour and others, 1999). Degraded habitat conditions are one of the primary stressors affecting the diversity and abundance of aquatic organisms in streams (Karr and others, 1986). Total habitat scores were indicative of suboptimal conditions at all sites; however, total scores were about 10 percent lower at the downstream sites than the upstream site (fig. 11*A*). The habitat

Table 8. Computed total loads and yields for total nitrogen and phosphorus at the Kenneth and Blue Ridge sites on the upper Blue River, April 2008 through March 2009.

[mi^2, square miles; WWTF, wastewater treatment facility; --, not applicable]

	Kenneth (65.4 mi^2)	Blue River Main WWTF	Intervening area between Kenneth and Blue Ridge (27.1 mi^2)		Blue Ridge (92.5 mi^2)	Percent wastewater at Blue Ridge
			Not including wastewater	Including wastewater		
Total nitrogen load, tons	251	63	95	158	409	15
Total phosphorus load, tons	54	15	35	51	105	14
Total nitrogen yield, tons per mi^2	3.8	--	3.5	5.8	4.4	--
Total phosphorus yield, tons per mi^2	.8	--	1.3	1.9	1.1	--

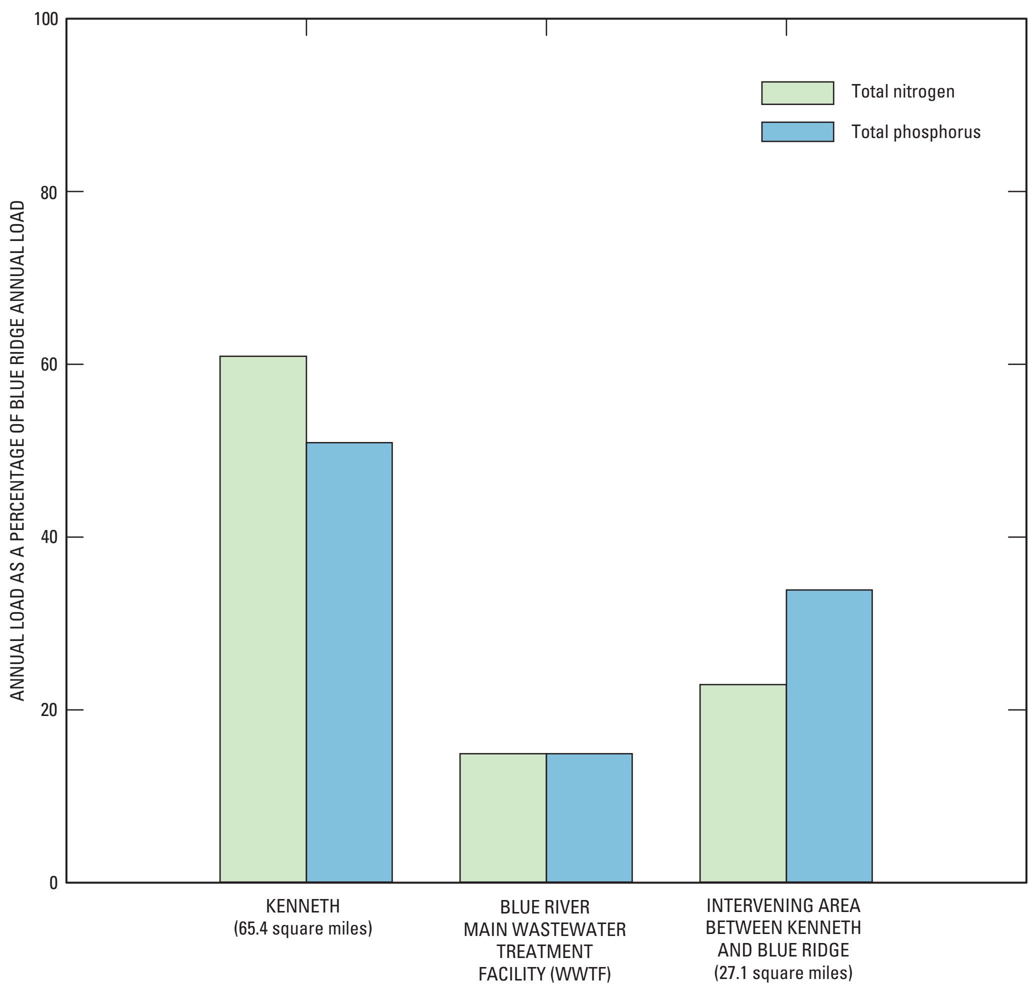

Figure 9. Nutrient loads from contributing upstream areas as a percentage of total load at the Blue Ridge site located downstream from the wastewater treatment facility on the upper Blue River during April 2008 through March 2009.

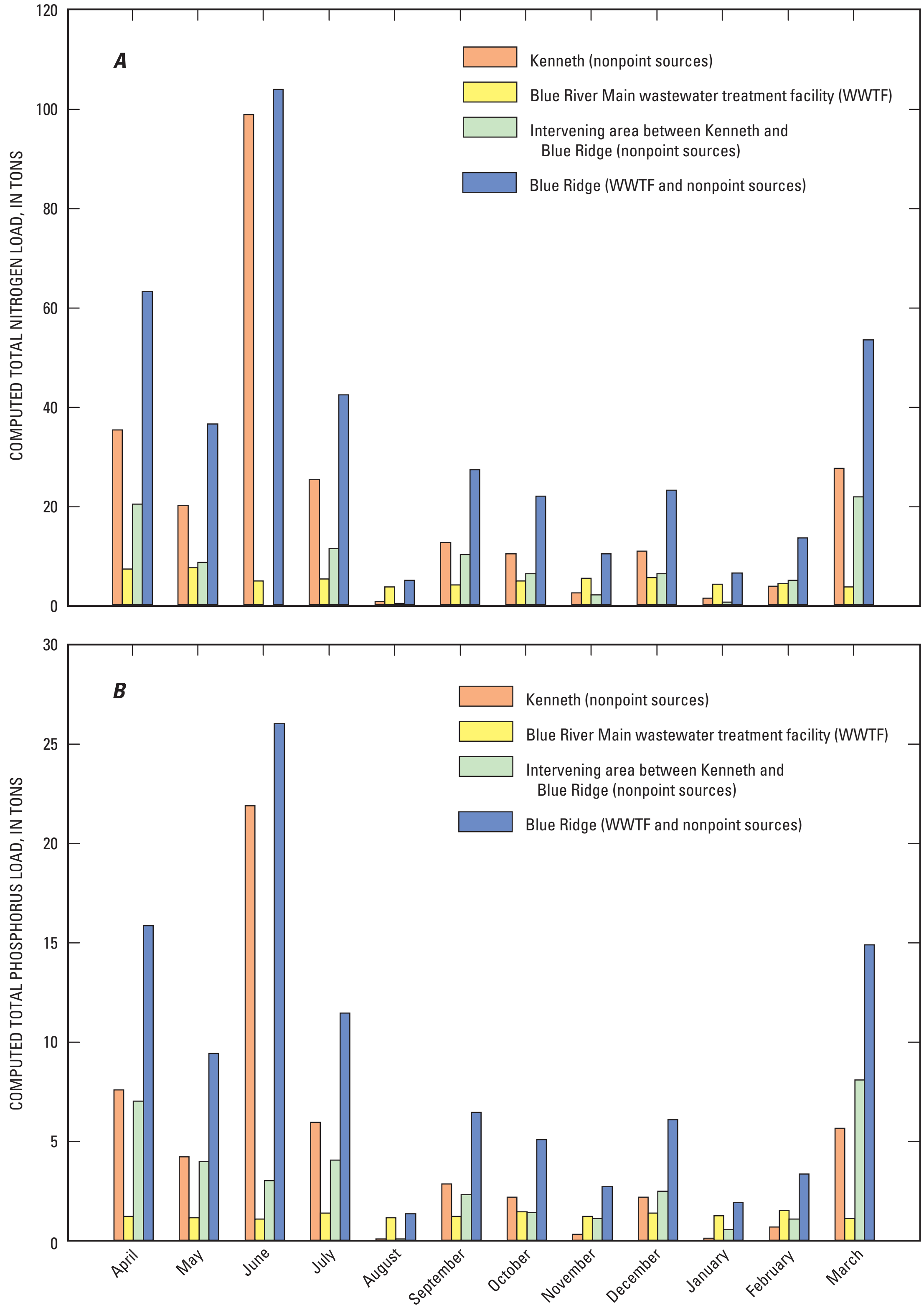

Figure 10. Computed monthly total nitrogen (*A*) and total phosphorus (*B*) loads originating from wastewater effluent discharge (WWTF) and nonpoint sources in the upper Blue River during April 2008 through March 2009.

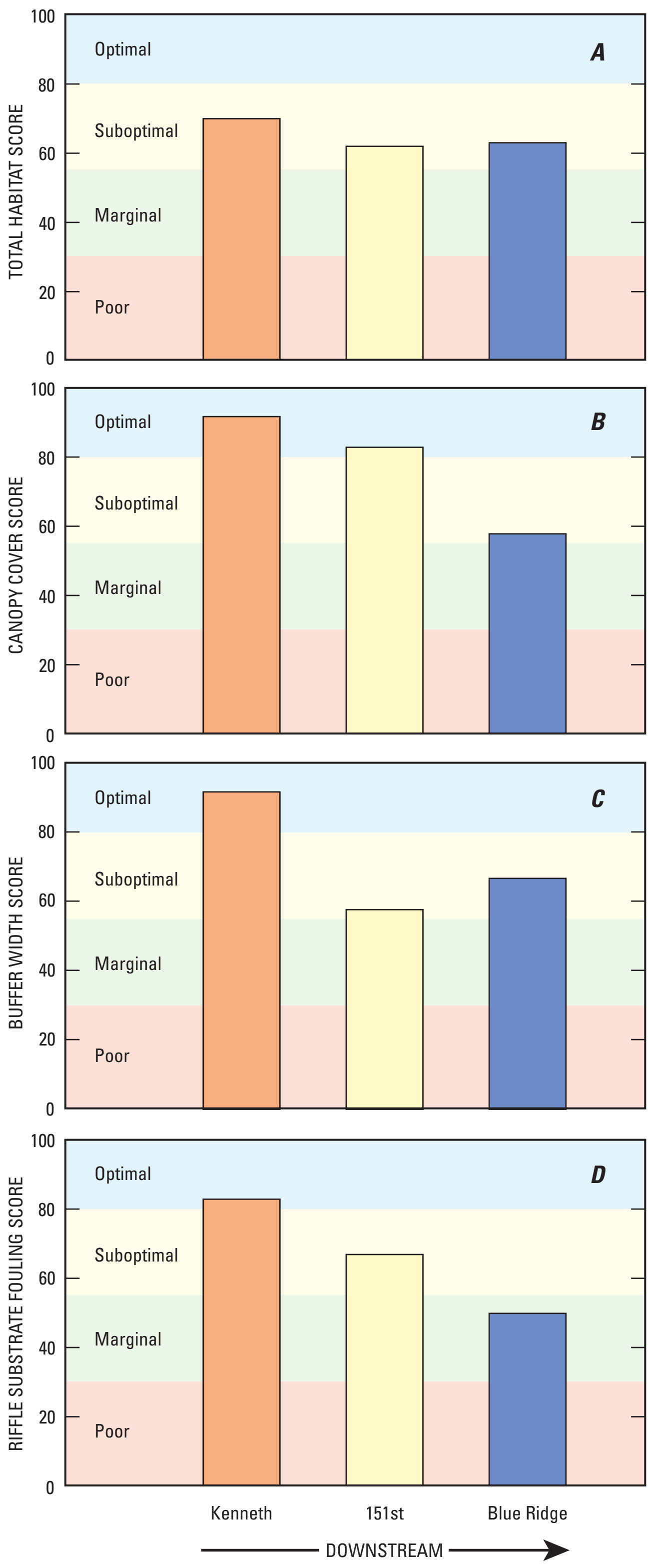

Figure 11. Total habitat score (*A*) and scores of selected individual habitat variables (*B–D*) at each biological sampling site on the upper Blue River during June 2008.

variables with the largest among-site differences in score were canopy cover, buffer width, and riffle-substrate fouling (fig. 11*B*-*D*). Habitat assessment scores for all 17 habitat variables are provided in appendix 9.

Canopy cover is the degree to which a stream is shaded by overhanging vegetation. Stream shading is important because it decreases light availability and helps to keep water temperatures cool, which limits excessive algae and vegetation growth (Natural Resources Conservation Service, 1998). Buffer width is a measure of natural vegetation (including forest, shrubs, and native grasses) from the edge of the streambank out through the riparian zone. A wide buffer acts as an erosion control and allows runoff more time to percolate into soils or to be filtered by vegetation before entering the stream (Barbour and others, 1999). Canopy cover and buffer width scores decreased in the downstream direction from optimal at the Kenneth site to suboptimal at the 151st and Blue Ridge sites (fig. 11*B*, *C*), likely because of the increasingly urban nature of the watershed. Urban land use and impervious surface area nearly doubled in the intervening area between the Kenneth and Blue Ridge sites (table 1, fig. 1). Canopy cover also may decrease in the downstream direction as stream order increases (Vannote and others, 1980); however, bankfull channel width was similar (about 90 feet) at all sites.

Riffle-substrate fouling scores also decreased in the downstream direction, with scores indicative of optimal conditions at the Kenneth site, suboptimal conditions at the 151st site and marginal conditions at the Blue Ridge site (fig. 11*D*). Riffle-substrate fouling is an estimate of the amount of periphyton growth and accumulation of fine materials that are covering the substrate in riffles. Excessive amounts of periphyton, sediment, and fine materials may clog interstitial spaces in gravel and cobble substrates, reducing the amount of habitat available for benthic organisms and riffle-dwelling fish (Rasmussen and others, 2009a). Several factors affected by urbanization and wastewater effluent discharge affect periphyton growth and the accumulation of fine materials including canopy cover, riparian buffer width, water clarity, nutrient concentrations, and streamflow.

Biological Conditions of the Upper Blue River

Biological conditions evaluated include periphyton and macroinvertebrate communities and stream metabolism. Periphyton and macroinvertebrate samples were collected during below-normal (August) and normal (April) streamflows and among-site differences in water-quality were similar to those observed in the long-term data set.

Periphyton

The attached algae that grow on submerged surfaces in streams, such as rocks and woody debris, commonly are referred to as periphyton. Periphyton are at the base of the food web in stream ecosystems and serve as a primary link between abiotic (nonliving) factors, such as nutrients, and higher trophic levels (higher place in the food web), such as macroinvertebrates. Algae have short life cycles and respond rapidly to changes in environmental conditions; thus, periphyton communities often are the first to respond to and recover from floods or contaminant pulses (Allan, 1995; Rosen, 1995; Lowe and Pan, 1996; Lowe and LaLiberte, 2007). Physical, chemical, and pollution tolerances and growth optima (autecological data) have been described for many periphytic algal species, which allows periphytic communities to be used as indicators of ecological conditions. Several states, including Kentucky (Kentucky Division of Water, 1993), Montana (Bahls, 1993), and Oklahoma (Oklahoma Conservation Commission, 1993) use periphyton in their bioassessment programs, but Kansas currently (2010) does not.

Periphyton Community Composition

Overall, 158 periphyton taxa were identified from the three upper Blue River sites (appendix 10). Most taxa (124) were in the division Bacillariophyta (diatoms); taxa in the divisions Chlorophyta (green algae), Cyanophyta (blue-green algae), Euglenophyta (euglenoids), and Cryptophyta (cryptomonads) also were present. About 60 percent of the taxa observed were relatively rare (contributing less than 1 percent to total periphyton abundance and/or biovolume), and only 23 taxa (14 percent) contributed more than 10 percent to total abundance and biovolume. Diverse communities with abundance and/or biovolume dominated by relatively few taxa are a common occurrence in Johnson County streams and streams throughout the nation (Bahls, 1973; Brown and Olive, 1995; Kutka and Richards, 1996; Rasmussen and others, 2009a).

Based on algal periphyton divisions, the largest difference in community composition among sites was the abundance and biovolume of the green algae. During April 2008, diatoms dominated (greater than 95 percent of total) and green algae represented less than 3 percent of periphyton abundance and biovolume at the Kenneth and 151st sites. Diatoms also were numerically dominant (about 90 percent of total) at the Blue Ridge site in April 2008, and green algae represented about 10 percent of total abundance; however, green algae represented a substantial part (about 23 percent) of the biovolume (table 9). During August 2008, green algae were more abundant at the Kenneth and 151st sites than at the Blue Ridge site; green algae represented 18 and 28 percent of total abundance at these sites, respectively and 36 and 50 percent of biovolume. In contrast, green algae contributed less than 2 percent of periphyton abundance and biovolume at the Blue Ridge site and diatoms were dominant (greater than 90 percent of the total; table 9).

In streams, green algae and cyanobacteria are most likely to occur during summer when temperatures are warmer and flows tend to be at seasonal lows (Allan, 1995; Stevenson and Rollins, 2007). The filamentous green algae *Cladophora* may become a nuisance under nutrient-rich conditions because of excessive growth (Dodds and Gudder, 1992). *Cladophora* occurred at the Blue Ridge site in April 2008 and at 151st in August 2008, but was never predominant. Cyanobacteria generally are considered a nuisance when present because of the potential for production of toxins and taste-and-odor compounds (Graham and others, 2008). Dominance by cyanobacteria typically is indicative of enrichment by nutrients and organic compounds (Stevenson and Rollins, 2007). Cyanobacteria contributed less than 2 percent to total periphyton and abundance at all upper Blue River sites (table 9).

In April 2008, the four dominant taxa at each site comprised 45 to 60 percent of total abundance and biovolume. Of the dominant taxa, the diatom *Surirella brebissonii* was the only one that occurred at all sites. In August 2008, the four dominant taxa at each site comprised 57 to 77 percent of total abundance and biovolume. As in April 2008, only one dominant taxa, the diatom *Cocconeis placentula*, occurred at all sites (appendix 11). These two taxa are generally indicative of somewhat degraded, mesoeutrophic to eutrophic conditions with small to moderate amounts of organic enrichment (Porter, 2008). In general, community composition at the upper Blue River sites seems similar to other streams throughout Johnson County. *Surirella bresbissonii* was among the most common taxa in spring and *Cocconeis placentula* among the most common in summer during a 2007 study of 11 Johnson County streams (Rasmussen and others, 2009a).

Periphyton Metrics

Autecological data define physical, chemical, and pollution tolerances and provide information about how organisms may respond to changing environmental conditions (Rosen, 1995; Van Dam and others, 1994). Metrics based on autecological information can provide insight into the environmental stresses experienced by organisms or be used to define organism response along an environmental gradient (Stevenson and Bahls, 1999). Among the algal periphyton, diatoms frequently are used as indicators of environmental change because they are known to be sensitive to many factors (for example, light, nutrients, oxygen, and organic carbon) (Porter, 2008). Among-site differences in periphyton community metrics were evaluated for 24 metrics in 5 categories (oxygen tolerance, saprobity, trophic condition, nitrogen-uptake metabolism, and other indices). The metrics calculated in four of the five categories (oxygen tolerance, saprobity, trophic condition, nitrogen-uptake metabolism) are indicative of a range of conditions from good to poor water quality, but interpretation is similar for all metrics. Thus, either a single metric or a combination of two metrics from each category are discussed

Table 9. Percent contributions of each algal periphyton division to total abundance and biovolume at each biological sampling site on the upper Blue River during April and August 2008.

[Percentages based on the mean of three samples; ± 1 standard deviation in parentheses; ±, plus or minus; Bacillariophyta, diatoms; Chlorophyta, green algae; Cyanophyta, blue-green algae or cyanobacteria; Cryptophyta, cryptomonads; Euglenophyta, euglenoids]

Month	Site	Percentage contributions to abundance[1]					Percentage contributions to biovolume[1]				
		Bacillario-phyta	Chloro-phyta	Crypto-phyta	Cyano-phyta	Eugleo-phyta	Bacillario-phyta	Chloro-phyta	Crypto-phyta	Cyano-phyta	Eugleno-phyta
April	Kenneth	96.1 (4.14)	1.96 (3.12)	1.00 (.341)	0.797 (1.38)	0.153 (.00265)	98.6 (1.14)	0.909 (1.33)	0.234 (.253)	0.0347 (.060)	0.189 (.328)
	151st	97.1 (3.71)	2.73 (3.33)	0 (0)	.224 (.384)	0 (0)	98.9 (1.04)	1.11 (1.01)	0 (0)	.0182 (.0312)	0 (0)
	Blue Ridge	90.4 (4.22)	9.60 (4.22)	0 (0)	0 (0)	0 (0)	76.8 (31.5)	23.2 (31.5)	0 (0)	0 (0)	0 (0)
August	Kenneth	78.7 (13.6)	17.8 (11.3)	2.23 (2.69)	1.05 (1.53)	.239 (.00143)	62.4 (32.0)	35.9 (31.5)	.628 (.618)	.0899 (.0497)	.971 (.606)
	151st	68.2 (22.4)	27.6 (22.6)	4.24 (3.68)	0 (0)	0 (0)	49.4 (40.0)	50.2 (40.3)	.343 (.579)	0 (0)	0 (0)
	Blue Ridge	90.6 (8.52)	1.53 (1.83)	7.89 (6.70)	.0136 (.0236)	0 (0)	98.3 (1.16)	.442 (.219)	1.25 (1.28)	0 (0)	0 (0)

[1]Total percentages may not sum to 100 because of rounding errors.

in this section. The metrics discussed indicated the largest differences among sites. All 24 metric scores, the environmental conditions associated with each metric, and statistical comparisons among sites are presented in appendix 12.

Oxygen Tolerance

Oxygen tolerance defines the oxygen conditions where targeted organisms frequently occur. The Algal Data Analysis System (ADAS) program calculates the percentage of diatoms in each of five oxygen tolerance categories: always high (near 100 percent saturation), fairly high (greater than 75 percent), moderate (greater than 50 percent), low (greater than 30 percent), and very low (less than 10 percent; Porter, 2008; Cuffney, 2003). The percentage of diatoms in the low and moderate categories were summed, treated as one category, and are discussed in this section.

During April 2008, the percentage of diatoms in the low and moderate oxygen tolerance categories more than doubled between the Kenneth (20 percent of total) and Blue Ridge sites (47 percent; fig. 12*A*); these differences were statistically significant (ANOVA: F=10.79, p=0.01). The increase in low and moderate oxygen tolerant diatoms in the downstream direction during April 2008 does not appear to be directly related to oxygen concentration because dissolved oxygen concentrations typically were greater at the downstream site (table 3, fig. 4*D*). In a national assessment, the low-oxygen-tolerance metric was one of the best indicators of nutrient enrichment (Porter and others, 2008); thus, the increase in low and moderate oxygen tolerant diatoms in the downstream direction may reflect the increase in nutrient concentrations rather than a decrease in oxygen concentrations.

August 2008 communities were dominated (85 percent or greater) by the low and moderate categories at all sites and among-site differences were not statistically different (ANOVA: F=1.34, p=0.33; fig. 12*A*). Increased dominance by low to moderate oxygen-tolerant diatoms during August 2008 may be due to the lower dissolved oxygen concentrations during summer months or may reflect poorer water-quality conditions during summer low-flow conditions.

Saprobity

Saprobes are organisms that live in and derive nourishment from decaying organic matter. The saprobien index, a measure of saprobity, was developed to evaluate diatom communities with respect to sensitivity to organic pollution, and combines organism tolerance to the presence of biodegradable organic matter and oxygen concentrations (Van Dam and others, 1994). The five saprobity categories calculated by ADAS are: oligosaprobic, beta-mesosaprobic, alpha-mesosaprobic, alpha-mesosaprobic/polysaprobic, and polysaprobic. These categories represent a gradient of conditions ranging from relatively pristine, with increased oxygen and decreased concentrations of biodegradable organic matter (oligosaprobic) to highly polluted, with decreased oxygen and increased concentrations of organic matter (polysaprobic; Van Dam and others, 1994; Porter, 2008). The percentage of diatoms in the oligosaprobic and beta-mesosaprobic categories were summed, treated as one category, and are discussed in this section. These two categories are indicative of relatively

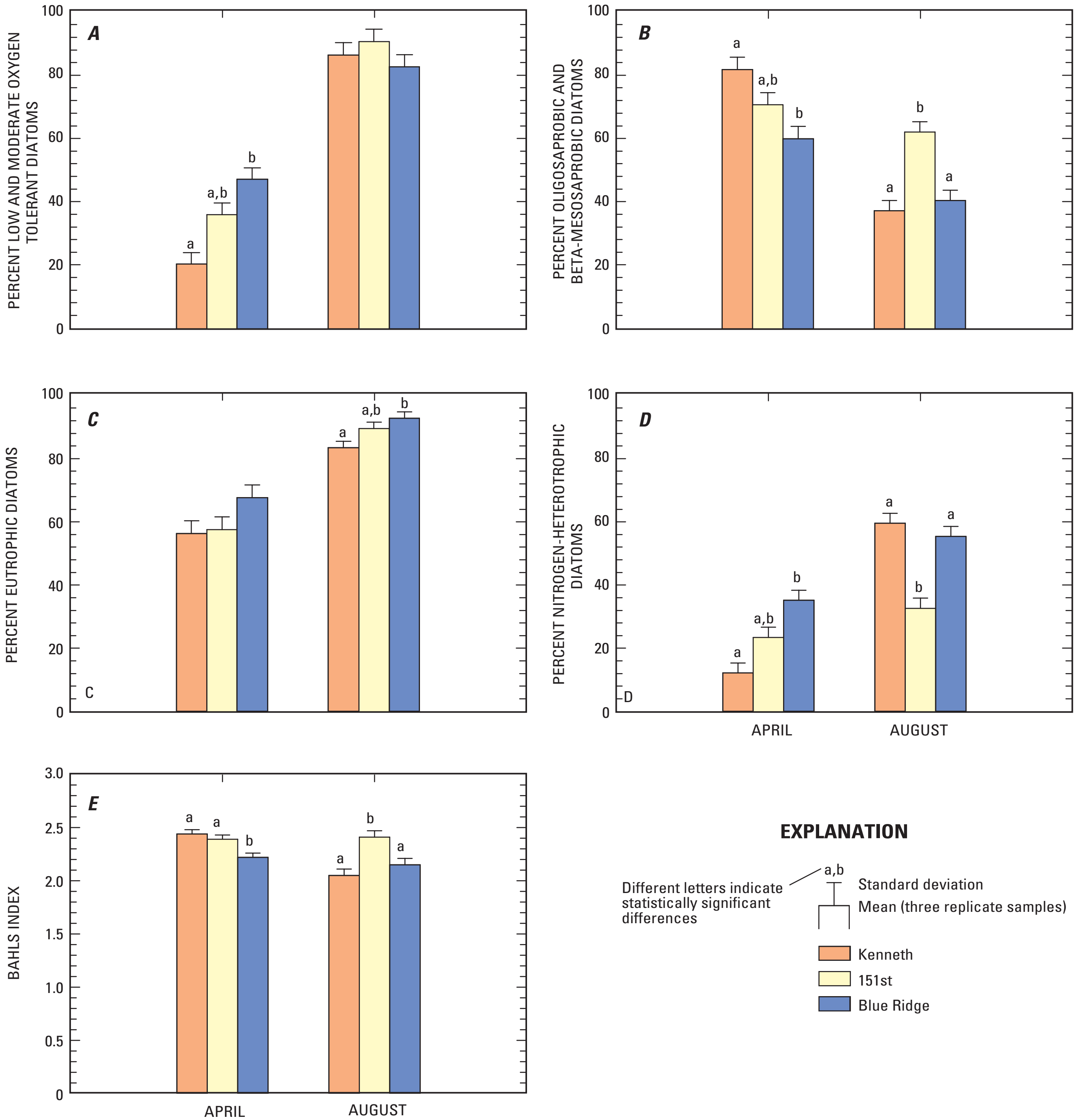

Figure 12. Percent low and moderate oxygen tolerant diatoms (*A*), oligosaprobic and beta-mesosaprobic diatoms (*B*), eutrophic diatoms (*C*), nitrogen-heterotrophic diatoms (*D*), and Bahls Index values (*E*) at each biological sampling site on the upper Blue River during April and August 2008.

unpolluted conditions, with BOD less than 4 mg/L and percent oxygen saturation greater than 70 (appendix 12).

During April 2008, oligosaprobic and beta-mesosaprobic diatoms dominated (about 60 percent or greater of total) at all sites, but the relative abundance of these groups decreased from 81 percent at the Kenneth site to about 60 percent at the Blue Ridge site; these differences were statistically significant (ANOVA: F=7.94, p=0.02; fig. 12*B*). Overall, diatom community composition in April 2008 reflected water-quality conditions when samples were collected. BOD was relatively small (less than or equal to 3 mg/L) and dissolved oxygen was relatively large (greater than 10 mg/L) at all sites (appendix 3). Water-quality conditions were conducive to dominance by oligosaprobic and beta-mesosaprobic diatoms (Van Dam and others, 1994; Porter, 2008).

During August 2008, the percentage of oligosaprobic and beta-mesosaprobic diatoms declined by 32 to 55 percent at the Kenneth and Blue Ridge sites but the 151st site was still dominated (about 62 percent) by oligosaprobic and beta-mesosaprobic taxa (fig. 12*B*). These among-site differences in community composition were statistically significant (ANOVA: F=11.93, p-value less than 0.01; fig. 12*B*). The decrease in oligosaprobic and beta-mesosaprobic taxa at the Kenneth and Blue Ridge sites in August 2008 does not match patterns in water quality; BOD was low (less than 2 mg/L) and dissolved oxygen was moderate (greater than 6 mg/L) at all sites during August 2008 (fig. 4*D*; appendix 3).

Trophic Condition

Trophic condition indicates productivity of aquatic ecosystems with respect to concentrations of nitrogen and phosphorus and associated levels of primary productivity. Oligotrophic ecosystems have low levels of nutrients and productivity, mesotrophic systems have moderate levels of nutrients and productivity, and eutrophic systems have high levels of nutrients and productivity (Graham and others, 2008). The seven trophic condition categories that ADAS uses to classify diatoms are: oligotrophic, oligo-mesotrophic, mesotrophic, meso-eutrophic, eutrophic, hypereutrophic, and ubiquitous. With the exception of ubiquitous, these categories represent a gradient in tolerance to trophic conditions. Ubiquitous diatoms have a wide range of nutrient tolerance and may be found under a range of trophic conditions. The eutrophic category is discussed in this section.

Diatom community composition is indicative of eutrophic conditions at all sites (fig. 12*C*), despite the large differences in total and inorganic nutrient concentrations between the Kenneth site and the 151st and Blue Ridge sites during below-normal and normal streamflows (table 4, fig. 5). During April 2008, more than 56 percent of diatoms collected at all sites were classified as eutrophic, with the percentage about 10 percent larger at the Blue Ridge site than the Kenneth and 151st sites (fig. 12*C*). The percentage of eutrophic diatoms increased by about 30 percent at all sites in August 2008, but the relative pattern among sites was similar to April 2008 (fig. 12*C*). Among-site differences were statistically significant in August 2008 (ANOVA: F=5.35, p=0.05), but not April 2008 (ANOVA: F=2.43, p=0.17). The increase in eutrophic diatoms along the upstream-downstream gradient reflects the downstream increase in nutrient concentrations, but dominance at all sites indicates nutrients are replete for algal growth throughout the study reach.

Nitrogen-Uptake Metabolism

Nitrogen-uptake metabolism refers to the source of nitrogen that periphyton or diatoms require for growth. Nitrogen-autotrophic diatoms require inorganic nitrogen sources (such as nitrate or ammonia) for growth and nitrogen-heterotrophic diatoms require organic nitrogen sources (such as amino acids; Werner, 1977). Obligate nitrogen heterotrophs require organic sources of nitrogen, whereas facultative nitrogen heterotrophs may utilize inorganic and organic sources of nitrogen. The four categories of nitrogen-uptake metabolism calculated by ADAS are: nitrogen autotrophs with a low tolerance for organic nitrogen, nitrogen autotrophs with a high tolerance for organic nitrogen, facultative heterotrophs, and obligate heterotrophs. In general, nitrogen autotrophs with a low tolerance for organic nitrogen develop optimally in oligotrophic waters and obligate nitrogen heterotrophs develop optimally in eutrophic waters (Werner, 1977). The percentage of diatoms in the facultative and obligate nitrogen-heterotroph categories were summed, treated as one category, and are discussed in this section.

During April 2008, the percentage of nitrogen heterotrophs increased in the downstream direction, nearly tripling between the Kenneth site and the Blue Ridge site (fig. 12*D*). This increase reflects the substantial increase (double to an order of magnitude difference depending on streamflow conditions) in nitrogen concentrations at the downstream sites (table 4; appendix 3). In August 2008, the percentage of nitrogen-heterotrophic diatoms increased at all sites; however, patterns did not reflect increases in nitrogen concentrations along the upstream-downstream gradient. The percentage of nitrogen-heterotrophic diatoms at the 151st site was nearly half that of the other two sites (fig. 12*D*). These among-site differences were statistically significant (April 2008 ANOVA: F=6.89, p=0.03; August 2008 ANOVA: F=12.11, p-value less than 0.01).

Bahls Index

Bahls index is a multimetric score based on the relative abundance of diatoms in three categories: sensitive, somewhat tolerant, and tolerant. For this metric, diatom tolerance was based on nutrients, organics, salts, temperature, toxics, substrate stability, and suspended solids. The resulting score is a scaled value ranging from 1 to 3, with 3 representing a community composed of sensitive taxa and 1 representing a community composed of tolerant taxa. Thus, values of 3 indicate relatively good water-quality conditions and values of 1 represent relatively poor water-quality conditions (Porter, 2008; Bahls, 1993).

During April 2008, Bahls Index values decreased in the downstream direction and were significantly less (ANOVA: F=9.95, p=0.01) at the Blue Ridge site than at the Kenneth or 151st sites. In contrast, Index values in August 2008 were significantly larger (ANOVA: F=9.47, p=0.01) at the 151st site than the Kenneth or Blue Ridge sites (fig. 12*E*). Despite these patterns, Bahls Index values spanned a relatively narrow range (2.0 to 2.5), indicative of moderately tolerant diatom communities at all sites during April and August 2008.

Periphyton Chlorophyll, Abundance, and Biovolume

Chlorophyll, a light-gathering pigment present in all photosynthetic organisms, often is used to describe algal communities because it is simpler and less time consuming than identifying, counting, and measuring algal cells. Periphyton abundance reflects the total number of cells present, whereas chlorophyll concentrations and biovolume are indicators of periphyton biomass. Nuisance algal conditions have been suggested to occur when periphytic chlorophyll concentrations exceed 100 milligrams per square meter (mg/m^2; Horner and others, 1983; Welch and others, 1988; Lohman and others, 1992); similar threshold concentrations have not been established for periphytic algal abundance and biovolume.

In April 2008, mean chlorophyll concentrations ranged from 208 to 415 mg/m^2, and increased in the downstream direction (table 10). Mean concentration at the Blue Ridge site was double that observed at the Kenneth site, though differences were not statistically significant (April 2008 ANOVA: F=1.63, p=0.27). August 2008 mean chlorophyll concentrations were nearly an order of magnitude less, ranging from 33.8 mg/m^2 at the Kenneth site to 48.4 mg/m^2 at the Blue Ridge site (table 10). As observed in April 2008, chlorophyll concentrations increased in the downstream direction, though differences were not statistically significant (August 2008 ANOVA: F=3.98, p=0.08). Chlorophyll concentrations exceeded the nuisance threshold value of 100 mg/m^2 at all sites in April 2008.

Seasonal patterns in periphyton abundance and biovolume were similar to chlorophyll concentrations; April 2008 mean concentrations were generally 2 to 11 times greater than August 2008 mean concentrations at all sites (table 10). However, among-site patterns were not as clear as patterns in chlorophyll. In April 2008, periphyton abundance and biovolume at the Kenneth and Blue Ridge sites were nearly double that observed at the 151st site (table 10). Abundance was significantly less at 151st than at the other sites (ANOVA: F=5.41, p=0.04), though differences in biovolume were not significant (ANOVA: F=0.89, p=0.46). Periphyton abundance in August 2008 was about 6 to 7 times greater at the Blue Ridge site than at the Kenneth and 151st sites, while biovolume at the Kenneth site was about 7 to 9 times less than observed at the 151st and Blue Ridge sites (table 10). Despite patterns among sites, differences were not significant (abundance ANOVA: F=1.0, p=0.42; biovolume ANOVA: F=0.57, p=0.59). The discrepancy between abundance and biovolume in August 2008 is likely because of the presence of *Cladophora* at the 151st site. *Cladophora* is relatively large, and though not numerically abundant contributed substantially to algal biovolume (appendix 10).

Summer Periphyton Biomass

Algal biomass in streams may change rapidly in response to runoff events or changing environmental conditions (Stienmann and others, 2006; Lohman and others, 1992; Murdock and others, 2004). Because of these rapid changes, drawing conclusions about differences in algal biomass among sites based only on a few samples can be misleading (Stienmann and others, 2006). Therefore, during June through September 2008 weekly chlorophyll samples were collected at the Kenneth and Blue Ridge sites to determine longer-term

Table 10. Mean and standard deviation of chlorophyll concentration, algal abundance, and biovolume at each biological sampling site on the upper Blue River during April and August 2008.

[Means and standard deviations are based on three replicate samples; mg, milligram; m^2, square meter; mm^3/m^2, cubic millimeters per square meter]

Month	Site	Chlorophyll (mg/m^2)		Abundance (billion cells/m^2)		Biovolume (mm^3/m^2)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
April	Kenneth	208	58.7	33.6	8.22	21,800	12,000
	151st	276	51.0	17.6	2.03	11,400	3,790
	Blue Ridge	415	234	28.7	6.28	24,000	17,200
August	Kenneth	33.8	9.10	3.04	1.50	956	571
	151st	43.0	4.92	2.36	1.23	8,910	13,700
	Blue Ridge	48.4	4.01	17.0	24.6	6,570	8,690

patterns in algal biomass in a range of streamflow conditions. Chlorophyll concentrations were consistently larger at the Blue Ridge site than the Kenneth site during summer 2008 (fig. 13). Summer mean and maximum concentrations at the Blue Ridge site (57 and 230 mg/m^2, respectively) were three to four times larger than at the Kenneth site (17 and 59 mg/m^2, respectively). Increased periphyton abundance likely contributed to the increase in riffle-substrate fouling that occurred at the Blue Ridge site (fig. 11*D*).

Flow regime has a substantial effect on algal biomass because the frequency between floods dictates the amount of time available for algal accumulation (Lohman and others, 1992; Murdock and others, 2004). However, algal biomass may recover rapidly (within days) after flooding (Murdock and others, 2004). Several runoff events with streamflows greater than 1,000 ft^3/s occurred during summer 2008, but no clear patterns between streamflow and periods of chlorophyll decline and increase were evident (fig. 13).

Macroinvertebrate Communities

Macroinvertebrate community-level responses are commonly used for evaluating biological conditions, long-term monitoring, diagnosis of specific sources and causes of stream impairment, measuring the success of restoration activities, and developing biological criteria in support of water-quality compliance and regulation (Rosenberg and Resh, 1993; Southerland and Stribling, 1995). Macroinvertebrate communities have also been widely used as an indicator of stream quality in urban basins (Paul and Meyer, 2001). Macroinvertebrate community evaluations include examination of changes in dominance or abundance of ecologically important taxa and/or sensitive taxa that have been eliminated or reduced as a result of changes in stream conditions. Abundance, richness, and diversity are used to calculate specific indicator metrics. These metrics provide diagnostic information related to stressor responses and effects on community function.

Macroinvertebrate Community Composition

Overall, 210 macroinvertebrate taxa were identified from the three upper Blue River sites (appendix 13). Most taxa (179) were insects (Insecta); non-insect taxa included mollusks (Bivalvia and Gastropoda), worms (Enopla, Nematoda, Oligochaeta, and Turbellaria), leeches (Hirudinea), and crustaceans (Malacostraca). About 21 percent of the insect taxa were in the three dominant orders of insects typically associated with healthy stream communities (Ephemeroptera, mayflies; Plecoptera, stoneflies; and Trichoptera, caddisflies; referred to as EPT taxa). Between 14 and 22 EPT taxa occurred at each site and relative abundance ranged from about 33 to 42 percent in April 2008 and 20 to 28 percent in August 2008. In addition to EPT taxa, other aquatic insects including midges (Diptera: Chironomidae), dragonflies and damselflies (Odonata), riffle beetles (Coleoptera: Elmidae), and aquatic heteropterans (Hemiptera) were common.

In April 2008, midges in the *Cricotopus/Orthocladius* species complex occurred the most frequently and, among the

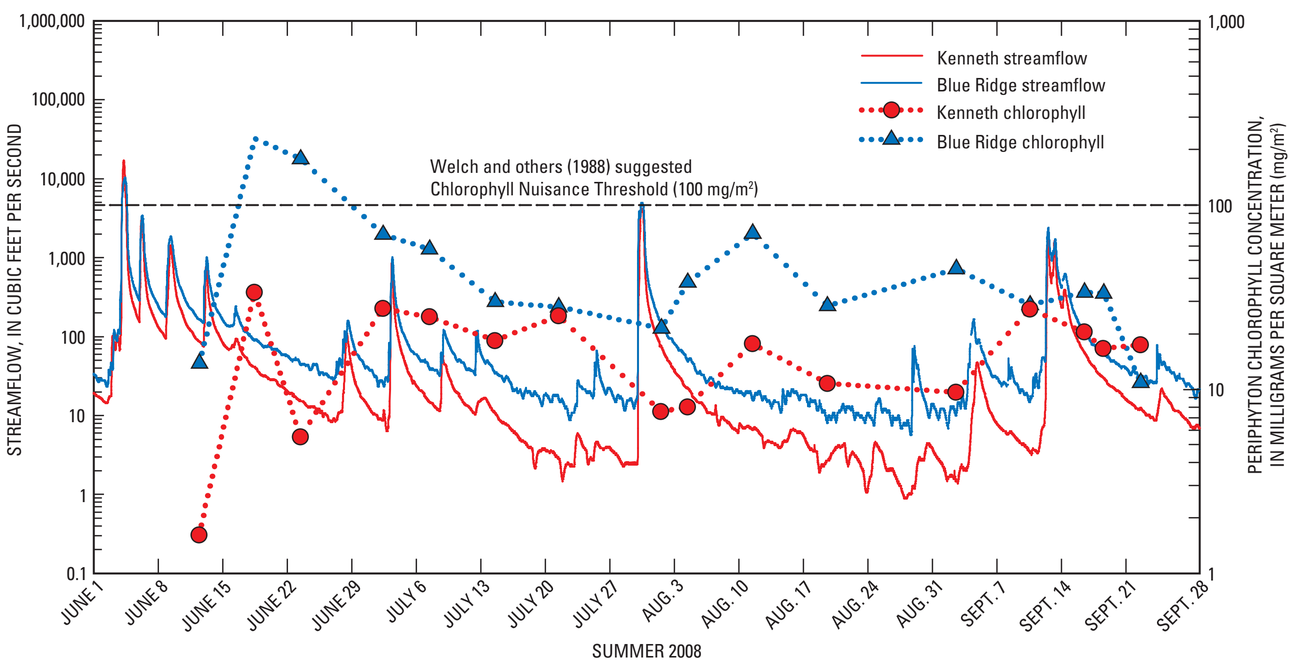

Figure 13. Chlorophyll concentrations and streamflow at the Kenneth and Blue Ridge sites on the upper Blue River during June through September 2008.

four most dominant organisms, were the only taxa present at all sites (appendix 14). *Cricotopus/Orthocladius* taxa are tolerant to a wide range of anthropogenic effects and relative abundance increased in the downstream direction, nearly doubling between the Kenneth (11 percent) and Blue Ridge (20 percent) sites (fig. 14*A*). In general, community composition shifted from more sensitive taxa at the Kenneth site to more tolerant taxa at the downstream sites. Stoneflies (Plecoptera) and the caddisfly *Rhyacophila*, relatively sensitive taxa, were most abundant at the Kenneth site and completely absent from the Blue Ridge site (fig. 14*A*). In contrast, tolerant net-spinning caddisflies (Hydropsychidae) were most abundant immediately downstream from the wastewater effluent discharge (151st; fig. 14*A*).

In August 2008, the midge *Polypedilum*, the caddisfly *Cheumatopsyche*, and the riffle beetle *Stenelmis* were among the most dominant taxa at all sites, comprising between 24 and 32 percent of total abundance (appendix 14). As in April 2008, among-site differences in community composition were largely because of shifts from more sensitive taxa at the Kenneth site to more tolerant taxa at the downstream sites. Mayfly (family Heptageniidae) abundance was less at the downstream sites than the Kenneth site, whereas the midge *Dicrotendipes* (Chironomidae) increased (fig. 14*B*). In addition, four caddisflies present at the Kenneth site were absent at both downstream sites, and four mayflies and the hellgrammite *Corydalus* (Megaloptera) were present at the Kenneth and 151st sites, but not the Blue Ridge site (appendix 13).

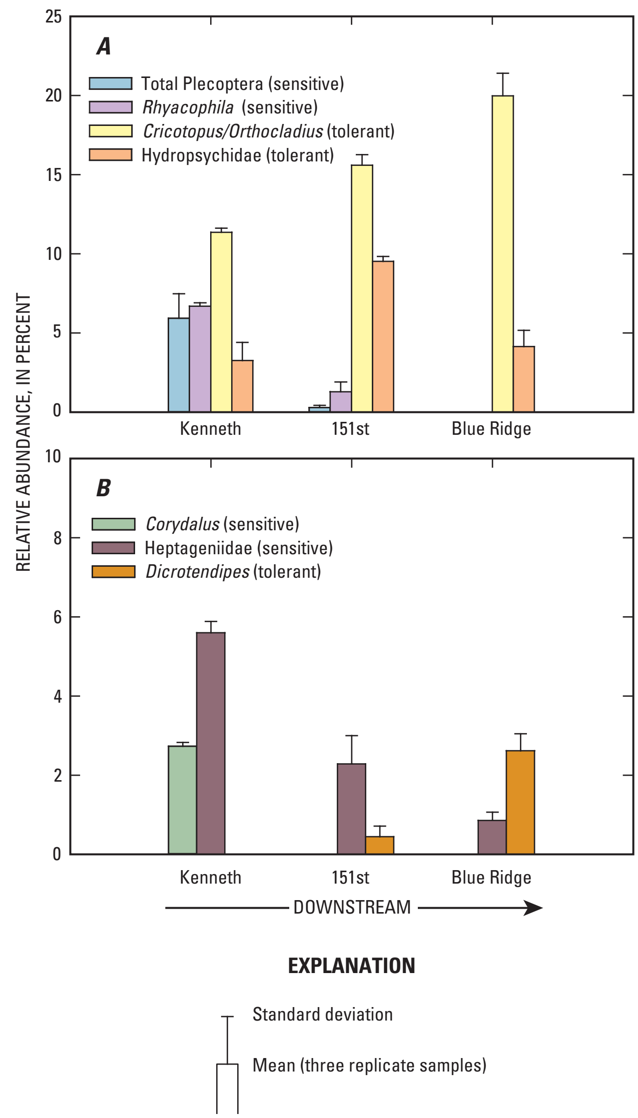

Figure 14. Relative abundance of selected macroinvertebrate taxa at each biological sampling site on the upper Blue River during April (*A*) and August (*B*) 2008.

Macroinvertebrate Metrics

Of the 34 calculated metrics, results for 11 metrics are summarized in this section. Selected metrics include the four KDHE aquatic-life metrics (Kansas Department of Health and Environment, 2008a) plus those used by Rasmussen and others (2009a) to describe among-site differences in Johnson County streams (table 11). These metrics represent core metrics used in many State evaluation programs, and those known to be sensitive and reliable for measuring degradation of stream assemblages based on available literature. The KDHE aquatic-life status metrics (MBI, KBI-NO, EPT richness, and percent EPT) and aquatic-life-support status are described first and the others are discussed in the order they are listed in table 11. The ranges used for scoring the four aquatic-life status metrics are based on the statewide KDHE database for all streams in Kansas (Kansas Department of Health and Environment, 2008a) and are shown in table 12. Metric values and statistical comparisons among sites for all calculated metrics are presented in appendix 15.

Macroinvertebrate Biotic Index (MBI)

The MBI is used to evaluate the effects of oxygen-demanding substances, nutrients, and organic enrichment on macroinvertebrate populations. It is a family level biotic index that uses tolerance values ranging from 1 to 11 for insect and mollusk taxa, with smaller values corresponding to less tolerance and a lesser degree of stream degradation (Davenport and Kelly, 1983). MBI values were consistently smaller at the Kenneth site than the two downstream sites and ranged from 5.05 to 5.65. None of the sites met KDHE criteria for fully supporting aquatic life for MBI. Based on the MBI, the Kenneth site was partially supporting of aquatic life and the 151st and Blue Ridge sites were non-supporting of aquatic life during April and August 2008 (tables 11 and 12). MBI scores during 2008 were within the range of those observed in previous studies. The Kenneth site consistently scored as partially supporting during assessments conducted in 2003, 2004, and 2007 (Poulton and others, 2007; Rasmussen and others, 2009a). Similarly, the Blue Ridge site scored as partially supporting in 2003 and non-supporting in 2004 (Wilkison and others, 2006; Poulton and others, 2007).

Kansas Biotic Index (KBI-NO)

The KBI-NO was specifically developed for Kansas and is based on aquatic organism tolerances to nutrients and oxygen-demanding substances (Huggins and Moffet, 1988). It is a genus-level biotic index calculated in a similar manner as the MBI, with a scoring range of 0 to 5. Small values indicate less tolerance and minimal biological degradation. KBI-NO values were consistently smallest at the Kenneth site and largest at the 151st site during April and August 2008, with values ranging from 2.48 to 2.85 (table 11). Based on the KBI-NO, the Kenneth site was fully supporting of aquatic life and the 151st and Blue Ridge sites were partially supporting of aquatic life in April 2008. During August 2008, all sites were partially supporting of aquatic life and metric values and differences among sites were relatively small (tables 11 and 12). KBI-NO scores at the Kenneth and Blue Ridge sites were generally larger than previously reported. The Kenneth site scored as partially supporting aquatic life for this metric in 2003, 2004, and 2007, and in 2003 and 2004 the Blue Ridge site scored as non-supporting (Wilkison and others, 2006; Poulton and others, 2007; Rasmussen and others, 2009a).

EPT Taxa Richness

EPT taxa richness is the sum of the number of species belonging to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Most species belonging to each of these orders are considered to be intolerant of stressors and larger numbers of these species indicate greater stream quality (Barbour and others, 1999). EPT taxa richness was largest at the Kenneth site and smallest at the Blue Ridge site during April and August 2008, with values ranging from 8.67 to 13.3. Based on EPT taxa richness, the Kenneth site was fully supporting of aquatic life and the 151st and Blue Ridge sites were partially supporting of aquatic life during April and August 2008 (tables 11 and 12). EPT taxa richness at the Kenneth and Blue Ridge sites was generally larger than previously reported. The Kenneth site scored as non-supporting aquatic life for this metric in 2003 and as partially supporting in 2004 and 2007; in 2003 and 2004 the Blue Ridge site scored as non-supporting (Wilkison and others, 2006; Poulton and others, 2007; Rasmussen and others, 2009a).

Percentage of EPT

The percentage of EPT metric is the number of organisms belonging to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) expressed as a percentage of the total number of organisms. It provides information about the relative abundance of the three intolerant orders of aquatic insects, so large populations of a few species can result in large values. The percentage of EPT taxa was the only KDHE aquatic-life status metric that was significantly different among sites during April and August 2008 (table 11). During April 2008, percent EPT was significantly larger at the Kenneth site (42.2 percent) than at the Blue Ridge site (32.9 percent) and the 151st site was intermediate between the two (39.2 percent). In August 2008, percent EPT at the Kenneth and 151st sites (28.0 and 26.5 percent, respectively) was significantly larger than at the Blue Ridge site (20.5 percent). Despite among-site differences, based on percentage EPT, all sites were partially supporting of aquatic life during April and non-supporting of aquatic life in August 2008 (tables 11 and 12). The percentage of EPT at the Kenneth and Blue Ridge sites during 2008 was consistent with previous studies; previously both sites scored as either partially supporting or non-supporting of aquatic life (Wilkison and others, 2006; Poulton and others, 2007; Rasmussen and others, 2009a).

Aquatic-Life-Support Status

Aquatic-life-support categories are determined by the numeric mean of scores attained by each of the four KDHE metrics, and the mean value is used as an indication of the ability of a stream to support an acceptable level of aquatic life. During April 2008, all three sites attained a score indicative of partially supporting aquatic-life status, though scores at the two downstream sites (151st and Blue Ridge) were significantly lower than the score at the upstream (Kenneth) site (fig. 15). Scores at all sites were less in August 2008 than in April 2008; however, the Kenneth and Blue Ridge sites were partially supporting of aquatic-life status, while the site immediately downstream from the wastewater effluent discharge (151st) was non-supporting (fig. 15).

Aquatic-life status results for the Kenneth site were similar to previous studies; a partially supporting status was reported in 2003, 2004, and 2007 (Poulton and others, 2007; Rasmussen and others, 2009a). In contrast, the Blue Ridge site was reported as partially supporting in 2003 and non-supporting in 2004 (Wilkison and others, 2006; Poulton and others, 2007). Previous studies indicate that biological conditions in the upper Blue River are generally among the least affected by human disturbance as compared to other stream sites in Johnson County, Kansas and in the Blue River Basin (Poulton and others, 2007; Rasmussen and others, 2009a; Wilkison and others, 2009); however, in the most recent assessment of Johnson County streams (2007), only 1 of the 20 stream sites examined was rated as fully supporting based on the KDHE multimetric score, and that site (Camp Branch, fig. 1) is located in the upper Blue River basin (Rasmussen and others, 2009a).

Total Taxa Richness

Total taxa richness represents the number of distinct taxa within a sample. The presence of relatively large numbers of distinct taxa indicates that the habitats and food sources present at a site can support many species (Barbour and others, 1999). Total taxa richness ranged from 42 to 54 organisms, with between 7 and 10 more taxa occurring at each site in August 2008 than in April 2008. The increase in taxa richness in August 2008 was largely because of an increase in tolerant taxa. Richness was slightly larger at the Kenneth site (between 2 and 6 more taxa) than the downstream sites, though among-site differences were not significant (table 11).

Percentage of Intolerant Organisms

This metric represents the relative abundance of organisms that have KBI-NO tolerance values less than 3.0 (Huggins and Moffett, 1988). The percentage of intolerant organisms was significantly larger at the Kenneth site than at the two downstream sites during April and August 2008 and was the only calculated individual metric to indicate a consistent, statistically significant pattern among sites and months (table 11; appendix 15). During April 2008, intolerant taxa were most abundant at the Kenneth site (37.9 percent of organisms) and least abundant at the 151st site (21.1 percent); the Blue Ridge site was intermediate (27.2 percent). Intolerant taxa were about 10 to 20 percent less abundant at all sites in August 2008, but among-site patterns were similar, with intolerant taxa most abundant at the Kenneth site (18.1 percent) and least abundant at the 151st site (10.5 percent; table 11).

Percentage of Scrapers

Measures of functional groups associated with specific feeding strategies provide information on community balance and shifts in composition may be indicative of altered energy pathways (Cummins, 1974; Barbour and others, 1999). Scrapers, those taxa that remove periphyton and fungal communities from surfaces by scraping, represent one example of a functional group. Scrapers represented between 22.6 and 27.1 percent of organisms during April 2008 and 14.0 and 21.2 percent in August 2008. Scraper abundance declined in the downstream direction, with the largest values at the Kenneth site and smallest values at the Blue Ridge site. During August 2008, the percentage of scrapers at the Kenneth site was significantly larger than at the downstream sites (table 11).

Table 11. Macroinvertebrate metric scores and statistically significant (*p*-value less than 0.05) differences among sites at each biological sampling site on the upper Blue River during April and August 2008.

[Metric scores in **bold** indicate significant differences among sites (all *p*-values less than 0.05); Metric scores are based on the mean score of three replicate samples; ± 1 standard deviation in parentheses; ±, plus or minus; KDHE, Kansas Department of Health and Environment; E, Ephemeroptera; P, Plecoptera; T, Trichoptera; >, greater than; =, equals; <, less than; NS, not statistically significant; 1, Kenneth site; 2, 151st site; 3, Blue Ridge site]

Metric	April				August			
	Kenneth	151st	Blue Ridge	Statistically significant differences among sites	Kenneth	151st	Blue Ridge	Statistically significant differences among sites
KDHE Aquatic Life Support Score Metrics								
Macroinvertebrate Biotic Index	5.23 (0.25)	5.47 (0.02)	5.65 (0.16)	NS	**5.05 (0.17)**	**5.58 (0.09)**	**5.45 (0.19)**	1 < 3 only
Kansas Biotic Index	**2.48 (.05)**	**2.81 (.01)**	**2.72 (.03)**	1 < 2 < 3	2.76 (.03)	2.85 (.06)	2.77 (.01)	NS
EPT taxa richness	**13.3 (1.15)**	**10.33 (.58)**	**9.33 (1.15)**	1 > 2 = 3	12.3 (1.53)	9.00 (2.65)	8.67 (1.53)	NS
EPT, percent	**42.2 (3.26)**	**39.24 (4.40)**	**32.9 (4.21)**	1 > 3 only	**28.0 (1.55)**	**26.5 (.75)**	**20.5 (.62)**	1 = 2 > 3
Other metrics								
Total taxa richness	45.0 (4.36)	42.3 (1.53)	41.7 (9.24)	NS	54.7 (2.89)	49 (3.61)	52.3 (6.03)	NS
Intolerant organisms, percent	**37.9 (2.85)**	**21.1 (3.80)**	**27.2 (3.00)**	1 > 2 = 3	**18.1 (2.11)**	**10.5 (2.61)**	**12.1 (2.59)**	1 > 2 = 3
Scrapers, percent	27.1 (1.15)	25.9 (1.17)	22.6 (5.07)	NS	**21.2 (1.38)**	**16.3 (1.45)**	**14.0 (2.67)**	1 > 2 = 3
Oligochaeta, percent	.63 (.55)	3.33 (1.01)	2.20 (.82)	NS	**.69 (.25)**	**.14 (.25)**	**.44 (.04)**	2 < 1 = 3
Tanytarsini midges, percent	.92 (.78)	.57 (.23)	.49 (.47)	NS	1.90 (.80)	1.98 (.73)	2.47 (.29)	NS
Ephemeroptera and Plecoptera, percent	30.2 (4.27)	27.9 (2.99)	28.1 (4.56)	NS	**15.0 (.70)**	**12.9 (2.44)**	**9.42 (1.51)**	1 = 2 > 3
Shannon Diversity Index	3.29 (.094)	3.16 (.040)	3.12 (.18)	NS	3.43 (.012)	3.37 (.045)	3.45 (.096)	NS

Table 12. Criteria for four macroinvertebrate metrics used in Kansas to evaluate aquatic-life-support status of streams (Kansas Department of Health and Environment, 2008).

[MBI, Macroinvertebrate Biotic Index; KBI-NO, Kansas Biotic Index with tolerances for nutrients and oxygen-demanding substances; EPTRich, Ephemoeroptera-Plecoptera-Trichoptera (EPT) species richness; %EPT, percentage of EPT species; <, less than, >, greater than]

Aquatic-life-support	Score	MBI	KBI-NO	EPTRich	%EPT	Mean score
Fully supporting	3	< 4.51	< 2.61	> 12	> 48	> 2.49
Partially supporting	2	4.51–5.39	2.61–2.99	8–12	31–47	1.5–2.49
Non-supporting	1	> 5.39	> 2.99	< 8	< 31	1.0–1.49

Percentage of Oligochaeta

Many oligochaete taxa are pollution tolerant. During April 2008, oligochaetes were most abundant at the 151st site (3.33 percent of organisms) and least abundant at the Kenneth site (0.63 percent). In August 2008, oligochaetes represented less than 1 percent of organisms at all sites (table 11). Oligochaetes typically represent a small percentage of organism abundance in Johnson County and the upper Blue River, though values of nearly 50 percent have occasionally been reported from some of the most urban sites (Poulton and others, 2007; Rasmussen and others, 2009a; Wilkison and others, 2009).

Percentage of Tanytarsini

Tanytarsini, an intolerant tribe of midges (Diptera: Chironomidae) indicative of unpolluted waters, made up less than 1 percent of the organisms at all three sites in April 2008 and less than 3 percent in August 2008 (table 11). Tanytarsini midges typically represent a small percentage of organism abundance in Johnson County and the Blue River, and values larger than 3 percent are rarely reported (Poulton and others, 2007; Rasmussen and others, 2009a; Wilkison and others, 2009).

Percentage of Ephemeroptera and Plecoptera

This metric represents a modification of the percent EPT metric and omits the Trichoptera to account for the effect of larger relative abundances of tolerant net-spinning caddisflies often encountered in macroinvertebrate samples from larger urban streams (Poulton and others, 2007). In April 2008, the percentage of Ephemeroptera and Plecoptera was similar among sites and ranged from 27.9 to 30.2 percent. Ephemeroptera and Plecoptera represented a smaller percentage of organisms during August 2008, and values were significantly larger at the Kenneth and 151st sites (15.0 and 12.9 percent, respectively) than the Blue Ridge site (9.42 percent; table 11).

Shannon Diversity Index

The Shannon Diversity Index is a core metric that measures community diversity and evenness. Larger values indicate more diversity and evenness of species. Shannon Diversity Index values ranged from 3.12 to 3.45 and values were relatively similar among sites and months (table 11).

Stream Metabolism

Measures of ecosystem function, such as stream metabolism, can be indicators of stream health because function is affected by a combination of physical, chemical, and biological characteristics, all of which are embedded in metabolism rate (Mulholland and others, 2005; Fellows and others, 2006; Young and others, 2008). Stream metabolism is an estimate of how much organic carbon is produced and/or consumed in a given period of time. Diel variation in dissolved oxygen concentration is commonly used to estimate stream metabolism. Under steady flow conditions, the changes in dissolved oxygen concentration are the result of photosynthesis (primary productivity), respiration (cellular processes that require oxygen to generate energy), and gas exchange with the atmosphere (reaeration; Lewis, 2006). The stream metabolism variables calculated by the NAWQA Nutrient Enrichment Effects Team (NEET) whole-stream metabolism program include gross primary production (GPP), community respiration (CR), net ecosystem production (NEP), and production to respiration ratio (P/R; Bales and Nardi, 2007). Combined, these variables give an indication of ecosystem response to changing environmental conditions. GPP, CR, and NEP are expressed as grams of oxygen per meter squared per day (g $O_2/m^2/d$). There is some uncertainty associated with estimating reaeration coefficients; therefore, emphasis is placed on the relative differences in metabolism rate among sites rather than on the absolute values of GPP, CR, and NEP.

There are no established procedures or criteria for using stream metabolism data to assess stream health. However, Young and others (2008) proposed a preliminary framework, based on meta-analysis of data available in the scientific literature, for assessing functional stream health using GPP and CR (table 13). The framework proposes criteria-based ratios that describe the relative difference in GPP or CR between a test site and a reference site. Young and others (2008) define a test site as a site that is potentially impacted and a reference site as

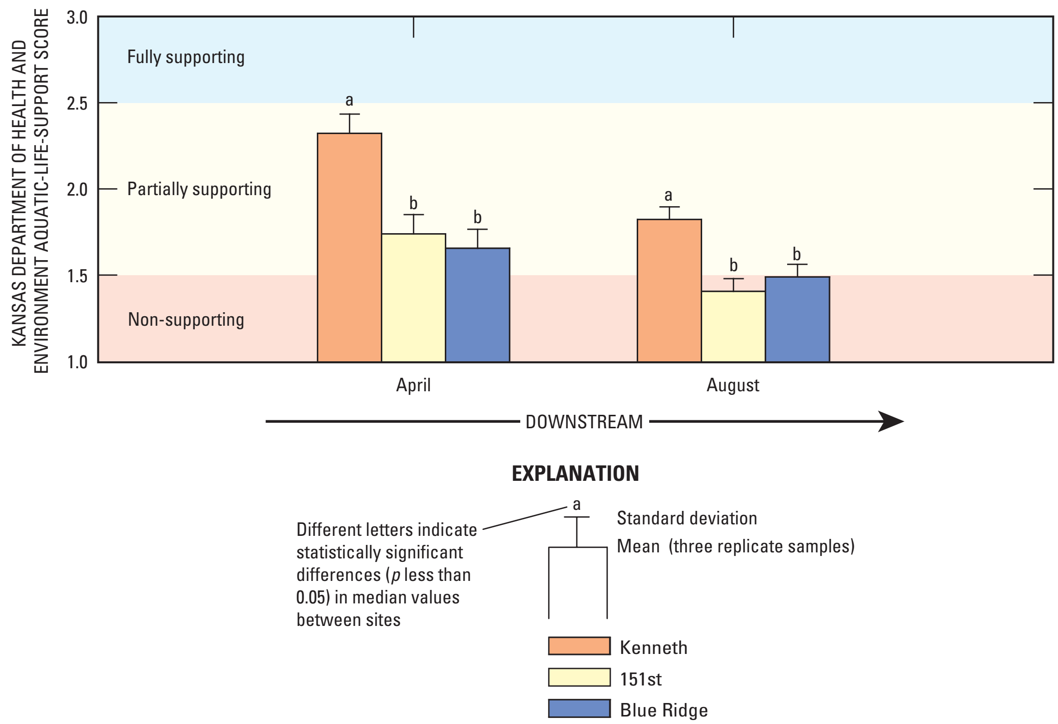

Figure 15. Multimetric aquatic-life-support scores (Kansas Department of Health and Environment, 2008) at each biological sampling site on the upper Blue River during April and August 2008.

a site that is more pristine. For the upper Blue River study the Blue Ridge site was considered the test site and the Kenneth site was considered the reference site. Whereas the preliminary criteria proposed by the framework are based on a global range of data and additional research is required to develop more region-specific criteria, the framework provides a useful method of comparing functional stream health upstream and downstream from the wastewater effluent discharge into the upper Blue River.

Gross Primary Production (GPP)

Gross primary production is net primary productivity by autotrophs minus respiration losses. Annual (April 2008 through March 2009) median GPP at the Blue Ridge site was about 2.5 times larger than at the Kenneth site (table 14, fig. 16*A*), a pattern that matches the larger chlorophyll concentrations at the downstream site (fig. 13). Seasonal differences among sites were similar to the overall annual difference. Seasonal median GPP was about 1.5 to 7 times larger at the Blue Ridge site than the Kenneth site, with the smallest difference occurring in fall and the largest during summer. Differences among sites were statistically significant during all seasons except spring, when seasonal GPP maxima were observed at both sites (table 14). The spring GPP maxima corresponds with the spring maxima in chlorophyll observed at all upper Blue River sites (table 10). Annual median and seasonal median GPP ratios between sites were indicative of normal ecosystem function at the Blue Ridge site, except during summer when the GPP ratio was indicative of mild impairment (tables 13 and 14). Other studies have documented that larger rates of GPP tend to occur at sites that receive wastewater effluent discharges (Bott and others, 2006; Gücker and others, 2006), likely because of increased growth of aquatic plants and algae stimulated by elevated nutrient concentrations.

Gross primary production was about 2 to 30 times larger in May 2008 than during other months at both upper Blue River sites. Monthly median GPP at the Kenneth site was about 1.5 times larger than at the Blue Ridge site during May 2008, the only period where GPP at the Kenneth site was greater than at the downstream site (fig. 16*A*). The seasonal minima in GPP occurred during January 2009 at the Blue Ridge site. GPP at the Kenneth site was relatively small in January 2009, and also during July through October 2008 (fig. 16*A*). Uehlinger (2006) documented similar results with 15 years of stream metabolism data, where GPP typically reached annual maxima in May and declined to seasonal minima in January. Houser and others (2005) and Acuna and others (2004) also found maximum GPP values typically occur during spring. Seasonal spring maxima in GPP are likely because of longer day length and associated increases in light

Table 13. Framework and ratio criteria proposed by Young and others (2008) for assessing functional stream health using stream metabolism data.

[GPP, gross primary production; CR, community respiration; t, test site; r, reference site; <, less than; >, greater than]

Ecosystem function	GPP_t/GPP_r	CR_t/CR_r
No impairment	<2.5	0.4–1.6
Mildly impaired	2.5–5.0	.2–.4 or 1.6–2.7
Severly impaired	>5.0	<.2 or >2.7

Table 14. Seasonal and overall summary of stream metabolism results at the Kenneth and Blue Ridge sites on the upper Blue River during April 2008 through March 2009.

[Two-sample Wilcoxon tests were used to compare median values among sites; *p*-values in **bold** indicate values were significantly different (less than 0.05). Impact assessment based on Young and others (2008) proposed ratio criteria; *n*, number of observatons; g O_2/m_2/day, grams of oxygen per meter squared per day; <, less than; --, not applicable]

Time period	Kenneth			Blue Ridge			*p*-value	Ratio (Blue Ridge:Kenneth)			Ecosystem function
	n	Range	Median	*n*	Range	Median		*n*	Range	Median	
Gross primary production (g O_2/m^2/day)											
Spring	25	0.10–4.50	0.60	25	0.50–2.70	1.30	0.28	25	0.28–5.00	1.55	No impairment
Summer	54	0–1.80	.10	54	.20–1.10	.70	**<.01**	43	.50–11.0	5.00	**Mildly impaired**
Fall	53	0–.40	.20	53	0–.90	.30	**<.01**	46	0–6.00	2.00	No impairment
Winter	59	0–.70	.10	59	.10–1.10	.30	**<.01**	56	.75–5.00	1.33	No impairment
April 2008–March 2009	191	0–4.50	.20	191	0–2.70	.50	**<.01**	170	0–11.0	2.00	No impairment
Community respiration (g O_2/m^2/day)											
Spring	25	0.06–4.92	2.10	25	0.34–3.18	2.08	0.60	25	0.20–37.2	0.88	No impairment
Summer	54	.01–3.68	.74	54	.49–3.02	1.39	**<.01**	54	.57–133	1.96	**Mildly impaired**
Fall	53	.04–4.82	.91	53	.02–2.28	.67	.13	53	.02–21.3	.78	No impairment
Winter	59	.07–2.21	.59	59	.01–2.48	.55	.39	59	.02–8.38	.87	No impairment
April 2008–March 2009	191	.01–4.92	.80	191	.01–3.18	1.00	.1	191	.02–133	1.01	No impairment
Net ecosystem productivity (g O_2/m^2/day)											
Spring	25	3.37–0.89	-0.23	25	-2.27–1.36	-0.72	0.72	25	-43.3–3.87	-0.60	--
Summer	54	-2.33–.07	-.56	54	-2.22–.05	-.65	.28	54	-37.5–63.0	1.11	--
Fall	53	-4.62–.12	-.77	53	-2.18–.21	-.27	**<.01**	53	-14.0–16.3	.45	--
Winter	59	-1.71–.43	-.41	59	-1.83–.91	-.21	.07	58	-18.5–9.50	.50	--
April 2008–March 2009	191	-4.62–.89	-.54	191	-2.27–1.36	-.46	.10	190	-43.3–63.0	.54	--
Production/respiration ratio											
Spring	25	0.13–7.14	0.92	25	0.18–5.00	0.69	0.85	25	0.67–7.32	0.83	--
Summer	54	0–3.33	.19	54	.14–1.07	.51	**<.01**	43	.18–9.09	2.48	--
Fall	53	0–2.50	.14	53	0–.90	.30	**<.01**	46	0–64.0	3.67	--
Winter	59	0–3.53	.34	59	.11–10.0	.51	**<.01**	56	.30–16.8	1.71	--
April 2008–March 2009	191	0–7.14	.24	191	0–10.0	.53	**<.01**	170	0–64.0	2.05	--

and temperature. Light limitation because of canopy cover, photoinhibition of photosynthesis, and high temperatures may all contribute to reduced GPP during summer months (Allan, 1995; Hill and others, 2001; Franklin and others, 2003).

Community Respiration (CR)

Community respiration is respiration by autotrophs (photosynthetic organisms such as algae) and heterotrophs (non-photosynthetic organisms such as fish, macroinvertebrates, and bacteria). Annual median CR values were generally similar at the Blue Ridge and Kenneth sites (table 14*)*. Seasonal differences between sites corresponded with the overall annual difference, with the exception of summer. During summer, seasonal median CR was about 2 times larger at the Blue Ridge site than the Kenneth site. The significant difference in CR between sites during summer is likely due, in part, to the 7-fold difference in GPP between sites (table 14). Annual median and seasonal median CR ratios between sites were indicative of normal ecosystem function at the Blue Ridge site, except during summer when the CR ratio was indicative of mild impairment (tables 13 and 14).

CR was about 1.8 to 16 times greater in May 2008 than during other months at both upper Blue River sites, likely in response to the peak in GPP (fig. 16*B*). Minima occurred in February 2009 at the Kenneth site and November 2008 at the Blue Ridge site (fig. 16*B*). Seasonal CR patterns in the upper Blue River generally are similar to what Uehlinger (2006) observed in 15 years of stream metabolism data, where CR typically reached annual maxima in May and declined to seasonal minima in December. Seasonal patterns in CR are closely related to temperature conditions because metabolic activity generally increases with increasing water temperature, though seasonal temperature maxima may stress some aquatic organisms (Sinsabaugh, 1997; Hill and others, 2000).

Net Ecosystem Production (NEP) and Production to Respiration Ratio (P/R ratio)

Net ecosystem productivity is the net gain or loss of carbon from the stream as a result of biological activity and is the difference between GPP and CR. The production to respiration ratio (P/R) is the ratio of GPP to CR and is a measure of the amount of respiration that may be supported by autotrophic production. If NEP is greater than 0 and P/R is greater than 1, autotrophic production of carbon supports respiration and carbon is accumulating in the system, and if NEP is less than 0 and the P/R ratio is less than 1, autotrophic production and/or allochthonous inputs of carbon support respiration and carbon is being consumed (Odum, 1956; Meyer and Edwards, 1990).

NEP was less than 0 and P/R less than 1 about 80 percent of the time during April 2008 through March 2009 at both study sites, indicating autotrophic carbon production usually is not sufficient to support respiration in the upper Blue River (table 14, fig. 16*D*). P/R is generally a better measure of the extent to which respiration is supported by autotrophic carbon production because it compares the relative difference between gross primary production and community respiration (Meyer and Edwards, 1990). Therefore, P/R is used to compare the amount of respiration supported by autotrophic carbon production upstream and downstream from the WWTF wastewater effluent discharge on the upper Blue River.

Annual median P/R at the Blue Ridge site was about 2.2 times larger than at the Kenneth site (table 14, fig. 16*D*). Seasonal differences between sites corresponded with the overall annual difference, with the exception of spring. During spring, seasonal median P/R was about 1.3 times larger at the Kenneth site than the Blue Ridge site, though the difference was not statistically significant (table 14). P/R at both sites was about 1.5 to 6.5 times larger during the spring than other seasons, a pattern that matches the seasonal peak in GPP.

Larger P/R ratios during most of the year may indicate that more autotrophic carbon production supported respiration at the Blue Ridge site than at the Kenneth site, a finding that is consistent with differences in chlorophyll and GPP between sites (table 10, figs. 13 and 16*A*). However, because P/R ratios usually were less than 1 at both sites, both relied on external carbon sources to support respiration. Organic material from upstream or the surrounding basin is likely maintaining the food web for both sites (Meyer, 1989).

Effects of Wastewater Effluent Discharge on Environmental and Biological Conditions of the Upper Blue River

A key goal of the Kansas nutrient reduction plan is a 30-percent reduction in annual total nitrogen and phosphorus loads exported from the state (Kansas Department of Health and Environment, 2004). Therefore, KDHE established target nutrient concentrations in wastewater effluent as part of the Kansas Surface Water Nutrient Reduction Plan. After the addition of biological nutrient removal to the Blue River Main WWTF, target total nitrogen concentrations were achieved and annual total nitrogen loads from the WWTF decreased despite capacity upgrades. During the study period, biological nutrient removal did not substantially affect total phosphorus concentrations and annual loads increased with discharge volume; however, the biological phosphorus removal process was optimized after the study was complete, and target total phosphorus concentrations in wastewater effluent were achieved during summer 2009. During 2007 and 2008 annual discharge from the WWTF was about one-half maximum capacity, and estimated potential maximum nutrient loads are 1.6 to 2.4 times larger than annual loads before capacity upgrades. Even when target nutrient concentrations are met, annual

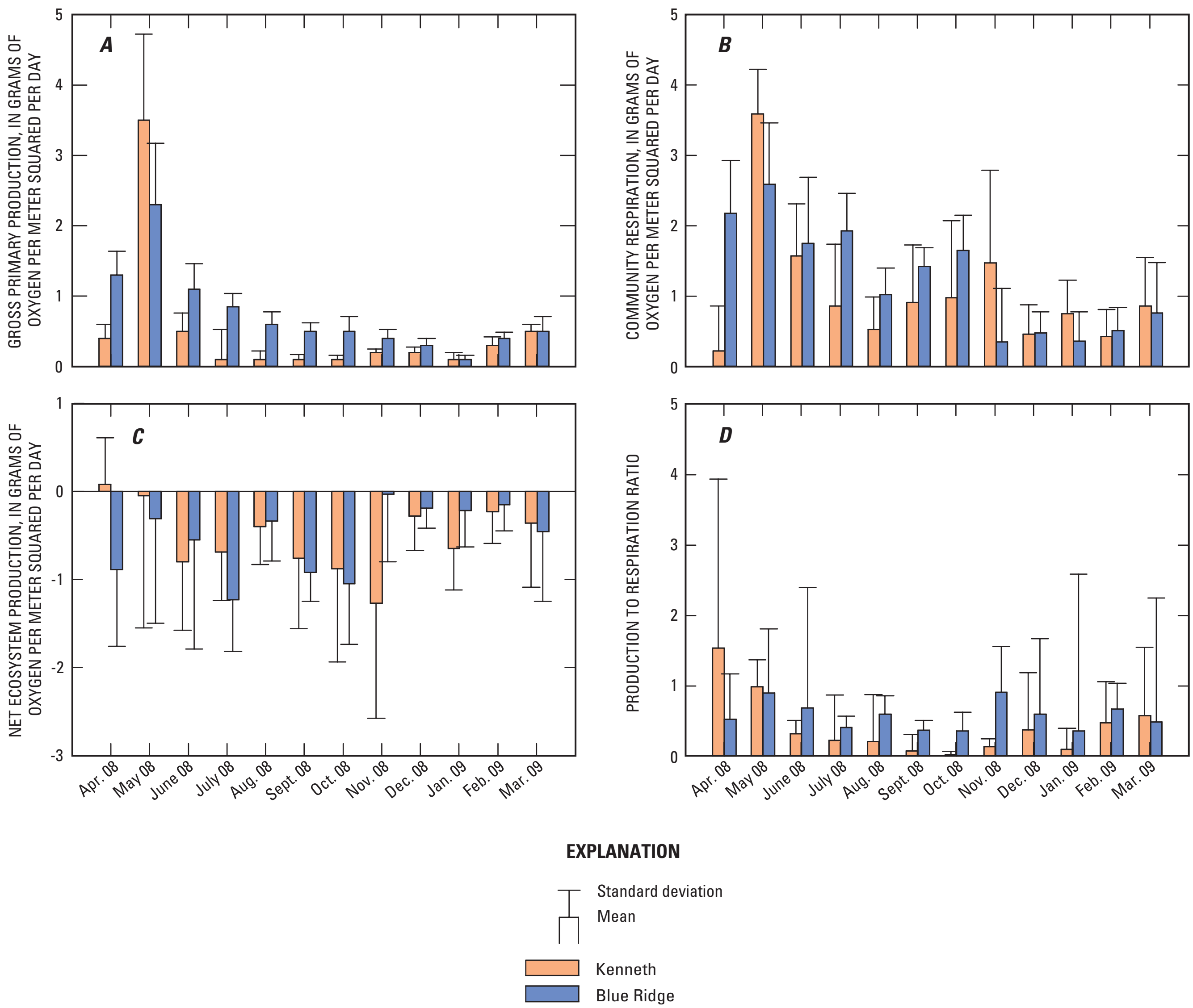

Figure 16. Seasonal patterns in gross primary production (*A*), community respiration (*B*), net ecosystem production (*C*), and production to respiration ratio (*D*) at the Kenneth and Blue Ridge sites on the upper Blue River during April 2008 through March 2009.

nutrient loads from the WWTF will increase when operated at full capacity.

Annual nutrient loads are important when considering effects on downstream areas where nutrients are sequestered, such as impoundments or, on a national scale, the Gulf of Mexico. Reducing overall nutrient loads to reduce or prevent eutrophication effects on downstream areas is important. However, biological communities respond to the concentration of nutrients and other water-quality constituents rather than overall loads (Welch and Lindell, 1992). Biological community responses to excess nutrients typically include loss of biodiversity and shifts to more tolerant taxa (Carpenter and others, 1998; Wetzel, 2001). The effect of wastewater effluent on ecosystem processes, such as primary productivity and community respiration, are less well understood (Gücker and others, 2006). The reduction of nutrient concentrations in the Blue River Main wastewater effluent will help prevent further degradation of the receiving stream regardless of changes in annual nutrient loads.

The effect of wastewater effluent on the water-quality of the upper Blue River was most evident during below-normal and normal streamflows (about 75 percent of the time), when wastewater effluent represented about 20 percent or more of total streamflow. The Blue River Main WWTF wastewater effluent caused changes in the concentration of some water-quality constituents that may affect biological community structure and ecosystem processes, including greater concentrations of bioavailable nutrients (nitrate and orthophosphorus) and smaller turbidities. These wastewater effluent effects on water quality were evident before and after upgrades to the

Blue River Main WWTF. Concentrations of nutrients downstream from the Blue River Main WWTF always exceeded ecoregion-based criteria, even after biological nutrient removal substantially reduced wastewater effluent total nitrogen concentrations. Concentrations of nutrients and other water-quality constituents downstream from the Blue River Main WWTF are in the mid-range of conditions reported from other stream sites in Johnson County and the lower reaches of the Blue River (Lee and others, 2005; Wilkison and others, 2006, 2009; Poulton and others, 2007; Rasmussen and others, 2008, 2009a).

With the possible exception of increased riffle-substrate fouling, wastewater effluent did not have a measurable effect on in-stream habitat conditions at the downstream sites. Canopy cover and riparian buffer width declined along the upstream-downstream gradient, likely because of increased urban land use and impervious cover. Algal biomass, primary production, and the percentage of eutrophic (nutrient-tolerant) diatoms significantly increased and the abundance of intolerant macroinvertebrate taxa and KDHE aquatic-life-support scores significantly decreased downstream from the WWTF. Though KDHE aquatic-life-support scores decreased along the upstream-downstream gradient, all scores, with the exception of the 151st site in August 2008, were indicative of conditions partially supporting of aquatic life. By comparison, sites located further downstream in the increasingly urban portions of the basin typically are indicative of conditions nonsupporting of aquatic life (Poulton and others, 2007; Rasmussen and others, 2009a; Wilkison and others, 2009). Ecosystem functional health downstream from the WWTF was mildly impaired relative to the upstream site during summer 2008 but not during other times of the year.

Periphyton community composition at all study sites was indicative of somewhat degraded, meso-eutrophic conditions with small to moderate amounts of organic enrichment (Bahls, 1993; Porter, 2008). Eutrophic diatoms, indicative of nutrient enrichment, were dominant at all study sites, but relative abundance increased in the downstream direction, reflecting nutrient increases at the downstream sites. Excessive growth of notorious nuisance taxa, such as cyanobacteria and *Cladophora*, which tend to proliferate under nutrient-rich conditions, was not observed during the study.

Algal biomass and primary production increased along the upstream-downstream gradient, indicating conditions were more favorable for algal growth downstream from the WWTF. The increase in primary production downstream from the WWTF was substantial enough during summer to indicate mild impairment of ecosystem functional health. Algal growth commonly increases downstream from WWTFs because of the relatively constant source of bioavailable nutrients (Welch and others, 1992; Lewis and others, 2002; Dyer and others, 2003; Bott and others, 2006; Gücker and others, 2006). Increased algal growth and primary production along the upstream-downstream gradient in the upper Blue River may be a direct result of nutrient enrichment. However, there are other factors that affect algal biomass and primary production in streams that may have affected algal growth in the upper Blue River, including light, streamflow, and grazer abundance (Welch and Lindell, 1992; Allan, 1995; Young and others, 2008).

Light is a key factor limiting algal growth and primary production in temperate streams (Allan, 1995; Hill and others, 2001; Young and others, 2008) and may have played a role in limiting algal biomass and primary production at the upstream site during summer 2008. Canopy cover and turbidity decreased along the upstream-downstream gradient, likely resulting in increased light availability. Algal biomass exceeded the nuisance threshold at all sites during April 2008 and primary production was about 1.5 times larger at the upstream site than the downstream site in May 2008. By comparison, algal biomass and primary production were consistently lower at the upstream site during summer 2008 and annual minima in primary production occurred during July through October 2008 when streamside trees were fully leafed out.

During relatively low-flow conditions, increases in streamflow may enhance nutrient uptake and growth of algal periphyton (Welch and Lindell, 1992). Streamflow at the downstream site was always greater than the upstream site because of wastewater effluent contributions, and may have been sufficient to enhance uptake and stimulate algal growth. Macroinvertebrate grazers may effectively reduce algal biomass in streams, even under nutrient enriched conditions (Welch and Lindell, 1992). Some macroinvertebrates have developed a specific feeding strategy to remove algae and other periphyton from surfaces by scraping (Cummins, 1974; Barbour and others, 1999). Within the upper Blue River study reach the relative abundance of scrapers decreased along the upstream-downstream gradient. The greater abundance of scrapers at the upstream site may have played a role in keeping algal biomass low relative to the downstream site.

Macroinvertebrate communities were indicative of some level of impairment at all sites in the upper Blue River; however, macroinvertebrate metrics were indicative of declines in stream quality along the upstream-downstream gradient. There were distinct shifts from sensitive to more tolerant taxa along the study reach and some sensitive taxa were absent from downstream sites. The abundance of intolerant macroinvertebrate taxa and KDHE aquatic-life-support scores significantly decreased downstream from the WWTF. Several macroinvertebrate metric responses reflect the greater nutrient concentrations downstream from the WWTF. The KBI-NO and MBI biotic indices are calculated based on macroinvertebrate tolerances to nutrients (Huggins and Moffet, 1988; Davenport and Kelly, 1983). These indices reflected nutrient conditions along the upstream-downstream gradient (metric scores increased with increasing nutrient concentrations) and were indicative of the negative effect of high nutrient concentrations on macroinvertebrate communities. Individual macroinvertebrate taxa known to be tolerant of high nutrient concentrations, including the tendipid midge *Dicrotendipes*, and orthoclad midges in the *Cricotopus*/*Orthocladius* species complexes (Adamus and Brandt, 1990;

Davies and Tsomides, 2002; Jacobsen, 2008), also increased in abundance downstream from the WWTF.

Nutrients may affect macroinvertebrates directly by disrupting or altering physiological processes (Carmago and Alonso, 2006) or indirectly by stimulating algal growth. Increased algal biomass likely caused some degradation of macroinvertebrate habitats downstream from the WWTF, as evidenced by the decline in riffle-substrate fouling scores along the upstream-downstream gradient. Excessive algal growth may degrade habitats, become embedded with fine substrate particles making it a less palatable food source for macroinvertebrate scrapers, and decrease dissolved oxygen concentrations during decay, thereby affecting macroinvertebrate communities (Garie and McIntosh, 1986; Adamus and Brandt, 1990; Davies and Tsomides, 2002; Jacobsen, 2008).

In addition to nutrients, other factors associated with wastewater effluent and increased urban land use that affect water quality, habitat quality, and hydrology likely also affected macroinvertebrate community composition along the upstream-downstream gradient. Several studies have indicated that common wastewater effluent constituents such as chloride, trace metals, or organic wastewater effluent compounds in water and sediments may be important in structuring macroinvertebrate community composition downstream from WWTFs (Birge and others, 1989; Dickson and others, 1992; Diamond and Daley, 2000; U.S. Environmental Protection Agency, 2000b; Dyer and Wang, 2002). Concentrations of measured constituents in water and sediments did not exceed probable effects concentrations; however, the effects of exposure to mixtures of potentially toxic compounds on macroinvertebrate communities are largely unknown. Macroinvertebrate communities also are sensitive to nonpoint source effects of urbanization on streams, and loss of sensitive taxa begin to occur at relatively low levels of urban land use (Booth and Jackson, 1997; Richards and others, 1996; Roth and others, 1996; Roy and others, 2003; Rasmussen and others, 2009a).

Patterns in periphyton community metrics along the upstream-downstream gradient reflected changes in water-quality conditions downstream from the WWTF during April 2008, but were indicative of relatively poor conditions at all sites in August 2008. Many of the macroinvertebrate community metrics also were indicative of poorer conditions at all sites in August than April 2008, likely because of the stress associated with seasonal low-flow conditions and high temperatures. Natural seasonal variation in the life-cycles of aquatic organisms may affect the sensitivity of some metrics used to evaluate biological conditions (Barbour and others, 1999). Comparison of biological metrics among years and studies need to consider when samples were collected and the natural seasonal variation that occurs in biological communities.

Whereas periphyton metrics were able to discriminate among sites along the upstream-downstream gradient in April 2008, all metrics likely reflected seasonal stressors in August 2008. By comparison, the KDHE aquatic-life-support score was able to discriminate among sites during April and August 2008. Indices based on multimetric combinations, such as the KDHE aquatic-life-support score, minimize the bias that might occur when relying on individual metrics for evaluation (Karr and Kerans, 1991; Karr, 1993; Fore and others, 1994; Barbour and others, 1995). In addition, the KDHE aquatic-life-support score was developed using macroinvertebrate autecological data specific to the State of Kansas. The periphyton metrics were developed using autecological data from throughout the world—autecological data were not available for all taxa identified in the upper Blue River (Porter, 2008; Porter and others, 2008), and multimetric indices specific to the region have not been developed. Development of region-specific autecological periphyton data and multimetric periphyton indices may improve the ability to contrast among sites through a broad range of seasonal and water-quality conditions.

Evaluation of ecosystem functional health is complementary to traditional water-quality and biological monitoring approaches because measures of ecosystem function, such as stream metabolism, integrate the influence of physical, chemical, and biological stressors. Environmental stressors may affect habitat, water quality, and/or biological communities (ecosystem structure) but not overall ecosystem function, ecosystem function but not structure, or both; therefore, comprehensive assessments of stream impairment need to include measures of ecosystem structure and function (Mullholland and others, 2005; Fellows and others, 2006; Young and others, 2008). Stream metabolism was calculated for most days during April 2008 through March 2009, allowing the evaluation of primary production and community respiration along the upstream-downstream gradient at a temporal resolution that is not feasible for more traditional biological monitoring approaches.

Summer was the only season when ecosystem functional health was mildly impaired downstream from the WWTF. Biological communities typically experience increased stress during summer because of seasonal low-flow conditions and high temperatures, as indicated by the relatively poor biological conditions that occurred at all sites in August 2008. Wastewater effluent likely represented more than 20 percent of total streamflow during most of the summer, thereby having a substantial influence on water-quality conditions and causing additional stress on biological communities. Differences in environmental and biological conditions along the upstream-downstream gradient likely were more extreme during summer than other times of the year, resulting in seasonal impairment of ecosystem functional health.

A complex range of physical, chemical, and biological factors may potentially affect biological community composition and ecosystem processes, and these factors may vary seasonally (Robinson and Minshall, 1986; Allan, 1995; Welch and Lindell, 1992; Linke and others, 1999; Hill and others, 2001). Cause-and-effect relations are difficult to determine without conducting manipulative field and/or laboratory experiments through a range of spatial and temporal conditions. This complexity makes it difficult to determine which environmental factors most affect biological conditions and ecosystem function in the upper Blue River. For example, results from this study indicate nutrients, light, streamflow, and macroinvertebrate grazers may all play a role in controlling periphyton biomass and primary production in the upper Blue River. Wastewater effluent may directly affect algal biomass and primary production through increased nutrient concentrations, improved water clarity, and increased streamflow, or may have indirect effects by influencing the abundance of macroinvertebrate grazers; however, urbanization factors that reduce riparian cover also may have a direct effect by increasing light availability.

Upgrades to the Blue River Main WWTF improved wastewater effluent quality, but the wastewater effluent discharge still had negative effects on the environmental and biological conditions at the downstream sites. Wastewater effluent discharge into the upper Blue River likely contributed to the changes in measures of ecosystem structure (streamflow, water chemistry, algal biomass, algal periphyton and macroinvertebrate community composition) and primary production, a measure of ecosystem function, along the upstream-downstream gradient. Because the Blue River Main WWTF is located in a rapidly urbanizing area, urbanization effects also may play a role in the decline in environmental and biological conditions along the upstream-downstream gradient. Despite these differences in environmental and biological conditions, ecosystem functional health was not impaired downstream from the WWTF during most times of the year, indicating the declines in environmental and biological conditions along the upstream-downstream gradient were not substantial enough to cause persistent changes in ecosystem function.

Summary

The Johnson County Blue River Main Wastewater Treatment Facility (WWTF) discharges into the upper Blue River near the border between Johnson County, Kansas and Jackson County, Missouri. During 2005 through 2007 the WWTF underwent upgrades to increase capacity and include biological nutrient removal. The purpose of this report is to describe the effects of wastewater effluent discharge and treatment facility upgrades on environmental and biological conditions in the upper Blue River, downstream from the Blue River Main WWTF. This report includes: (1) an evaluation of streamflow and water-quality conditions upstream and downstream from the WWTF and before and after upgrades using previously and newly collected discrete and continuous data, (2) estimates of total nutrient concentrations, loads, and yields at an upstream and a downstream site based on regression models developed using previously and newly collected discrete and continuous data, (3) evaluation of streambed-sediment chemistry, (4) habitat assessment, and (5) a comparison of algal periphyton and macroinvertebrate community metrics and ecosystem function (primary production and community respiration) along the upstream-downstream gradient. This information can be used to help achieve NPDES wastewater effluent permit requirements after additional studies are conducted.

Three sites along a 6.4-mile reach of the upper Blue River were included in the study. One site (Kenneth) was located about 2.0 miles upstream from the wastewater effluent discharge and two sites were located downstream from the wastewater effluent discharge; the downstream sites were about 0.25 and 4.1 miles downstream from the wastewater effluent discharge (the 151st and Blue Ridge sites, respectively). Previously collected streamflow and water-quality data (discrete and continuous), stream-bed sediment, habitat, algal periphyton, and macroinvertebrate data were available for the Kenneth and Blue Ridge sites. Continuous water-quality monitors were operated and discrete water-quality samples were collected at the Kenneth and Blue Ridge sites from April 1, 2008 through March 31, 2009. Water-quality, algal periphyton, and macroinvertebrate samples were collected from all three sites during normal streamflow conditions in April 2008 and below-normal streamflow conditions in August 2008. In addition, sediment-quality samples were collected in April 2008 and habitat conditions were assessed in June 2008.

The contribution of wastewater effluent to streamflow at the Blue Ridge site ranged from negligible (less than 1 percent) during large runoff events to nearly 100 percent during the lowest streamflows. Wastewater effluent represented more than 90 percent of total streamflow about 6 percent of the time during the study period (January 2003 through March 2009). After capacity upgrades, the wastewater effluent contribution to streamflow during normal streamflows increased from about 16 percent to about 23 percent of total streamflow.

The Blue River Main WWTF wastewater effluent caused changes in the concentration of some water-quality constituents that may affect biological community structure and function including smaller turbidities and greater concentrations of bioavailable nutrients (nitrate and orthophosphorus). The effects of wastewater effluent on the water-quality conditions of the upper Blue River were most evident during below-normal and normal streamflows (about 75 percent of the time), when wastewater effluent contributed more than 20 percent to total streamflow. Turbidities were about 7 times larger at the upstream site than the downstream sites during below-normal and normal streamflows because of the increased clarity of wastewater effluent discharge relative to natural conditions in the upper Blue River. Nutrients changed more than other measures of water chemistry as a result of the effect of wastewater effluent. Total and inorganic nutrient concentrations at the downstream sites during below-normal and normal streamflows were 4 to 15 times larger than at the upstream site.

After the addition of biological nutrient removal to the Blue River Main WWTF, annual mean total nitrogen concentrations were below the NPDES wastewater effluent permit target in 2008, and annual total nitrogen loads from the WWTF decreased despite capacity increases. NPDES

wastewater effluent permit target total phosphorus concentrations were achieved in 2007 but not 2008, and annual loads increased with wastewater effluent discharge volume; however, the biological phosphorus removal process was optimized after the study was complete, and target total phosphorus concentrations in wastewater effluent were achieved during summer 2009. During 2007 and 2008 annual wastewater effluent discharge from the WWTF was about one-half maximum capacity, and estimated potential maximum annual nutrient loads are 1.6 to 2.4 times larger than annual loads before capacity upgrades. Nitrogen concentrations at the downstream site decreased after WWTF upgrades, indicating the addition of biological nutrient removal to the wastewater treatment process resulted in reduced nitrogen concentrations in the upper Blue River during below-normal and normal streamflows.

Nutrient loads at the sites were estimated during April 2008 through March 2009 based on regression models developed using discrete and continuous data. During this period total nitrogen and phosphorus from the WWTF contributed a relatively small percentage (14 to 15 percent) to the annual nutrient load in the upper Blue River, but contributed substantially (as much as 85 percent) to monthly loads during seasonal low-flows in winter and summer. Urbanization had a negligible effect on nitrogen yields; however, when wastewater effluent contributions were excluded, phosphorus yields from the more urban portions of the study area were about 1.6 times larger than rural areas.

Streambed-sediment conditions were similar along the upstream-downstream gradient and measured constituents did not exceed probable effect concentrations. Total habitat scores were indicative of suboptimal conditions at all sites; however, total scores were about 10 percent lower at the downstream sites than the upstream site. The individual habitat variables with the largest among-site differences in score were canopy cover, buffer width, and riffle-substrate fouling. Scores for these variables decreased from optimal at the upstream site to suboptimal at the downstream sites. Decreases in canopy cover and buffer width are likely because of the increasingly urban nature of the watershed.

Periphyton community composition at all study sites was indicative of somewhat degraded, meso-eutrophic conditions with small to moderate amounts of organic enrichment. Eutrophic diatoms, indicative of nutrient enrichment, were dominant at all study sites, but relative abundance increased in the downstream direction, reflecting nutrient increases at the downstream sites. Algal periphyton biomass, as estimated by chlorophyll, and primary production increased in the downstream direction, indicating conditions for algal growth were more favorable at the downstream sites. Increased algal biomass at the downstream sites likely caused the decrease in riffle substrate fouling scores observed in the upstream-downstream direction. Increased algal biomass and primary production at the downstream sites may be a direct response to nutrient enrichment at these sites; however, many other environmental factors also affect algal growth. Increased light because of reduced canopy cover and turbidity, increased streamflow, and decreased scraper abundance at the downstream sites all may have contributed to the increases in algal biomass and primary production at the downstream sites.

Macroinvertebrate metrics are indicative of declines in stream quality along the upstream-downstream gradient. There were distinct shifts from sensitive to more tolerant taxa along the study reach and some sensitive taxa were absent from the two downstream sites. The abundance of intolerant macroinvertebrate taxa and KDHE aquatic-life-support scores significantly decreased downstream from the WWTF. During August 2008 the site immediately downstream from the WWTF was classified as non-supporting of aquatic life. Macroinvertebrate community responses are likely because of a combination of stressors related to changes in water quality, habitat quality, and hydrology, which are, in turn, affected by wastewater effluent discharge and land-use practices.

Primary production was typically larger at the downstream site than the upstream site, with the smallest difference between sites occurring in fall and the largest during summer. Community respiration was generally similar along the upstream-downstream gradient with the exception of summer, when community respiration was about 2 times larger at the downstream site than the upstream site. Ecosystem functional health, evaluated using a preliminary framework based on primary production and community respiration, downstream from the wastewater treatment facility was mildly impaired relative to the upstream site during summer 2008 but not during other times of the year. Differences in environmental and biological conditions along the upstream-downstream gradient likely were more extreme during summer than other times of the year, resulting in seasonal impairment of ecosystem functional health. Net ecosystem production and production to respiration ratio indicated that both upper Blue River sites relied on external carbon sources to maintain the food web.

Upgrades to the Blue River Main WWTF improved wastewater effluent quality, but the wastewater effluent discharge still had negative effects on the environmental and biological conditions at the downstream sites. Wastewater effluent discharge into the upper Blue River likely contributed to changes in measures of ecosystem structure (streamflow, water chemistry, algal biomass, algal periphyton, and macroinvertebrate community composition) and primary production, a measure of ecosystem function, along the upstream-downstream gradient. Because the Blue River Main WWTF is located in a rapidly urbanizing area, urbanization effects also may play a role in the decline in environmental and biological conditions along the upstream-downstream gradient. Despite these differences in environmental and biological conditions, ecosystem functional health was not impaired downstream from the WWTF during most times of the year, indicating the declines in environmental and biological conditions along the upstream-downstream gradient were not substantial enough to cause persistent changes in ecosystem function.

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Appendixes

Appendix 1. Sample collection dates, streamflow conditions, and sample collection methods for discrete water-quality samples included in regression model development for the Kenneth (July 2003 through March 2009) and Blue Ridge (April 2008 through March 2009) sites on the upper Blue River.

[ft^3/s, cubic feet per second; KSWSC, Kansas Water Science Center; BN, below normal; AN, above normal; N, normal; SV, single vertical; EWI, equal width increment; SLPP, suction lift peristaltic pump; MOWSC, Missouri Water Science Center]

Sampling date	Collecting agency	Streamflow (ft^3/s)	Streamflow condition	Sample collection method
		Kenneth		
7/18/2003	KSWSC	0.16	BN	SV
3/4/2004	KSWSC	3,370	AN	EWI
3/28/2004	KSWSC	825	AN	EWI
5/18/2004	KSWSC	47.0	AN	EWI
5/19/2004	KSWSC	10,945	AN	EWI
5/25/2004	KSWSC	872	AN	EWI
6/10/2004	KSWSC	1,452	AN	EWI
9/8/2004	KSWSC	19.0	N	SV
12/7/2004	KSWSC	129	AN	EWI
12/21/2004	KSWSC	23.0	N	EWI
1/3/2005	KSWSC	865	AN	SV
3/22/2005	KSWSC	28.0	N	EWI
5/13/2005	KSWSC	346	AN	EWI
6/4/2005	KSWSC	9,770	AN	SLPP
6/11/2005	KSWSC	830	AN	EWI
7/13/2005	KSWSC	.41	BN	EWI
8/25/2005	KSWSC	1,650	AN	EWI
4/24/2006	KSWSC	118	AN	EWI
6/16/2006	KSWSC	2.90	BN	SV
7/12/2006	KSWSC	348	AN	EWI
8/28/2006	KSWSC	92.0	AN	EWI
11/15/2006	KSWSC	.67	BN	SV
3/14/2007	KSWSC	27.0	N	EWI
5/7/2007	KSWSC	5,690	AN	EWI
6/29/2007	KSWSC	4,990	AN	EWI
3/17/2008	KSWSC	787	AN	EWI
4/2/2008	KSWSC	36.0	N	EWI
4/18/2008	KSWSC	224	AN	EWI
4/22/2008	KSWSC	1,450	AN	EWI
6/4/2008	KSWSC	3,850	AN	EWI
8/26/2008	KSWSC	2.70	BN	EWI
3/10/2009	KSWSC	717	AN	EWI

Sampling date	Collecting agency	Streamflow (ft^3/s)	Streamflow condition	Sample collection method
		Blue Ridge		
4/1/2008	KSWSC	47.0	N	EWI
4/8/2008	KSWSC	900	AN	EWI
4/18/2008	KSWSC	373	AN	EWI
4/22/2008	KSWSC	3,380	AN	EWI
5/2/2008	KSWSC	3,020	AN	EWI
6/4/2008	KSWSC	10,100	AN	EWI
6/6/2008	KSWSC	3,110	AN	EWI
6/9/2008	KSWSC	1,700	AN	EWI
6/24/2008	MOWSC	30.0	N	EWI
7/3/2008	KSWSC	840	AN	EWI
7/30/2008	KSWSC	4,940	AN	EWI
8/12/2008	MOWSC	15.0	N	EWI
8/26/2008	KSWSC	6.30	BN	EWI
9/4/2008	KSWSC	152	AN	EWI
9/12/2008	KSWSC	1,710	AN	EWI
10/15/2008	KSWSC	446	AN	EWI
10/22/2008	KSWSC	63.0	AN	EWI
11/6/2008	KSWSC	568	AN	EWI
12/17/2008	KSWSC	27.0	N	EWI
3/10/2009	KSWSC	1,200	AN	EWI

Appendix 2. Mean, median, and range of the physical stream reach parameters used in metabolism calculations for the Kenneth and Blue Ridge sites on the upper Blue River during April 2008 through March 2009.

[*n*, number of observations; ft^3/s, cubic feet per second; ft, feet; s, second; m, meter, $K_{2(20°C)}$, oxygen exchange coefficient at 20 degrees Celsius; --, not applicable]

Parameter	Kenneth				Blue Ridge		
	n	**Mean**	**Median**	**Range**	**Mean**	**Median**	**Range**
Discharge (ft^3/s)	191	15.1	13.7	1.47–61.6	30.5	28.0	8.30–97.0
Velocity (ft/s)	191	.17	.16	.02–.55	.30	.28	.10–.79
Wetted width (ft)	191	51.0	51.1	47.7–55.2	74.7	74.7	73.1–77.7
Depth (ft)	191	1.62	1.63	1.29–2.04	1.32	1.32	1.09–1.73
Area (ft^2)	191	83.0	83.5	61.6–113	98.6	98.3	79.7–134
Reach length (ft)	191	154	147	21.4–493	270	254	88.9–710
Reaeration coefficient $K_{2(20°C)}$	191	.003	.003	.0005–.006	.003	0	.001–.007
Slope (m/m)	1	--	--	.004	--	--	.003

Appendix 3. Water-quality conditions at each biological sampling site on the upper Blue River during April 1–2, 2008 and August 26, 2008.

[ft³/s, cubic feet per second; %, percent; --, not applicable; µS/cm, microsiemens per centimeter at 25 degrees Celsius; FNU, formazin nephelometric units; µg/L, micrograms per liter; mg/L, milligrams per liter; col/100 ml, colonies per 100 milliliters of sample; <, less than]

Water-quality property or chemical (unit of measure)	April 1–2, 2008			August 26, 2008		
	Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Physical properties, suspended solids, and sediment						
Streamflow (ft^3/s)	36	40	47	2.7	7.6	6.3
Wastewater effluent (% streamflow)	--	22	18	--	73	63
Dissolved oxygen, field (mg/L)	10.2	11.3	10.6	6.1	7.5	10.8
pH, field (standard units)	8.2	8.3	8.3	7.9	7.9	8.4
Specific conductance, field (µS/cm)	577	664	666	591	714	737
Water temperature, field (degrees Celsius)	10.1	10.4	10.3	22.2	21.5	23.8
Turbidity, laboratory (FNU)	18	12	9.3	9.2	7.2	3.3
Total suspended solids (mg/L)	27	10	11	12	<10	10
Suspended sediment (mg/L)	87	95	110	91	36	30
Dissolved solids and major ions						
Dissolved solids (mg/L)	347	402	397	364	442	457
Calcium (mg/L)	89.2	90.3	91.6	86.6	67.9	76.3
Magnesium (mg/L)	8.6	11	10.6	11.1	12.6	12.9
Potassium (mg/L)	2.6	4.2	4	3.9	10.5	9.8
Sodium (mg/L)	23.7	35	34.8	24.7	58.8	58.5
Chloride (mg/L)	39	54	51	30	63	65
Sulfate (mg/L)	37	61	62	45	80	82
Nutrients and carbon						
Ammonia plus organic, total, as nitrogen (mg/L)	0.44	0.48	0.47	0.56	0.82	0.74
Nitrite plus nitrate as nitrogen, dissolved (mg/L)	.43	1.31	1.19	.06	4	2.52
Ammonia, as nitrogen (mg/L)	.03	.08	.09	<.02	<.02	.02
Total nitrogen (mg/L)[1]	.87	1.79	1.66	.62	4.82	3.26
Orthophosphorus, as phosphorus (mg/L)	<.01	.23	.18	<.01	1.18	1.06
Dissolved phosphorus (mg/L)	<.01	.31	.26	.02	1.26	1.08
Total phosphorus (mg/L)	.05	.33	.29	.06	1.26	1.13
Particulate phosphorus (mg/L)[2]	<.01	.02	.03	.04	0	.05
Dissolved organic carbon (mg/L)	2.8	3.3	3.1	4.6	5.1	5.2
Total organic carbon (mg/L)	3.2	3.9	4.9	7.1	7.2	5.9
Bacteria and biochemical						
Biochemical oxygen demand (mg/L)	3	2	<2	<2	<2	<2
Chemical oxygen demand (mg/L)	15	21	18	17	19	14
Enterococci (col/100 mL)	<4	8	4	210	74	<10
Escherichia coli (col/100 mL)	20	10	31	180	130	58
Fecal coliform (col/100 mL)	20	20	40	280	240	70

[1]Calculated as the sum of nitrite plus nitrate and dissolved and ammonia plus organic, total.

[2]Calculated as the difference between total phosphorus and dissolved phosphorus.

Appendix 4. Regression models and summary statistics for computing selected constituent concentrations and densities in water at the Kenneth and Blue Ridge sites on the upper Blue River.

[Discrete sample data for the Kenneth site were collected from July 2003 through March 2009. Discrete sample data for the Blue Ridge site were collected from April 2008 through March 2009; R^2, coefficient of determination; RMSE, root mean square error; MSPE, model standard percentage error; *n*, number of discrete samples; mg/L, milligrams per liter; log, $\log_{10}$; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; TBY, turbidity, in formazin nephelometric units (FNUs)]

Site	Regression model	R^2	RMSE	MSPE (upper)	MSPE (lower)	Bias correction factor (Duan, 1983)	Standard error for calculated parameter intercept	Standard error for first dependent variable	Covariance for calculated parameter and first dependent variable	Discrete sample data: *n*	Discrete sample data: Range of values in variable measurements	Discrete sample data: Mean	Discrete sample data: Median	Discrete sample data: Standard deviation
Suspended-sediment concentration (SSC), mg/L														
Kenneth	logSSC=0.973logTBY+0.352	0.93	0.2007	59	37	1.11	0.1029	0.0480	-0.9387	32	SSC 7–4,170	595	311	850
											TBY 3–1,270	270	188	306
Blue Ridge	logSSC=.761logTBY+.896	.88	.2590	82	45	1.15	.1667	.0706	-.9305	18	SSC 5-3,990	818	686	925
											TBY 2– 1,480	403	327	372
Total suspended solids (TSS), mg/L														
Kenneth	logTSS=1.13logTBY-0.085	0.98	0.1252	33	25	1.05	0.0642	0.0300	-0.9387	32	TSS 3–4,470	549	274	874
											TBY 3–1,270	270	188	306
Blue Ridge	logTSS=.982logTBY+.273	.94	.2239	67	40	1.10	.1441	.0610	-.9305	18	TSS 4–4,100	804	705	961
											TBY 2– 1,480	403	327	372
Escherichia coli bacteria (ECB), colonies per 100 milliliters														
Kenneth	logECB=1.32logTBY+0.572	0.72	0.6318	328	77	1.97	0.3241	0.1513	-0.9387	32	ECB 10–46,000	10,000	5,200	12,700
											TBY 3–1,270	270	188	306
Blue Ridge	logECB=.995logTBY+1.42	.84	.4346	172	63	1.52	.2467	.1079	-.9097	18	ECB 31–22,000	10,300	12,500	7,960
											TBY 2– 1,480	384	270	384
Acid neutralizing capacity (ANC), mg/L as calcium carbonate														
Kenneth	logANC=0.905logSC-0.203	0.91	0.0561	14	12	1.01	0.1391	0.0538	-0.9975	32	ANC 65–270	147	158	56
											SC 175–708	416	421	162
Blue Ridge	logANC=.720logSC+.186	.75	.0821	21	17	1.02	.2741	.1051	-.9975	18	ANC 60–195	122	113	43
											SC 182–832	437	418	186
Dissolved solids (DS), mg/L														
Kenneth	logDS=0.735logSC+0.514	0.92	0.0424	10	9	1.00	0.1052	0.0406	-0.9975	32	DS 125–440	271	260	84
											SC 175–708	416	421	162
Blue Ridge	logDS=.765logSC+.441	.98	.0244	6	5	1.00	.0816	.0313	-.9974	17	DS 159–464	287	287	99
											SC 182–832	440	459	192
Calcium (Ca), dissolved, mg/L														
Kenneth	logCa=1.07logSC-1.05	0.95	0.0453	11	10	1.01	0.1125	0.0435	-0.9975	32	Ca 2.8–110	57	59	25
											SC 175–708	416	421	162
Blue Ridge	logCa=.902logSC-.657	.92	.0534	13	12	1.01	.1782	.0683	-.9975	18	Ca 23.1–95.9	53	47	21
											SC 182–832	437	418	186

Appendix 4. Regression models and summary statistics for computing selected constituent concentrations and densities in water at the Kenneth and Blue Ridge sites on the upper Blue River.—Continued

[Discrete sample data for the Kenneth site were collected from July 2003 through March 2009. Discrete sample data for the Blue Ridge site were collected from April 2008 through March 2009; R^2, coefficient of determination; RMSE, root mean square error; MSPE, model standard percentage error; *n*, number of discrete samples; mg/L, milligrams per liter; log, log_{10}; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; TBY, turbidity, in formazin nephelometric units (FNUs)]

Site	Regression model	R^2	RMSE	MSPE (upper)	MSPE (lower)	Bias correction factor (Duan, 1983)	Standard error for calculated parameter intercept	Standard error for first dependent variable	Covariance for calculated parameter and first dependent variable	Discrete sample data				
										n	Range of values in variable measurements	Mean	Median	Standard deviation
Chloride (Cl), dissolved, mg/L														
Kenneth	logCl=1.29logSC-2.01	0.79	0.1279	34	26	1.04	0.3174	0.1226	-0.9975	32	Cl 6–55	25	24	13
											SC 175–708	416	421	162
Blue Ridge	logCl=1.59logSC-2.71	.86	.1267	34	25	1.04	.4025	.1531	-.9975	20	Cl 7–98	36	37	24
											SC 182–832	457	460	187
Magnesium (Mg), dissolved, mg/L														
Kenneth	logMg=1.08logSC-2.02	0.97	0.0369	9	8	1.00	0.0916	0.0354	-0.9975	32	Mg 2.5–13.3	7	7	3
											SC 175–708	416	421	162
Blue Ridge	logMg=1.05logSC-1.93	.95	.0476	12	10	1.01	.1589	.0609	-.9975	18	Mg 2.8–12.9	7	6	3
											SC 182–832	437	418	186
Sodium (Na), dissolved, mg/L														
Kenneth	logNa=1.20logSC-1.94	0.87	0.0902	23	19	1.02	0.2238	0.0865	-0.9975	32	Na 4.9–35.3	17	16	8
											SC 175–708	416	421	162
Blue Ridge	logNa=1.53logSC-2.67	.89	.1043	27	21	1.03	.3484	.1335	-.9975	18	Na 6–63.2	26	21	17
											SC 182–832	437	418	186
Sulfate (SO_4), dissolved, mg/L														
Kenneth	$logSO_4$=1.21logSC-1.71	0.92	0.0679	17	14	1.01	0.1779	0.0685	-0.9976	31	SO_4 9–74	30	27	15
											SC 175–708	423	433	159
Blue Ridge	$logSO_4$=1.44logSC-2.30	.93	.0778	20	16	1.01	.2600	.0997	-.9975	18	SO_4 9–82	34	26	22
											SC 182–832	437	418	186

Appendix 5. Regression models and summary statistics for computing selected constituent concentrations and densities in water from suspended-sediment concentration at the Kenneth and Blue Ridge sites on the upper Blue River.

[Discrete sample data for the Kenneth site were collected from July 2003 through March 2009; discrete sample data for the Blue Ridge site were collected from April 2008 through March 2009. R^2, coefficient of determination; RMSE, root mean square error; MSPE, model standard percentage error; *n*, number of discrete samples; mg/L, milligrams per liter; log, log10; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); TBY, turbidity, in formazin nephelometric units (FNUs)]

Site	Regression model	R^2	RMSE	MSPE (upper)	MSPE (lower)	Bias correction factor (Duan, 1983)	Discrete sample data				
							n	Range of values in variable measurements	Mean	Median	Standard deviation
Total suspended solids (TSS), mg/L											
Kenneth	logTSS=1.10logSSC-0.36	0.95	0.197	57	36	1.08	32	TSS 3–4,470	549	274	874
								SSC 7–4,170	595	311	850
Blue Ridge	logTSS=1.20logSSC-.66	.93	.246	76	43	1.12	18	TSS 4–4,100	804	705	961
								SSC 5–3,990	818	686	925
Nitrogen, total (TN), mg/L											
Kenneth	TN=0.0019SSC+1.25	0.82	0.745	455	82	1.00	32	TN 0.53–8.75	2.36	2.10	1.75
								SSC 7–4,170	595	311	850
Blue Ridge	TN=.0008SSC+2.47	.39	.928	746	88	1.00	18	TN 1.29–6.21	3.16	3.02	1.19
								SSC 5–3,990	818	686	925
Phosphorus, total (TP), mg/L											
Kenneth	TP=0.0006SC+0.17	0.92	0.140	38	28	1.00	18	TP 0.05–2.45	0.51	0.39	0.51
								SSC 7–4,170	595	311	850
Blue Ridge	TP=.0004SSC+.51	.54	.323	110	52	1.00	18	TP .28–2.05	.83	.73	.48
								SSC 5–3,990	818	686	925
Nitrogen, ammonia plus organic (TON), total, mg/L											
Kenneth	logTON=0.44logSSC-0.93	0.72	0.210	62	38	1.08	32	TON 0.1–7.6	1.78	1.40	1.56
								SSC 7–4,170	595	311	850
Blue Ridge	TON=.0011SSC+1.35	.54	.912	716	88	1.00	18	TON .1–5.6	2.24	2.10	1.34
								SSC–3,990	818	686	925
Orthophosphate, filtered (OrthoP), mg/L as phosphate											
Kenneth	logOrthoP=0.14logSSC-1.69	0.04	0.397	150	60	1.37	32	OrthoP 0.005–.19	0.06	0.06	0.04
								SSC 7–4,170	595	311	850
Blue Ridge	logOrthoP=-.48logSSC+.32	.29	.501	217	68	1.89	18	OrthoP .01–1.06	.27	.08	.33
								SSC 5–3,990	818	686	925
Phosphorous, filtered (P_{diss}), mg/L as phosphate											
Kenneth	logP_{diss}=0.21logSSC-1.68	0.14	.352	125	56	1.26	32	P_{diss} 0.05–.19	0.08	0.08	0.05
								SSC 7–4,170	595	311	850
Blue Ridge	logP_{diss}=-.35logSSC+.14	.32	.352	125	56	1.50	18	P_{diss} .05–1.08	.28	.13	.31
								SSC 5–3,990	818	686	925
Total organic carbon (TOC), mg/L											
Kenneth	logTOC=0.0004logSSC+0.82	0.73	0.212	63	39	1.08	7	TOC 3.2–55.4	19	15	18
								SSC 87–2,210	695	385	807
Blue Ridge	logTOC=.43logSSC+.12	.81	.145	40	28	1.05	18	TOC 4.9–85.9	22	20	19
								SSC 5–3,990	818	686	925
Escherichia coli bacteria (ECB), colonies per 100 milliliters											
Kenneth	logECB=1.26logSSC+0.33	0.65	0.697	398	80	2.31	32	ECB 10–46,000	10,007	5,200	12,699
								SSC 7–4,170	595	311	850
Blue Ridge	logECB=.98logSSC+.89	.74	.537	244	71	1.80	18	ECB 31–22,000	10,257	13,500	7,963
								SSC 5–3,990	818	686	925

Appendix 6. Wastewater-effluent and pharmaceutical compounds detected in stream water samples collected April 1–2, 2008 at the biological sampling sites on the upper Blue River.

[µg/L, micrograms per liter; <, less than; E, estimated]

Compound	General use[1]	Laboratory reporting level (µg/L)	Site		
			Kenneth	151st	Blue Ridge
Wastewater indicator compounds (µg/L)					
4-Nonylphenol diethoxylate (NP2EO)	Detergent	5.00	E1.44	E2.52	E2.42
Tributyl phosphate	Fire retardant	.20	<.20	<.20	E.014
Tris(2-butoxyethyl) phosphate	Fire retardant	.40	<.40	<.40	E.098
Tris(2-chloroethyl) phosphate (Fyrol CEF)	Fire retardant	.10	<.10	E.075	E.084
Tris (dichloroisopropyl) phosphate (Fyrol PCF)	Fire retardant	.12	<.12	E.079	E.078
Acetyl-hexamethyl-tetrahydro-napthalene (AHTN)	Fragrance	.50	<.50	E.031	E.022
Hexahydro-hexamethyl-cyclopentabenzopyran (HHCB)	Fragrance	.50	<.50	E.226	E.176
1, 4-Dichlorobenzene	Pesticide	.08	<.08	E.013	<.08
Metalochlor	Pesticide	.08	E.021	E.020	E.018
N, N-diethyl-meta-toluamide (DEET)	Pesticide	.10	E.029	E.064	E.054
Triethyl citrate	Plastics	.20	<.20	E.047	E.047
Triphenyl phosphate	Plastics	.10	<.10	E.015	<.10
Isophorone	Solvent	.08	E.011	E.008	E.009
Caffeine	Stimulant	.10	<.10	<.10	E.025
Pharmaceutical compounds (µg/L)					
Carbamazepine	Anticonvulsant, mood stabilizer	0.04	<0.04	E0.024	E0.022
Sulfamethoxazole	Sulfonamide antibiotic	.10	<.10	E.106	E.072

[1]Compound uses and sources from Zaugg and others, 2002, Lee and others, 2005, and Wilkison and others, 2006.

Appendix 7. Carbon, nutrients, and trace elements in streambed sediment samples collected April 1–2, 2008 at the biological sampling sites on the upper Blue River.

[mg/kg, milligrams per kilogram; --, not applicable; <, less than]

Compound	Probable effect concentration[1] (mg/kg)	Background concentration[2] (mg/kg)	Site		
			Kenneth	151st	Blue Ridge
Nutrients and carbon (mg/kg)					
Nitrogen	--	--	1,000	1,000	1,000
Phosphorus	--	1,000	530	820	710
Organic carbon	--	24,000	12,000	12,000	11,000
Total carbon	--	33,000	14,000	14,000	13,000
Trace elements (mg/kg)					
Aluminum	--	59,000	53,000	58,000	58,000
Antimony	--	.7	.9	.9	.9
Arsenic	33.0	6.6	7.4	11	9.7
Barium	--	490	640	700	680
Beryllium	--	1.8	1.5	1.8	1.7
Cadmium	4.98	.4	.3	.4	.5
Chromium	111	58	64	68	75
Cobalt	--	12	10	13	12
Copper	149	20	19	24	22
Iron	--	29,000	24,000	30,000	28,000
Lead	128	20	22	27	23
Lithium	--	30	29	33	35
Manganese	--	840	630	800	820
Mercury	1.06	.4	.02	.02	.02
Molybdenum	--	1	1	1	1
Nickel	48.6	23	25	30	32
Selenium	--	.7	.4	.4	.3
Silver	1.77	.2	<.5	<.5	<.5
Strontium	--	150	130	140	140
Sulfur	--	800	280	270	240
Thallium	--	--	<50	<50	<50
Titanium	--	3,300	4,100	4,200	4,300
Uranium	--	--	<50	<50	<50
Vanadium	--	83	70	85	80
Zinc	459	91	74	90	84

[1]From MacDonald and others, 2000, with the exception of silver which is from U.S. Environmental Protection Agency, 1998.

[2]From Horowitz and Stevens, 2008; background concentrations for the conterminous United States.

Appendix 8. Wastewater-effluent compounds detected in streambed sediment samples collected April 1–2, 2008 at the biological sampling sites on the upper Blue River.

[All concentrations are in micrograms per kilogram (µg/kg); µg/kg, micrograms per kilogram; PAH, polycyclic aromatic hydrocarbon; --, not applicable; E, estimated; <, less than]

Compound	General use[1]	Laboratory Reporting Level (µg/kg)	Probable effect concentration[2]	Site		
				Kenneth	151st	Blue Ridge
1-Methylnapthalene	PAH or combustion by-product	30.0	--	E6.7	<30	<30
2,6-Dimethylnapthalene	PAH or combustion by-product	30.0	--	E9.7	E6.6	E6.1
2-Methylnapthalene	PAH or combustion by-product	30.0	--	E9.7	<30	<30
3-Beta-coprostanol	Sterol or stanol	300	--	<300	E62	E78
3-Methyl-1(H)-indole (Skatol)	Fragrance	30.0	--	E6.8	E5.5	<30
9,10-Anthraquinone	Bird repellant	30.0	--	E12	E8.6	E16
Acetyl-hexamethyl-tetrahydro-naphthalene (AHTN)	Fragrance	30.0	--	<30.0	E1.3	<30
Anthracene	PAH or combustion by-product	30.0	845	92	<30.0	E5.9
Benzo [a] pyrene	PAH or combustion by-product	30.0	1,450	89	E12	36
beta-Sitosterol	Sterol or stanol	300	--	E1,300	E1,400	E1,200
beta-Stigmastanol	Sterol or stanol	300	--	E260	E21	E250
Carbazole	PAH or combustion by-product	30.0	--	E27	E7.2	E12
Cholesterol	Sterol or stanol	150	--	E44	E52	E610
Fluoranthene	PAH or combustion by-product	30.0	2,230	280	E20	130
Hexahydro-hexamethyl-cyclo-pentabenzopyran (HHCB)	Fragrance	30.0	--	<30.0	E4.8	<30
Indole	Fragrance	60.0	--	72	86	E19
Napthalene	PAH or combustion by-product	30.0	561	E10	<30	<30
para-Cresol	PAH or combustion by-product	150	--	E37	E24	E13
Phenanthrene	PAH or combustion by-product	30.0	1,170	270	<30	67
Phenol	Disinfectant	30.0	--	E87	E46	E50
Pyrene	PAH or combustion by-product	30.0	1,520	220	E18	98

[1]Compound uses and sources from Zaugg and others, 2002, Lee and others, 2005, and Wilkison and others, 2006.

[2]From MacDonald and others, 2000.

Appendix 9. Habitat assessment variables and site scores at each biological sampling site on the upper Blue River during June 2008.

[Raw scores of 10–12 indicate optimal conditions, 7–9 are suboptimal, 4–6 are marginal, and 1–3 are poor; Normalized scores are based on a scale of 0–100 and scores of 80–100 indicate optimal conditions, 55–79 are suboptimal, 30–54 are marginal, and less than 30 are poor]

	Raw score			Normalized score		
	Kenneth	**151st**	**Blue Ridge**	**Kenneth**	**151st**	**Blue Ridge**
Channel conditions						
A. Flow status	10	7	9	83	58	75
B. Channel slope and morphological status (reach)	7	7	9	58	58	75
C. Sinuosity (segment)	5	4	5	42	33	42
D. Pool status (reach)	9	10	10	75	83	83
E. Riffle frequency (segment)	5	5	3	42	42	25
Bank/riparian conditions						
A. Bank stability (reach)	5	5	7	42	42	58
B. Canopy cover (reach)	11	10	7	92	83	58
C. Bank/riparian protection (reach)	5	3	3	42	25	25
D. Length and extent of buffers (segment)	9	8	7	75	67	58
E. Average buffer width (reach)	11	7	8	92	58	67
F. Percent (%) altered banks (reach)	10	11	11	83	92	92
In-stream habitat conditions						
A. Riffle-substrate fouling (reach)	10	8	6	83	67	50
B. Velocity/depth combinations (reach)	10	9	10	83	75	83
C. Riffle-substrate embeddedness (reach)	8	7	8	67	58	67
D. Sediment deposition (reach)	10	9	8	83	75	67
E. Substrate and cover diversity (reach)	11	9	10	92	75	83
F. Riffle-substrate composition (reach)	7	8	8	58	67	67
Site total	143	127	129	70	62	63

Appendix 10. Periphyton taxa identified at each biological sampling site on the upper Blue River during April and August 2008.

[Bacillariophyta, diatoms; Chlorophyta, green algae; Chryptophyta, cryptomonads; Cyanophyta, blue-green algae or cyanobacteria; Euglenophyta, euglenoids; --, not identified; X, taxa present]

Division	Taxa	April			August		
		Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Bacillariophyta	*Achnanthes conspicua*	--	--	--	X	--	--
	Achnanthes sp.	--	--	--	--	X	--
	Achnanthidium exiguum	--	--	--	--	--	X
	Achnanthidium minutissimum	X	X	X	--	--	--
	Actinocyclus normanii	--	--	--	X	X	X
	Amphipleura pellucida	--	--	--	X	--	--
	Amphora delicatissima	--	X	--	--	--	--
	Amphora inariensis	X	X	X	X	X	X
	Amphora montana	--	--	--	--	--	X
	Amphora ovalis	--	--	--	X	X	X
	Amphora pediculus	X	X	X	--	--	X
	Asterionella formosa	X	X	X	--	--	--
	Aulacoseira alpigena	--	--	--	X	--	--
	Aulacoseira granulata	--	--	--	X	--	--
	Aulacoseira sp.	--	--	--	X	--	--
	Caloneis hyalina	X	X		--	--	--
	Caloneis molaris	--	--	--	--	X	X
	Cocconeis pediculus	--	--	--	--	--	X
	Cocconeis placentula	X	X	X	X	X	X
	Cyclostephanos dubius	--	X	--	--	--	--
	Cyclostephanos tholiformis	--	--	--	--	--	X
	Cyclotella atomus	--	--	--	X	X	--
	Cyclotella bodanica	X	--	--	--	--	--
	Cyclotella distinguenda	--	--	--	X	X	--
	Cyclotella glabriuscula	X	--	--	--	--	X
	Cyclotella meneghiniana	--	--	X	--	--	--
	Cyclotella pseudostelligera	--	--	X	X	X	--
	Cyclotella sp.	--	--	--	X	--	--
	Cyclotella stelligera	--	--	--	X	--	--
	Cymatopleura solea	--	--	--	X	X	X
	Cymbella caespitosa	X	--	X	--	X	X
	Cymbella elginensis	--	--	--	--	--	X
	Cymbella lacustris	--	X	--	--	--	--
	Cymbella prostrata	--	X	X	--	--	--
	Cymbella silesiaca	X	X	--	X	X	X
	Cymbella sp.	--	X	--	X	X	X
	Cymbella tumida	--	--	--	--	X	X
	Diatoma vulgaris	X	X	X	--	--	X
	Diploneis parma	--	--	--	X	X	X
	Diploneis peterseni	--	--	--	--	X	--
	Eunotia incisa	--	--	X	--	--	--

Appendix 10. Periphyton taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[Bacillariophyta, diatoms; Chlorophyta, green algae; Chryptophyta, cryptomonads; Cyanophyta, blue-green algae or cyanobacteria; Euglenophyta, euglenoids; --, not identified; X, taxa present]

Division	Taxa	April			August		
		Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Bacillariophyta—Continued	*Fragilaria capucina*	X	X	X	--	X	X
	Fragilaria famelica	X	--	X	--	--	--
	Fragilaria fasciculata	--	X	--	--	--	--
	Fragilaria pinnata	--	--	X	--	--	--
	Gomphonema angustatum	X	X	X	X	X	X
	Gomphonema angustum	X	X	--	--	--	--
	Gomphonema augur	--	--	--	--	--	X
	Gomphonema clevei	--	--	--	X	X	X
	Gomphonema grovei	--	--	--	X	X	X
	Gomphonema minutum	--	--	X	--	--	--
	Gomphonema olivaceum	X	X	X	X	X	X
	Gomphonema parvulum	X	X	X	X	X	X
	Gomphonema sphaerophorum	--	X	--	--	--	--
	Gomphonema truncatum	--	X	--	--	--	--
	Gyrosigma acuminatum	--	--	--	--	X	--
	Gyrosigma attenuatum	--	--	--	X	--	X
	Gyrosigma nodiferum	--	X	--	--	--	--
	Gyrosigma scalproides	--	--	--	--	X	X
	Gyrosigma sp.	--	--	--	--	X	X
	Gyrosigma wansbeckii	--	X	--	X	X	--
	Hippodonta capitata	--	--	--	--	--	X
	Melosira varians	X	X	X	X	X	X
	Meridion circulare	X	X	X	--	--	--
	Navicula absoluta	--	--	--	X	--	--
	Navicula bryophila	--	--	--	X	--	--
	Navicula capitatoradiata	X	X	X	X	X	X
	Navicula cari	--	--	--	X	--	X
	Navicula cryptocephala	--	--	--	X	X	X
	Navicula cryptotenella	X	X	X	X	X	X
	Navicula difficillima	--	--	--	--	--	X
	Navicula digitulus	--	--	--	--	X	--
	Navicula exigua	--	--	--	X	X	X
	Navicula festiva	--	--	--	X	--	--
	Navicula gregaria	--	--	X	--	--	--
	Navicula impexa	--	--	--	X	--	--
	Navicula joubaudii	X	--	--	--	--	--
	Navicula margalithii	X	X	X	X	X	--
	Navicula menisculus	X	X	X	X	X	X
	Navicula minima	X	X	X	X	X	X
	Navicula phyllepta	X	X	X	X	--	X
	Navicula pseudobryophila	--	--	--	--	X	--
	Navicula pseudolanceolata	--	--	X	--	--	--

Appendix 10. Periphyton taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[Bacillariophyta, diatoms; Chlorophyta, green algae; Chryptophyta, cryptomonads; Cyanophyta, blue-green algae or cyanobacteria; Euglenophyta, euglenoids; --, not identified; X, taxa present]

Division	Taxa	April			August		
		Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Bacillariophyta—Continued	*Navicula recens*	--	--	--	X	X	X
	Navicula stankovicii	--	--	--	X	--	--
	Navicula subminuscula	X	X	X	X	X	X
	Navicula subrhynchocephala	--	--	--	X	--	--
	Navicula subtilissima	--	--	--	--	X	--
	Navicula suchlandtii	--	--	--	--	X	X
	Navicula tripunctata	--	X	--	--	--	--
	Navicula trivialis	--	--	X	X	--	--
	Navicula veneta	X	X	X	X	X	--
	Navicula viridula	--	--	--	--	--	X
	Nitzschia acicularis	--	X	--	--	--	--
	Nitzschia amphibia	--	X	--	X	X	X
	Nitzschia compressa	--	--	--	X	X	X
	Nitzschia constricta	--	X	X	X	X	X
	Nitzschia dissipata	X	X	X	X	X	X
	Nitzschia dubia	--	X	X	--	--	--
	Nitzschia inconspicua	X	X	X	X	X	X
	Nitzschia linearis	--	--	--	X	--	X
	Nitzschia palea	--	X	X	X	X	X
	Nitzschia paleacea	X	--	--	--	--	--
	Nitzschia perminuta	X	X	X	X	X	X
	Nitzschia sp.	X	--	--	--	--	--
	Nitzschia vermicularis	--	X	--	--	--	--
	Pinnularia brevicostata	--	--	X	--	--	--
	Pinnularia gibba	--	--	--	--	--	X
	Pinnularia sp.	--	--	--	X	--	--
	Pinnularia stomatophora	--	--	--	--	X	X
	Planothidium lanceolata	--	--	X	--	--	--
	Planothidium lanceolatum	X	X	X	--	X	X
	Pleurosira laevis	--	--	--	--	X	X
	Reimeria sinuata	--	--	--	X	X	X
	Rhoicosphenia curvata	X	X	X	X	X	--
	Stauroneis anceps	--	--	X	--	--	--
	Stauroneis producta	--	--	--	X	X	X
	Staurosirella pinnata	X	--	--	--	X	--
	Stephanocyclus meneghiniana	--	--	--	X	X	X
	Stephanodiscus alpinus	--	--	X	--	--	--
	Stephanodiscus hantzschii	X	X	X	--	--	--
	Stephanodiscus niagarae	--	--	X	--	--	--
	Stephanodiscus parvus	X	X	X	--	--	--
	Stephanodiscus sp.	--	--	--	X	--	--
	Surirella angusta	X	--	--	X	X	--

Appendix 10. Periphyton taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[Bacillariophyta, diatoms; Chlorophyta, green algae; Chryptophyta, cryptomonads; Cyanophyta, blue-green algae or cyanobacteria; Euglenophyta, euglenoids; --, not identified; X, taxa present]

Division	Taxa	April			August		
		Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Bacillariophyta—Continued	*Surirella brebissonii*	X	X	X	X	X	X
	Surirella minuta	--	--	--	X	--	--
	Surirella robusta	--	--	--	X	--	--
	Surirella sp.	--	--	--	X	--	X
	Synedra fasciculata	--	X	--	--	--	--
	Synedra pulchella	X	X	--	--	--	--
	Synedra tenera	--	X	--	--	--	--
	Synedra ulna	X	X	X	--	X	X
Chlorophyta	*Characium* sp.	--	--	--	--	--	X
	Chlamydomonas sp.	--	--	--	X	--	--
	Cladophora glomerata	--	--	X	--	X	--
	Closterium sp.	X	--	--	X	--	--
	Coelastrum astroideum	--	--	--	--	X	--
	Coelastrum microporum	--	--	--	--	--	X
	Cosmarium sp.	--	--	--	X	X	X
	Dictyosphaerium pulchellum	--	--	--	X	--	--
	Kirchneriella contorta	--	--	--	X	--	--
	Oedogonium sp.	--	X	--	--	--	--
	Pandorina sp.	--	--	--	X	--	--
	Pediastrum duplex	--	--	--	--	X	--
	Pediastrum simplex	--	--	--	--	X	--
	Pediastrum tetras	--	--	--	X	--	--
	Pyramimonas tetrarhynchus	--	X	--	--	--	--
	Scenedesmus bijuga	--	--	--	--	X	X
	Scenedesmus brasiliensis	--	--	--	--	X	X
	Scenedesmus incrassatulus	--	--	--	--	X	
	Scenedesmus sp.	--	--	--	X	X	X
	Sphaerocystis schroeteri	X	X	X	X	--	--
	Stichococcus subtilis	X	X	X	--	--	--
	Stigeoclonium sp.	--	--	--	--	--	X
	Stigeoclonium tenue	X	X	X	X	X	--
	Tetraedron minimum	--	--	--	--	X	--
	Ulothrix subtilissima	--	X	X	--	--	--
	Westella botryoides	--	--	--	X	--	--
Cryptophyta	*Rhodomonas* sp.	X	--	--	X	X	X
Cyanobacteria	*Aphanocapsa holsatica*	--	--	--	X	--	--
	Anabaenopsis sp.	--	--	--	X	--	--
	Phormidium lividium	X	X	--	--	--	--
	Merismopedia sp.	--	--	--	--	--	X
	Oscillatoria tenuis	--	--	--	X	--	--
Euglenophyta	*Phacus* sp.	--	--	--	X	--	--
	Trachelomonas sp.	--	--	--	X	--	--
	Trachelomonas volvocina	X	--	--	--	--	--

Appendix 11. Four most dominant algal taxa based on percentage of total abundance and biovolume at each biological sampling site on the upper Blue River during April and August 2008.

[Percentages based on the mean of three samples.]

Month	Site	Measure	Four most dominant taxa (percentage of total)
April	Kenneth	Abundance	*Gomphonema olivaceum* (23), *Surirella brebissonii* (20), *Nitzschia perminuta* (11), *Gomphonema angustatum* (4)
	151st		*Nitzschia perminuta* (15), *Surirella brebissonii* (14), *Gomphonema olivaceum* (13), *Nitzschia inconspicua* (9)
	Blue Ridge		*Navicula subminuscula* (14), *Nitzschia perminuta* (13), *Surirella brebissonii* (12), *Rhoicosphenia curvata* (6)
	Kenneth	Biovolume	*Surirella brebissonii* (25), *Gomphonema olivaceum* (20), *Synedra ulna* (8), *Meridion circulare* (7)
	151st		*Surirella brebissonii* (17), *Diatoma vulgaris* (16), *Rhoicosphenia curvata* (11), *Synedra ulna* (10)
	Blue Ridge		*Cladophora glomerata* (19), *Surirella brebissonii* (18), *Diatoma vulgaris* (9), *Rhoicosphenia curvata* (8)
August	Kenneth	Abundance	*Stigeoclonium tenue* (19), *Navicula minima* (17), *Nitzschia amphibia* (13), *Cocconeis placentula* (12)
	151st		*Stigeoclonium tenue* (27), *Cocconeis placentula* (26), *Rhodomonas* sp. (9), *Navicula minima* (5)
	Blue Ridge		*Nitzschia amphibia* (20), *Cocconeis placentula* (15), *Rhodomonas* sp. (15), *Nitzschia inconspicua* (7)
	Kenneth	Biovolume	*Stigeoclonium tenue* (42), *Stephanocyclus meneghiniana* (8), *Cocconeis placentula* (7), *Rhoicosphenia curvata* (5)
	151st		*Cladophora glomerata* (32), *Stigeoclonium tenue* (22), *Cocconeis placentula* (13), *Actinocyclus normanii* (10)
	Blue Ridge		*Pleurosira laevis* (20), *Cocconeis pediculus* (19), *Actinocyclus normanii* (10), *Cocconeis placentula* (10)

Appendix 12. Periphyton metrics, conditions associated with each metric, and metric scores at each biological sampling site on the upper Blue River during April and August 2008.

[Metric scores in **bold** indicate significant differences among sites (all *p*-values less than 0.05); metric scores are based on the mean score of three samples; ± 1 standard error in parentheses; ±, plus or minus; %, percent; DO, dissolved oxygen; >, greater than; <, less than; BOD, biochemical oxygen demand; mg/L, milligrams per liter; N, nitrogen]

Metric	Conditions	April			August		
		Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
		Oxygen tolerance					
Always high	Nearly 100% DO saturation	21.6 (2.48)	17.9 (5.45)	20.3 (4.11)	5.08 (0.69)	3.94 (2.35)	2.19 (0.64)
Fairly High	>75% DO Saturation	58.0 (4.95)	46.2 (16.4)	32.6 (3.74)	5.61 (2.36)	4.03 (2.60)	13.3 (8.09)
Moderate	>50% DO Saturation	13.0 (4.75)	23.3 (5.98)	17.9 (.80)	47.5 (12.5)	69.7 (6.94)	57.3 (7.11)
Low	>30% DO Saturation	**7.42 (4.22)**	**12.6 (6.69)**	**29.1 (.80)**	38.4 (12.1)	20.4 (3.31)	24.9 (3.99)
Very low	About 10% DO Saturation or less	0 (0)	0 (0)	.11 (.20)	3.46 (3.55)	1.91 (2.60)	2.36 (1.67)
		Saprobity					
Oligosaprobic	>85% oxygen saturation/BOD<2 mg/L	19.7 (3.03)	15.8 (5.38)	17.7 (5.12)	2.82 (0.68)	1.87 (1.26)	2.17 (1.12)
Beta-mesosaprobic	70–85% oxygen saturation/ BOD 2–4 mg/L	61.6 (5.88)	54.5 (13.9)	41.9 (8.70)	**34.2 (7.39)**	**59.9 (7.20)**	**38.2 (6.97)**
Alpha-mesosaprobic	25–70% oxygen saturation/ BOD 4–13 mg/L	9.69 (4.48)	16.9 (3.72)	12.0 (2.50)	**22.3 (6.35)**	**16.9 (5.93)**	**34.0 (3.21)**
Alpha-mesosaprobic/polysaprobic	10–25% oxygen saturation/BOD 13–22 mg/L	**8.99 (1.33)**	**12.7 (6.21)**	**28.0 (2.64)**	**37.8 (12.1)**	**19.3 (2.89)**	**23.3 (4.15)**
Polysaprobic	<10% oxygen saturation/BOD>22%	0 (0)	.22 (.37)	.29 (.50)	2.9 (2.53)	2.04 (1.05)	2.36 (1.19)
		Trophic condition					
Oligotrophic	Low nutrient concentrations	10.1 (5.15)	4.47 (1.39)	3.01 (1.28)	**5.94 (0.81)**	**1.05 (0.25)**	**0.59 (0.52)**
Oligo-mesotrophic	Low to moderate nutrient concentrations	9.90 (6.41)	14.1 (6.56)	12.6 (6.36)	2.06 (1.57)	.80 (.55)	.34 (.59)
Mesotrophic	Moderate nutrient concentrations	4.24 (4.01)	2.72 (2.66)	2.05 (1.25)	1.83 (.99)	1.67 (.70)	.51 (.02)
Meso-eutrophic	Moderate to high nutrient concentrations	6.57 (11.1)	5.64 (4.56)	4.59 (1.07)	.87 (1.04)	2.21 (1.50)	.84 (.62)
Eutrophic	High nutrient concentrations	56.3 (10.0)	57.6 (2.32)	67.7 (6.16)	**83.4 (3.12)**	**89.5 (4.35)**	**92.8 (3.06)**
Hypereutrophic	Very high nutrient concentrations	2.03 (1.47)	1.66 (.47)	2.89 (.73)	2.74 (2.39)	2.04 (1.06)	2.32 (1.15)
Ubiquitous	Widespread across nutrient concentrations	10.9 (.55)	13.8 (8.71)	7.13 (4.07)	3.15 (1.22)	2.73 (.72)	2.62 (1.78)
		Nitrogen uptake metabolism					
Autotroph, low tolerance	Low tolerance for organic N	20.8 (2.61)	17.4 (5.69)	19.3 (4.16)	3.03 (0.88)	1.90 (1.64)	1.17 (0.79)
Autotroph, high tolerance	High tolerance for organic N	67.1 (6.03)	59.4 (15.9)	45.8 (2.17)	**38.0 (7.36)**	**65.7 (4.67)**	**44.0 (6.37)**
Facultative heterotroph	Needing periodically elevated N	8.24 (5.58)	13.9 (5.56)	8.76 (3.48)	**53.0 (8.80)**	**26.9 (3.14)**	**39.1 (5.32)**
Obligate heterotroph	Needing constantly elevated N	**3.83 (1.09)**	**9.38 (5.66)**	**26.1 (1.39)**	**6.01 (2.30)**	**5.42 (2.15)**	**15.7 (1.77)**
		Other indices					
Bahls Index		**2.44 (0.06)**	**2.39 (0.08)**	**2.22 (0.04)**	**2.05 (0.14)**	**2.41 (0.07)**	**2.15 (0.10)**
Shannon Diversity Index		**2.48 (.12)**	**2.88 (.11)**	**2.87 (.11)**	2.63 (.21)	2.18 (.36)	2.68 (.09)
Siltation Index		36.7 (5.51)	40.1 (6.45)	40.4 (2.71)	**17.0 (6.44)**	**15.3 (6.32)**	**34.8 (7.74)**

Appendix 13. Macroinvertebrate taxa identified at each biological sampling site on the upper Blue River during April and August 2008.

[X, taxa present; --, not identified]

Phylum	Class	Order	Family	Taxa	April			August		
					Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Annelida	Hirudinea	Arhynchobdellae	Erpobdellidae	Erpobdellidae	X	X	X	X	X	X
Annelida	Hirudinea	Rhynchobdellae	Glossiphoniidae	Glossiphoniidae	--	--	X	--	X	X
Annelida	Hirudinea	Rhynchobdellae	Glossiphoniidae	*Helobdella stagnalis* (Linnaeus)	X	--	--	--	X	--
Annelida	Hirudinea	Rhynchobdellae	Glossiphoniidae	*Placobdella papillifera* (Verrill)	--	--	--	--	X	--
Annelida	Hirudinea	Rhynchobdellae	Glossiphoniidae	*Placobdella parasitica* (Say)	--	X	--	--	X	--
Annelida	Hirudinea	Rhynchobdellae	Piscicolidae	Piscicolidae	X	--	--	--	--	--
Annelida	Oligochaeta	--	--	Megadrile	X	X	X	X	--	X
Annelida	Oligochaeta	Lumbriculida	Lumbriculidae	Lumbriculidae	--	--	--	X	--	--
Annelida	Oligochaeta	Tubificida	Naididae	Naididae	--	X	X	--	X	--
Annelida	Oligochaeta	Tubificida	Tubificidae	*Branchiura sowerbyi* (Beddard)	--	--	--	X	--	--
Annelida	Oligochaeta	Tubificida	Tubificidae	Tubificidae	X	X	X	X	X	X
Arthropoda	Arachnida	--	--	*Acari*	--	--	--	X	X	X
Arthropoda	Insecta	Coleoptera	Dryopidae	*Helichus basalis* (LeConte)	--	--	--	X	--	--
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Copelatus* sp.	--	--	--	--	X	X
Arthropoda	Insecta	Coleoptera	Dytiscidae	Hydroporinae	X	X	X	--	--	--
Arthropoda	Insecta	Coleoptera	Dytiscidae	*Neoporus* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Coleoptera	Elmidae	*Dubiraphia* sp.	X	--	--	X	X	X
Arthropoda	Insecta	Coleoptera	Elmidae	*Macronychus glabratus* (Say)	--	--	--	--	X	X
Arthropoda	Insecta	Coleoptera	Elmidae	*Stenelmis sexlineata* (Sanderson)	X	X	X	X	X	X
Arthropoda	Insecta	Coleoptera	Elmidae	*Stenelmis* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Coleoptera	Gyrinidae	*Dineutus assimilis* (Kirby)	--	X	--	--	--	--
Arthropoda	Insecta	Coleoptera	Gyrinidae	*Gyrinus* sp.	--	--	--	--	X	--
Arthropoda	Insecta	Coleoptera	Haliplidae	*Haliplus* sp.	--	--	X	--	--	--
Arthropoda	Insecta	Coleoptera	Haliplidae	*Peltodytes* sp.	X	X	X	--	X	X
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus* sp.	--	--	X	--	X	X
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Paracymus* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Tropisternus* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Coleoptera	Scirtidae	Scirtidae	--	--	--	X	X	--
Arthropoda	Insecta	Coleoptera	Staphylinidae	Staphylinidae	--	--	--	X	X	--
Arthropoda	Insecta	Collembola	--	Collembola	--	--	X	--	--	X
Arthropoda	Insecta	Diptera	--	Brachycera	--	--	--	--	X	--

Appendix 13. Macroinvertebrate taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[X, taxa present; --, not identified]

Phylum	Class	Order	Family	Taxa	April			August		
					Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Arthropoda	Insecta	Diptera	Ceratopogonidae	Ceratopogonidae	--	X	X	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Ablabesmyia* sp.	X	X	--	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Axarus* sp.	--	--	--	--	X	--
Arthropoda	Insecta	Diptera	Chironomidae	Chironomidae	--	X	X	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	--	--	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	Chironomini	X	X	X	--	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Chironomus* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Cladotanytarsus* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Coelotanypus* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Corynoneura* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Cricotopus bicinctus* group	X	X	X	--	X	--
Arthropoda	Insecta	Diptera	Chironomidae	*Cricotopus* sp.	X	X	X	--	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Cricotopus/Orthocladius* sp.	X	X	X	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Cryptochironomus* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Cryptotendipes* sp.	--	--	X	--	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Diamesa* sp.	--	--	X	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Dicrotendipes* sp.	--	X	X	--	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Diplocladius cultriger* (Kieffer)	X	X	--	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Endochironomus* sp.	X	--	--	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Eukiefferiella* sp.	X	X	X	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Glyptotendipes* sp.	X	X	--	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Hydrobaenus* sp.	X	X	X	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Labrundinia* sp.	--	--	--	--	X	--
Arthropoda	Insecta	Diptera	Chironomidae	*Micropsectra/Tanytarsus* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Microtendipes* sp.	X	X	X	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Nanocladius* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	X	X	X	--	X	--
Arthropoda	Insecta	Diptera	Chironomidae	*Parachironomus* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Paralauterborniella nigrohalterale* (Malloch)	--	X	X	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Parametriocnemus* sp.	X	--	--	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Paratanytarsus* sp.	--	X	X	--	X	--
Arthropoda	Insecta	Diptera	Chironomidae	*Paratendipes* sp.	X	X	--	--	--	--

Appendix 13. Macroinvertebrate taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[X, taxa present; --, not identified]

Phylum	Class	Order	Family	Taxa	April			August		
					Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Arthropoda	Insecta	Diptera	Chironomidae	*Pentaneura* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Phaenopsectra* sp.	--	X	X	X	X	--
Arthropoda	Insecta	Diptera	Chironomidae	*Phaenopsectra/Tribelos* sp.	--	X	X	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum ontario* (Walley)	--	--	--	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Polypedilum* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Procladius* sp.	--	X	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Pseudochironomus* sp.	--	--	X	--	--	--
Arthropoda	Insecta	Diptera	Chironomidae	*Rheotanytarsus* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Stenochironomus* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Stictochironomus* sp.	--	X	X	X	--	--
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	X	--	--	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Tanytarsus* sp.	X	--	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Thienemanniella* sp.	--	--	X	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Thienemannimyia group* sp. (Coffman and Ferrington, 1996)	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	*Tribelos* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Diptera	Chironomidae	*Xestochironomus* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Diptera	Culicidae	*Anopheles* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Diptera	Empididae	*Clinocera* sp.	X	--	--	--	--	--
Arthropoda	Insecta	Diptera	Simuliidae	Simuliidae	--	--	--	X	X	X
Arthropoda	Insecta	Diptera	Simuliidae	*Simulium* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Stratiomyidae	*Odontomyia* sp.	--	--	--	--	X	--
Arthropoda	Insecta	Diptera	Tabanidae	*Tabanus* sp.	X	--	--	X	--	--
Arthropoda	Insecta	Diptera	Tipulidae	*Helius* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Diptera	Tipulidae	*Tipula* sp.	X	X	X	--	X	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Acerpenna pygmaea* (Hagen)	X	X	X	X	X	--
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetidae	--	--	--	--	--	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Baetis intercalaris* (McDunnough)	--	--	--	X	X	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Baetis* sp.	--	--	--	X	X	--
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Callibaetis* sp.	--	--	--	X	X	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Centroptilum* sp.	--	--	X	--	--	--

Appendix 13. Macroinvertebrate taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[X, taxa present; --, not identified]

Phylum	Class	Order	Family	Taxa	April			August		
					Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Centroptilum/Procloeon* sp.	--	--	--	X	X	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Fallceon quilleri* (Dodds)	X	X	--	X	X	--
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Procloeon* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Caenis* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Ephemeroptera	Ephemeridae	*Hexagenia limbata* (Serville)	X	--	--	--	--	--
Arthropoda	Insecta	Ephemeroptera	Ephemeridae	*Hexagenia* sp.	--	--	X	--	--	--
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	Heptageniidae	--	--	--	X	--	--
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	*Stenacron interpunctatum* (Say)	X	X	X	X	X	X
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	*Stenacron* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	*Stenonema femoratum* (Say)	X	X	X	X	X	X
Arthropoda	Insecta	Ephemeroptera	Isonychiidae	*Isonychia* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	*Tricorythodes* sp.	--	X	X	X	X	X
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	*Choroterpes* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	*Leptophlebia* sp.	X	X	X	--	--	--
Arthropoda	Insecta	Hemiptera	--	Heteroptera	--	--	--	--	X	X
Arthropoda	Insecta	Hemiptera	Belostomatidae	*Belostoma flumineum* (Say)	X	--	X	--	--	--
Arthropoda	Insecta	Hemiptera	Belostomatidae	*Belostoma* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Hemiptera	Corixidae	Corixidae	--	--	--	X	--	--
Arthropoda	Insecta	Hemiptera	Corixidae	*Sigara* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Hemiptera	Corixidae	*Trichocorixa* sp.	--	--	--	--	--	X
Arthropoda	Insecta	Hemiptera	Gerridae	Gerridae	--	--	--	X	--	X
Arthropoda	Insecta	Hemiptera	Gerridae	Gerrinae	--	--	--	X	X	--
Arthropoda	Insecta	Hemiptera	Gerridae	*Metrobates hesperius* (Uhler)	--	--	--	X	X	--
Arthropoda	Insecta	Hemiptera	Gerridae	*Rheumatobates hungerfordi* (Wiley)	--	--	--	--	--	X
Arthropoda	Insecta	Hemiptera	Gerridae	*Rheumatobates palosi* (Blatchley)	--	--	--	--	--	X
Arthropoda	Insecta	Hemiptera	Gerridae	*Rheumatobates* sp.	--	--	--	X	X	X
Arthropoda	Insecta	Hemiptera	Gerridae	*Trepobates* sp.	--	--	--	X	X	X
Arthropoda	Insecta	Hemiptera	Mesoveliidae	*Mesovelia mulsanti* (White)	--	--	--	X	--	X
Arthropoda	Insecta	Hemiptera	Mesoveliidae	*Mesovelia* sp.	--	--	--	X	X	--
Arthropoda	Insecta	Hemiptera	Naucoridae	*Pelocoris femoratus* (Palisot de Beauvois)	--	--	X	--	X	--
Arthropoda	Insecta	Hemiptera	Nepidae	*Ranatra fusca* (Palisot de Beauvois)	--	--	--	X	X	X
Arthropoda	Insecta	Hemiptera	Nepidae	*Ranatra nigra* (Herrich-Schaeffer)	--	--	X	X	X	X

Appendix 13. Macroinvertebrate taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[X, taxa present; --, not identified]

Phylum	Class	Order	Family	Taxa	April			August		
					Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Arthropoda	Insecta	Hemiptera	Nepidae	*Ranatra* sp.	--	--	--	X	--	X
Arthropoda	Insecta	Hemiptera	Pleidae	*Neoplea striola* (Fieber)	--	--	--	X	X	X
Arthropoda	Insecta	Hemiptera	Veliidae	*Microvelia* sp.	--	X	--	X	X	X
Arthropoda	Insecta	Hemiptera	Veliidae	*Rhagovelia oriander* (Parshley)	--	--	--	X	X	X
Arthropoda	Insecta	Hemiptera	Veliidae	*Rhagovelia* sp.	--	--	--	X	X	--
Arthropoda	Insecta	Lepidoptera	--	Lepidoptera	--	--	--	--	X	--
Arthropoda	Insecta	Megaloptera	Corydalidae	*Corydalus cornutus* (Linnaeus)	X	X	--	X	--	--
Arthropoda	Insecta	Odonata	--	Corduliidae/Libellulidae	--	--	--	--	--	X
Arthropoda	Insecta	Odonata	Aeshnidae	*Basiaeschna janata* (Say)	X	--	--	--	--	X
Arthropoda	Insecta	Odonata	Aeshnidae	*Nasiaeschna pentacantha* (Rambur)	X	X	X	X	X	X
Arthropoda	Insecta	Odonata	Calopterygidae	*Calopteryx maculata* (Beauvois)	--	X	X	--	X	--
Arthropoda	Insecta	Odonata	Calopterygidae	*Calopteryx* sp.	--	--	X	X	X	X
Arthropoda	Insecta	Odonata	Calopterygidae	*Hetaerina americana* (Fabricius)	X	X	X	X	X	X
Arthropoda	Insecta	Odonata	Calopterygidae	*Hetaerina* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Odonata	Coenagrionidae	*Argia plana* (Calvert)	--	--	--	--	--	X
Arthropoda	Insecta	Odonata	Coenagrionidae	*Argia* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Odonata	Coenagrionidae	*Argia translata* (Hagen)	X	--	X	--	X	X
Arthropoda	Insecta	Odonata	Coenagrionidae	Coenagrionidae	X	X	X	X	--	X
Arthropoda	Insecta	Odonata	Coenagrionidae	*Enallagma* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Odonata	Corduliidae	Corduliidae	--	--	--	--	--	X
Arthropoda	Insecta	Odonata	Corduliidae	*Epitheca princeps* (Hagen)	X	--	--	--	--	X
Arthropoda	Insecta	Odonata	Gomphidae	*Dromogomphus* sp.	--	--	--	X	--	X
Arthropoda	Insecta	Odonata	Gomphidae	*Gomphus* sp.	--	--	--	--	X	--
Arthropoda	Insecta	Odonata	Libellulidae	*Libellula* sp.	--	--	X	--	X	--
Arthropoda	Insecta	Odonata	Libellulidae	Libellulidae	--	--	X	--	--	X
Arthropoda	Insecta	Odonata	Libellulidae	*Plathemis lydia* (Drury)	--	--	--	--	--	X
Arthropoda	Insecta	Odonata	Macromiidae	*Macromia* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Plecoptera	Capniidae	*Allocapnia* sp.	X	--	--	--	--	--
Arthropoda	Insecta	Plecoptera	Capniidae	*Allocapnia vivipara* (Claassen)	X	--	--	--	--	--
Arthropoda	Insecta	Plecoptera	Leuctridae	*Zealeuctra* sp.	X	--	--	--	--	--
Arthropoda	Insecta	Plecoptera	Perlidae	*Perlesta* sp.	X	X	--	--	--	--
Arthropoda	Insecta	Plecoptera	Perlodidae	*Hydroperla* sp.	X	--	--	--	--	--

Appendix 13. Macroinvertebrate taxa identified at each biological sampling site on the upper Blue River during April and August 2008.—Continued

[X, taxa present; --, not identified]

Phylum	Class	Order	Family	Taxa	April			August		
					Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Arthropoda	Insecta	Plecoptera	Perlodidae	*Isoperla* sp.	X	X	--	--	--	--
Arthropoda	Insecta	Trichoptera	Helicopsychidae	*Helicopsyche borealis* (Hagen)	--	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche* sp.	X	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Hydropsyche betteni* (Ross)	--	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Hydropsyche* sp.	--	--	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsychidae	--	--	--	--	X	--
Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Hydroptila* sp.	--	--	--	X	X	X
Arthropoda	Insecta	Trichoptera	Leptoceridae	*Ceraclea* sp.	X	--	--	X	--	--
Arthropoda	Insecta	Trichoptera	Limnephilidae	*Ironoquia* sp.	X	X	X	--	--	--
Arthropoda	Insecta	Trichoptera	Limnephilidae	*Pycnopsyche* sp.	X	X	X	X	--	--
Arthropoda	Insecta	Trichoptera	Philopotamidae	*Chimarra* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Trichoptera	Polycentropodidae	*Polycentropus* sp.	--	--	--	X	--	--
Arthropoda	Insecta	Trichoptera	Rhyacophilidae	*Rhyacophila lobifera* (Betten)	X	X	--	--	--	--
Arthropoda	Malacostraca	Amphipoda	Crangonyctidae	*Crangonyx* sp.	X	X	X	--	X	X
Arthropoda	Malacostraca	Amphipoda	Hyalellidae	*Hyalella azteca* (Saussure)	X	X	X	X	X	X
Arthropoda	Malacostraca	Decapoda	Cambaridae	Cambaridae	X	X	--	X	X	X
Arthropoda	Malacostraca	Decapoda	Cambaridae	*Orconectes* sp.	X	--	X	X	X	X
Arthropoda	Malacostraca	Isopoda	Asellidae	*Lirceus* sp.	X	--	--	--	--	--
Bryozoa	--	--	--	Bryozoa	--	--	--	--	X	--
Mollusca	Bivalvia	Veneroida	Corbiculidae	*Corbicula* sp.	X	X	X	X	X	X
Mollusca	Bivalvia	Veneroida	Sphaeriidae	*Musculium* sp.	X	X	--	X	X	--
Mollusca	Bivalvia	Veneroida	Sphaeriidae	*Pisidium* sp.	--	X	--	X	--	X
Mollusca	Bivalvia	Veneroida	Sphaeriidae	*Sphaerium* sp.	X	X	--	X	--	--
Mollusca	Gastropoda	--	--	Gastropoda	--	X	--	--	--	--
Mollusca	Gastropoda	Basommatophora	Ancylidae	*Ferrissia* sp.	--	X	X	X	X	X
Mollusca	Gastropoda	Basommatophora	Lymnaeidae	*Fossaria* sp.	--	--	X	--	--	--
Mollusca	Gastropoda	Basommatophora	Physidae	*Physa* sp.	X	X	X	X	X	X
Mollusca	Gastropoda	Basommatophora	Planorbidae	*Micromenetus dilatatus* (Gould)	X	--	--	--	X	--
Mollusca	Gastropoda	Basommatophora	Planorbidae	*Planorbella* sp.	--	--	--	--	X	X
Mollusca	Gastropoda	Mesogastropoda	Hydrobiidae	Hydrobiidae	X	--	X	X	--	X
Nematoda	--	--	--	Nematoda	--	--	--	X	--	X
Nemertea	Enopla	Hoplonemertea	Tetrastemmatidae	*Prostoma* sp.	--	X	--	--	--	--
Platyhelminthes	Turbellaria	--	--	Turbellaria	X	X	X	X	X	X

Appendix 14. Four most dominant macroinvertebrate taxa based on relative abundance at each biological sampling site on the upper Blue River during April and August 2008.

[Percentages based on the mean of three samples.]

Month	Site	Four most dominant taxa (percentage of total abundance)
April	Kenneth	*Cricotopus/Orthocladius* sp. (11), *Stenelmis* sp. (9), *Rhyacophila lobifera* (7), *Acerpenna pygmaea* (6)
	151st	*Cricotopus/Orthocladius* sp. (16), *Stenonema femoratum* (10), *Cheumatopsyche* sp. (7), *Stenelmis* sp. (6)
	Blue Ridge	*Cricotopus/Orthocladius* sp. (20), *Acerpenna pygmaea* (8), *Caenis* sp.(6), *Stenonema femoratum* (6)
August	Kenneth	*Stenelmis* sp. (11), *Polypedilum* sp. (11),*Cheumatopsyche* sp. (10), *Enallagma* sp. (5)
	151st	*Polypedilum* sp. (12), *Cheumatopsyche* sp. (9), *Stenelmis* sp. (8), *Baetis* sp. (7)
	Blue Ridge	*Enallagma* sp. (10), *Cheumatopsyche* sp. (9), *Polypedilum* sp. (8), *Stenelmis* sp. (7)

Appendix 15. Macroinvertebrate metric scores at each biological sampling site on the upper Blue River during April and August 2008.

[Metric scores in **bold** indicate significant differences among sites (all p-value less than 0.05); Metric scores are based on the mean score of three replicate samples; ± 1 standard error in parentheses; ±, plus or minus; E, Ephemeroptera; P, Plecoptera; T, Trichoptera]

Metric	April			August		
	Kenneth	151st	Blue Ridge	Kenneth	151st	Blue Ridge
Richness metrics						
Chironomidae richness	12.0 (2.65)	12.0 (2.00)	11.3 (5.51)	9.33 (0.58)	9.67 (1.15)	13.3 (3.21)
Clinger richness	12.7 (2.89)	14.7 (2.08)	15.3 (2.31)	25.3 (.58)	22.7 (4.04)	24.3 (2.89)
Diptera richness	15.0 (2.65)	13.7 (1.53)	13.7 (5.86)	11.7 (.58)	11.3 (1.53)	15.0 (3.61)
Ephemeroptera richness	6.00 (0)	6.00 (1.00)	6.67 (1.15)	7.33 (1.53)	6.33 (2.08)	5.67 (.58)
EPT taxa richness	**13.3 (1.15)**	**10.3 (.58)**	**9.33 (1.15)**	12.3 (1.53)	9.00 (2.65)	8.67 (1.53)
Plecoptera richness	**3.33 (1.15)**	**.67 (.58)**	**0 (0)**	0 (0)	0 (0)	0 (0)
Trichoptera richness	4.00 (0)	3.67 (1.53)	2.67 (1.15)	**5.00 (1.00)**	**2.67 (.57)**	**3.00 (1.00)**
Total taxa richness	45.0 (4.36)	42.3 (1.53)	41.7 (9.24)	54.7 (2.89)	49.0 (3.61)	52.3 (6.03)
Taxonomic percentage abundance metrics						
Chironomidae, percent	24.4 (3.44)	26.2 (1.77)	30.2 (6.42)	20.7 (2.57)	25.6 (3.17)	24.5 (4.04)
Corbicula, percent	**.15 (.26)**	**2.46 (.91)**	**1.70 (.37)**	**.41 (.41)**	**1.69 (.74)**	**3.09 (.82)**
Diptera, percent	31.9 (2.05)	32.6 (2.40)	35.3 (5.33)	22.6 (3.68)	29.3 (3.21)	26.5 (3.19)
Dominant taxon, percent	**11.4 (.45)**	**15.6 (1.12)**	**20.0 (2.49)**	12.9 (1.07)	12.0 (1.26)	11.2 (1.67)
Ephemeroptera, percent	24.3 (3.38)	27.6 (3.23)	28.1 (4.56)	**15.0 (.70)**	**12.9 (2.44)**	**9.42 (1.51)**
Ephemeroptera and Plecoptera, percent	30.2 (4.27)	27.9 (2.99)	28.1 (4.56)	**15.0 (.70)**	**12.9 (2.44)**	**9.42 (1.51)**
EPT, percent	**42.2 (3.26)**	**39.2 (4.40)**	**32.9 (4.21)**	**28.0 (1.55)**	**26.5 (.75)**	**20.5 (.62)**
Five dominant taxa, percent	39.6 (2.58)	46.3 (3.94)	47.2 (3.58)	42.5 (1.62)	41.8 (4.35)	38.8 (.46)
Hydropsychidae Trichoptera, percent	**.26 (.15)**	**.84 (.09)**	**.88 (.10)**	.89 (.04)	.95 (.06)	.91 (.02)
Oligochaeta, percent	.63 (.55)	3.33 (1.01)	2.20 (.82)	**0.69 (.25)**	**.14 (.25)**	**.44 (.04)**
Other Diptera[1] and non-insects, percent	17.2 (2.94)	20.1 (3.25)	19.4 (3.00)	**12.7 (1.88)**	**20.3 (3.06)**	**16.5 (1.49)**
Plecoptera, percent	5.95 (2.65)	.29 (.25)	0 (0)	0 (0)	0 (0)	0 (0)
Tanytarsini midges, percent	.92 (.78)	.57 (.23)	.49 (.47)	1.90 (.80)	2.48 (.73)	2.47 (.29)
Trichoptera, percent	**12.0 (1.02)**	**11.4 (1.49)**	**4.79 (2.40)**	13.0 (1.15)	13.6 (1.84)	11.1 (2.03)
Two dominant taxa, percent	**20.1 (1.77)**	**26.1 (1.83)**	**29.3 (2.48)**	23.5 (1.19)	21.5 (.94)	20.4 (1.77)
Functional group percentage abundance metrics						
Clingers, percent	0.27 (0.01)	0.28 (0.02)	0.27 (0.01)	0.39 (0.01)	0.41 (0.04)	0.44 (0.07)
Filterers, percent	**11.0 (1.66)**	**19.7 (1.36)**	**10.6 (2.76)**	17.8 (1.66)	21.2 (2.41)	17.1 (1.75)
Predators, percent	25.6 (3.64)	13.6 (.55)	17.2 (4.71)	30.4 (3.53)	27.0 (3.61)	34.2 (4.26)
Scrapers, percent	27.1 (1.15)	25.9 (1.17)	22.6 (5.07)	**21.2 (1.38)**	**16.3 (1.45)**	**14.0 (2.67)**
Shredders, percent	4.68 (1.43)	4.05 (.27)	2.37 (1.33)	11.5 (2.24)	13.6 (.65)	10.2 (3.06)
Multiple indicator metrics						
Kansas Biotic Index	**2.48 (0.05)**	**2.81 (0.01)**	**2.72 (0.03)**	2.76 (0.03)	2.85 (0.06)	2.77 (0.01)
Macroinvertebrate Biotic Index	5.23 (.25)	5.47 (.02)	5.65 (.16)	**5.05 (.17)**	**5.58 (.09)**	**5.45 (.19)**
Other metrics						
EPT / Chironomidae ratio	**1.75 (0.26)**	**1.50 (0.20)**	**1.14 (0.34)**	**1.37 (0.20)**	**1.04 (0.11)**	**0.86 (0.16)**
Intolerant Taxa, percent	37.9 (2.85)	21.1 (3.80)	27.2 (3.00)	18.1 (2.11)	10.5 (2.61)	12.1 (2.59)
Scraper/filtering collector ratio	**2.50 (.47)**	**1.32 (.13)**	**2.16 (.22)**	**1.20 (.11)**	**0.78 (.10)**	**.84 (.24)**
Shannon Diversity Index	3.29 (.094)	3.16 (.040)	3.12 (.180)	3.43 (.012)	3.37 (.045)	3.45 (.096)

[1]Diptera other than Chironomidae.

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