Prepared in cooperation with the
JOHNSON COUNTY STORMWATER MANAGEMENT PROGRAM

Assessment of Biological Conditions at Selected Stream Sites in Johnson County, Kansas, and Cass and Jackson Counties, Missouri, 2003 and 2004

Scientific Investigations Report 2007–5108

U.S. Department of the Interior
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Front cover: Cedar Creek near 83rd Street, October 26, 2006 (photograph taken by Amber Johnstun, U.S. Geological Survey, Lawrence, Kansas).

Back cover: (Top left) Blue River near Kenneth Road, October 30, 2006 (photograph taken by Amber Johnstun, U.S. Geological Survey, Lawrence, Kansas); (Top right) Mill Creek near Shawnee Mission Park, April 29, 2006 (photograph taken by Teresa Rasmussen, U.S. Geological Survey, Lawrence, Kansas); (Bottom) Blue River near Kenneth Road, December 9, 2005 (photograph taken by Teresa Rasmussen, U.S. Geological Survey, Lawrence, Kansas).

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Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
micrometer (µm)	0.00003937	inch (in.)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
milliliter (mL)	0.0338	ounce, fluid (oz)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.4381	cubic meters per second (m^3/s)
	Mass	
microgram per milligram (µg/mg)	1.0×10^{-3}	ounce per ounce (oz/oz)
microgram per kilogram (µg/kg)	1.0×10^{-9}	ounce per ounce (oz/oz)

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

$$°F=(1.8\times°C)+32.$$

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

$$°C=(°F-32)/1.8.$$

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

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

Assessment of Biological Conditions at Selected Stream Sites in Johnson County, Kansas, and Cass and Jackson Counties, Missouri, 2003 and 2004

By Barry C. Poulton[1], Teresa J. Rasmussen[2], and Casey J. Lee[2]

Abstract

Macroinvertebrate samples were collected at 15 stream sites representing 11 different watersheds in Johnson County, Kansas, in 2003 and 2004 to assess biological conditions in streams and relations to environmental variables. Published data from an additional seven stream sites, one in Johnson County, Kansas, and six others in adjacent Cass and Jackson Counties in Missouri also were evaluated. Multimetric scores, which integrated a combination of measures that describe various aspects of biological community abundance and diversity, were used to evaluate and compare the biological health of streams. In addition, for 15 of 16 Johnson County stream sites, environmental data (streamflow, precipitation, and land use) and water- and sediment-quality data (primarily nutrients, indicator bacteria, and organic wastewater compounds) were used in statistical analyses to evaluate relations between macroinvertebrate metrics and variables that may affect them. The information is useful for defining current conditions, evaluating conditions relative to State aquatic-life support and total maximum daily load requirements, evaluating effects of urbanization, developing effective water-quality management plans, and documenting changes in biological condition and water quality.

Biological conditions in selected Johnson County streams generally reflected a gradient in the degree of human disturbances upstream from the sites, including percentage of urban and agricultural land use as well as the presence, absence, and proximity of wastewater treatment discharges. In this report, the term gradient is used to describe a continuum in the conditions (biological, environmental, or land use) observed at the study sites. Upstream Blue River sites, downstream from primarily agricultural land use, consistently scored among the sites least impacted by human disturbance, and in some metrics these sites scored higher than the State reference site (Captain Creek). The term impact, as used in this report, refers to a negative biological response at a site associated with one or more human-induced sources of disturbance or stress. However, no sites, including the Captain Creek reference site, met Kansas Department of Health and Environment criteria for full support of aquatic life during the 2 years of sample collection. Upstream sites on Kill and Cedar Creeks also consistently scored among the least impacted. Sites less than 3 miles downstream from municipal wastewater treatment facility discharges (two Indian Creek sites) and sites with no wastewater discharge but with substantial impervious surface area within their respective watersheds (Tomahawk, Turkey, and Brush Creeks) consistently scored among the sites most impacted by human disturbance.

Introduction

Johnson County, with a population of 496,700 people in 2004 (U.S. Census Bureau, 2005), is the fastest growing and most populous county in Kansas. Urban development affects streams by altering stream hydrology, geomorphology, water chemistry, fish and macroinvertebrate communities (Paul and Meyer, 2001) and increases public health concerns associated with exposure to and consumption of contaminated water (U.S. Environmental Protection Agency, 1999). The water quality of Johnson County streams is affected by point sources, including municipal wastewater and industrial discharges, and by nonpoint sources, including stormwater runoff from urban and agricultural watersheds.

Water-quality management is governed by several regulatory programs administered by the U.S. Environmental Protection Agency (USEPA) and State environmental agencies. The basic structure for regulating water quality was established by the Clean Water Act (CWA) of 1972, which states that "the objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" [Public Law 92-500, Clean Water Act, Section 101(a)]. Section 208 of the CWA requires every State to establish effective best management practices (BMPs) to control nonpoint-source pollution. The Water Quality Act (WQA), which added section 402 to the CWA in 1987, requires control of stormwater through the National Pollutant Discharge Elimination System

[1]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, Missouri.

[2]U.S. Geological Survey, Water Science Center, Lawrence, Kansas.

(NPDES) permit program. Johnson County municipalities are subject to requirements of the CWA and the NPDES program. In addition, section 303(d) of the CWA requires States to list water bodies that do not meet water-quality standards and to develop total maximum daily loads (TMDLs) that quantify the maximum pollutant loads allowed to attain established standards. Five major watersheds in Johnson County (Blue River, Cedar Creek, Indian Creek, Kill Creek, and Mill Creek) have stream segments that have been included on the 303(d) list or have had TMDLs developed by the Kansas Department of Health and Environment (KDHE) as a result of impaired water quality (Kansas Department of Health and Environment, 2004). Most stream impairments are related to excessive nutrients, bacteria, and sediment. One of several new TMDLs submitted to USEPA for approval early in 2006 was developed to address biological impairments in the Mill Creek watershed. It is the first TMDL in Kansas that considers biological endpoints to indicate full support of aquatic life (Kansas Department of Health and Environment, 2006a).

In 2002, the U.S. Geological Survey (USGS), in cooperation with the Johnson County Stormwater Management Program, began an investigation to characterize the water quality of Johnson County streams and to provide information for use by municipalities in developing effective water-quality management plans. Initial study efforts described the effects of nonpoint and selected point contaminant sources on stream-water quality and their relation to land use (Lee and others, 2005). Subsequent phases of the investigation were designed to characterize biological conditions of county streams and to estimate water-quality constituent loads for different watersheds.

Biological assessments are crucial components of water-quality programs because they determine how well a water body supports aquatic life (U.S. Environmental Protection Agency, 2002). Aquatic life integrates the cumulative effects of various stressors over time, including variable streamflow, nutrients, potentially toxic chemicals, and excessive sediment and, therefore, provides information that measurements of water chemistry alone may not detect (U.S. Environmental Protection Agency, 2002). Biological assessments involve the systematic examination of aquatic communities including vegetation, algae, zooplankton, fish, amphibians, and aquatic macroinvertebrates. These components are used separately or together along with other indicators such as water chemistry to provide a thorough evaluation of biological integrity and stream health. Biological integrity is the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition, diversity, and functional organization comparable to that of the natural habitats of the region (Frey, 1977; U.S. Environmental Protection Agency, 1990). In addition, biological information can be used by States to develop biological criteria and establish aquatic-life goals for particular water bodies. Macroinvertebrate communities were evaluated for this biological assessment because they are reliable indicators of biological conditions in streams, data exist for comparison, and the State of Kansas was developing TMDLs using macroinvertebrate endpoints.

As urban development in Johnson County increases in the future, water quality will change at a rate that will be dictated by the degree of protection from water pollution or habitat loss, and urban planning efforts. Further, water resources generally are not fully judged on their ability to support healthy communities but often on evaluation criteria dictated by management objectives (intended resource use, for example). Management objectives designed to protect water quality may include land acquisition and set asides, protection of stream riparian corridors, bank stabilization techniques, and strategies related to the consolidation and proper discharge of wastewater.

Purpose and Scope

The purpose of this report is to describe relative biological conditions of 15 stream sites in Johnson County, Kansas, in 2003 and 2004 using macroinvertebrate community indicators and their relation to environmental variables such as land use and water and sediment quality. The report also includes a comparison to previously published data from seven downstream sites in Johnson County and in adjacent Cass and Jackson Counties in Missouri (Wilkison and others, 2005). The results in this report can be used by Johnson County officials to develop water-quality management strategies and to establish baseline information for comparing future conditions and changes at individual sites and within the watersheds being studied.

Relative biological conditions in Johnson County streams representing 11 watersheds were evaluated by: (1) examining community composition and relative abundance of resident aquatic macroinvertebrate communities, (2) scoring, ranking, and grouping the sites using combinations of macroinvertebrate metrics, (3) describing statistical relations between macroinvertebrate results and environmental variables (land use and water and sediment quality) that can be used to define a gradient in human-induced adverse effects, (4) assigning stream sites to impairment categories on the basis of ability to support aquatic life as defined by the biological indicators outlined by KDHE (Kansas Department of Health and Environment, 2006b), (5) evaluating the effects of urbanization on macroinvertebrate communities, (6) identifying the least-impacted sites remaining in the area that might be possible candidates for additional protection or for defining reference conditions in particular watersheds, (7) comparing data from Johnson County sites to published data from selected downstream sites in Missouri, and (8) providing an initial evaluation of the suitability of additional macroinvertebrate metrics that have potential for bioassessments in urban streams. In this report the term "gradient" is used to describe a continuum in the conditions (biological, environmental, or land use) observed at the study sites, and the term "impact" refers to a negative biological response at a site associated with one or more human-induced sources of disturbance or stress.

Acknowledgments

The authors are grateful to Eileen Hack of the Johnson County Public Works Department for technical assistance, support, and planning efforts for the macroinvertebrate sampling. The authors also thank Scott Grotheer at the USGS National Water Quality Laboratory in Lakewood, Colorado, for technical assistance with macroinvertebrate taxonomy and data entry. The authors appreciate the help of the Johnson County Environmental Laboratory (Tony Holt and Pedro Calderon) for their coordination efforts in laboratory analysis of water-quality samples and the Johnson County Automated Information Mapping System (Shannon Porter) for providing land-use data.

Previous Investigations

Macroinvertebrate communities have been investigated at several stream sites in Johnson County as part of various studies conducted by the county and the statewide biological monitoring program. However, no comprehensive reports on the subject have been published for Johnson County streams.

The most recent water-quality assessment of Johnson County streams was published by Lee and others (2005) and described the effects of contaminant sources on stream-water quality and their relation to varying land use. According to the report, during base-flow conditions, discharge from wastewater treatment facilities (WWTFs) comprised greater than 50 percent of streamflow at the farthest downstream sampling site in six of the seven watersheds studied. Nutrient, organic wastewater-indicator compound, and pharmaceutical compound concentrations generally were highest at sites at, or immediately downstream from, WWTFs during base flow. Stormflow samples had the highest suspended-sediment concentrations and indicator bacteria densities. Other than in samples from sites immediately downstream from wastewater treatment discharges, stormflow samples generally had the highest nutrient concentrations.

In addition to Lee and others (2005), USGS has examined components of urban stormwater runoff and point-source effluents within the Blue River and Indian Creek watersheds, located in the southern part of the Kansas City metropolitan area shared by Missouri and Kansas. In 2002, a macroinvertebrate bioassessment was added to these investigations (Wilkison and others, 2005, 2006). However, most of this work concentrated on hydrological modeling of nutrient loads, identification of tracer compounds and loads in streams and municipal effluents, water-quality monitoring, bacteriological source tracking, effluent discharge modeling, and determination of the loads of various contaminants in these receiving streams (Blevins, 1986; Wilkison and others, 2002, 2005, 2006).

The physical and hydrological effects of urbanization on stream systems have been well documented; however, the biological communities in urbanized watersheds have not been adequately studied in many of the larger metropolitan areas of the Midwest. Only a small percentage of studies that evaluate macroinvertebrate communities have been conducted in urban stream systems. Specifically, the responses of particular community-level attributes (in other words, metrics such as those related to functional feeding groups or specific indicator groups with known or suspected tolerances to different levels of water pollution) to combinations of urban runoff, municipal effluents, industrial discharges, and habitat destruction are poorly known. Existing literature suggests that the general response of macroinvertebrate communities to increased urban development includes diminished biological integrity resulting from a reduction in total species numbers and diversity and increased dominance of more pollution-tolerant species (U.S. Environmental Protection Agency, 1999). Examples of pollution-sensitive and pollution-tolerant organisms are shown in figure 1.

Description of Study Area

The study area includes Johnson County, Kansas, which is located in the western part of the Kansas City metropolitan area (fig. 2) and consists of 477 mi2 of surface area (U.S. Census Bureau, 2005). The county contains all or parts of 22 HUC–14 (Seaber and others, 1987) watersheds, the largest 11 of which are within the 15-site sampling network (fig. 2, table 1). Published data from an additional seven stream sites, one in Johnson County, Kansas, on Indian Creek and six others in adjacent Cass and Jackson Counties in Missouri (Wilkison and others, 2005), also were evaluated. Designated uses for streams within these counties include support of aquatic life, contact recreation, drinking-water supply, food procurement, ground-water recharge, irrigation, industrial use, and livestock watering. Fifteen municipal and five private wastewater treatment facilities are located within Johnson County watersheds.

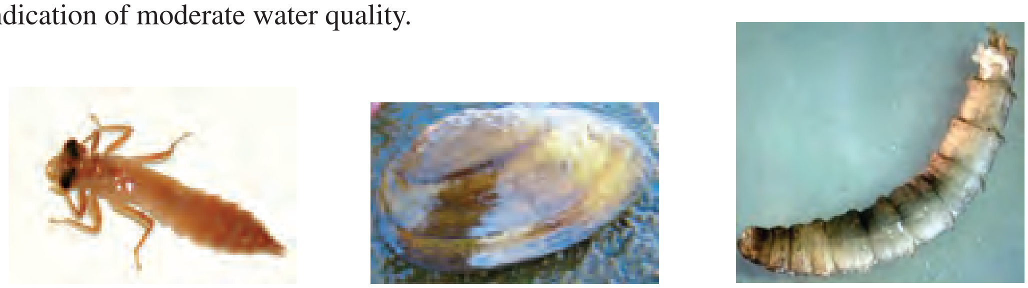
The mean annual temperature for Johnson County, Kansas, is about 55 °F, with a mean monthly range from 28 °F in January to 78 °F in July (National Oceanic and Atmospheric Administration, 1966–98). Mean annual precipitation (1961–90) is about 40 in., with 68 percent of the rain occurring from April through September (National Oceanic and Atmospheric Administration, 1966–98).

Population increases in Johnson County have resulted in increased urban and suburban land uses. Since 1990, land parcels dedicated to residential and commercial land use in Johnson County have increased more than 45 percent (K. Skridulis, Johnson County Appraiser's Office, written commun., 2004). Figure 3 shows urban (commercial, industrial, parks, and residential) and nonurban land use for Johnson County in 2003. The northeastern part of the county including the Brush Creek, Dykes Branch, Indian Creek, Rock Creek,

(A) The organisms shown below generally are pollution tolerant so they can live in streams with large amounts of contaminants. The presence of these organisms in large numbers is usually an indication of poor water quality.

Midges (Chironomidae) Leech (Hirudinea) Worm (Oligochaeta)

(B) The organisms shown below generally are moderately tolerant so they can live in streams with small amounts of contaminants. The presence of these organisms is usually an indication of moderate water quality.



Dragonfly (Odonata) Freshwater mussel (Mollusca) Cranefly (Tipulidae)

(C) The organisms shown below are sensitive to small amounts of contaminants. The presence of these organisms in large numbers is usually an indication of good water quality.

Mayfly (Ephemeroptera) Stoneflies (Plecoptera) Caddisfly (Trichoptera)

Figure 1. Examples of aquatic macroinvertebrates and their association with general water-quality conditions. Photographs from *http://www.epa.gov/bioindicators/html/photos_invertebrates.html*

Tomahawk Creek, and Turkey Creek watersheds contain the most urban development with more than 75 percent of the watersheds devoted to residential, commercial, industrial, and right-of-way land uses. More than 18 percent of these watersheds are covered by impervious surfaces. The Blue River and Mill Creek watersheds are experiencing the most recent development (Mid-America Regional Council, 2002). Figure 4 shows agricultural (commercial, cropland, grassland, canopy cover, and nonusable) and nonagricultural land use for 2003. Watersheds shown in figures 3 and 4 represent major watersheds recognized by Johnson County officials and in some cases include multiple HUC–14 watersheds.

Recreational development planning has been in progress in Johnson County since the 1950s when a parks and recreation district was created to provide funding for land acquisition and comprehensive planning began for recreational opportunities such as multi-use centers, impoundments, and streamway parks. In 1986, the district began implementation of the streamway park system, where lands adjacent to streams were acquired and developed into facilities connected with a

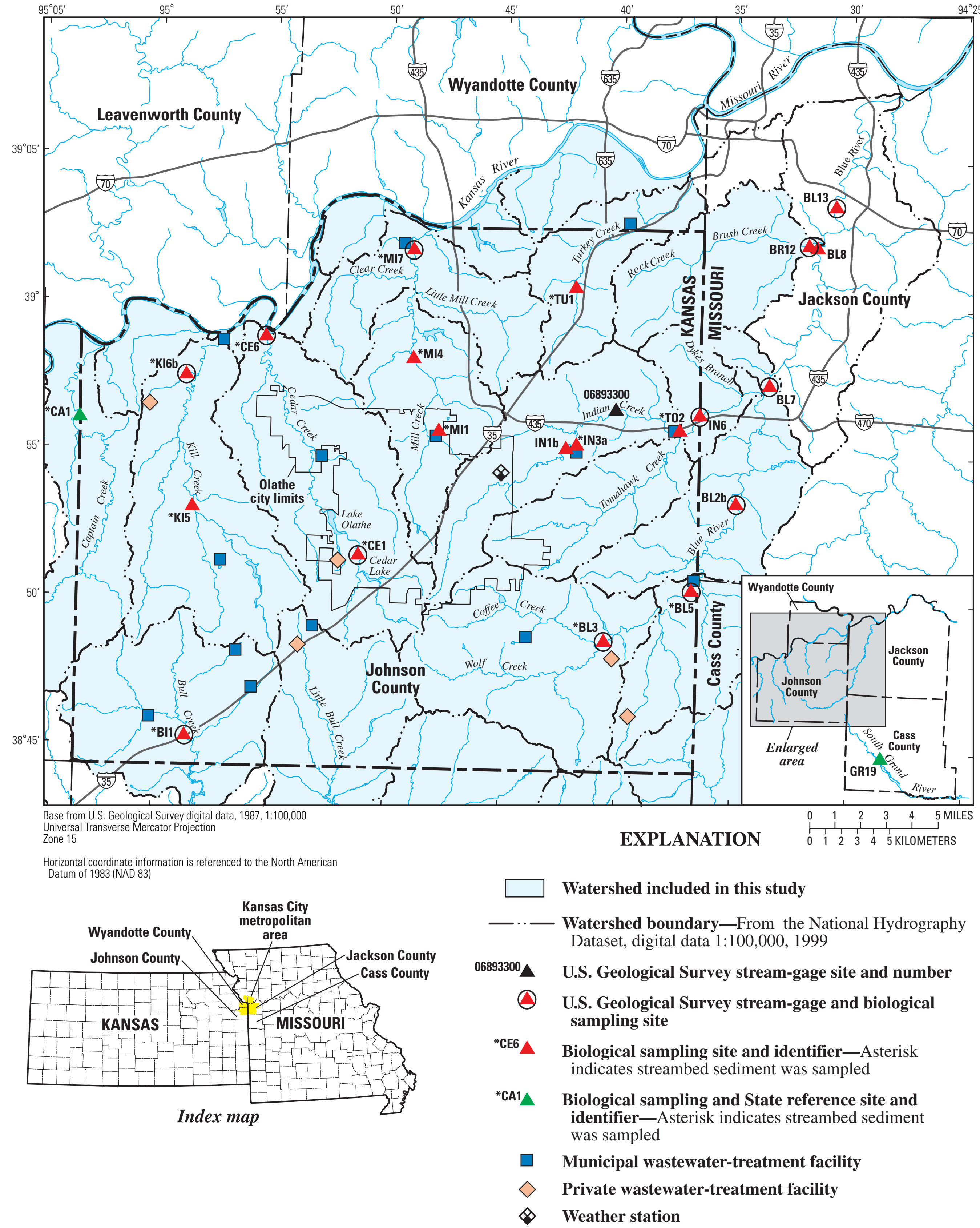


Figure 2. Location of biological sampling sites in Johnson County, Kansas, and Cass and Jackson Counties, Missouri, 2003 and 2004. Watershed boundaries are from the National Hydrography Dataset, digital data 1:100,000, 1999.

Table 1. Location and description of biological sampling sites in Johnson County, Kansas, and Cass and Jackson Counties, Missouri, 2003 and 2004, including drainage area, land cover, and distance downstream from nearest wastewater discharges.

[Land-cover percentages from Johnson County Automated Information Mapping System, written commun., 2003; --, not determined or not applicable]

Site identifier (fig. 2)	Site description				Approximate land cover (percent)		General land classification[1]	Distance downstream from nearest wastewater discharge (miles)
	Stream and location	U.S. Geological Survey station number	County	Drainage area (mi^2)	Urban	Impervious surface		
			Kansas					
BL3	Blue River near Stanley (Highway 69)[2]	06893080	Johnson	46.5	24.4	1.9	Rural	--
BL5	Blue River at Kenneth Road[2]	06893100	Johnson	65.7	21.6	3.0	Rural	--
IN3a	Indian Creek at College Blvd.	385520094420000	Johnson	15.8	76.4	22.5	Urban	0.6
IN6	Indian Creek at State Line Road[2]	06893390	Johnson	63.1	74.5	23.2	Urban	1.4
TO2	Tomahawk Creek at 111th Street	385539094372100	Johnson	23.0	70.0	18.4	Urban	--
TU1	Turkey Creek at 67th Street	390027094415600	Johnson	6.7	78.6	30.9	Urban	--
MI1	Mill Creek at 127th Street	385356094491200	Johnson	4.4	58.4	23.9	Urban	--
MI4	Mill Creek at 87th Street Lane	385800094485300	Johnson	19.4	47.9	15.0	Urban	5.8
MI7	Mill Creek at Johnson Drive[2]	06892513	Johnson	58.8	50.3	12.2	Urban	12.7
CE1	Cedar Creek at Old Highway 56[2]	06892440	Johnson	13.2	31.9	5.4	Rural	--
CE6	Cedar Creek near DeSoto (83rd Street)[2]	06892495	Johnson	58.5	26.9	3.9	Rural	9.7
KI5	Kill Creek at 135th Street	385303094582300	Johnson	18.9	25.0	3.6	Rural	4.4
KI6b	Kill Creek at 95th Street[2]	06892360	Johnson	48.6	16.7	2.9	Rural	13.1
BI1	Big Bull Creek near Edgerton[2]	06914950	Johnson	26.5	8.7	1.9	Rural	2.9
CA1	Captain Creek at 119th Street[3]	385540095032800	Johnson	16.0	2.5	1.0	Rural	--
			Kansas and Missouri (Wilkison and others, 2005)					
BL2b	Blue River at Blue Ridge Blvd. Extension[2]	06893150	Jackson, MO	93.1	32.9	16.0	Urban	4.7
BL7	Blue River near Kansas City, MO (Bannister Road)[2]	06893500	Jackson, MO	184	50.4	18.7	Urban	[5]5.1
BL8	Blue River at Blue Parkway[2]	06893552	Jackson, MO	213	53.4	19.2	Urban	[5]13.8
BL13	Blue River at Stadium Drive[2]	06893578	Jackson, MO	259	60.0	21.8	Urban	[5]23
IN1b	Indian Creek at Highway 69[4]	06893270	Johnson, KS	26.6	62.3	20.0	Urban	--
BR12	Brush Creek at Elmwood Avenue[2]	06893564	Jackson, MO	29.9	94.1	47.1	Urban	--
GR19	South Fork Grand River below Freeman[3]	06921582	Cass, MO	150	.1	2.0	Rural	--

[1]Urban sites have greater than 32 percent urban land use and greater than 10 percent impervious surface.

[2]U.S. Geological Survey stream-gage station name; data available at *http://waterdata.usgs.gov/nwis*. Station number 06893300 on Indian Creek was not a biological sampling site and is not listed in the table.

[3]State reference site.

[4]Located in Johnson County, Kansas, but sampled as part of the Missouri study.

[5]Receives wastewater discharge from more than one facility.

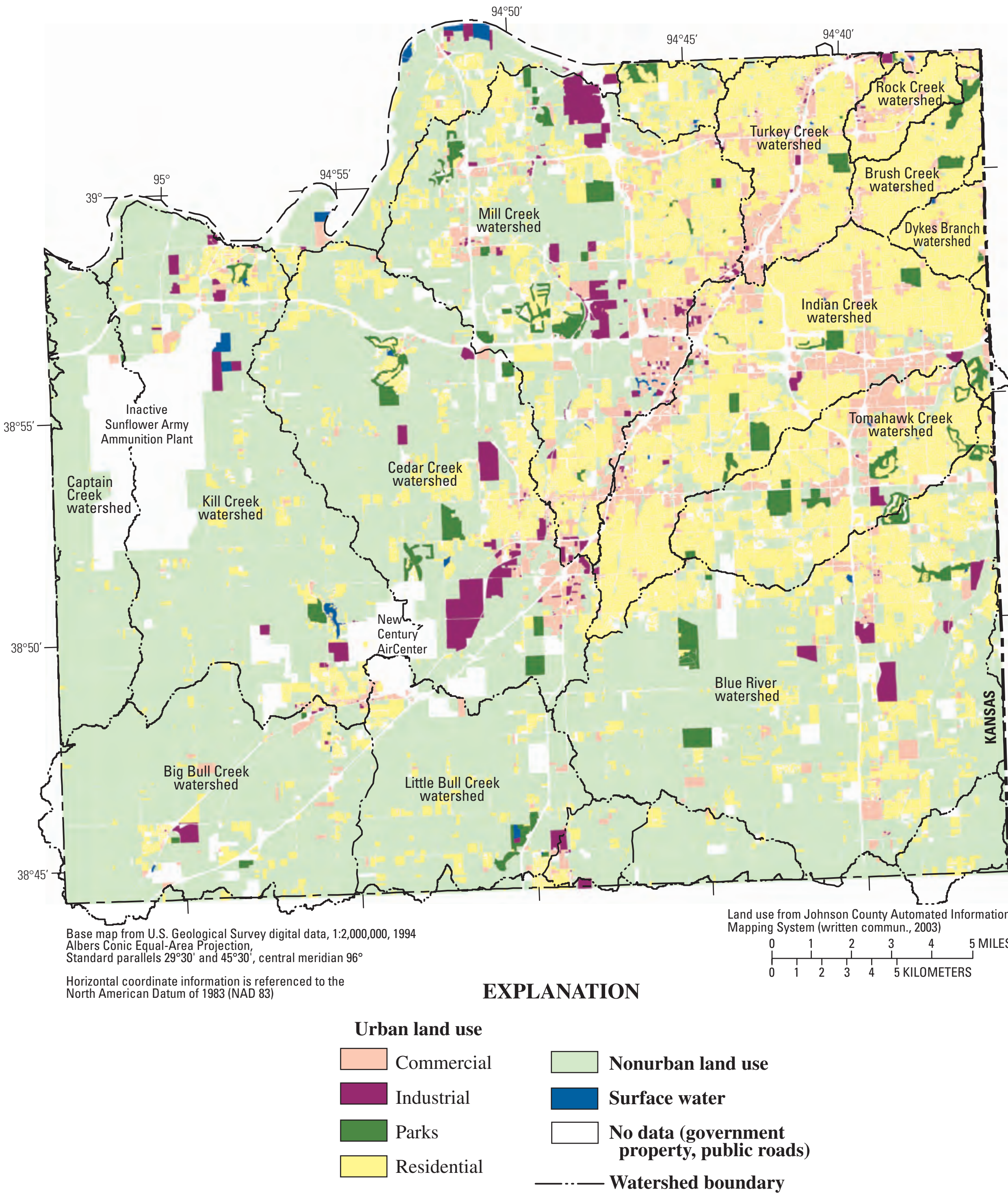


Figure 3. Urban (commercial, industrial, parks, residential), nonurban, and surface-water land use in Johnson County, northeastern Kansas, 2003.

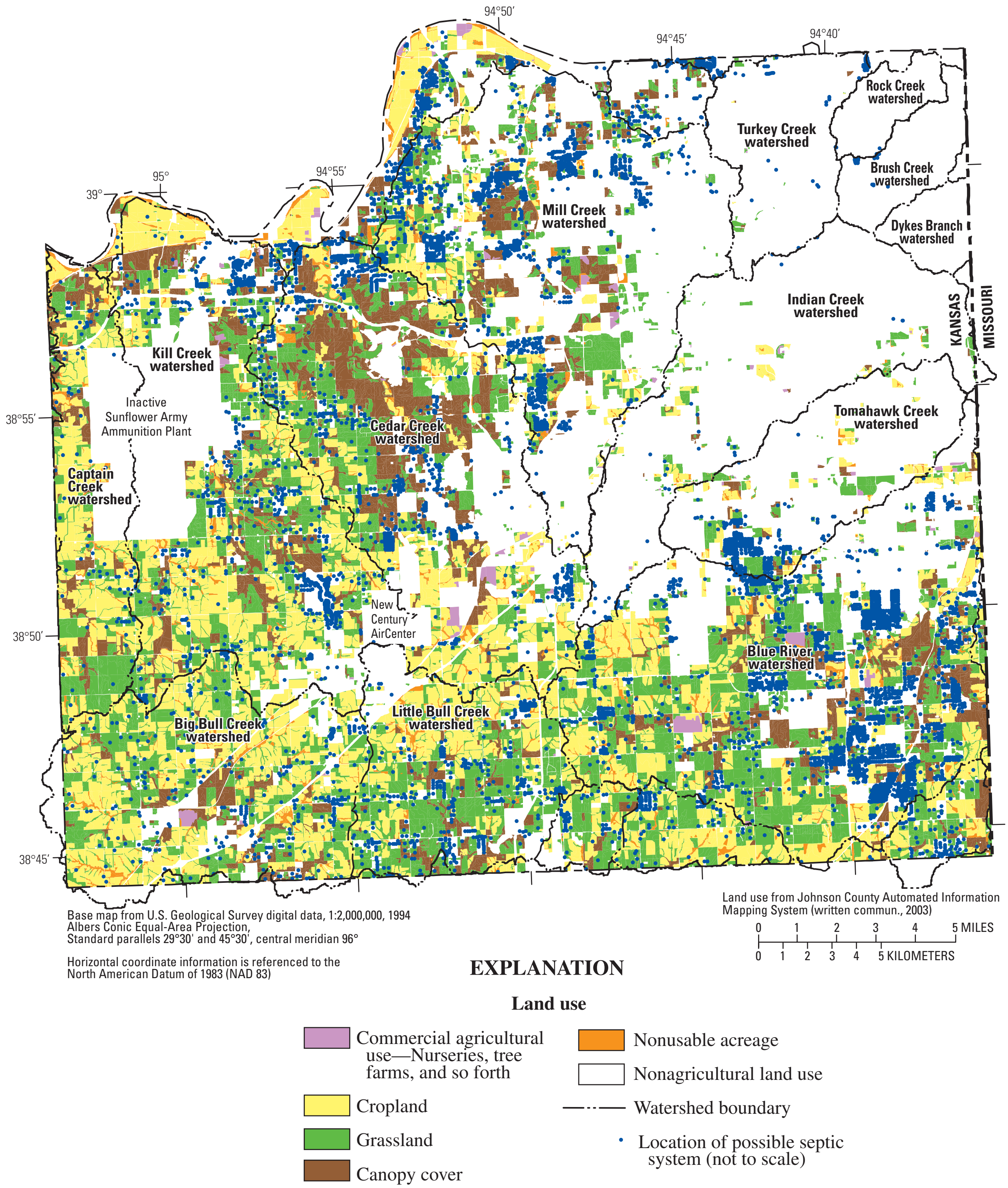


Figure 4. Agricultural and nonagricultural land use in Johnson County, northeastern Kansas, 2003.

network of accessible trails that followed the stream riparian corridors (Johnson County, 2003). Streamway parks exist along several of the streams sampled in this study including Cedar, Indian, Kill, Mill, and Turkey Creeks. More streamway parks are planned for the future, and in many parts of Johnson County, these lands are being acquired and improved into parks before urban development has occurred. Many of the sites included in this study are located within the streamway park system, and several Missouri sites are also located adjacent to park lands. Other locations within Johnson County have been selected for planned residential development and the construction of impoundments to enhance recreational opportunities.

Methods

The general approach used in this study was to collect macroinvertebrate samples during early spring of two consecutive years (2003 and 2004). Data then were evaluated by calculating various macroinvertebrate metrics and comparing results to previously published macroinvertebrate data for sites primarily in downstream locations in Missouri (Wilkison and others, 2005). Data also were compared to previously published water and sediment data for Johnson County (Lee and others, 2005).

Macroinvertebrate samples were collected using KDHE protocol outlined in the Quality Assurance Management Plan for the Stream Biological Monitoring Program implemented by the State of Kansas (Kansas Department of Health and Environment, 2000). This protocol was used because it provided an opportunity to place stream sites into aquatic-life impairment categories defined by the State of Kansas and to reduce sample cost as compared to protocols that normally include more extensive laboratory sorting. A brief summary of the procedure follows.

Onsite water-quality properties were measured concurrently with macroinvertebrate collection. However, sampling for other constituents at these sites, including streamflow and water and streambed sediment, was performed at various times between October 2002 and March 2003. A flowchart depicting the sequence of approaches and procedures that were applied to the data is provided in figure 5 and summarized in the following sections. For the purposes of this study, urban sites are those sites with drainage areas containing more than 32 percent urban land use and more than 10 percent impervious surface area.

Site Selection

Fifteen sampling sites (fig. 2) in Johnson County were selected on the basis of availability of previously collected data (by USGS, KDHE or Johnson County), concurrent studies related to monitoring of streamflow, water quality, contaminant loading in sediment, and both chemical and biological (bacteriological) components of stormwater runoff (Lee and others, 2005). An additional seven sites, all of which are located downstream in Cass and Jackson Counties in Missouri except one (site IN1b, Indian Creek at Highway 69 in Johnson County), also were sampled as part of a separate study with similar objectives being conducted in conjunction with the city of Kansas City, Missouri (Wilkison and others, 2005, 2006). The study sites also included two streams (Captain Creek in Kansas and South Fork Grand River in Missouri, sites CA1 and G19, respectively) that both States consider as suitable reference sites.

Although the focus of this study was on sites in Johnson County, Kansas, data from the seven sites associated with the Missouri study were evaluated in some parts of this report because their inclusion enabled a watershed-based evaluation with a continuum in the amount of adverse effects related to nutrient loading and urban point and nonpoint-source runoff within selected watersheds in the southern part of the Kansas City metropolitan area (fig. 2, table 1). Also, both Kansas and Missouri sites are included together in some parts of this report because the same sampling protocol was used concurrently at all of the sites in both years, and many of the assessment results can be strengthened by the inclusion of more than one reference stream site and a larger total number of sites. Further, the political boundary that exists was not expected to have a direct effect on the results.

Macroinvertebrate Community Indicators

Sample Collection

Macroinvertebrate community samples were collected at the 15 Kansas study sites and the 7 Missouri study sites (Wilkison and others, 2005) during base-flow conditions on March 4–13, 2003, and February 24–March 3, 2004. Sampling was conducted in late February and early March to obtain samples representative of benthic communities and to precede pulses of early spring runoff that may have disrupted benthic populations. In addition, macroinvertebrate samples collected from small streams in late winter and early spring seasons often have greater diversity compared to samples collected in other seasons (Feminella, 1996) because emergence periods of many stream insect species coincide with spring and early summer periods.

To provide maximum consistency in sampling macroinvertebrates using KDHE protocol at all of the stream sites, additional guidance and equipment was provided to the field personnel. KDHE protocol includes two independently collected 100-organism samples that are counted in the field by two scientists (Kansas Department of Health and Environment, 2000). In this study, the two samples were combined into one 200-organism sample after laboratory enumeration and identification were completed. To minimize bias in the sampling and field-sorting process, a checklist of the major stream habitats (pools, riffles, runs) was completed at each site

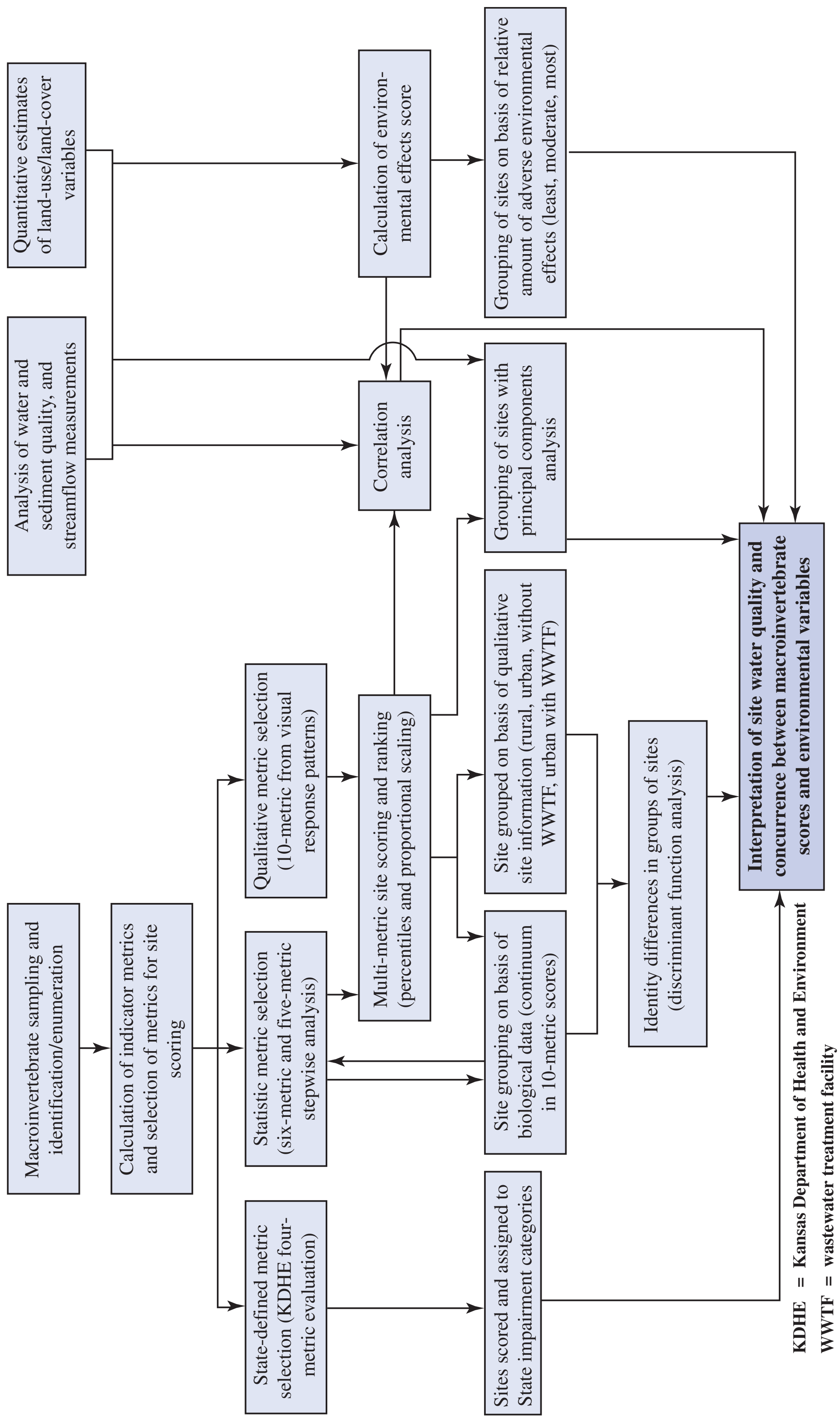


Figure 5. Approach used to evaluate relative biological conditions at Johnson County sampling sites and relations with environmental variables.

to assure thorough sample coverage. In addition, a large white sorting tray (31 in. x 25 in. x 2.75 in.) elevated on a portable stand at streamside was used to spread out debris during sorting and enhanced the visibility of the organisms. These changes did not represent a major deviation from KDHE protocol but rather provided more detail in an attempt to improve consistency among samples and between sample collections.

Macroinvertebrate samples were collected with a standard 9- x 18-in. rectangular frame kicknet with a mesh size of approximately 500 µm following physical disturbance of the substrate upstream from the net. In standing-water habitats, the net was used with a sweeping or scooping motion. A small amount of water was placed in the sorting tray along with the sample debris to enhance the visibility of the organisms. A hand counter was used to count the organisms as they were removed from the tray with forceps. Each site was sampled with two scientists sorting simultaneously using their own set of equipment for no more than approximately 1 hour. If 100 organisms were not obtained in the allotted time period, sampling ended. Not more than 50 percent of the organisms sorted came from any one of the habitats available. Every attempt was made to assure that the maximum diversity of organisms was obtained during sorting and that each sample represented relatively uniform coverage of the habitats present. Removal of organisms followed the morphospecies principle, meaning that any organism visually appearing different than those previously sorted was included in the sample. Every attempt was made to consider organism size, making certain that both large and small animals were included.

All of the stream habitats encountered were not always present at every site, but those habitats or substrate types that were included to obtain the 100 organisms were noted on the field sheet. The habitats generally were located in both fast-flowing areas as well as slack water. These habitats 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 along margins or around snags, and large moveable objects such as logs or rocks where handpicking may reveal additional taxa. After sampling any one habitat, if there were no taxa that appeared different, or if no organisms from that habitat were included in the sample container, this was noted on the field sheet. The two, 100-organism samples were preserved in 80-percent ethanol onsite in 125-mL polyethylene bottles. The sample bottles were labeled with site name, date, and collector's initials. Samples were topped off with preservative and sealed with tape before sending them to the USGS National Water Quality Laboratory in Lakewood, Colorado, for identification and enumeration.

Identification and Enumeration

Identification and enumeration of the organisms and the taxonomic references used for each of the organism groups are outlined in Moulton and others (2000) and represent the same procedure utilized by the USGS National Water-Quality Assessment (NAWQA) Program for obtaining biological data from stream samples. This included examination of most specimens under a dissecting microscope and mounting of midge specimens (Diptera: Chironomidae) on glass slides for identification under a compound microscope. In general, identification was to the lowest practical taxonomic level (usually genus or species).

In several cases, the raw data included certain groups of organisms that represent taxonomic complexes where individual genera or species could not be readily distinguished from one another. In part, this dilemma can be caused by damage to organisms and loss of key structures, or slide mounts that did not clearly show diagnostic characters. Because these problems have varying effects among samples, a few of these taxa had to be lumped before mathematical calculations and analyses were performed. In a few cases, some terrestrial (non-aquatic) organisms or life stages were included in the samples, and these organisms were omitted. The data initially were recorded in a spreadsheet.

Calculation of Metrics

Benthic macroinvertebrate metrics were determined from the data using appropriate mathematical or statistical equations. A total of 22 different metrics were calculated, a complete list of which is given in table 2. All metrics were calculated for each sampling year separately and were determined from categories outlined by Barbour and others (1992, 1995). These included: (1) metrics that provided a visual response pattern across the sites (distinct increase or decrease throughout the range of observed site conditions on the basis of known or expected sources of disturbance or stress such as urbanization, land use, or point-source discharges), (2) core metrics used in many State evaluation programs, and (3) metrics known to be sensitive and reliable for measuring degradation of stream assemblages on the basis of available literature. Unless otherwise indicated, individual metrics were calculated as described in the references listed in table 2.

An independence test was performed on the relative percentage difference (RPD) of individual metric values between 2003 and 2004 data. The Mann-Whitney nonparametric test for independence (using a probability of error, or p-value, of 0.05; Helsel and Hirsch, 1992) was used to identify any significant differences between sampling years, between sampling sites, and between rural and urban sampling sites.

Selection of Metrics for Site Evaluation

Biological conditions were determined for the sampling sites by calculating different combinations of indicator metrics, which resulted in an overall multimetric site score that was used for evaluating site quality (Karr, 1993; Fore and others, 1994). The site scores were generated by different approaches or rating methods and used as a guide to evaluate the relative conditions or degree of biological impacts at the

Table 2. List of benthic macroinvertebrate metrics and abbreviations determined for sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), 2003 and 2004, and their status for inclusion in different multimetric combinations.

[KDHE metrics are those used for evaluating the condition of aquatic life in Kansas streams (Kansas Department of Health and Environment, 2006a). Metric selection from the STEPWISE statistical procedure is described in the "Methods" section; KDHE, Kansas Department of Health and Environment; X, metric included in evaluation; %, percentage; <, less than]

Metric name and reference (if available)	Abbreviation	KDHE metrics	Best 10 metrics	STEPWISE		Metric status[1]
				Five-metric solution	Six-metric solution	
Macroinvertebrate Biotic Index (MBI) (Davenport and Kelly, 1983)	MBI	X	X			CM
Kansas Biotic Index (KBI–NO) (Huggins and Moffett, 1988)	KBI–NO	X	X			CM, RP
Ephemeroptera-Plecoptera-Trichoptera (EPT) taxa richness (Klemm and others, 1990)	EPTRich	X	X	X	X	CM
EPT abundance (Barbour and others, 1999)	%EPT	X				CM, HR, WP
Total taxa richness (Barbour and others, 1999)	TRich		X	X	X	CM
Chironomidae taxa richness (Hayslip, 1993)	ChRich					WP
Percentage of Chironomidae, (Lenat, 1983; Barbour and others, 1994)	%Chir					WP
Percentage of filterers (Hayslip, 1993)	%Fil					WP
Percentage of scrapers (Barbour and others, 1999)	%Sc		X		X	RP
Ratio of abundances EPT/Chironomidae (Ferrington, 1987)	EPT/Chir					WP
Ratio of abundances scrapers /filtering collectors (Plafkin and others, 1989)	Sc/Fc			X	X	HR
Percentage of COP midges (*Cricotopus, Orthocladius, Paratrissocladius*)	%COP					WP
Percentage of Oligochaeta (Lenat, 1993; Kerans and Karr, 1994)	%Olig		X			RP
Ratio of abundances EPT/Oligochaeta	EPT/Olig					HR, WP
Percentage of Ephemeroptera (Schloesser and others, 1991)	%Eph					HR
Percentage of Filtering Trichoptera (Camargo, 1992)	%FT					WP
Percentage of *Tanytarsini* midges (DeShon, 1995)	%Tany		X	X	X	RP
Percentage of intolerant organisms (MBI < 6), (DeShon, 1995)	%Int–MBI					HR
Percentage of intolerant organisms (KBI < 3) (Huggins and Moffett, 1988)	%Int–KBI		X	X	X	RP, MM
Percentage of dominant taxon (Shackleford, 1988)	PDT					WP
Percentage of Ephemeroptera and Plecoptera	%EP		X			RP, MM
Shannon-Weiner Diversity Index (SWDI) (Washington, 1984)	SWDI		X			CM

[1]Metric status:
CM = Core metric in State assessment evaluations or commonly used in literature.
MM = Represents a modification of a commonly used metric adapted for particular assessment situations.
RP = A reasonable response pattern was evident.
HR = Not included in one or more site rating schemes, possible high redundancy with other metrics that were included.
WP = Not included in one or more site rating schemes; response pattern bimodal, weak, or not evident.

sites. In this study, metric combinations were used to represent a measure of stream condition on the basis of resident biota and to provide a continuum of biological response to overall human-induced disturbances among the study sites as outlined by the Biological Condition Gradient conceptual model (Davies and Jackson, 2006). The continuum of biological response as indicated by these metric combinations also provided a basis for grouping or categorizing sites for statistical analysis and further screening of metrics for site scoring. In addition, integrating individual metrics into multimetric combinations minimized the bias that might occur when relying on only one or two metrics for evaluation.

The choice of metrics to be utilized in each multimetric combination and the number of metrics included in these combinations were determined by three methods: (1) four metrics pre-selected by the State of Kansas (KDHE metrics) to evaluate the stream's ability to support aquatic life defined by the State 305(b) water-quality assessment (Kansas Department of Health and Environment, 2006b), (2) examination of the visual response patterns among the sampling sites, and (3) the results of statistical analysis. Each of these choices were based on the underlying assumption that macroinvertebrate metrics, both taken individually or integrated together as a multimetric index or score, provided an acceptable measurement of the relative biological conditions at the sampling sites.

The State of Kansas uses four or sometimes five macroinvertebrate metrics for determining the ability of a stream site to support aquatic life and for placement of sites into impairment categories (Kansas Department of Health and Environment, 2006b). These metrics include the Macroinvertebrate Biotic Index (MBI), the Kansas Biotic Index (KBI–NO), EPT (Ephemeroptera-Plecoptera-Trichoptera) taxa richness (EPTRich), EPT abundance (%EPT), and if adequate data are available, mussel community loss. The latter metric is used only if the site is known to support at least five mussel species. The percentage of mussel loss was not evaluated in this study because several watersheds were too small in size to contain at least five mussel species. Therefore, the remaining four metrics, all of which are core metrics in many State bioassessment programs, were used in this multimetric combination method.

Metrics also were selected on the basis of response patterns throughout the range in known site conditions. Ideally, metrics are screened and selected on the basis of quantitative measures that evaluate their ability to discriminate between reference and impacted sites (Barbour and others, 1992). However, these quantitative metric-selection methods use coefficient of variation, sensitivity analysis, and calibration techniques that require within-site replication and multiseasonal and multiyear macroinvertebrate data from throughout a geographic region or watershed (Kerans and Karr, 1994). Because these data were not available for statistically screening metrics and testing the ability of individual metrics to discriminate between Johnson County stream sites, a more qualitative approach was used. Metrics were selected that demonstrated a distinct response that was based on metric expectations, as described by Simon and Lyons (1995), throughout the range in known site conditions (higher values for metrics that increase as adverse effects increase, or lower values for metrics that decrease as adverse effects increase) and considering basic knowledge on sources of stream degradation such as presence of municipal or industrial discharges and whether sites were located in primarily rural or urban landscapes. This approach to metric selection was qualitative only and was not designed to evaluate actual metric performance but rather to provide an initial filter for reducing the number of overall metrics included in further evaluation methods.

To improve isolation of the best indicator metrics to be included in the multimetric scores, stepwise regression analysis (Draper and Smith, 1998) was applied to the metric data to rate indicator performance and to determine which metrics had the highest level of agreement with preselected groups or classes of sites (described in section on "Site Groupings"). The stepwise procedure developed a model that included all of the indicator metrics that met the model acceptance criteria of 15 percent as outlined in the procedure (p-value greater than 0.15). After the entire list of metrics was added individually into the model using this criterion, the procedure began removing metrics that were not important for separating or discriminating between groups of sites. The stepwise analysis was used to generate two possible solutions to be used for multimetric scoring by selecting: (1) all metrics meeting the acceptance criteria, without a metric-removal step, and (2) only those metrics that create the best overall model for predicting future placement of a site into the correct grouping, including the metric-removal step. Multimetric scores and rating of sites were determined for both the five- and six-metric solutions resulting from this analysis.

Rating Methods Used For Site Scoring and Ranking

Because there are several approaches for presenting and reporting multimetric data, three different rating methods were used for site evaluation so that several site scoring and ranking solutions could be generated to compare for consistencies. The sequence of evaluation components and their resulting solutions are outlined in the flowchart (fig. 5). These methods were: (1) site scoring on the basis of scaling transformation**,** where the metric values were proportionally scaled across all sites for each metric, (2) site scoring on the basis of percentiles or quartiles**,** where the mathematical distribution of individual metric values for all sites were split into percentiles so that an approximately equal number of sites fell into each of the ranges, and (3) the State of Kansas 305(b) water-quality assessment (KDHE metrics), which defines stream-impairment categories and measures the ability of a stream site to support aquatic life (Kansas Department of Health and Environment, 2006b),

In the first rating method, values for each metric were proportionally scaled among all of the sites. This approach transformed the metric values to numbers between 1 and 100, assigning 1 to the value representing the lowest biological quality and 100 to the value representing the highest biological quality (Kreis, 1988). This method has three important features: (1) it spreads out the distribution of metric values, and when multimetric scores are obtained, there is less chance of having ties during the site-ranking process, (2) it retains the relative (or proportional) distances among the metric values, and (3) each metric has equal weight in the assessment results because each metric is transformed to the same numerical scale. This method has been used successfully for ranking sites on the basis of benthic macroinvertebrate data (Poulton and others, 1995). Multimetric scores for sites were determined by summing proportionally transformed values for each metric included in the evaluation. For each multimetric combination, a ranking of sites was obtained on the basis of the sum of the scores. The scaling equations for individual metrics are given below:

If the maximum value (Max) represents the highest biological quality, use:

$$1 + [(\text{Value} - \text{Min}) / (\text{Max} - \text{Min}) \times 99]; \quad (1)$$

If the minimum value (Min) represents the highest biological quality, use:

$$1 + [\ \{\ 1 - (\text{Value} - \text{Min}) / (\text{Max} - \text{Min})\ \} \times 99]; \quad (2)$$

where Value = number to be scaled.

In the second rating method, quartiles or percentiles are used to designate cutoff boundaries for site scoring, where metric values determined for all of the sites are divided into ranges that are defined by mathematical data distributions (Southerland and Stribling, 1995). Even though the scores are unitless values, they can be used for site rating to provide a relative measure of biological condition (Lenat, 1993). The distribution of metric values for sites was divided into generally equivalent categories, and each category was given a score. When all 22 sites sampled in Johnson County and nearby Missouri were considered for comparisons, four categories (generally equal quartiles with scores of 1, 2, 3, 4, and distribution boundaries at approximately the 25th, 50th, and 75th percentiles) were designated for relative scoring of sites. For some metrics, several sites had zero values; in these instances, three categories (trisection with scores of 1, 3, and 5, and distribution boundaries at the 33rd and 66th percentiles) were designated. A score for each category then was assigned for each metric included in the evaluation. A multimetric score for each site was determined by adding the scores attained for all of the individual metrics included in the evaluation. Site ranks for each multimetric combination were determined according to these scores.

For the third rating method, site scores were determined using the four metrics used by the State of Kansas for evaluating aquatic-life status of Kansas streams (MBI, KBI–NO, EPTRich, and %EPT). Each metric was scored on a three-point system that was based on State criteria (Kansas Department of Health and Environment, 2006b; table 3). Impairment status for each site was determined by combining these metric scores into an overall site score representing an average across all of the metrics included.

Site Groupings

Study sampling sites were divided into groups on the basis of available knowledge on the types of disturbance sources that were documented from previous investigations and on the initial study results. This approach was used for the following reasons: (1) lack of within-site replication reduced the ability of the sampling protocol to statistically discriminate between individual sites; (2) placing sites together that have similar characteristics or known adverse effects from human activities, and treating each site as a replicate provided the opportunity to statistically discriminate between groups; (3) site grouping allowed statistical identification of macroinvertebrate metrics with the best discriminatory power; and (4) site groups provided confirmation that a meaningful gradient in biological conditions existed for the sampling sites.

Categorizing sites into groups or classes is a valid technique for defining a gradient in biological response (Davies and Jackson, 2006) and is useful in cases where no site replication is included in the study design (Fore and others, 1994). Results from one of the rating methods (rank in multimetric site scores on the basis of scaling transformation) were used to initially place the 22 sampling sites into three generally equal groups (seven to eight sites per group) that were assumed to have similar characteristics or relative degree of overall biological impacts from human activities (A, least impacted; B, moderately impacted; C, most impacted), as indicated by site rankings and the continuum of multimetric site scores. A second site grouping was generated on the basis of a combination of existing site knowledge, including predominant land use and WWTF effects. In both of these approaches for categorizing or grouping sites, significant differences between groups were determined by analyzing group means in multimetric scores, treating each site as a replicate within each group (discriminant function analysis, $\alpha = 0.05$; Johnson, 1998).

The rationale for combining multiple indicator metrics into different metric combinations and overall site scores is to integrate the levels of macroinvertebrate responses to improve site discrimination and the accuracy of site placement into groups or rating categories (Fore and others, 1994). The resulting site arrangement provided the basis for direct comparisons with gradients in human disturbance and environmental variables, as defined by the Biological Condition Gradient conceptual model (Davies and Jackson, 2006). These qualitative site groupings were designed to provide additional indications of the underlying causes of adverse effects as measured by other variables included in this report rather than to develop numerical cutoff ranges for site scores or rating categories.

Table 3. Criteria for four macroinvertebrate metrics used in Kansas to evaluate aquatic-life support (Kansas Department of Health and Environment, 2006b).

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

Aquatic-life-support category	Values				
	MBI	KBI–NO	EPTRich	%EPT	Average
Fully supporting	< 4.51	< 2.61	> 12	> 48	> 2.49
Partially supporting	4.51–5.39	2.61–2.99	8–12	31–47	1.5–2.49
Nonsupporting	> 5.39	> 2.99	< 8	< 31	1.0–1.49

Environmental Variables

Quantitative site data were used for streamflow, precipitation, water quality, sediment quality, and land-use variables. This information was taken from several sources to provide a basis for understanding observed differences in biological conditions and the degree of human-induced adverse effects among the study sites. Because the KDHE macroinvertebrate sampling protocol is considered a screening-level tool for evaluation of stream condition, these variables are included in this report to provide a basis for comparisons with macroinvertebrate results. Relations between observed macroinvertebrate response and environmental variables also were designed to measure concurrence among the indicators examined.

This study did not attempt to fully integrate all of the environmental variables affecting aquatic life in streams. However, available site data were examined to improve understanding of integrated biological response to degrees of adverse effects because of human disturbances, such as those related to urbanization, nutrient enrichment from both agricultural and municipal sources, and presence of chemical contaminants. Comparable information for the Missouri sites (Wilkison and others, 2005) was not available for all variables, and therefore, some relations were examined utilizing only data from the 15 Johnson County sites.

Streamflow and Precipitation

Six USGS stream gages downstream from watersheds with varying land use, and in the same approximate location as some of the macroinvertebrate collection sites, were in operation throughout Johnson County from November 2002 through 2004 (fig. 2). These USGS gages included two gages on Cedar Creek (station numbers 06892440 and 06892495, sites CE1 and CE6), and one gage each on the Blue River (06893080, site BL3), and Big Bull (06914950, site BI1), Indian (06893300), and Mill (06892513, site MI7) Creeks. Three additional sites (06892360, 06893100, and 06893390; sites KI6b, BL5, and IN6) had stream gages operating part of that period. Streamflow data are available on the Web at *http://ks.water.usgs.gov/Kansas/waterdata.html/* . Macroinvertebrate collection at all of the sites generally was completed before the occurrence of streamflow increases normally associated with spring storm runoff. The only exception to this was in 2004 at the Tomahawk Creek site (TO2), when macroinvertebrate collection was being completed during the beginning of a stormwater pulse on March 3, 2004.

Trends in streamflow and precipitation were examined for these gages to help interpret macroinvertebrate results between the two sampling years. To examine these trends, duration curves were plotted to compare streamflow during the months prior to sampling. The periods from November 1 through March 15, 2002–03 and 2003–04, were chosen to represent streamflow conditions relevant to macroinvertebrate populations collected in March 2003 and 2004, respectively. Snowfall totals for these same time periods also were compared using the data from a weather station in Olathe, Kansas (fig. 2), centrally located in Johnson County (M. Knapp, State Climatologist, Weather Data Library, written commun., 2005).

Water and Sediment Quality

Pearson correlation coefficients (Helsel and Hirsch, 1992) were used to measure the strength of relations between various macroinvertebrate site scores and other available constituents that were used to define sampling-site water and sediment quality. Water- and sediment-quality samples collected from the sites in 2002 and 2003 as part of a previous study were used to provide a basis for comparison between indicators (Lee and others, 2005). Samples were collected during base-flow conditions in November 2002 and July 2003. Lee and others (2005) used much of the data on water and sediment quality to estimate the distribution of contaminants relative to point and nonpoint sources and varying land-use characteristics.

Constituents analyzed from water- and sediment-quality samples included major ions, nutrients, metals, pesticides, and wastewater-indicator compounds. Methods and results of analysis of stream-water and streambed-sediment quality data also are reported in Lee and others (2005). Only those compounds that were detected in a majority of stream-water and (or) streambed-sediment samples and exhibited variability among the sampled sites were included in the analysis for the study described herein.

Water-quality constituents used for this analysis included total nitrogen, total phosphorus, indicator bacteria, and the total concentration of a set of 55 organic wastewater compounds. Total concentration of wastewater compounds is the sum of detected concentrations in filtered water samples. Concentrations for the water-quality constituents represented a mean of both base-flow samples, unless only one sample was collected at the site. Although two samples from each site do not provide a statistical basis for thoroughly evaluating stream water-quality conditions at any given site, they do provide an estimate of relative water-quality conditions during base flow (Lee and others, 2005). No water-quality samples were collected from the Captain Creek site (CA1) because it was dry during scheduled sample collections. To maintain comparability between sediment and macroinvertebrate data sets, the median value of water-quality constituents from other rural sites in Johnson County (sites BI1, BL3, BL5, CE1, CE6, KI5, KI6b) were used to estimate water-quality data for site CA1. Because water and sediment samples were not collected concurrently with macroinvertebrates, the data are not intended to fully characterize conditions at the time of macroinvertebrate sampling but rather to provide an estimate of potential exposure at each site.

Streambed-sediment samples were collected in March and April 2003 and analyzed for total nitrogen, total phosphorus, indicator bacteria, total concentration of wastewater indicator compounds, and metals (arsenic, cadmium, copper, lead, manganese, nickel, and zinc). Stream-water, streambed-sediment, and macroinvertebrate data were log-10 transformed to approximate normal data distribution. Pearson correlation coefficients then were determined between macroinvertebrate scores, water- and sediment-quality indicators, and available land-use variables at the 15 sampling sites in Johnson County, Kansas. Only data collected in Johnson County, Kansas, were used in this analysis because water- and sediment-quality data sets for Missouri sites differed in number and timing of samples. A detailed description of all the constituents measured in sediment and overlying water and the results of sample analysis are given in Lee and others (2005).

Land Use

Estimates for land-use percentages were determined for all of the sites sampled for macroinvertebrates in both Johnson County, Kansas, and in adjacent counties in Missouri. Land-use data for Johnson County came from the Johnson County Automated Information Mapping System (AIMS) (S. Porter, Johnson County, written commun., 2003). Land-use data for Missouri came from Wilkison and others (2006), which used 2004 data modified from the National Map (U.S. Geological Survey, 2007). Impervious surface data were estimated by adding the total area of all buildings, courtyards, and paved and unpaved roads and parking lots. In addition to the percentages of impervious surfaces and agricultural land use within the watershed area upstream from each sampling site, a more broad land-use category (percentage of urban land use) was generated by combining some of the estimates for more specific categories. This was necessary because of slight differences between the sources used to estimate land-use categories for Kansas and Missouri sites. The percentage of urban category in this report included combined percentages of commercial, industrial, parks, and residential land use.

Spearman-rho correlation coefficients (Helsel and Hirsch, 1992) were determined for ranks of the estimates of land-use percentages (percentage of urban, percentage of agricultural, percentage of impervious surface) and the macroinvertebrate site scores that were based on proportional scaling for the three different multimetric combinations in both years. Rank correlations were used for this analysis to provide an indication of how well the arrangement of the site ranks (in other words, the pattern of biological impacts from least to most, as defined by macroinvertebrate scores) corresponded with the gradient in these land-use percentages. Because comparable data on percentage of agriculture land use were not available for the Missouri sites, this variable was only included in the Pearson correlation matrix.

Site Groupings and Scoring

To provide information that can be directly compared with macroinvertebrate results, sampling sites were grouped and scored on the basis of several individual indicator variables (water and sediment quality, land use, wastewater effluent) that have been known to be sources or causes of adverse effects in stream systems. Available data from Lee and others (2005) and additional data generated as part of this study were integrated to provide evidence that a gradient in these variables does exist among the sites that were sampled.

KDHE macroinvertebrate sampling protocol mentioned previously is a screening-level procedure, and it is not known whether resulting data can be used to identify individual stressors present at a stream site. Therefore, no attempt was made to fully integrate all of the environmental variables into one measurement of relative effects.

Principal Components Analysis

For 15 of the 16 Johnson County sites, several of the important environmental variables previously described were included in a principal components analysis (PCA) that was performed on the correlation matrix (Johnson, 1998). This matrix included stream-water and streambed-sediment quality, estimates of land-use percentages (impervious surfaces, agriculture), and macroinvertebrate site scores to identify patterns in the data and to examine how variables were interrelated and distributed across the sample sites. PCA was performed as another method for separating sites or groups of sites along axes that are described on the basis of the variance associated with each of the variables included. Log transformations were applied to land-use and water- and sediment-quality data to approximate normality. This analysis was used to demonstrate how the sampling sites grouped compared to environmental variables and macroinvertebrate site scores.

Environmental Effects Score

To enhance comparisons between macroinvertebrate data and environmental variables, an environmental effects score was developed that included the best available environmental data gathered from Johnson County stream sites. This unitless score was developed from variables that generated among the highest correlation coefficients with many of the individual macroinvertebrate metrics and overall multimetric scores and indicators of sources known to affect macroinvertebrates such as WWTF discharges. This integration approach is similar to that used in recent macroinvertebrate studies on urban streams (Cuffney and others, 2005) and was designed to provide a more meaningful representation of the relation between macroinvertebrate response and the overall adverse effects these variables have on aquatic life. The score incorporated environmental variables that were significantly correlated with macroinvertebrate metrics and incorporated one land-use variable (percentage of impervious surface), one water-quality variable (total nitrogen in stream water), and one sediment-quality variable [total polycyclic aromatic hydrocarbons (PAHs) in streambed sediment]. Values for each variable were derived from Lee and others (2005) and represented a mean of two samples collected during base flow (if data from two samples were available). The values were scaled proportionately among the study sites. The environmental effects score was calculated for each site by summation of scaled values for each of the three variables. This score allowed interpretation of biological data in light of the rapid land-use changes occurring in Johnson County because the variables selected also were related to the degree of urbanization. Presence or absence of WWTF discharges was not included in the score because some of the variables included (wastewater compound concentration and total nitrogen) represent indicators of wastewater effects.

The following two statistical procedures were used to analyze the strength of the relation between the environmental effects score and macroinvertebrate site scores: (1) Spearman-rho rank correlation for measuring concurrence among site-ranking solutions, made on the basis of multimetric scores (least- to most-impacted) and the environmental effects score, and (2) simple regression for measuring the ability of environmental variables (both individually and as an integrated score) to predict relative biological conditions as indicated by macroinvertebrate data. The environmental effects scores and the 10-metric macroinvertebrate scores were used as the basis for qualitative assignment of sites to rating categories that corresponded with relative quality of the stream sites.

Quality Assurance and Quality Control

Quality assurance and quality control for macroinvertebrate identification and enumeration procedures generally followed those outlined in Moulton and others (2000) and included within-laboratory cross checking of individual samples and individual specimens. Updated taxonomic keys and voucher specimens are kept on file with the Biological Group of the USGS National Water Quality Laboratory, Lakewood, Colorado. 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.

Quality-assurance and quality-control samples were collected during both stream-water and streambed-sediment sampling in 2003 and 2004. Specific descriptions of these samples and their purpose are given in Lee and others (2005).

Assessment of Biological Conditions

Results from macroinvertebrate evaluations, metric combinations, analysis of environmental variables, and evaluation of relations between variables and macroinvertebrate measures, and discussion of these topics, are presented in this section. Complete data files and results of analysis are available on the USGS Web site (*http://ks.water.usgs.gov/kansas/studies/qw/joco)*, or on file at the USGS Water Science Center in Lawrence, Kansas.

Macroinvertebrate Communities

A complete listing of macroinvertebrate taxa found at stream-sampling sites is in Appendix 1, and a list of the four most dominant macroinvertebrate taxa observed at the sites is in Appendix 2. Values for macroinvertebrate metrics are in Appendix 3.

Summary of Community Structure

A total of 190 macroinvertebrate taxa were collected from the 16 Kansas and 6 Missouri sampling sites using KDHE sampling protocol during 2003 and 2004 (Appendix 1). Two taxa were found only in Missouri and not in Johnson County (unkeyed Lepidoptera, and the midge *Parachironomus*), both of which were collected in small numbers (less than three individuals) only at the Brush Creek site (BR12, fig. 2). Among the total list of taxa, there was a 68-percent overlap between the two sampling years, and a total of 43 non-insect taxa. The insects collected included 147 taxa, of which 56 (38 percent) were midges (Diptera: Chironomidae) and 13 (9 percent) were other Dipterans.

Among the three dominant orders of insects that are normally associated with streams, Ephemeroptera, Plecoptera, and Trichoptera (EPT), most sites contained abundances of between 10 and 50 percent of the total number of organisms (EPT abundance, Appendix 3), and the total number of taxa ranged from 0 to 11 species at all sites (Appendix 3). In general, most of the rural sites included in this study contained a wide diversity of aquatic macroinvertebrates, with good representation of the insect orders normally associated with healthy communities such as mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), dragonflies and damselflies (Odonata), and riffle beetles (Coleoptera: Elmidae). Several of the rural sites in Johnson County, including the reference site (CA1), both Kill Creek sites (KI5, KI6b), the upstream Blue River sites (BL3, BL5), and both Cedar Creek sites (CE1, CE6) contained at least 23 taxa in 2003 and more than 40 taxa in 2004 (Appendix 3). The midges (Diptera: Chironomidae) also were well represented at these sites, with most collections including from 8 to 18 taxa in one or both years (Appendix 3). In contrast, the more urban sites had none or very few EPT taxa and were dominated by pollution-tolerant organisms such as leeches [Hirudinea: *Mooreobdella microstoma* (Moore)], planarians (Platyhelminthes: Turbellaria), Oligochaeta worms (Annelida: Oligochaeta, families Naididae and Tubificidae), and midges in the *Cricotopus* and *Orthocladius* (Diptera: Chironomidae) groups (Appendix 2). These sites included the two Indian Creek sites downstream from WWTF discharges (sites IN3a, IN6).

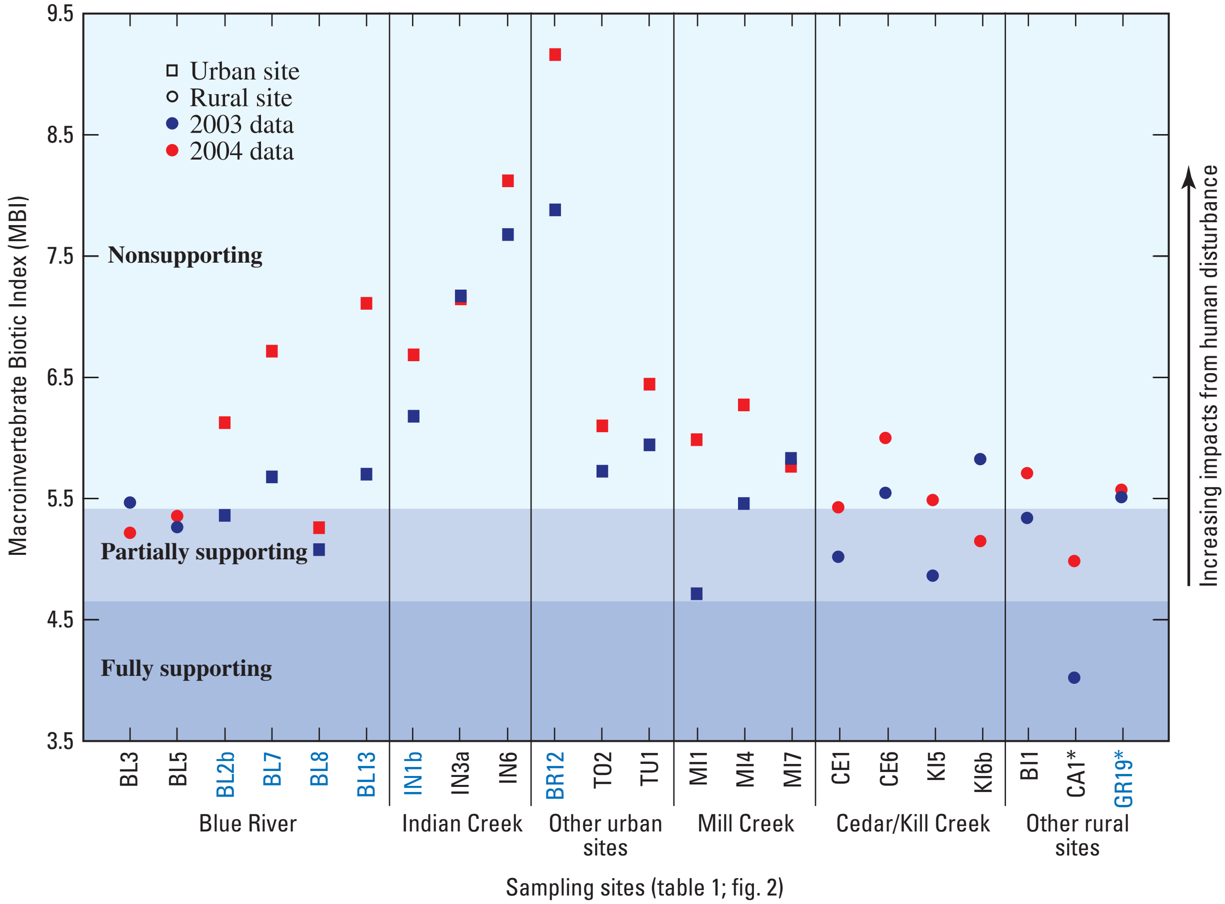
Individual Metric Values

Values for all 22 metrics resulting from both 2003 and 2004 sampling periods are given in Appendix 3. Figures for the KDHE metrics (MBI, KBI–NO, EPTRich, and %EPT) are discussed in the following paragraphs. Among the metrics determined in this study, results for a total of 12 metrics are summarized in this section, with the KDHE aquatic-life status metrics described first and the others given in the order they are listed in table 2. Most of these metrics were included in one or more rating methods because they were considered core metrics (used in the Kansas water-quality assessment or very common in literature), they demonstrated a distinct visual response pattern among the sites, or they were chosen by statistical analysis as being the best metrics for correctly placing sites into meaningful groups. Some metrics were not included in multimetric combinations because they had a bimodal response pattern or had redundancy with other metrics that were included (table 2). Among the metrics examined in this study, two of the richness metrics (TRich, EPTRich) were the only ones that were significantly different between 2003 and 2004. This was only observed at the rural sites (Mann-Whitney U test for independence, $\alpha = 0.05$, p-value = 0.01).

Macroinvertebrate Biotic Index (MBI).—This metric is a family-level biotic index that uses tolerance values for insect and mollusk taxa, with lower values corresponding to minimal biological impacts. Most sampling sites had values between 5.0 and 7.0 in 2003 and 2004 (fig. 6). Both of the downstream Indian Creek sites (Indian Creek at State Line, site IN6, and Indian Creek at College Blvd., site IN3a) and downstream Blue River sites (Brush Creek at Elmwood, site BR12, and Blue River at Stadium Drive, site BL13) had the highest values, between 7.0 and 9.0. Most (18 of 22) of the sites had higher MBI values in 2004 as compared to 2003. The Kansas reference site (Captain Creek, site CA1) was the only site that met MBI criteria for full support of aquatic life (less than 4.51, table 3) and only in 2003. Two sites on the Blue River (sites BL5 and BL8) met criteria for partial support of aquatic life (4.51 to 5.39, table 3) both years. The remaining sites were nonsupportive at least one of the two sampled years. The Mill Creek TMDL (Kansas Department of Health and Environment, 2006a) establishes a goal of 4.5 or less as the average MBI score for 2006 through 2015. That goal was not achieved in 2003 or 2004 when the Mill Creek MBI scores ranged from 4.71 to 6.27 (Appendix 3). The MBI metric was not selected in the stepwise statistical procedure and, therefore, was not included in the five- or six-metric combinations.

Kansas Biotic Index (KBI–NO).—This metric is one component of a much larger overall index (KBI) and utilizes aquatic organism tolerances to nutrients (N in the acronym) and oxygen-demanding substances (O in the acronym) (Huggins and Moffett, 1988). It is a genus-level biotic index calculated in a similar manner as the MBI, with low values indicating minimal biological impacts. KBI–NO values ranged from 1.61 (Captain Creek, site CA1, in 2003) to 4.55 (Brush Creek at Elmwood Ave., site BR12, in 2003) (Appendix 3). The State reference stream for Kansas (Captain Creek, site CA1) had the lowest values in both years, and the most downstream site on Indian Creek (site IN6) had the highest values among the Johnson County sites (fig. 7). Four of the 22 sites met Kansas criteria for full support of aquatic life (less than 2.61, table 3) on the basis of KBI–NO in 2003, two of which also met criteria in 2004 (Captain Creek, site CA1, and Cedar Creek, site CE1). Fifteen of 22 sites had higher values in 2004 than in 2003, indicating conditions less supportive of aquatic life in 2004, and this difference was most pronounced at the middle site on Mill Creek (site MI4). Brush Creek at Elmwood Ave. (site BR12) and the most downstream site on the Blue River (site BL13) had among the highest KBI–NO values of all the sites sampled. The KBI–NO metric was included in the 10-metric score but was not selected by the stepwise statistical procedure and, therefore, was not used in the five- or six-metric scores.

EPT Taxa Richness (EPTRich).—EPT taxa richness is the sum of the number of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) taxa; most species belonging to each of these orders are considered to be intolerant of stressors (Barbour and others, 1999). EPTRich values ranged from 0 to 7 in 2003 and 0 to 11 in 2004 (Appendix 3). At 11 of the 22 sites, EPTRich values in 2004 were greater than in 2003 (fig. 8) indicating conditions more supportive of aquatic life in 2004. This difference was most pronounced at the less urban sites including Captain Creek (site CA1), the upstream Blue River sites (BL3, BL5), and the upstream sites on Cedar (site CE1) and Kill (site KI5) Creeks. No sites met the EPTRich criterion (greater than 12, table 3) for full support of aquatic life. Five sites met the criterion for partial support (8–12) in 2004 only. The remaining sites were nonsupportive both years. No EPT taxa were present at the Brush Creek site (BR12) in either of the 2 years, and downstream Indian



EXPLANATION

BL5 **Sites identified in black analyzed for this study**

BL7 **Sites identified in blue analyzed in previous study** (Wilkison and others, 2005)

* **Asterisk indicates State reference site**

Figure 6. Macroinvertebrate Biotic Index (MBI) for Johnson County, Kansas, sites sampled in 2003 and 2004, and selected sites in Cass and Jackson Counties, Missouri, showing Kansas aquatic-life-support categories (table 3; Kansas Department of Health and Environment, 2006b).

Creek and Blue River sites (IN3a, IN6, and BL8; Appendix 3) contained three EPT taxa or less during one or both years. The EPTRich metric was selected by the stepwise procedure and was included in all three multimetric site-scoring combinations.

EPT Abundance (%EPT).—This metric is EPT expressed as a percentage of the total number of organisms and provides information about relative abundance of the three intolerant orders of aquatic insects. Compared to other metrics, %EPT did not demonstrate a distinct pattern among the study sites. Sixteen sites had lower values in 2004 than in 2003 (fig. 9). Greater abundances of the pollution-tolerant net-spinning caddisfly larvae *Cheumatopsyche spp.* (Trichoptera: Hydropsychidae), and to a lesser extent *Hydropsyche betteni* Ross (same order and family), were observed at many of the more urbanized sites where they made up most or all of the EPT abundance value. In addition, the upstream Mill Creek site (MI1) had large numbers of a moderately tolerant mayfly *Stenacron sp*. (Ephemeroptera: Heptageniidae) during 2003 (Appendix 2). The Brush Creek site (BR12) had 0 percent EPT abundance in both years. The %EPT metric was not included in any of the three multimetric site-scoring combinations.

Total Taxa Richness (TRich).—This metric represents the number of distinct taxa within a sample. The presence of relatively large numbers of distinct taxa suggests that the habitats and food sources present at a site can support many species (Barbour and others, 1999). Values for this metric ranged from 20 to 47 taxa in 2003 and 17 to 56 taxa in 2004 (Appendix 3). Taxa richness (TRich) values were greater in 2004 than in 2003 at 16 of 22 sites (fig. 10) indicating

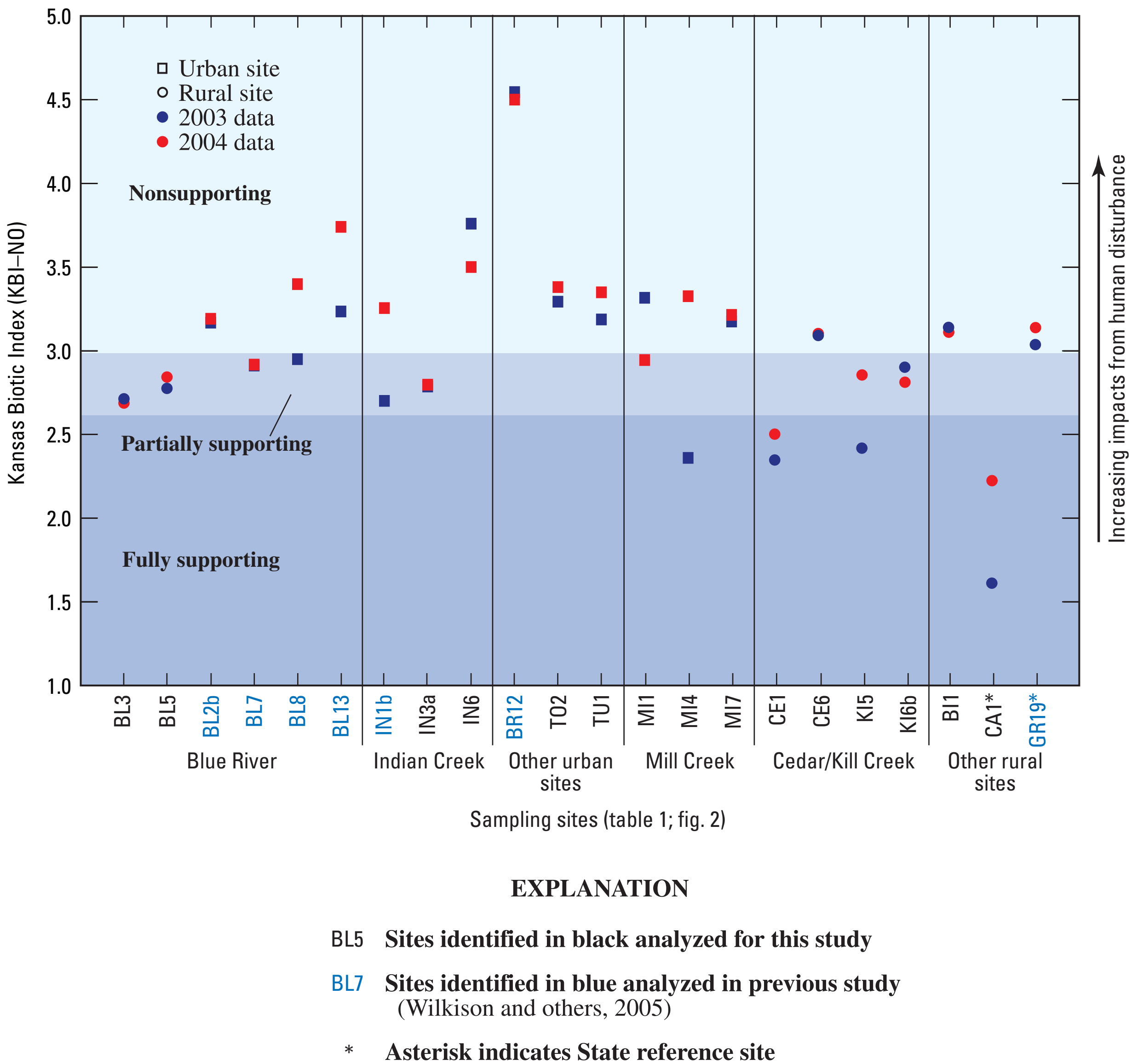


Figure 7. Kansas Biotic Index (KBI–NO) for Johnson County, Kansas, sites sampled in 2003 and 2004 and selected sites in Cass and Jackson Counties, Missouri, showing Kansas aquatic-life-support categories (table 3; Kansas Department of Health and Environment, 2006b).

conditions less supportive of aquatic life in 2003. This difference was most pronounced at less urban sites including Captain Creek (site CA1), upstream sites on the Blue River (sites BL3, BL5), and the upstream sites on Cedar (site CE1) and Kill (site KI5) Creeks. The TRich metric was selected by the stepwise procedure and was included in all three of the multimetric site-scoring combinations.

Percentage Scrapers (%Sc).—Measures of functional groups associated with specific feeding strategies, such as those taxa that remove periphyton from surfaces by scraping, provide information on community balance (Barbour and others, 1999). Values for the %SC metric were generally lower at the urban sites and ranged from 1.6 to 41.9 percent in 2003 and from 1.0 to 28.3 percent in 2004 (Appendix 3). Among the Johnson County sites, the lowest values were observed at Tomahawk Creek (site TO2), Turkey Creek (site TU1), and the downstream Indian Creek sites (IN6, IN3a) in both years. The downstream Blue River sites (BL8, BL13) and Brush Creek (site BR12) all had values less than 10 percent for this metric. The stepwise procedure selected the %Sc metric as meeting the acceptance criteria for grouping sites, but it was removed from the final model. This metric was included in both the 10-metric and 6-metric site-scoring combinations.

Ratio of Abundance of Scrapers and Filters (Sc/Fc)—In both 2003 and 2004, the lowest values for this metric were observed at sites receiving WWTF discharge. Most of these sites had metric values less than 0.5, and most rural sites had values greater than 1.0 (Appendix 3). The Sc/Fc metric was

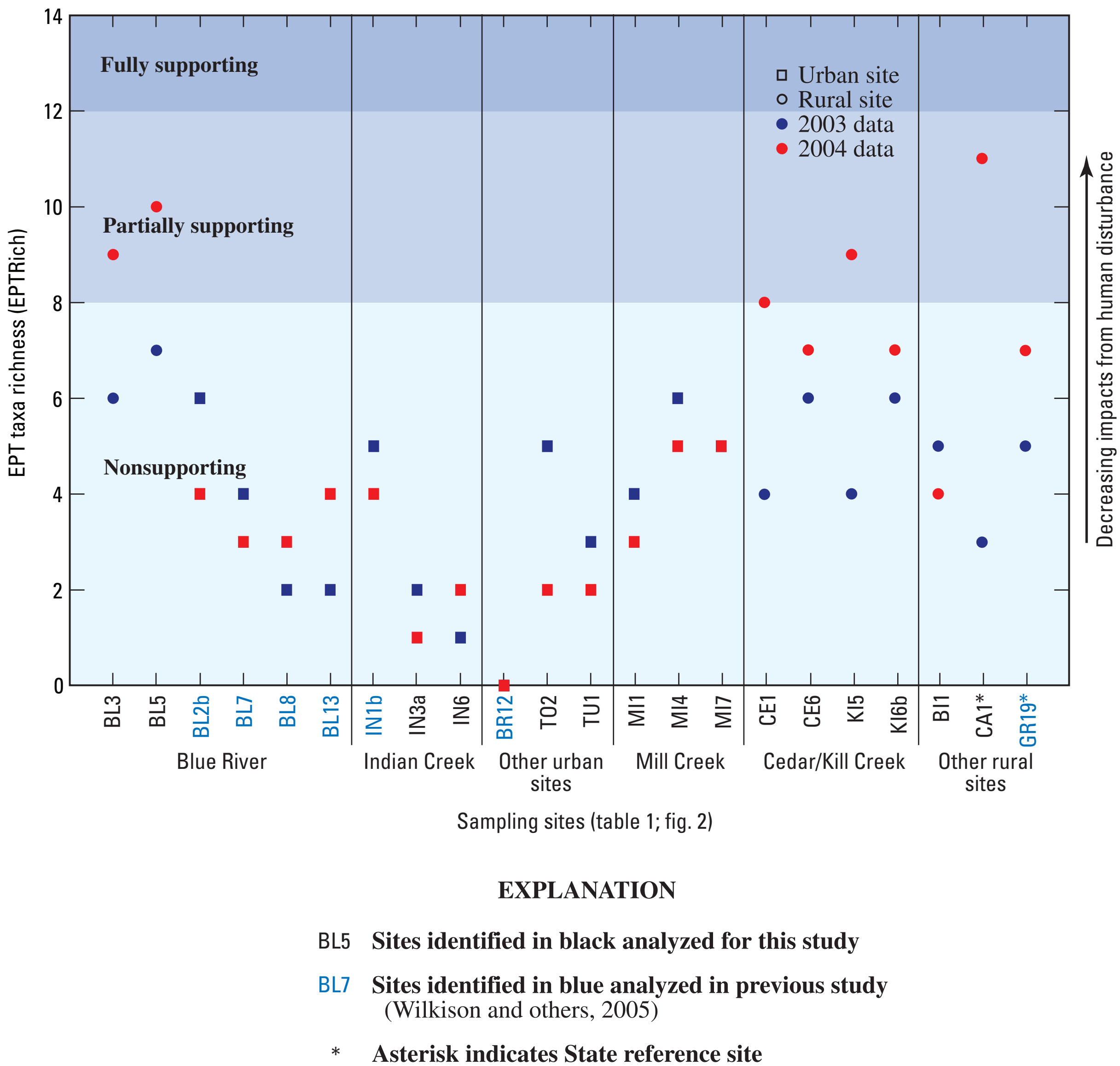


Figure 8. EPT taxa richness (EPTRich) for Johnson County, Kansas, sites sampled in 2003 and 2004 and selected sites in Cass and Jackson Counties, Missouri, showing Kansas aquatic-life-support categories (table 3; Kansas Department of Health and Environment, 2006b).

not included in the 10-metric site scoring but was selected by the stepwise procedure as one of the best metrics for placing sites into meaningful groups.

Percentage of Oligochaeta (%Olig).—Many of the members of this macroinvertebrate group are considered pollution tolerant, but they were not identified below the family level in this study. Most of the urban sites and those directly affected by WWTF discharges had values for this metric that ranged from 8 to 49 percent. Most of the other sites in Johnson County had metric values less than 5 percent in both years (Appendix 3). The %Olig metric was included in the 10-metric combination of site scoring but was not chosen by the stepwise procedure and, therefore, was not included in either the 5-metric or 6-metric combinations.

Percentage of Tanytarsini Midges (%Tany).—*Tanytarsini*, an intolerant tribe of midges (Diptera: Chironomidae), made up less than 2 percent of the organisms at all of the sites in 2003, with slightly higher percentages in 2004. A total of 11 sites had no *Tanytarsini* midges in one or both years, and most of these sites were urban or those receiving WWTF discharge (Appendix 3). The %Tany metric was included in all three of the multimetric site-scoring combinations and was selected by the stepwise procedure as one of the best metrics for separating site groups.

Percentage of Intolerant Organisms, KBI<3 (%Int–KBI).—This metric represents the relative abundance of organisms that have KBI–NO tolerance values less than (<) 3.0. This metric is normally calculated using tolerance values given in Hilsenhoff (1987) or Lenat (1988). For this study,

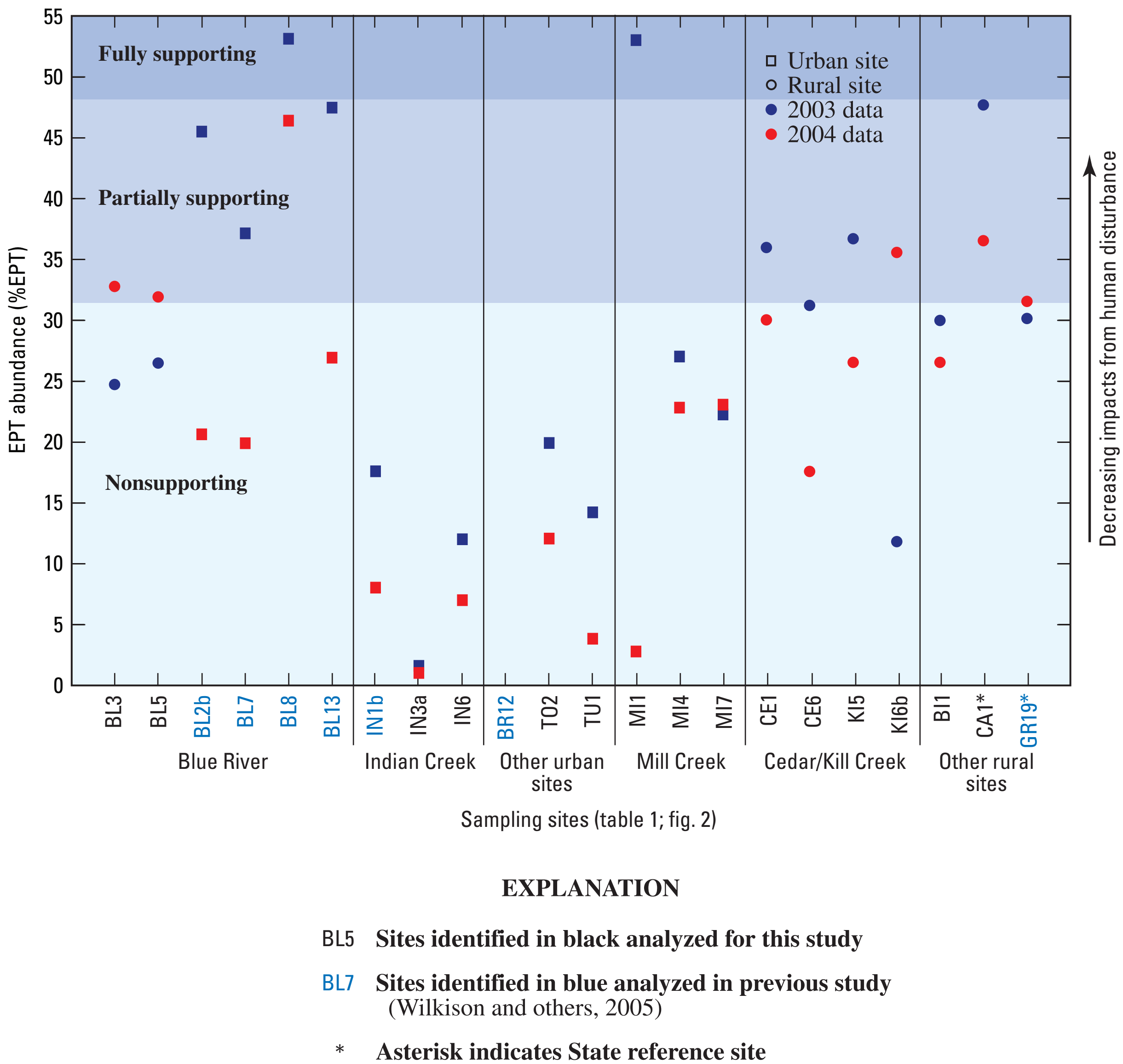
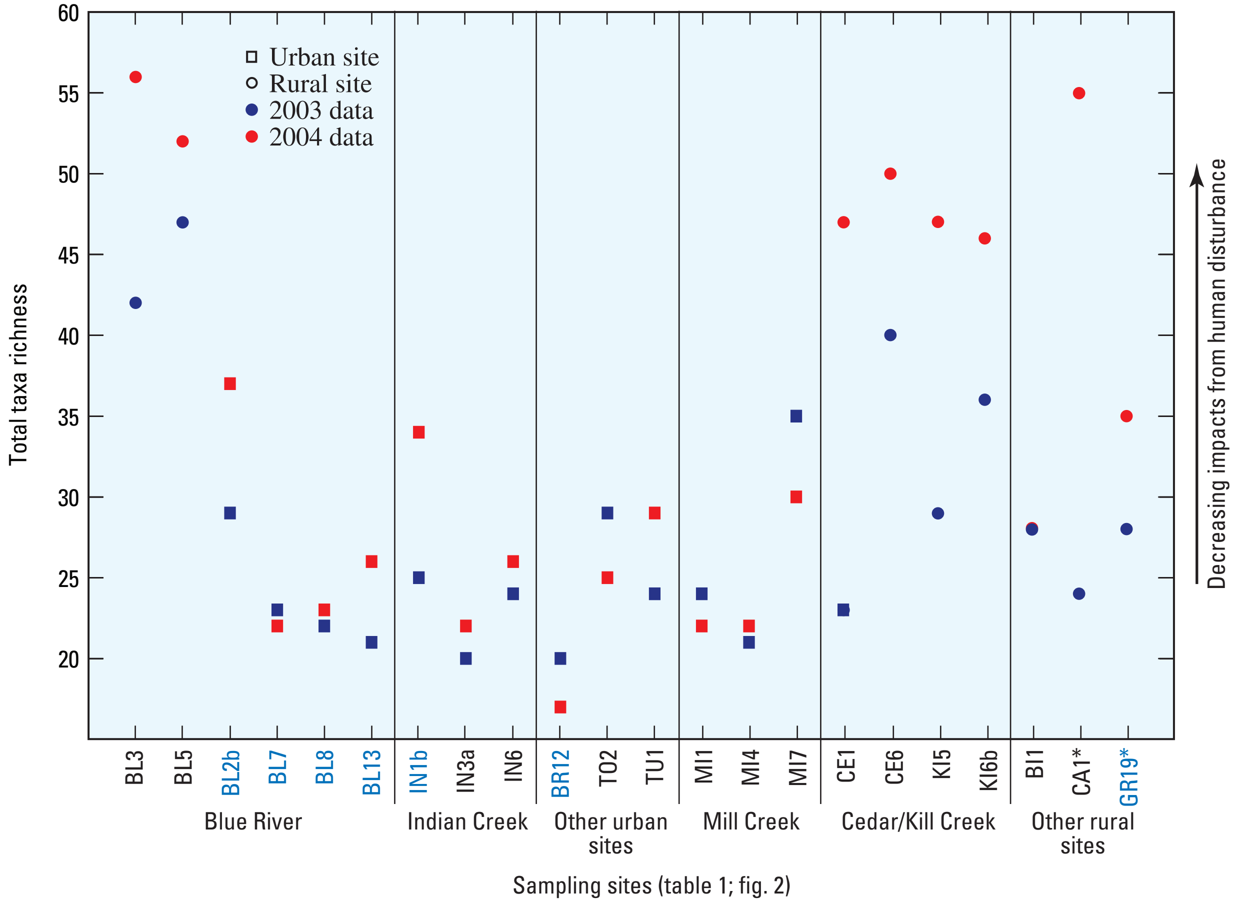


Figure 9. EPT abundance (%EPT) for Johnson County, Kansas, sites sampled in 2003 and 2004 and selected sites in Cass and Jackson Counties, Missouri, showing Kansas aquatic-life-support categories (table 3; Kansas Department of Health and Environment, 2006b).

KBI–NO tolerance values were used instead because of their regional specificity for Kansas (Huggins and Moffett, 1988). In general, most of the urban sites had lower %Int–KBI values in 2003 and 2004 (Appendix 3). The %Int–KBI metric was included in all three of the multimetric site-scoring combinations and was selected by the stepwise procedure as one of the best metrics for separating site groups.

Percentage of Ephemeroptera and Plecoptera (%EP).—This metric represents a modification of the %EPT metric and omits Trichoptera to account for the effect of greater abundances of tolerant net-spinning caddisflies often encountered in macroinvertebrate samples from larger urban streams. Three Blue River sites (BL3, BL5, BL8), the two State reference sites (CA1, GR19), the Cedar Creek sites (CE1, CE6), the Kill Creek sites (KI5, KI6b), and the Big Bull Creek site (BI1) all had values greater than 10 percent for this metric in 2003 and 2004 (Appendix 3). The %EP metric was included in the 10-metric site-scoring combination but was not chosen by the stepwise procedure.

Shannon-Weiner Diversity Index (SWDI).—This core metric that measures community diversity ranged from 1.9 to 3.6 and, for most of the sites, was slightly higher in 2004 as compared to 2003. In general, most of the urban sites had lower values (Appendix 3). The SWDI was included in the 10-metric site-scoring combination but was not chosen by the stepwise procedure.



EXPLANATION

BL5 **Sites identified in black analyzed for this study**

BL7 **Sites identified in blue analyzed in previous study** (Wilkison and others, 2005)

* **Asterisk indicates State reference site**

Figure 10. Total taxa richness (TRich) for Johnson County, Kansas, sites sampled in 2003 and 2004 and selected sites in Cass and Jackson Counties, Missouri.

Site Scoring and Ranking Using Multimetric Combinations

A list of metrics and their inclusion in the different multimetric combinations (10 metric, 6 metric, and 5 metric) resulting from the site-rating methods are given in table 2. Results from the proportional scaling and percentile methods of scoring and ranking sites using metric combinations are summarized in Appendixes 4 and 5, respectively.

A total of 12 metrics were selected on the basis of distinct response patterns throughout the range in known site conditions. In this study, MBI, KBI–NO, EPTRich, and %EPT were included in the 10-metric score because they are used in Kansas aquatic-life-support assessments. The %Sc, %Olig, %Tany, %Int–KBI, and %EP metrics also were included because of their distinct response patterns throughout the range of known site conditions. The TRich and SWDI metrics were included because they represent common metrics in State assessment evaluations and because they often are used in macroinvertebrate literature. Using the stepwise regression procedure, six metrics met the model acceptance criterion of p equal to or less than 0.15 (table 2) and were included in the six-metric site scoring (EPTRich, TRich, %Sc, Sc/Fc, %Tany, %Int–KBI). The %Sc metric was removed by the procedure before the final model was generated. The five metrics remaining after completion of the stepwise procedure were used to generate the five-metric site scores (EPTRich, TRich, Sc/Fc, %Tany, %Int–KBI).

Table 4. Grouping of sampling sites based on rank of 10-metric macroinvertebrate scores in 2003 and 2004, for 22 stream sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005).

[A, lowest levels of biological impacts from human disturbance; B, moderate levels of biological impacts from human disturbance; C, highest levels of biological impacts from human disturbance]

Site identifier (fig. 2)	2003			2004			Average 2003–04		
	10-metric score	10-metric rank	Site group	10-metric score	10-metric rank	Site group	10-metric score	10-metric rank	Site group
CA1	654	3	**A**	862	1	**A**	758	1	**A**
KI5	695	1	**A**	738	2	**A**	717	2	**A**
BL5	683	2	**A**	720	5	**A**	702	3	**A**
BL3	639	4	**A**	734	4	**A**	687	4	**A**
CE1	606	5	**A**	755	3	**A**	681	5	**A**
KI6b	586	7	**A**	696	6	**A**	641	6	**A**
CE6	594	6	**A**	579	7	**A**	587	7	**A**
BL2b	574	8	**B**	489	10	**B**	532	8	**B**
GR19	447	14	**B**	576	9	**B**	512	9	**B**
BI1	484	10	**B**	527	8	**B**	506	10	**B**
IN1b	510	11	**B**	439	13	**B**	475	11	**B**
BL8	373	17	**C**	466	12	**B**	420	12	**B**
MI7	434	12	**B**	390	11	**B**	412	13	**B**
MI1	491	9	**B**	321	14	**B**	406	14	**B**
BL7	417	16	**C**	384	15	**B**	401	15	**B**
MI4	438	13	**B**	241	17	**C**	340	16	**C**
TO2	409	15	**B**	237	19	**C**	323	17	**C**
BL13	267	19	**C**	328	18	**C**	298	18	**C**
TU1	299	18	**C**	266	16	**C**	283	19	**C**
IN3a	118	21	**C**	193	20	**C**	156	20	**C**
IN6	117	20	**C**	55	21	**C**	86	21	**C**
BR12	59	22	**C**	33	22	**C**	46	22	**C**

The 10-metric combination is an integration of multiple metrics that measure diversity, composition, tolerance, and feeding characteristics of the communities present at each site. Appendix 4 lists sampling-site rankings in 2003 and 2004 according to three multimetric combinations. Sampling sites did not have identical rankings in both years, but most sites were similar. Among the Johnson County sites ranked using the 10-metric scoring, there were six sites that increased slightly in rank between 2003 and 2004, six that declined in rank, and three sites that remained the same. Among all 22 sites scored using the 10-metric combination, the greatest differences in rank between 2003 and 2004 were observed at one of the Blue River sites in Missouri (site BL8) and the Missouri reference site (South Fork of the Grand River, site GR19), both of which decreased by five rank positions, and the upstream Mill Creek site (MI1), which increased by five rank positions.

Site Groupings

Sampling sites were divided into three groups on the basis of their 10-metric rankings (table 4, Appendix 4) and a general knowledge of environmental conditions and sources of human disturbance at the sites. Sites in group A include those with the highest ranks representing the best biological conditions, sites in group B include those with ranks representing intermediate biological conditions, and sites in group C include those with the lowest ranks representing the worst biological conditions (table 4). The mean 10-metric macroinvertebrate scores of the three site groups were significantly different from one another (group A scores greater than group B scores, and group B scores greater than group C scores. Discriminant function analysis indicated that the probability that groups are different merely by chance (F statistic) was less than 0.0001 for both 2003 and 2004) (fig. 11), indicating that this grouping was reasonable for placing sites together that have similar biological conditions. Mean 10-

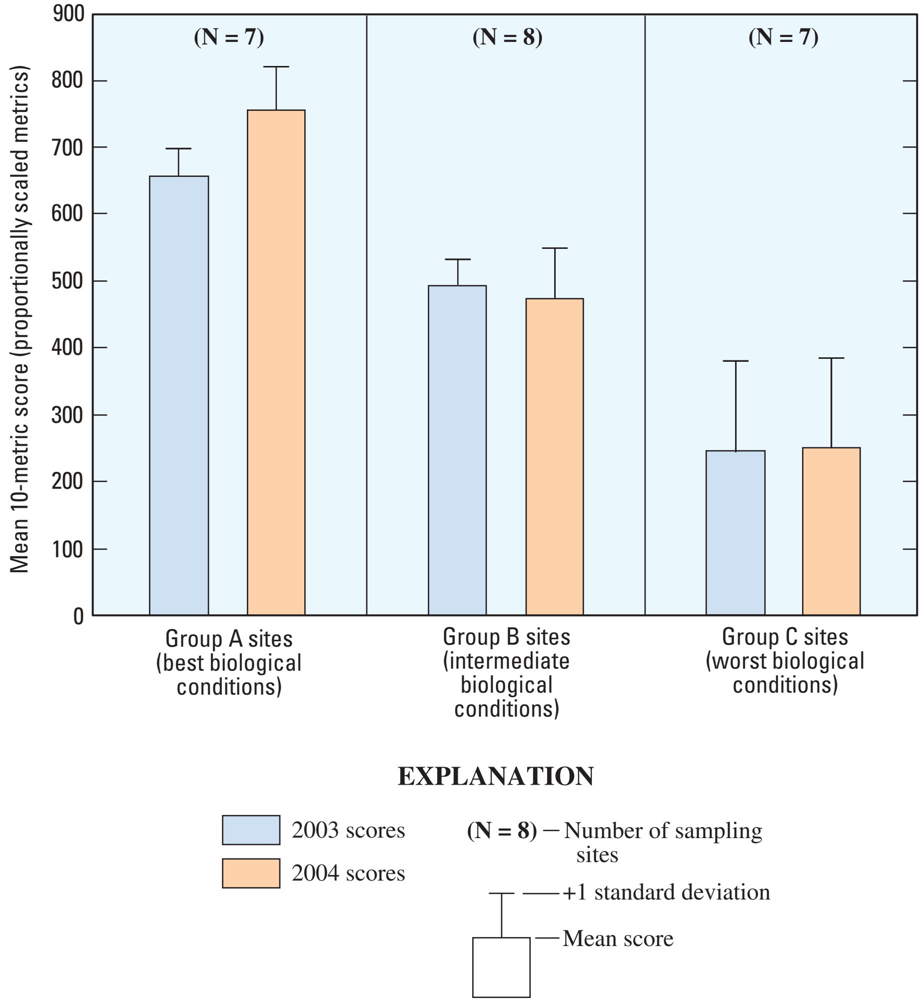


Figure 11. Mean 10-metric macroinvertebrate scores (plus one standard deviation) for 22 stream sites in Kansas and Missouri in 2003 and 2004, with similar sites grouped together as A, B, and C according to biological conditions (table 4). Discriminant function analysis, Pr is greater than F, was less than 0.0001 for both 2003 and 2004.

metric macroinvertebrate scores at rural sites also were significantly different from that of urban sites (rural site scores were greater than scores for urban sites with WWTF discharges, and scores for urban sites with WWTF discharges were equal to scores for urban sites without WWTF discharges). The F statistic was 0.03 for 2003 and less than 0.0001 for 2004) (fig. 12), indicating that grouping was reasonable. However, mean 10-metric scores for the two urban site groups (with and without the presence of discharges from WWTFs) were not significantly different from one another. This grouping did not fully account for the distance that WWTFs were located upstream from the sampling sites.

The average of the 10-metric macroinvertebrate scores (or ranks) for 2003–04 for each site was used to assign three categories of biological impact—least impacted, moderately impacted, and most impacted (table 4, fig. 13). The categories have approximately equal numbers of sites and show relative biological conditions among the 22 sites.

The percentile site-scoring method resulted in many sites with ties in rank based on their scores (Appendix 5). However, the resulting scores and ranks were similar to those resulting from the proportional scaling method, at least for most of the sites. In general, urban sites had lower rankings (highest metric scores) in both years, and these included the two Indian Creek sites in Johnson County that are less than 3 mi downstream from wastewater discharges (sites IN3a, IN6) and three Missouri sites that included Brush Creek (site BR12) and the most downstream Blue River sites (BL8, BL13). Rural sites such as the Captain Creek (site CA1), the upper Cedar (site CE1) and Kill Creek sites (KI5, KI6b), and the two most upstream Blue River sites in Johnson County (sites BL3, BL5) consistently ranked among sites with the least-impacted biological conditions (lowest ranking), regardless of which

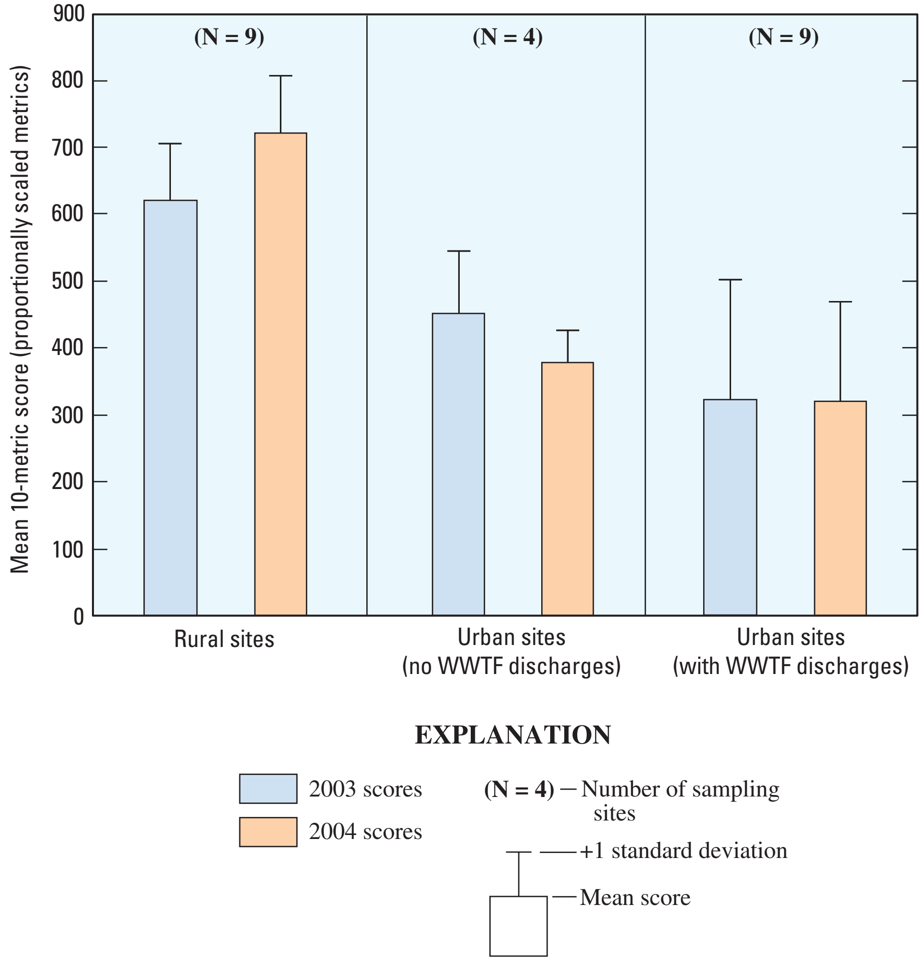


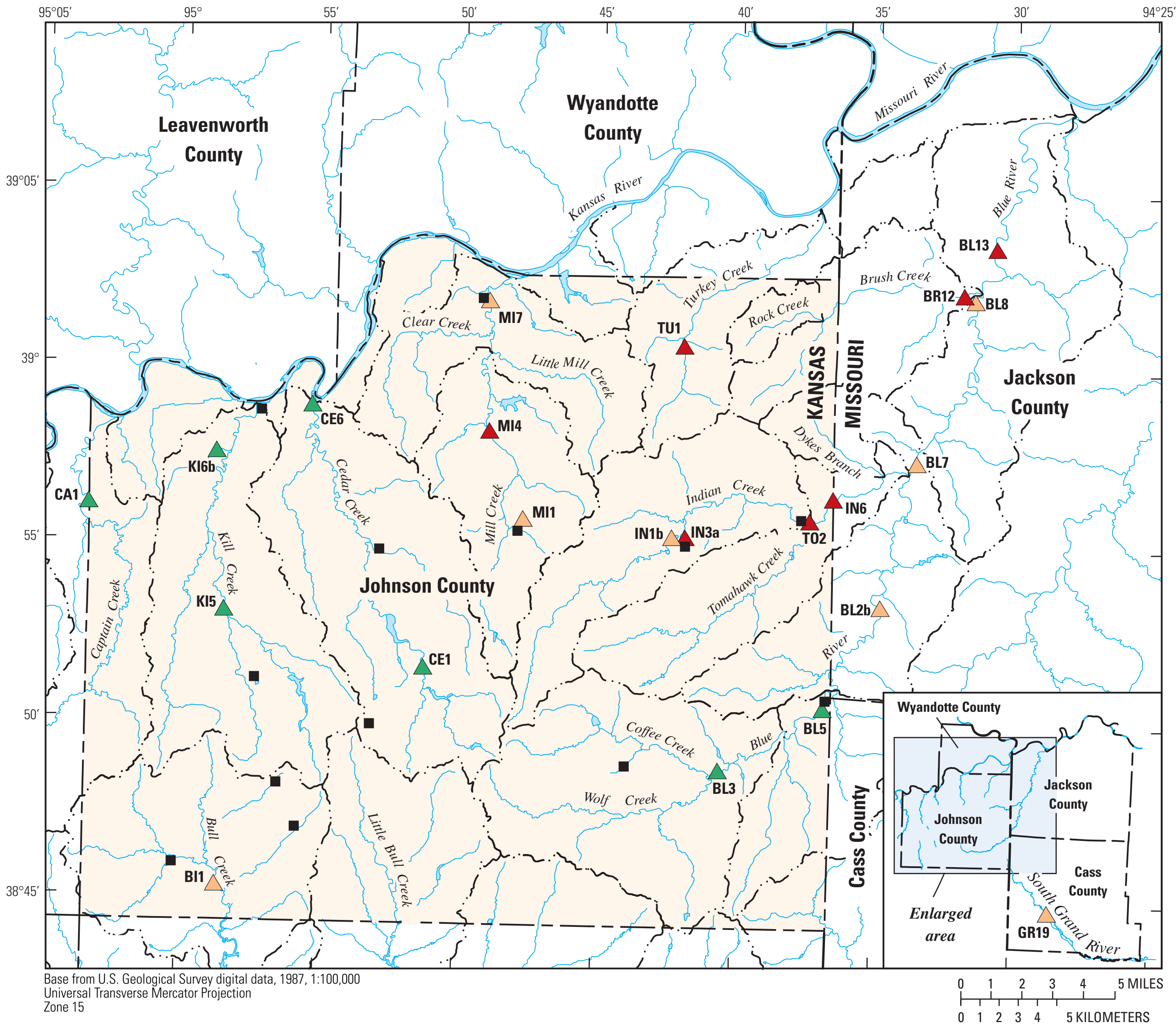
Figure 12. Mean 10-metric macroinvertebrate scores (plus one standard deviation) for 22 stream sites in Kansas and Missouri in 2003 and 2004, grouped according to rural and urban land use (table 1) and wastewater treatment (WWTF) discharges. Discriminant function analysis, Pr greater than F, is 0.03 for 2003 and less than 0.0001 for 2004.

multimetric combination was used. Overall, either the proportional scaling or percentile scoring approaches could be used as a basis for grouping and ranking sites according to macroinvertebrate responses.

Aquatic-Life-Support Status

The KDHE macroinvertebrate sampling protocol used to evaluate the biological conditions in Kansas streams was chosen for this study in part so that stream sites could be assigned to one of the three categories of aquatic-life-support status (fully supporting, partially supporting, nonsupporting) as defined by the State 305(b) water-quality assessment. The status categories are used as a guideline for indicating the ability of a stream site to support an acceptable level of aquatic life. The ranges for the four macroinvertebrate metrics described in this report are based on the statewide KDHE database for all streams in Kansas (Kansas Department of Health and Environment, 2006b) and metric performance at reference stream sites that represent the best-available or least-disturbed biological condition. Captain Creek (site CA1) in Johnson County was selected as one of the sampling sites in part because it is a State reference stream and, therefore, useful for comparison purposes. The South Fork of the Grand River (site GR19) was evaluated among the Missouri sites because it was a candidate for reference status in Missouri.

The placement of sampling sites into categories of aquatic-life-support status defined by the four KDHE stream-assessment metrics is shown in table 5. All sites evaluated have some level of impairment as defined by KDHE. Sixty-two percent of the Johnson County sites (10 of 16) in each of 2003 and 2004 were nonsupportive of aquatic life, and 38 percent (6 of 16) were partially supportive. Captain Creek (site CA1) and upstream sites on Cedar (site CE1), Kill (site KI5), and Mill (sites MI1, MI4) Creeks were the only Johnson County sites given a score of 3 for any of the individual metrics in either sampling year, indicating full support of aquatic-life use. However, no sites obtained an average score that would have met the fully supporting category in 2003 and 2004. Captain Creek (site CA1) had the maximum



Base from U.S. Geological Survey digital data, 1987, 1:100,000
Universal Transverse Mercator Projection
Zone 15

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

EXPLANATION

—·—·— **Watershed boundary**

Biological sampling site, identifier, and relative biological impacts from human disturbance

MI4 ▲ High

BI1 ▲ Moderate

BL3 ▲ Low

■ **Municipal wastewater-treatment facility**

Figure 13. Relative biological impacts indicated by average 10-metric macroinvertebrate scores for 2003–04 for 22 macroinvertebrate sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005).

Table 5. Aquatic-life-support status for sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), 2003 and 2004.

[Status based on average site scores for Kansas Department of Health and Environment (2006b) stream-assessment metrics. MBI, Macroinvertebrate Biotic Index; KBI–NO, Kansas Biotic Index; EPT, Ephemeroptera, Plecoptera, and Trichoptera]

Site identification (fig. 2)	General land classification[1]	2003 metric scores						2004 metric scores					
		MBI	KBI–NO	EPT taxa richness	EPT abundance	Average score of four metrics	Aquatic-life-support-status[2]	MBI	KBI–NO	EPT taxa richness	EPT abundance	Average score of four metrics	Aquatic-life-support-status[2]
Kansas													
BL3	Rural	1	2	1	1	1.25	N	2	2	2	2	2.00	P
BL5	Rural	2	2	1	1	1.50	P	2	2	2	2	2.00	P
IN3a	*Urban	1	2	1	1	1.25	N	1	2	1	1	1.25	N
IN6	*Urban	1	1	1	1	1.00	N	1	1	1	1	1.00	N
TO2	Urban	1	1	1	1	1.00	N	1	1	1	1	1.00	N
TU1	Urban	1	1	1	1	1.00	N	1	1	1	1	1.00	N
MI1	Urban	2	1	1	3	1.75	P	1	2	1	1	1.25	N
MI4	*Urban	1	3	1	1	1.50	P	1	1	1	1	1.00	N
MI7	*Urban	1	1	1	1	1.00	N	1	1	1	1	1.00	N
CE1	Rural	2	3	1	2	2.00	P	1	3	2	2	2.00	P
CE6	*Rural	1	1	1	2	1.25	N	1	1	1	1	1.00	N
KI5	*Rural	2	3	1	2	2.00	P	1	2	2	1	1.50	P
KI6b	*Rural	1	2	1	1	1.25	N	2	2	1	2	1.75	P
BI1	*Rural	2	1	1	1	1.25	N	1	1	1	1	1.00	N
CA1	Rural	3	3	1	2	2.25	P	2	3	2	2	2.25	P
Kansas and Missouri (Wilkison and others, 2005)													
BL2b	*Urban	2	1	1	2	1.50	P	1	1	1	1	1.00	N
BL7	*Urban	1	2	1	2	1.50	P	1	2	1	1	1.25	N
BL8	*Urban	2	2	1	3	2.00	P	2	1	1	2	1.50	P
BL13	*Urban	1	1	1	2	1.25	N	1	1	1	1	1.00	N
IN1b	Urban	1	2	1	1	1.25	N	1	1	1	1	1.00	N
BR12	Urban	1	1	1	1	1.00	N	1	1	1	1	1.00	N
GR19	Rural	1	1	1	2	1.25	N	1	1	1	2	1.25	N

[1]Urban sites have greater than 32 percent urban land use and greater than 10 percent impervious surface. Asterisk (*) indicates downstream from wastewater discharge.

[2]Aquatic-life-support status (Kansas Department of Health and Environment, 2006b): F = fully supporting, average score greater than 2.49; P = partially supporting, average score 1.5–2.49; N = nonsupporting, average score 1.0–1.49.

average score of the four KDHE metrics in both 2003 and 2004 (2.25), yet did not score high enough to fall into the fully supporting category (greater than 2.49). All sampling sites in the study were assigned the minimum score of 1 for EPTRich in 2003, and most of the sites that had a score of 3 in 2003 were assigned a score of 2 for this metric in 2004. Ten of the 16 Johnson County sites scored in the nonsupporting category for each of 2003 and 2004, and these sites included eight of the urban sites and six sites receiving wastewater effluent. Most rural sites were partially supporting, whereas most of the urban sites in Johnson County were assigned a nonsupporting status in one or both years (table 5). Brush Creek (site BR12), the most downstream site on the Blue River (site BL13), the upstream Indian Creek site (site IN1b), and the candidate State reference stream in Missouri (site GR19) also were placed in the nonsupporting category for 2003 and 2004. In general, many of the sites scored in the same status category in both years, but two of the Johnson County sites (Mill Creek sites MI1, MI4) and two of the Blue River sites in Missouri (sites BL2b, BL7) scored in the nonsupporting category in 2004 as compared to the partially supporting category in 2003 (table 5).

The data indicate that EPTRich values had the most negative effect on the aquatic-life status results; every site was given the minimum score (1) for this metric in 2003. Even though Captain Creek (site CA1) had the highest EPTRich value in 2004, a total of 12 taxa or more are needed to reach a score of 3 for this metric (Kansas Department of Health and Environment, 2006b), and no sites had more than 11 EPT taxa in either sampling period (Appendix 3). This was unexpected because macroinvertebrate samples collected from small streams in late winter and early spring seasons can contain a higher diversity as compared to samples collected in other seasons (Feminella, 1996).

In the study that included many of the same Missouri sites discussed in this report, Wilkison and others (2005, 2006) found that, in 2002, 36 percent of 11 macroinvertebrate sampling sites met the criteria for full support when they were evaluated using Missouri Department of Natural Resources bioassessment protocols (Missouri Department of Natural Resources, 2001a). By comparison, none of the same sites met the full-support criteria using the Kansas bioassessment protocols in either 2003 or 2004. Currently (2007), the effects of different sampling protocols and index periods on macroinvertebrate results are unknown.

The criteria for determining aquatic-life-support status as defined by the State of Kansas are based on data from monitoring stations that are evaluated on a seasonal or yearly rotation. Most biological monitoring stations in Kansas are streams that are fourth order and (or) watersheds larger than 150 mi^2, which may have naturally higher macroinvertebrate diversity than smaller streams such as those included in this study (S. Cringan, Kansas Department of Health and Environment, oral commun., 2006). This may account for the failure of Johnson County streams in meeting full or partial support for EPTRich and other metrics when evaluated with the Kansas protocol. The Missouri macroinvertebrate protocols (Missouri Department of Natural Resources, 2001a) and aquatic-life criteria were developed for smaller stream sizes (Missouri Department of Natural Resources, 2001b), which may account for the full-support status observed in 2002 at some of the sites in the Blue River watershed as reported by Wilkison and others (2005, 2006). Another plausible reason for this inconsistency in aquatic-life status is the possible effects of generally below-normal precipitation during the summer months in eastern Kansas in 2002 and 2003 (*http://www.ncdc.noaa.gov/oa/ncdc.html*). However, other macroinvertebrate metrics included for evaluating relative biological conditions in this study indicate that some sites fully meet expectations outlined in the Missouri protocol (Missouri Department of Natural Resources, 2001b), with four sites that have among the lowest levels of biological impacts and containing a total taxa richness of 50 or greater in the 2004 sampling (fig. 10, Appendix 3).

Mill Creek currently is the only stream in Johnson County with a TMDL for biological water-quality impairment (Kansas Department of Health and Environment, 2006a). Water-quality standards for nutrients and suspended solids, and their interference with aquatic-life support, are cited as the basis for the TMDL. Historical MBI and %EPT values were described in the TMDL, and Mill Creek sites were found to be nonsupportive during most years, as defined by the established ranges in those metrics. The metrics calculated for this study generally were in agreement with those findings. However, %EPT at the upstream Mill Creek site (MI1) showed substantial variability between 2003 and 2004 (fig. 9) because of the large number of a moderately tolerant mayfly in 2003 (Ephemeroptera: Heptageniidae, *Stenacron interpunctatum*). The variability between years in individual metrics such as %EPT demonstrates one potential drawback of using a small number of individual metrics rather than a combination of metrics for site evaluation. The TMDL goal is to achieve an average MBI of 4.5 or less from 2006 through 2015. Of all the sites evaluated in this study, only the Kansas reference site (Captain Creek, site CA1) achieved that goal and only during 2003.

Relations Between Macroinvertebrate Indicators and Environmental Variables

Data from the recently published report by Lee and others (2005) were used to examine the strength of relations between macroinvertebrate indicators and environmental variables. Additional streamflow volume and flow-exceedance data during the months prior to the 2003 and 2004 sampling periods were used to help explain differences in metric values between the two sampling years. Correlations were examined between 2003 and 2004 individual metric values and the 10-metric scores, and land use and water- and sediment-quality data. Correlations were expected to provide an indication of how well the range in multimetric scores for the sites (in other words, the gradient in relative biological conditions) corresponded with other environmental indicators that were measured in this study (land use and water and sediment quality). The strength of these relations provides insight on the overall impacts of cumulative stressors on the sites, as well as future selection of metrics to be used for monitoring and bioassessments. However, because evaluations are based on a small number of water and sediment samples, the data are not intended to fully characterize those conditions or the relations between water and sediment variables and macroinvertebrate indicators. Even though the sediment-quality data used in the correlations came from only one set of sediment samples in 2003, the levels of contaminants in streambed sediment were used as an estimate of sediment conditions and the past and present exposure of this sediment to aquatic organisms in both 2003 and 2004; therefore, most correlations were generated from separate macroinvertebrate data sets for both years.

Streamflow

Streamflow values were higher at all nine USGS streamgage sites in Johnson County (fig. 2) before and during the 2004 sampling period than before and during 2003 sampling.

Snowfall totals prior to macroinvertebrate collection in 2004 were nearly three times that of snowfall totals prior to the 2003 collection (28 in. and 10 in., respectively; data from weather station in Olathe, Kansas, fig. 2; M. Knapp, State Climatologist, Weather Data Library, written commun., 2005). Greater antecedent soil-moisture conditions, increased precipitation, and snowmelt led to increased streamflows at the nine stream gages coincident with sites at which macroinvertebrates were collected.

Streamflow at six of the nine stream gages during the 5 months prior to sampling in 2003 was compared to streamflow for the same period of time prior to sampling in 2004. Three of the nine stream gages were not installed until January 2004, and therefore, data were not available for this comparison. The relative percentage difference (RPD) between median streamflow values (50-percent exceedance) prior to the 2003 sampling (November 1, 2002, through March 15, 2003) and the 2004 sampling (November 1, 2003, through March 15, 2004) ranged from 191 percent (Blue River near Stanley, site BL3, station 06893080) to 33.3 percent (Indian Creek at Overland Park, station 06893300, a centrally located stream-gage site where no biological sampling occurred, shown in fig. 2) (fig. 14). The largest increases in streamflow between years were at predominantly rural sites upstream from wastewater discharges (such as at Blue River near Stanley, site BL3; fig. 14*A*). Changes to the hydrology of urban watersheds, such as increased wastewater discharges and disconnection from subsurface sources of water, may have contributed to less substantial changes in streamflow between the two sampling years (such as Indian Creek at Overland Park, fig. 14*B*).

Increases in streamflow may have led to increases in macroinvertebrate diversity at some sites between 2003 and 2004. Among the macroinvertebrate metrics calculated, TRich exhibited the greatest differences between 2003 and 2004. The number of total taxa represented in macroinvertebrate data typically increased between 2003 and 2004 at rural sites and was coincident with larger relative increases in streamflow at these sites (fig. 14*A*). The TRich metric exhibited a lesser (if any) increase at urban sites between 2003 and 2004, coincident with smaller relative increases in streamflow prior to macroinvertebrate collection (fig. 14*B*). The drainage area for the urban site provided as an example in figure 14*B* is about 38 percent larger than the drainage area of the rural site provided (fig. 14*A*), and therefore, the annual streamflow at the urban site is greater and relative response to precipitation differs. In addition, RPDs in annual streamflow differ because of the effects of WWTF effluent at the urban site. WWTFs discharges generally increase downstream base flow, and the effects of effluent can be more pronounced during drought years (Wilkison and others, 2006). At sites downstream from WWTFs, when precipitation is less than normal, a larger contribution of total streamflow originates from WWTF, which may result in less macroinvertebrate diversity. Lower base flows and increasing dry periods in small streams have been linked previously to decreases in macroinvertebrate diversity (Feminella, 1996; Meyer and Meyer, 2000).

Conversely, the pollution tolerance metrics MBI and KBI–NO were generally lower in 2003 than in 2004. Less streamflow, corresponding with less runoff, also can result in lesser amounts of nonpoint-source pollutants, which may have led to higher values for these metrics during the drier year (2003).

Land Use

Pearson's correlation coefficients (r values), calculated between macroinvertebrate data (10-metric site scores) and land use, water-quality, and streambed-sediment quality data, are listed in table 6. The table lists each of the individual environmental variables (and their corresponding coefficients) that were significantly correlated with at least one individual macroinvertebrate metric or the 10-metric site scores in 2003 and 2004. Correlations with other metrics are included to provide information on metric-specific trends.

The diversity of macroinvertebrate communities and the site ranks generated in this study generally reflected a pattern in the overall effects of predominant land use upstream from sampling sites. Land-use-related factors ranged from mostly urban sites with municipal WWTF discharge, urban sites with no WWTF discharge, mixed urban and rural sites, rural sites with municipal discharge, to rural sites. Among the individual environmental variables related to land use, 10-metric site scores were significantly correlated with percentage impervious surface, percentage urban, and percentage agriculture in both 2003 and 2004 (table 6). Percentage urban land use was correlated with MBI, %Sc, and %Olig in 2003, but neither of the other land-use variables were significantly correlated with any individual macroinvertebrate metrics in 2003. In 2004, however, all three land-use variables were significantly correlated with 5 of the 10 individual metrics (table 6).

Percentage of agricultural land is an indicator of nonurban land uses and generally has been found to be negatively correlated with macroinvertebrates. However, it also has been found to be positively correlated to some macroinvertebrate indices (Stepenuck and others, 2002). Approximately one-half of the total land use in Johnson County is nonurban, and of that, equal percentages are cropland and grassland (38 percent), 18 percent is forest, and 6 percent is miscellaneous including home sites (Johnson County Automated Information Mapping Systems, written commun., 2003). In this study, among the significant correlations between percentage agricultural land use and biological metrics, all correlations were positive except in 2004 when MBI was found to be negatively correlated. The significantly positive correlation between percentage agricultural land use and the 10-metric macroinvertebrate scores may be because of the rapid land-use changes occurring within the study area. In some areas of Johnson County and adjacent counties in both Kansas and Missouri, areas that experienced past or recent use for agriculture are rapidly being converted to a more urbanized landscape, which may have more adverse effects on stream communities. Therefore, when assessing effects on streams in

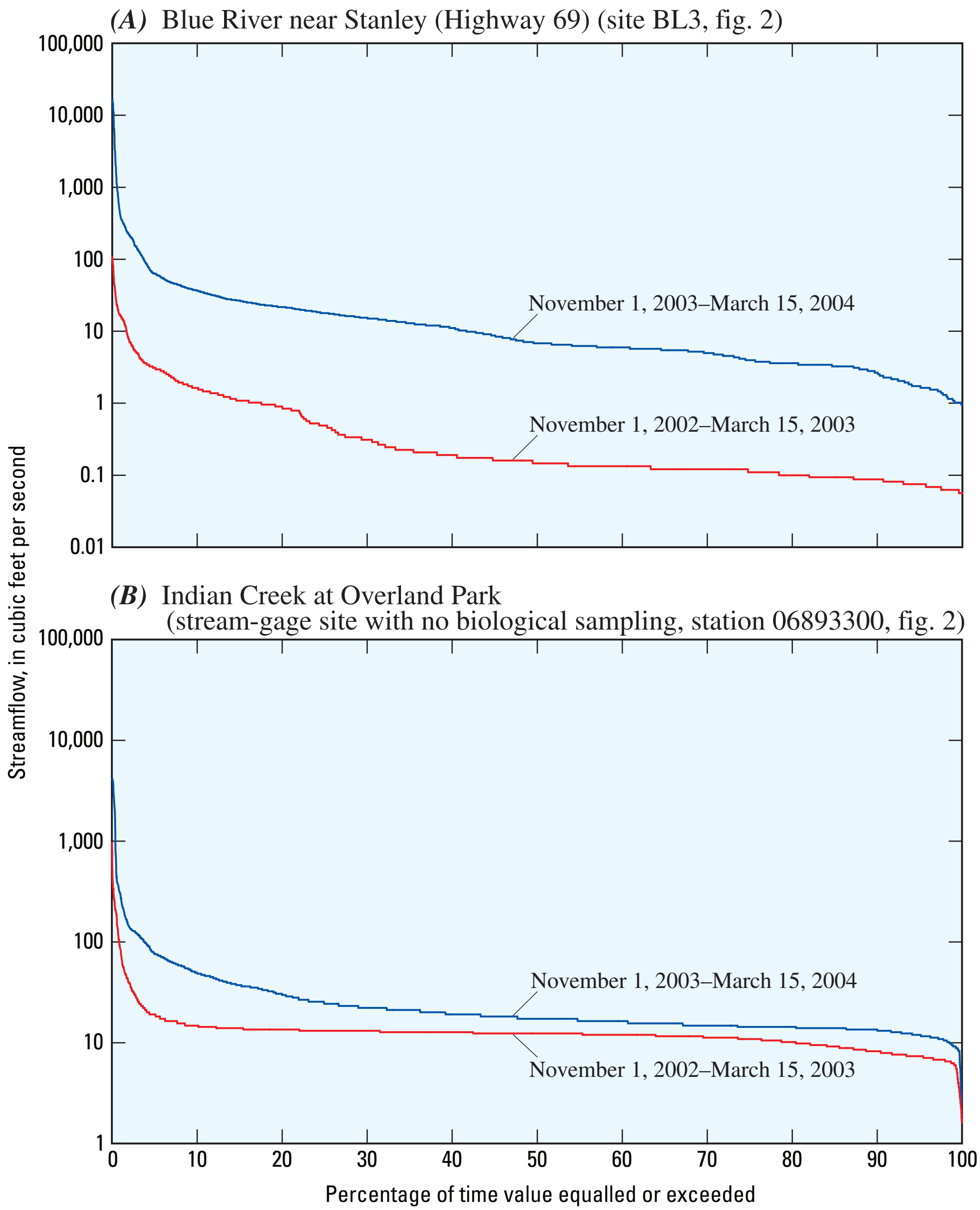


Figure 14. Streamflow duration curves for *(A)* Blue River near Stanley (representative of rural sites) and *(B)* Indian Creek at Overland Park (representative of urban sites with wastewater discharge) from November 1 through March 15, 2002–03, and 2003–04.

urban environments, one might expect land that is classified as agricultural and near urban areas to provide more positive benefits to streams as long as stream corridors are buffered from erosion and excessive nonpoint-source runoff.

Table 7 shows land-use variables (percentage urban, percentage impervious surface) and their corresponding coefficients resulting from the Spearman-rho rank correlations with the 5-, 6-, and 10-metric macroinvertebrate scoring solutions. These rank correlations provided concurrence in site arrangement (as measured by ranks in scores) between macroinvertebrate site ranks and the land-use variables. Relations between multimetric scores and land-use variables were similar regardless of whether 5-, 6- or 10-metric scores were used.

Water and Sediment Quality

Water and streambed-sediment contaminants can originate from point or nonpoint sources. Point sources of contamination typically are municipal and industrial discharges and may include nutrients in stream water and organic wastewater compounds in stream water and streambed sediment, metals and hydrocarbons in streambed sediment, and

Table 6. Pearson correlation coefficients (r values) for nine environmental variables (land use, and water and sediment quality) and both individual macroinvertebrate metrics and 10-metric site scores for 15 stream sampling sites in Johnson County, Kansas, 2003 and 2004.

[Macroinvertebrate metric abbreviations are listed in table 2. Values in bold are statistically significant (α = 0.05) with a p-value less than 0.001.]

Environmental variable	10-metric score	Macroinvertebrate metric									
		MBI	KBI	EP-TRich	TRich	%Sc	%Olig	%Tany	%Int–KBI	%EP	SWDI
2003											
Percentage impervious surface[1]	**-0.78**	0.48	0.50	-0.55	-0.58	-0.57	0.38	-0.34	-0.57	-0.38	-0.56
Percentage urban land use[2]	**-.83**	**-.84**	-.55	.67	-.55	**.82**	**-.73**	.56	.58	.70	.49
Percentage agriculture land use	**.81**	-.54	-.44	.61	.57	.55	-.47	.39	.50	.44	.58
Total concentration of organic wastewater compounds in filtered water	-.59	.63	.52	-.58	-.30	-.18	.38	-.37	-.40	-.30	-.16
Total nitrogen concentration in water	**-.82**	**.82**	.26	-.60	-.45	-.44	**.88**	-.51	-.24	-.58	-.44
Total phosphorus concentration in water	**-.75**	**.78**	.22	-.57	-.42	-.44	**.86**	-.42	-.20	-.54	-.42
Fecal coliforms (streambed sediment)	-.59	.37	.02	-.51	-.54	-.28	**.80**	-.28	-.09	-.11	-.60
Total polycyclic aromatic hydrocarbons (streambed sediment)	**-.89**	**.82**	.48	-.72	-.50	-.45	**.77**	-.50	-.46	-.53	-.42
Nonylphenol diethoxylate (streambed sediment)	-.70	.64	.06	-.55	-.48	-.26	**.91**	-.45	-.09	-.43	-.48
2004											
Percentage impervious surface[1]	**-.85**	.72	.55	**-.83**	**-.79**	**-.75**	.42	-.45	-.55	**-.88**	**-.84**
Percentage urban land use[2]	**-.89**	**-.88**	**-.80**	**.93**	**-.91**	**.84**	-.61	.41	**.74**	**.94**	**.96**
Percentage agriculture land use	**.86**	**-.76**	-.55	**.79**	**.75**	**.79**	-.51	.46	.53	**.88**	**.83**
Total concentration of organic wastewater compounds in filtered water	-.52	**.74**	.42	-.42	-.36	-.28	.73	-.03	-.38	-.44	-.45
Total nitrogen concentration in water	-.66	**.86**	.30	-.56	-.51	-.57	**.93**	-.30	-.18	-.56	-.66
Total phosphorus concentration in water	-.61	**.82**	.29	-.50	-.48	-.54	**.91**	-.16	-.18	-.49	-.62
Fecal coliforms (streambed sediment)	-.45	.49	-.11	-.50	-.51	-.53	.55	-.28	.17	-.46	-.53
Total polycyclic aromatic hydrocarbons (streambed sediment)	**-.78**	**.90**	.42	**-.73**	-.61	-.67	**.86**	-.43	-.31	-.68	-.72
Nonylphenol diethoxylate (streambed sediment)	-.49	.62	.01	-.50	-.43	-.47	.69	-.31	.09	-.44	-.52

[1]Impervious surfaces include buildings, courtyards, and paved and unpaved roads and parking lots.

[2]Urban includes park, residential, commercial, and industrial land use.

Table 7. Spearman-rho rank correlation coefficients (r values) between macroinvertebrate site scores and land-use variables, and between macroinvertebrate site scores and the environmental effects score, for sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), 2003 and 2004.

[Values in bold are statistically significant ($\alpha = 0.05$) with a p-value less than 0.001. JC, Johnson County; --, not applicable]

Year	Score type	Number of sites included	Land-use variable		Environmental effects score
			Urban	Impervious surface	
2003	5 Metric	JC (15)	**-0.80**	**-0.79**	**0.91**
	6 Metric	JC (15)	-.71	-.72	**.84**
	10 Metric	JC (15)	**-.77**	-.72	**.85**
	5 Metric	All (22)	-.71	-.74	--
	6 Metric	All (22)	-.68	-.72	--
	10 Metric	All (22)	-.76	-.75	--
2004	5 Metric	JC (15)	-.71	-.72	**.81**
	6 Metric	JC (15)	-.75	-.74	**.83**
	10 Metric	JC (15)	**-.78**	**-.77**	**.87**
	5 Metric	All (22)	**-.79**	**-.78**	--
	6 Metric	All (22)	**-.80**	**-.78**	--
	10 Metric	All (22)	**-.86**	**-.84**	--

bacteria in stream water and streambed sediment. Nonpoint sources of contamination include storm runoff from urban and agricultural lands and seepage from septic systems. Potential contaminants from nonpoint sources include indicator bacteria in stream water, and metals and hydrocarbons in streambed sediment.

Several water-quality variables were significantly correlated with macroinvertebrate community metrics. Total nitrogen and total phosphorus in water showed a significant negative correlation with the 10-metric score in 2003 (table 6). However, these relations were not significant in 2004, which may have been because of higher streamflows observed before the 2004 sampling and also may be related to the percentage of total streamflow originating from WWTFs. The individual metrics MBI and %Olig showed a significant positive correlation with the two nutrients in both years (table 6). Total concentration of organic wastewater compounds (the sum of detected concentrations in filtered water samples) was significantly correlated with MBI in 2004, but no other relations tested with this variable were significant.

Total polycyclic aromatic hydrocarbons (PAHs) in streambed sediment generally had the strongest relation to the 10-metric macroinvertebrate scores, and this environmental variable was significantly correlated with MBI and %Olig in 2003, and MBI, EPTRich, and %Olig in 2004 (table 6). PAHs, generally considered nonpoint contaminants but also found in WWTF discharge, typically are related to increases in vehicle exhaust (Van Metre and others, 2000; Yunker and others, 2002), incomplete combustion of fossil or biogenic fuels (Schauer and others, 2001, 2002), and the direct release of fossil fuels, such as oil leakage or parking-lot sealant (Wang and others, 2000; Mahler and others, 2005). Several PAH compounds were present in concentrations higher than USEPA probable effects level guidelines for streambed sediment (benzo(a)pyrene, fluoranthene, naphthalene, phenanthrene, pyrene). All PAHs analyzed from streambed-sediment samples had some concentrations higher than USEPA threshold effects level guidelines (U.S. Environmental Protection Agency, 1998; Lee and others, 2005).

Nonylphenol diethoxylate in sediment was significantly correlated with %Olig in 2003 but was not significantly correlated with any metric values generated from 2004 data (table 6). Among the other sediment-quality constituents, fecal coliforms had a weak relation with 10-metric macroinvertebrate scores (table 6). Fecal coliform in streambed sediment was not significantly correlated with any macroinvertebrate metric except %Olig in 2003.

Point sources of water- and sediment-quality contamination appear to have negative effects on macroinvertebrate communities related to the proximity downstream from WWTF discharges, whereas the effects of nonpoint-source contamination relate more broadly across all sites. Possible causes of decreased macroinvertebrate community diversity downstream from wastewater discharges include effects associated with nutrients or organic wastewater compounds or a combination of contaminants resulting from both urban nonpoint-source runoff and wastewater effluent sources.

Nutrient concentrations in stream water were higher at the Indian Creek sites in Johnson County (sites IN3a, IN6) than at other sites because of the greater volume of wastewater effluent discharges (Lee and others, 2005). Nonylphenol diethoxylate is one of the breakdown products of commonly used detergents and is found in wastewater effluent and in bed sediment of receiving streams (Giger and others, 1984). Levels of this contaminant were not significantly correlated with 10-metric site scores, but this class of detergent metabolites has been known to cause estrogenic effects in fish (Soto and others, 1991). The type of secondary treatment process at upstream WWTFs also may affect biological conditions at the sampling sites. Lee and others (2005) found that discharges from WWTFs with trickling filter secondary treatment processes had the highest concentrations of many potential contaminants during base-flow conditions.

During base-flow conditions, fecal coliform densities were significantly higher at urban sites than agricultural sites in Johnson County (Lee and others, 2005). Levels of fecal coliform bacteria may not affect macroinvertebrate populations directly but commonly are used as an indicator of agricultural or urban-related sources such as sediment/water interactions, leaking sewage lines, and increases in domestic animal waste. This variable, along with the total concentration of organic wastewater compounds, was not significantly correlated with 10-metric macroinvertebrate scores. Correlations between macroinvertebrate site scores and all six of the water- and sediment-quality constituents in this study generated lower r values when the two Indian Creek sites downstream from wastewater discharges (sites IN3a, IN6) were omitted from the correlations. This pattern was most pronounced with total phosphorus, suggesting that some point-source effects from discharges at these sites may be substantial. Lee and others (2005) found that WWTFs were the primary source of phosphorus in Johnson County streams during base flow. However, nonpoint-source contaminants such as PAHs in sediment still correlated at approximately the same level when the sites downstream from wastewater effluent discharges were omitted. On the basis of this information, water- and sediment-quality constituents that are related to nonpoint-source urban runoff may have more negative effects on macroinvertebrate scores at urban sites that do not receive wastewater effluent. Although point-source contributions may have substantial effects based on proximity of the source to a site, land use (and the corresponding nonpoint contributions) had the most substantial effect on overall macroinvertebrate communities in Johnson County streams.

Site Groupings and Scoring

Principal components analysis was used to determine the most important environmental variables that were measured in this study, including land use, water and sediment quality, and macroinvertebrate scores, for explaining variation among sampling sites. In addition, it was used to provide a basis for separating or clustering sites that have similar conditions or effects. Similarly, the environmental effects score was used as a multivariable indicator that could be compared directly to the integrated macroinvertebrate responses and that could provide some basis for qualitative assignment of sites to rating categories of relative stream quality.

Principal Components Analysis

Principal components analysis (PCA) of all Johnson County sites indicated that three components, each consisting of the 10-metric scores and multiple environmental variables listed in table 8, comprised about 75 percent of the total variance of the data set. Every variable analyzed, including the 10-metric site scores, contributed to component 1. Variables associated both with urban land use (percentage impervious surface, fecal coliform in stream water, total PAH concentration in streambed sediment, and cadmium, copper, and zinc in streambed sediment) and wastewater contamination (total concentrations of organic wastewater compounds in stream water, phosphorus in streambed sediment, nonylphenol diethoxylate in streambed sediment, and fecal coliform in streambed sediment) contributed the most to component 1. All of the land-use, stream-water, and streambed-sediment variables except percentage agricultural land use were negatively related to the 10-metric site scores (table 6). Component 2 did not include macroinvertebrate scores and was positively related to nutrients and some wastewater compounds associated with wastewater discharge and negatively related to some metals and impervious surface, which may be more linked to land use. Component 3 was positively related to macroinvertebrate scores and many metals in streambed sediment and negatively related to impervious surface and water- and sediment-quality constituents associated with both point and nonpoint sources of contamination.

The principal components analysis resulted in site separation that generally was based on urban-related factors in the form of both land use and the presence, absence, or proximity of WWTF discharges. Urban sites (greater than 32-percent urban land use and 10-percent impervious surface) without wastewater discharges were grouped together (lower right quadrant, fig. 15). Urban sites less than 3 mi downstream from wastewater discharges were grouped together (upper right quadrant, fig. 15). The six rural Johnson County sites, including sites without wastewater discharges (sites BL3, BL5, and CA1) and sites more than 3 mi downstream from wastewater discharges (sites CE6, KI5, and KI6b), were grouped together (upper left quadrant, fig. 15). There were two sites that were exceptions to the site-grouping results. The upstream Cedar Creek site (CE1), which is rural and has no municipal wastewater discharge, grouped with primarily urban sites without WWTF discharge (lower right quadrant, fig. 15). It is possible that the intermittent nature of the streamflow at site CE1 may lead to short periods of localized stresses related

Table 8. Sampling-site groupings based on principal component analysis of macroinvertebrate 10-metric scores and land-use, stream-water, and streambed-sediment quality data from sampling sites in Johnson County, Kansas, 2003 and 2004.

[Larger absolute component values indicate increased importance of variable. --, not applicable]

Variable	Component 1 (42.7 percent)	Component 2 (18.9 percent)	Component 3 (13.9 percent)
10-metric site score	-0.26	--	0.27
Percentage impervious surface	.24	-0.12	-.32
Percentage agricultural land use	-.18	.17	.31
Dissolved solids (stream water)	.11	--	.16
Total concentration of organic wastewater compounds (stream water)	.23	--	--
Total nitrogen (stream water)	.24	.27	-.17
Total phosphorus (stream water)	.12	.38	--
Fecal coliform bacteria (stream water)	.23	-.21	-.18
Nitrogen (streambed sediment)	.15	.25	.34
Phosphorus (streambed sediment)	.25	--	.27
Total polycyclic aromatic hydrocarbons (streambed sediment)	.24	--	-.29
Arsenic (streambed sediment)	.14	-.40	.16
Cadmium (streambed sediment)	.28	--	.10
Copper (streambed sediment)	.28	--	.12
Lead (streambed sediment)	.20	-.32	--
Manganese (streambed sediment)	.11	-.26	.28
Nickel (streambed sediment)	.12	-.34	.24
Zinc (streambed sediment)	.30	--	--
Organic carbon (streambed sediment)	.16	.19	.37
Nonylphenol diethoxylate (streambed sediment)	.26	.15	-.17
Para-cresol (streambed sediment)	.19	.27	--
Fecal coliform bacteria (streambed sediment)	.22	.15	--

to flow duration and water quality. Similarly, the Big Bull Creek site (BI1), which is rural and has WWTF discharge less than 3 mi upstream, grouped with the urban sites in the upper right quadrant. However, this site could have been grouped with the two downstream Mill Creek sites (MI4, MI7), which were in close proximity within this quadrant (fig. 15). The site groupings resulting from principal components analysis confirms that, overall, a combination of prevailing land use within the watershed area upstream from the sites and the presence or absence and proximity of WWTF discharges are important in explaining the variation in macroinvertebrate site scores.

Environmental Effects Score

Three environmental variables (percentage impervious surface, total nitrogen in stream water, and total PAHs in streambed sediment) were integrated (Appendix 6) so that their combined effects could be compared directly to the 10-metric macroinvertebrate site scores and because this approach was similar to that resulting from the integration of multiple macroinvertebrate metrics. Although this study was not designed to provide a fully integrated measurement of environmental effects, the human-disturbance component of the Biological Condition Gradient concept (Davies and Jackson, 2006) can be defined by variables that are appropriate for describing the causes or sources of human-induced impacts in aquatic systems. The environmental effects score includes the best information available for defining a gradient in overall human-induced disturbances for the sampling sites evaluated in the study. Values for these scores are given in Appendix 6. The scores could not be calculated for the Missouri sampling sites because comparable data were not available for many of the environmental indicators examined.

The environmental variables included in the environmental effects score were selected from the variables that showed significant correlations with the 10-metric site scores (table 6). The scores include one land-use variable (percentage impervious surface), one water-quality variable (total nitrogen), and one sediment-quality variable (total PAHs). Other significantly correlated indicators were not included

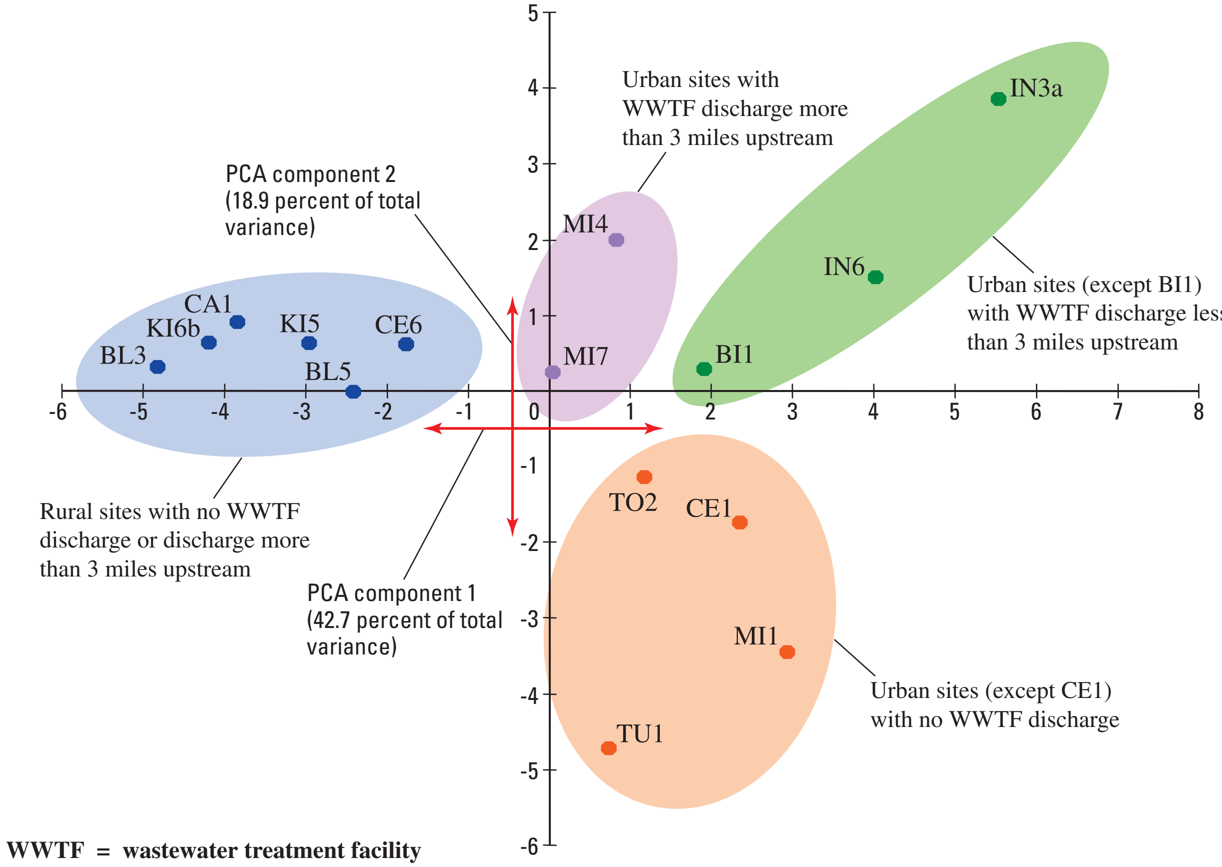


Figure 15. Results of principal component analysis (PCA) for 15 macroinvertebrate sampling sites in Johnson County, Kansas, 2003 and 2004. Rural sites are those with 32 percent or less urban land use; urban sites are those with more than 32 percent urban land use and impervious surface greater than 10 percent.

(percentage urban, percentage agricultural, and total phosphorus) because of possible redundancy with the other three environmental variables chosen. Even though the percentage agriculture land-use variable generated significant correlations with several metrics (table 6), the direction of the response was inconsistent (some were positive and some were negative) and, therefore, not incorporated into the environmental effects score.

The environmental effects scores ranged from a minimum of 45 at both of the downstream Indian Creek sites (IN3a, IN6) to a maximum of 300 at the Kansas reference site (CA1, table 9). Among the environmental variables used in the environmental effects score, total PAHs showed the strongest correlation with the 10-metric scores in 2003, and percentage impervious surface showed the strongest correlation in 2004 (table 6). Impervious surface area has been found to be highly correlated with urban intensity (McMahon and Cuffney, 2000). When impervious surface area is plotted in relation to the 10-metric scores, the two downstream Indian Creek sites (IN3a and IN6) plot below the lines of best fit, probably because of the effects of WWTF discharge on macroinvertebrates at those sites (fig. 16). The Grand River reference site (GR19) in Missouri, with no WWTF discharge upstream and impervious surface percentage lower than most other sites, also plotted below this line. The 10-metric scores for this site were less than expected based on impervious surface area, indicating that other factors may be affecting the biological condition at the site. The downstream Brush Creek site (BR12), with more than double the impervious surface area of most other sites (fig. 16), stands alone as the site with the highest level of biological impacts among the 22 sites (table 9). In general, sites in the category with low biological impacts had percentage urban land-use estimates that were less than 32 and percentage impervious surface less than 10. These sites included the Kansas reference stream site on Captain Creek (site CA1), the two upstream Blue River sites (BL3, BL5), both Cedar Creek sites (CE1, CE6), and both Kill Creek sites (KI5, KI6b).

Macroinvertebrate responses to total nitrogen in water (fig. 17) and total PAHs in streambed sediment (fig. 18) are most evident at sites affected either by WWTF discharges, urban land use, or both. WWTFs are a primary source of total nitrogen in streams during base flow (Wilkison and others, 2002, 2006; Lee and others, 2005), and macroinvertebrate communities typically are affected by the resulting organic enrichment. Three of the sites included in the category with

Table 9. Environmental effects scores, 10-metric macroinvertebrate scores, categories of relative biological impacts based on 10-metric macroinvertebrate scores, and sources of environmental effects for sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), 2003 and 2004.

[W1, wastewater discharge upstream, low volume (less than 4 million gallons per day); W2, wastewater discharge upstream more than 2 miles, high volume (greater than 10 million gallons per day); W3, wastewater discharge upstream less than 2 miles, high volume (greater than 10 million gallons per day); CU, cumulative urban, percentage impervious surface greater than 10, sediment polycyclic aromatic hydrocarbons greater than 1,470 micrograms per kilogram, and percentage urban land cover more than 32; CR, stream channelized with reveted banks; --, not applicable or unknown]

Site identifier (fig. 2)	Environ-mental effects score[1]	Site rank	10-metric score		Site rank[2]		Site group[3]		Average 10-metric score for 2003 and 2004	Category of biological impacts[4]	Source of environmental effects
			2003	2004	2003	2004	2003	2004			
Kansas[5]											
CA1	300	1	654	862	3	1	A	A	758	Low	--
BL3	292	2	639	734	4	4	A	A	687	Low	--
BL5	291	3	683	720	2	5	A	A	702	Low	--
BI1	290	4	484	527	10	8	B	B	506	Moderate	W1
KI5	287	5	695	738	1	2	A	A	717	Low	W1
KI6b	286	6	586	696	7	6	A	A	641	Low	W1
CE6	272	7	594	579	6	7	A	A	587	Low	W1
CE1	248	8	606	755	5	3	A	A	681	Low	--
MI7	239	9	434	390	12	11	B	B	412	Moderate	W1, CU
MI4	190	10	438	241	13	17	B	C	340	High	W1, CU
TO2	186	11	409	237	15	19	B	C	323	High	CU
MI1	185	12	491	321	9	14	B	B	406	Moderate	CU
TU1	170	13	299	266	18	16	C	C	283	High	CU
IN3a	45	14	118	193	21	20	C	C	156	High	W3, CU
IN6	45	15	117	55	20	21	C	C	86	High	W3, CU
Kansas and Missouri (Wilkison and others, 2005)[6]											
BL2b	--	--	574	489	8	10	B	B	532	Moderate	W1, CU
IN1b	--	--	510	439	11	13	B	B	475	Moderate	CU
GR19	--	--	447	576	14	9	B	B	512	Moderate	--
BL7	--	--	417	384	16	15	C	B	401	Moderate	W2, CU
BL8	--	--	373	466	17	12	C	B	420	Moderate	W2, CU
BL13	--	--	267	328	19	18	C	C	298	High	W2, CU, CR
BR12	--	--	59	33	22	22	C	C	46	High	CU

[1]Determined from percentage impervious surface area, total nitrogen in water, and polycyclic aromatic hydrocarbons in sediment (Appendix 6).

[2]From Appendix 4.

[3]From table 4.

[4]Determined on the basis of average 10-metric scores.

[5]10-metric macroinvertebrate scores and ranks based on proportional scaling across 15 Johnson County sites (number of sites=15).

[6]10-metric macroinvertebrate scores and ranks based on proportional scaling across all 22 sites (number of sites=22).

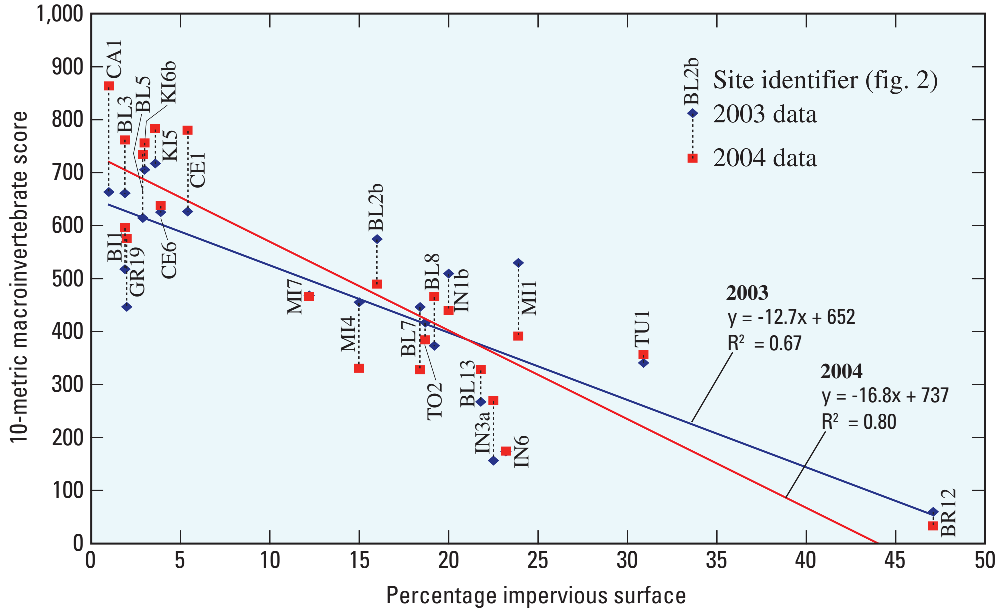


Figure 16. Comparison of 10-metric macroinvertebrate site scores for 2003 and 2004, and percentage impervious surface area for sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005).

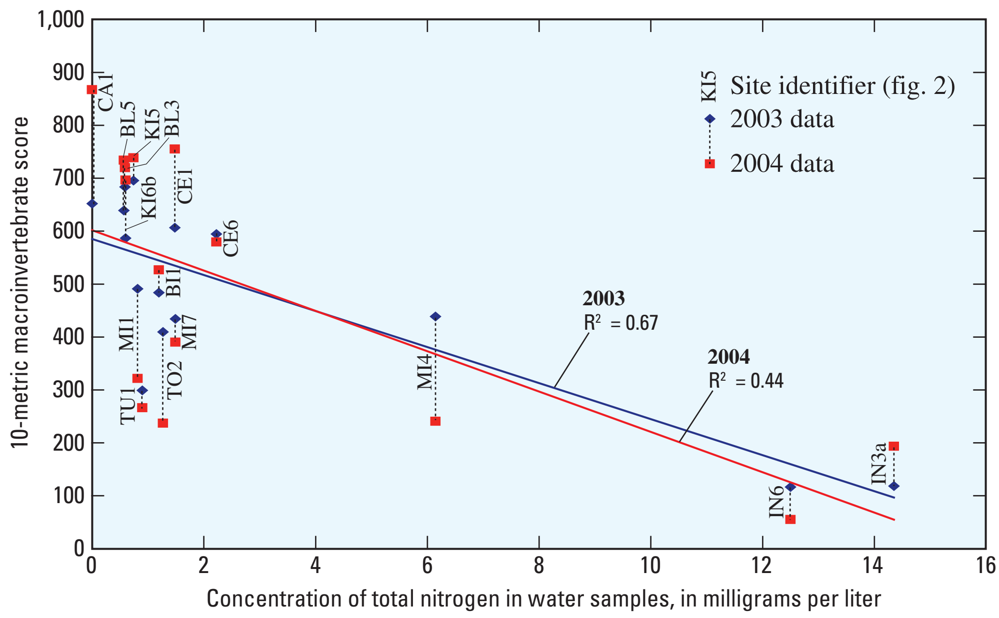


Figure 17. Comparison of 10-metric macroinvertebrate site scores for 2003 and 2004, and total nitrogen concentration in water from sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005).

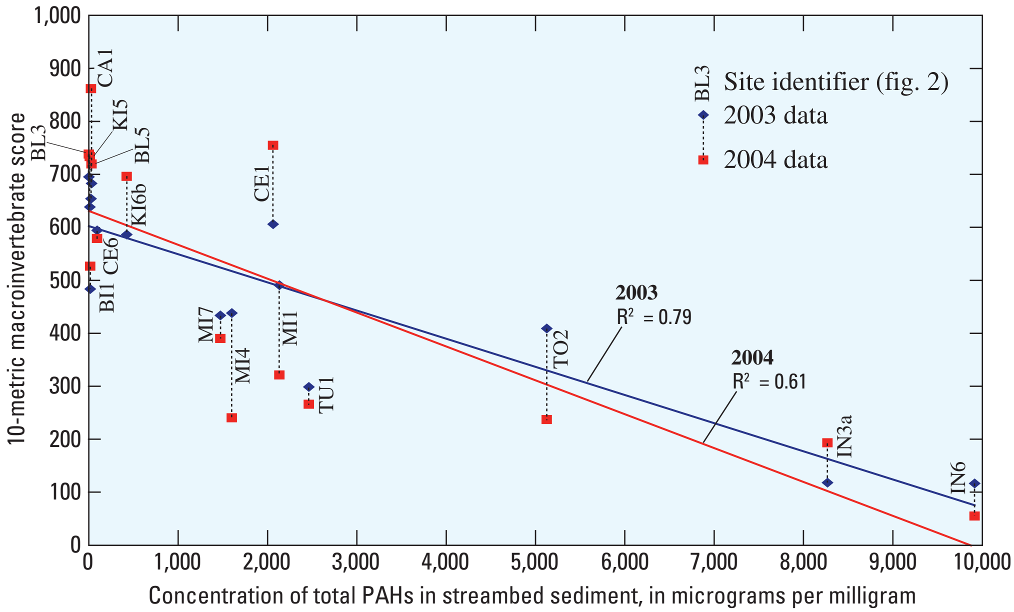


Figure 18. Comparison of 10-metric macroinvertebrate site scores for 2003 and 2004, and concentrations of total polycyclic aromatic hydrocarbons (PAHs) in streambed sediment from sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005).

low levels of biological impacts are downstream from WWTFs (sites CE6, KI5, and KI6b, tables 1 and 9). Among sites in the category representing a moderate level of biological impacts, the Big Bull Creek site (BI1) was the only one with WWTF discharges less than 3 mi upstream. Even though site BI1 was placed in the category of moderate levels of biological impacts (table 9), the percentage of impervious surface area and concentrations of total nitrogen and PAHs were low enough to attain an environmental effects score similar to the other sites in the low biological impact category. When total nitrogen in stream water is plotted in relation to 10-metric scores (fig. 17), lower metric scores at the two Indian Creek sites (IN3a and IN6) that are downstream from WWTF discharges correlate with higher concentrations of nitrogen. A similar pattern was observed with PAHs in streambed sediment, where 10-metric scores for both of the Indian Creek sites (IN3a, IN6) correlate with higher PAH concentrations (fig. 18). The upstream Cedar Creek site (CE1) plotted above the line of best fit, and the 10-metric scores at this site place it in the category with low levels of biological impacts (table 9). However, the environmental effects score at site CE1 is lower than other sites in the low-impact category because of higher concentrations of PAHs in sediment (fig. 18). This may be related to the percentage of urban land use at site CE1, which is higher (31.9 percent) than any other sites in the category with low biological impacts (tables 1 and 9).

The two downstream Indian Creek sites (IN3a, IN6) were placed in the category representing high levels of biological impacts (table 9) and had environmental effects scores that were widely separated from other sites (fig. 19). Three of the Johnson County sites [including two of the Mill Creek sites (MI1, MI7) and the Big Bull Creek site (BI1)] fell into the category representing a moderate level of biological impacts (table 9). Even though the Big Bull Creek site had an environmental effects score that ranked fourth among the Johnson County sites (table 9), the placement of this site in the category with moderate levels of biological impacts indicates that the environmental effects score may not fully account for wastewater effects on macroinvertebrates. However, Spearman-rho rank correlation coefficients determined with the three multimetric macroinvertebrate scores and the environmental effects scores ranged from 0.81 to 0.91 (table 7), indicating that there was good concurrence in site arrangement between macroinvertebrate results (from highest to lowest in biological impacts as measured by ranks) and that defined by the environmental variables.

Macroinvertebrate Responses to Environmental Variables

Effects of Urbanization on Macroinvertebrates

The structure and diversity of macroinvertebrate communities can be negatively affected by urbanization (Giller and Malmqvist, 1998). Urbanization generally leads to increases in impervious surface areas and stream re-channelization within the watershed, which in turn increases the frequency and magnitude of stormflows (Arnold and Gibbons, 1996). Larger variations in velocity and streamflow during stormwater runoff also may have negative effects on macroinvertebrate communities (Clausen and Biggs, 1997). Urban runoff and treated

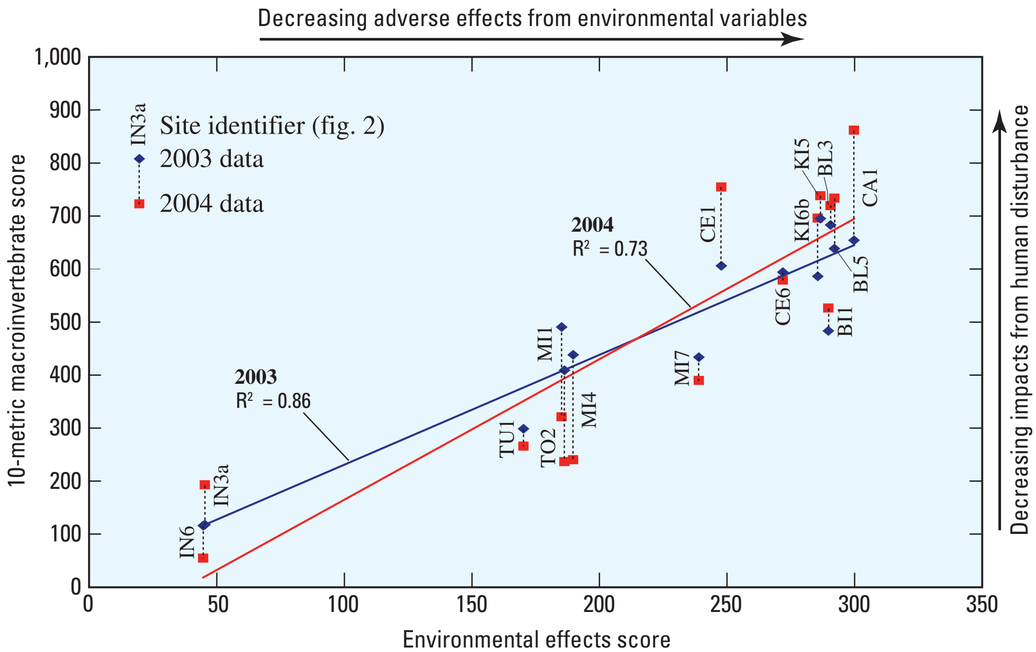


Figure 19. Comparison of 10-metric macroinvertebrate site scores and environmental effects scores for sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), 2003 and 2004.

wastewater, the primary sources of water in many urban areas, have increased concentrations of nutrients, pesticides, metals, and organic compounds (Heaney and Huber, 1984). Treated wastewater discharge also alters stream hydrology (Lee and others 2005; Wilkison and others, 2006).

Effects of urbanization are known to include decreased macroinvertebrate diversity and result in communities dominated by more tolerant species (Milner and Oswood, 2000; Gray, 2004). Organic enrichment associated with WWTF discharges in particular has been found to reduce macroinvertebrate diversity (Seager and Abrahams, 1990). Less infiltration capacity of watersheds in urban environments with greater impervious surface area may inhibit the ability of streams to sustain base flow (Finkenbine and others, 2000; Dodds, 2002), but this effect may be offset by WWTF discharge (Wilkison and others, 2006). Impervious surfaces alter stream hydrology and convey contaminants into water bodies. Impervious surface area has been found to be highly correlated with urban intensity and a good integrator of urban land-use conditions (Arnold and Gibbons, 1996). Impervious surface area also is known to be negatively correlated with macroinvertebrate assemblages (Stepenuck and others, 2002).

Cumulative urban is one of the impact types identified by Yoder and Rankin (1995) as a cause of impairment in flowing water and is described by situations when many different contaminants may be present from combinations of nonpoint-source urban runoff and point discharges of treated wastewater. In this study, estimates of impervious surface area, percentage urban, and percentage agricultural land use were strongly correlated with macroinvertebrate scores, and in general, these relations generated higher correlation coefficients (r values) than most of the water- and sediment-quality variables in both years (table 6). This indicates that the cumulative effects of land use on macroinvertebrate site scores were detected more easily than effects resulting from a particular chemical constituent.

Results of this study indicate that the biological condition of streams in Johnson County is being adversely affected by both urban land use and effects associated with wastewater discharges. The combined effects of these sources in Johnson County likely have altered the natural variability in flow regime and changed the inputs of contaminants and the quantity of available nutrients. These results are consistent with those reported in Wilkison and others (2006). Macroinvertebrate site scores and ranks for the Indian Creek sites in Johnson County that are less than 3 mi downstream from wastewater discharges (sites IN3a, IN6) were consistently rated among sites with the highest levels of biological impacts in one or both years. However, other urban sites in Johnson County and Missouri that do not receive wastewater discharges such as Tomahawk Creek (site TO2), Turkey Creek (site TU1), and Brush Creek (site BR12) have among the highest percentages of impervious surfaces in the watershed. These sites also consistently scored and ranked among those with the most impacts in terms of diversity metrics (TRich, EPTRich) and in overall site scores and ranks.

The macroinvertebrate data also indicate that biological conditions may fluctuate from year to year at some sites. Where wastewater discharges are present and comprise the majority of streamflow during base-flow conditions, year-to-year changes in weather likely have less pronounced effects during base-flow conditions at these sites (Lee and others, 2005). Wastewater discharges are typically warmer, more nutrient rich (which increases algal production and causes decreased dissolved oxygen values and large diurnal fluctuations) and have increased dissolved solids that cause larger specific conductance readings (Masters, 1991; Sprague, 2005).

Possible causes of decreased macroinvertebrate community diversity downstream from wastewater discharges include effects associated with nutrients and altered hydrology, contaminants resulting from urban nonpoint-source runoff, or a combination of these. Excess algae growth in riffles also retains fine particulates, resulting in greater substrate embeddedness and a corresponding decrease in interstitial living space for macroinvertebrates. This secondary effect of wastewater discharges may occur even when water-quality standards set for municipal wastewater discharges are met 100 percent of the time. However, macroinvertebrate data indicate that, overall, the effects of wastewater discharges and urbanization on biological communities cannot be fully separated from one another because metric scores for urban sites with no wastewater discharge often were as low as those for urban sites receiving wastewater discharge (table 9). Even though urban sites without WWTF discharges have slightly higher macroinvertebrate scores (fig. 12), future changes in wastewater treatment or modifications in stormwater pathways may not improve aquatic-life status to the levels observed at many of the rural sites. WWTF discharge volume (or percentage of base flow as effluent) and the location distance upstream from a site are both important factors that affect biological communities.

Water-quality constituents that could contribute to decreased macroinvertebrate diversity in urban streams also include specific conductance, which is usually positively correlated with chloride concentrations (Hem, 1992). Elevated chloride concentrations have been found at site IN6 and likely are related to road-salt application (concentration in one sample was higher than KDHE acute aquatic-life criteria) (Lee and others, 2005). Elevated chloride concentrations may be adversely affecting macroinvertebrate communities at other urban sites as well. Other urban-related water-quality factors also may be affecting macroinvertebrate communities, such as increased temperature from wastewater discharge and low dissolved oxygen associated with large diurnal fluctuations caused by increased algal production and decay.

Previous studies have found that macroinvertebrate community-level attributes decline to a maximum degradation level at a specific threshold of impervious surface area (Schueler, 1994). Degradation thresholds for impervious surface areas ranging from 10 to 20 percent have been described (Paul and Meyer, 2001). Even though specific thresholds in impervious surface area were not identified during this study, sites with impervious surface area greater than 10 percent were among those with the highest levels of impacts on the basis of both macroinvertebrate response and measurements of variables related to urbanization.

Macroinvertebrate Response to Gradients in Environmental Variables

Generally, it is assumed that the composition of resident aquatic communities reflects an integration of exposure to the combined effects of all disturbances measured. The Biological Condition Gradient concept, which is a model that describes biological responses to increasing levels of human disturbance, has been supported by USEPA as an effective tool for classifying stream condition and managing water-resource objectives (Davies and Jackson, 2006; U.S. Environmental Protection Agency, 2006). The foundation behind this concept is the expectation that the quality or condition as measured by biological indicators can be represented by categories or tiers that are defined on the basis of a gradient in degree of impacts resulting from a variety of human disturbances. In this study, changes in water quality, contaminant concentrations, and physical variables such as streamflow and habitat modifications, are all associated with a gradient in the degree of biological impacts for the sites evaluated. The different rating methods used to evaluate relative site quality in this study yielded similar rankings and groupings for most of the sites. The relative site rankings and groupings that were based on 10-metric macroinvertebrate site scores (table 4) were similar to those developed using the environmental effects score (table 9). These results indicate that an integrated macroinvertebrate score developed as a grading system for relative stream quality, although meaningless by itself, is a useful tool for comparing overall biological impacts at sites across gradients in environmental conditions that occur in rapidly changing landscapes such as Johnson County, Kansas.

Macroinvertebrate scores confirm that a combination of environmental variables is affecting the macroinvertebrate communities at the sampling sites used in this study. In general, the seven sampling sites included in site group A (table 4) were placed in the category with low levels of biological impacts (table 9). These sites also had the least urbanization and low values for variables related to organic enrichment (nutrients, and presence, volume, and proximity of WWTF discharges upstream). This is substantiated further by the analysis of the two urban site groups that were based on both land use and wastewater discharge (with and without WWTF discharges upstream) in which the mean macroinvertebrate scores were not significantly different from one another (fig. 12). Because both of these factors also have a direct effect on many of the individual variables that were measured at the Johnson County sites, there is a potential for developing land-use models and estimating the cumulative effects of these variables on biological communities in urban streams.

Spearman-rho rank correlations with the three multimetric scoring solutions also indicated strong relations between the site ranks generated by macroinvertebrate scores and with the site ranks that were based on estimates of percentage urban land use and percentage impervious surface (table 7). This pattern was observed both among the 15 Johnson County sites and when all 22 sites were included in the correlations (table 7). In addition, the site ranks derived from the environmental effects score were significantly correlated with site ranks resulting from all three of the multimetric scoring combinations in both years (table 7). These results indicate that, when the sites are ranked according to a gradient in the degree of adverse environmental effects as described by land use and water- and sediment-quality variables, the ranking of sites according to multimetric macroinvertebrate scores correlated well with this site arrangement (in other words, from high to low across the study sites). Further, when sites with similar known impact sources are grouped together in a subjective manner on the basis of qualitative site knowledge, the resulting estimates of relative biological condition correspond well with site groups derived from combinations of environmental variables. These results also suggest that multimetric scoring and ranking of sites according to biological data derived from screening-level protocols, such as those used by KDHE for macroinvertebrates, provide a good measurement of the biological condition and relative quality of Johnson County streams.

Even though a lack of within-site replication precluded discriminating between individual sites, results suggest that the combinations of macroinvertebrate metrics selected for this evaluation were effective in discriminating between groups of sites with similar degrees of human disturbance. Although aquatic-life status determined for the sites did not identify any that were fully supporting, one of the main goals was to determine site quality relative to other sites as a whole and to provide comparisons with the reference sites. The Captain Creek reference site (CA1) attained the highest average score for the four KDHE metrics (table 5), the highest value for the environmental effects score (table 9), and among the highest biological condition based on the 10-metric macroinvertebrate scores (table 9). Therefore, the upstream Kill Creek site (KI5) and the two upstream sites on the Blue River (sites BL3, BL5) can be considered similar to the reference site in biological quality even though they did not meet fully supporting aquatic-life status according to KDHE evaluation criteria.

Least- and Most-Impacted Stream Sites

Both of the upstream Blue River sites in Johnson County (sites BL3, BL5) consistently scored among the least-impacted sites. Both sites are surrounded by primarily rural land use (rural land use 32 percent or less and percentage of impervious surface of 10 percent or less) and contain a large diversity of macroinvertebrates dominated by clean-water organisms. These sites had among the three highest values for EPTRich, TRich, and SWDI in both 2003 and 2004 (Appendix 3). These noteworthy results indicate that in Johnson County, there is a remaining segment of the Blue River system that has a biological condition comparable to sites with the lowest levels of human disturbance that were included in this study. Even though urban development has moved progressively upstream in this watershed over the last 20 years, these sites presently are located upstream from most urban development.

The data also indicate that the Cedar and Kill Creek watersheds contain sampling sites that represent conditions similar to that of reference quality because some of these sites consistently ranked very close to the Captain Creek site (CA1). The upstream Kill Creek site (KI5) had the highest rank among all sites in Johnson County according to all the rating methods in 2003 and the second or third highest rank in 2004. In contrast, Johnson County sites on Indian Creek (sites IN3a, IN6) and downstream sites on the Blue River (site BL13) and Brush Creek (site BR12) in Missouri ranked among sites with the highest levels of biological impacts regardless of which rating method was used in the evaluation. These sites had very similar rankings among the different rating methods, with the Brush Creek site in Missouri being ranked most often as the lowest in biological quality. Turkey Creek (TU1) and Tomahawk Creek (TO2) sites also ranked among the lowest of the Johnson County sites according to multimetric macroinvertebrate scores in one or both years.

All sites in Johnson County showed some level of impairment on the basis of their ability to support an acceptable level of aquatic life as defined in the KDHE assessment protocol for macroinvertebrate communities (Kansas Department of Health and Environment, 2000). Downstream sites on Indian (sites IN6, IN3a), Turkey (site TU1), and Tomahawk (site TO2) Creeks in Johnson County also have the lowest biological condition relative to other sites included in this study according to 10-metric scores and site ranks. The Indian Creek (IN6, IN3a) and Turkey Creek (TU1) sites also had among the highest levels of adverse environmental effects from known or suspected sources of contaminants (table 9). Previous studies have shown that, at many of these sites, a significant percentage of the total streamflow consists of large-volume municipal wastewater discharges and urban runoff (Lee and others, 2005). Combined sewer overflows, PAHs, high BODs (biochemical oxygen demands), and many potentially toxic compounds associated with urban stormwater runoff and municipal discharges have been documented at the Indian Creek and (or) downstream Blue River sites (Blevins, 1986; Ryon and others, 2000; Wilkison and others, 2002, 2006; Lee and others, 2005).

Comparison to Downstream Sites in Missouri

Although the focus of this study was on sampling sites in Johnson County, Kansas, previously published data from the downstream seven sites in Kansas and Missouri (Wilkison and others, 2005, 2006) also were evaluated in some parts of this report because of the consistency in the sampling protocol and time period sampled, and their inclusion enabled a watershed-based evaluation with a continuum of impacts at sites related to urban and rural land use, and point and nonpoint-source runoff within selected watersheds in the southern part of the Kansas City metropolitan area (fig. 2, table 1). In addition, many of the assessment results can be strengthened by the inclusion of more than one reference stream site and a larger total number of sites. Methods used for enumeration of metrics for the seven Kansas and Missouri sites were the same as those used for the 15 Johnson County, Kansas, sites. The results of this study generally concur with relative site comparisons and identification of sites with the highest and lowest relative stream quality reported in Wilkison and others (2005, 2006).

The downstream Blue River sites and Brush Creek site in Missouri consistently scored among sites with the highest levels of biological impacts according to individual metric values and in multimetric scores. Similarly, all of the Blue River sites in Missouri, which are all downstream from one or more WWTF discharges (sites BL2b, BL7, BL8, BL13), scored and ranked lower than the two upstream Blue River sites in Johnson County (sites BL3, BL5). When Missouri sites were included in the site rankings, both intensely urbanized sites without WWTF discharges (site BR12) and the Blue River sites downstream from the confluence with Indian Creek (sites BL8, BL13) ranked among the most-impacted sites. The Missouri sites are affected by several WWTFs that discharge directly upstream from the Kansas State line (upstream from sites BL2b, BL7, and BL8). The most downstream Blue River site (BL13) has multiple potential sources of contaminants, including WWTF discharge from all upstream sources and tributaries, channelization for flood control, industrial discharges, and cumulative urban runoff, in addition to being located downstream from the confluence with Brush Creek (site BR12). All of the downstream Blue River sites were similar in ranks to the most-impacted Johnson County sites, including the two most downstream Indian Creek sites (IN3a, IN6), Tomahawk Creek (site TO2), and Turkey Creek (site TU1). In contrast, the upstream Blue River sites (BL3, BL5) in Johnson County, Kansas, ranked among the highest quality of sites that were included in this study, indicating clear upstream-to-downstream changes in biological condition within this watershed. This is also an indication that within the Blue River watershed, there is a potential for biological recovery of downstream Missouri segments if improvements in water quality and stream restoration techniques are implemented in the future.

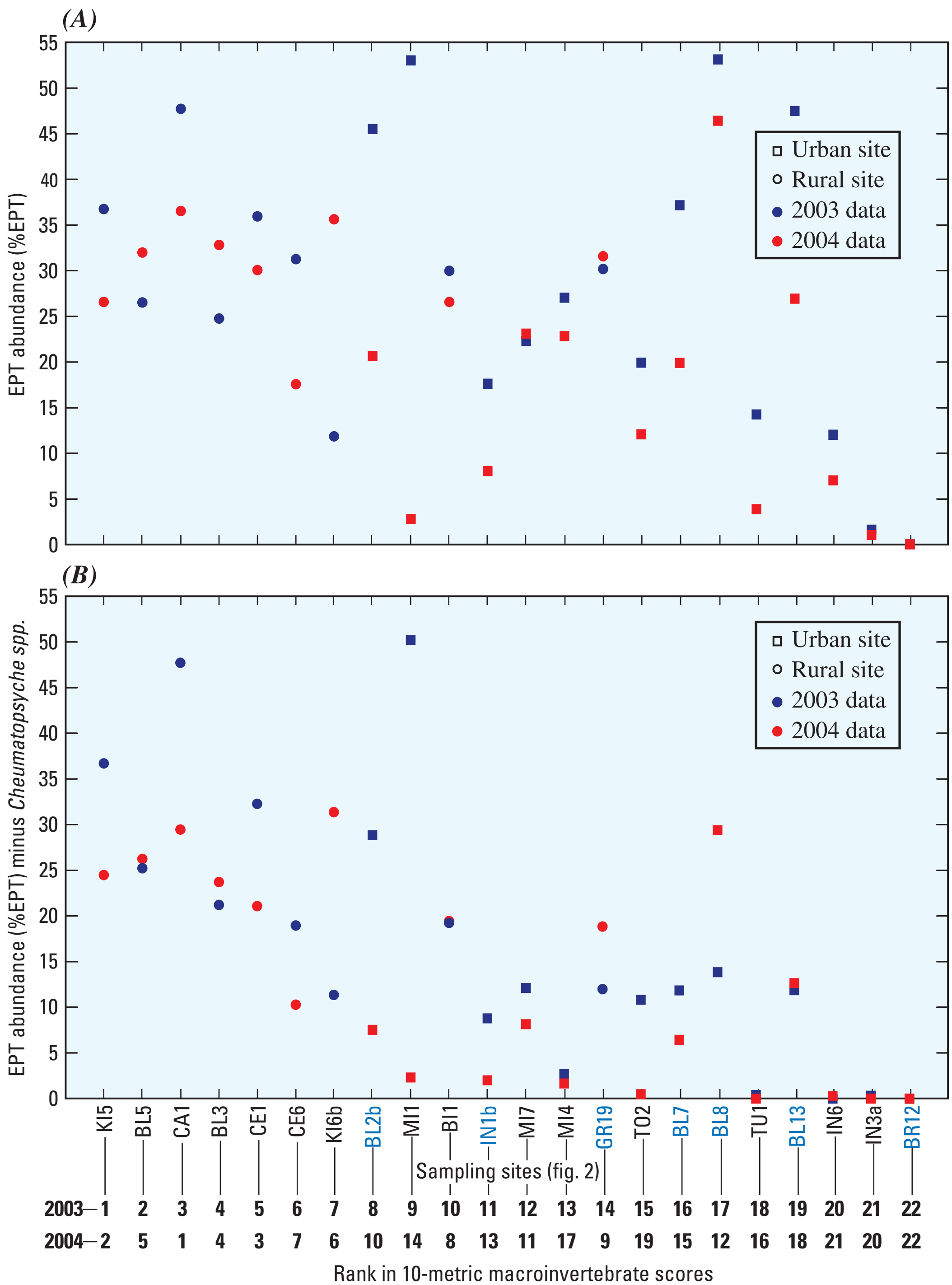
Evaluation of Metrics for Bioassessments in Urban Streams

In urban streams, response patterns for many macroinvertebrate metrics are poorly known. In this study, it was assumed that metrics often applied successfully in other regions of the United States would respond to changes in environmental variables that are related to urbanization. However, many of these metrics have not undergone rigorous validation procedures for use in evaluation of urban streams, and they have not been applied to data generated from particular types of sampling methods. When screening-level sampling protocols such as those used in this study are applied to a relatively small number of sites that are affected by a wide range of environmental variables, response patterns may not be readily detected.

The selection of metrics to be included in biological assessment studies is partly a subjective process, which can introduce uncertainty in evaluation results. These uncertainties may be greater when cumulative effects are involved, as is the case for urban streams. To increase the chance that an integrated score or rating system would accurately assess the relative quality of sites examined, a number of metrics were chosen that generated an expected biological response to amounts of human-induced stream degradation on the basis of existing site information. A similar situation exists for the selection of environmental variables that are the most important in explaining the biological results. Because the exact sources and causes of environmental effects are rarely known, the response expectations can only be inferred by available literature and the underlying assumptions associated with the numerous indicators used for stream-quality assessments.

In this study, clear response patterns were not evident in some commonly used metrics including percentage Chironomidae (%Chir), percentage COP (*Cricotopus, Orthocladius, Paratrissocladius*) midges (%COP), percentage filterers (%Fil), percentage filtering Trichoptera (%FT), and percentage dominant taxon (PDT). Other commonly reported macroinvertebrate metrics, such as %EPT, responded differently than expected, with higher values at some of the urban sites included in this study. In particular, the three downstream Blue River sites in Missouri (sites BL7, BL8, BL13) had %EPT values of 37 percent or higher in one or both years (fig. 20*A*). These sites have more than 50 percent urban land cover and greater than 18 percent impervious surface in addition to being located downstream from WWTF discharges (table 1). Even though %EPTs at these sites were among the highest percentages observed in this study, the pollution-tolerant caddisfly *Cheumatopsyche spp.* (Trichoptera: Hydropsychidae) accounted for 55 to 79 percent of EPT organisms in the samples (fig. 20*B*). The data from this study indicate that this metric may not be a good indicator for evaluating streams in urban landscapes especially when abundances of EPT taxa are dominated by one or two tolerant species. The dominance of tolerant filter-feeding Trichoptera species observed at some of the most impacted sites included in this study (fig. 20, Appendix 3) may result in high EPT abundances at sites in other urban areas as well.

Several metrics included in this study appear to have strong potential as indicators of relative biological conditions and effects related to the degree of urbanization in Johnson County. All of the metrics except %Tany were significantly correlated with one or more land-use or water- or sediment-quality variables (table 6). The MBI and %Olig metrics responded well throughout the ranges in conditions that occurred among the sites. Both of these metrics also had the strongest correlations with some water- and sediment-quality variables, including total nitrogen, total phosphorus, and PAHs (table 6). However, neither MBI nor %Olig was significantly correlated with percentage of impervious surface or percentage



EXPLANATION

BL5 **Sites identified in black analyzed for this study**

BL7 **Sites identified in blue analyzed in previous study** (Wilkison and others, 2005)

Figure 20. *(A)* EPT abundance (%EPT) and *(B)* EPT abundance (%EPT) minus the tolerant filter-feeding caddisfly *Cheumatopsyche spp.*, and annual rankings in 10-metric site scores, for sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), 2003 and 2004.

of agricultural land use. Even though the two taxa richness metrics (TRich, EPTRich) were significantly correlated with only two of the land-use variables during one of the sampling years (percentage impervious surface and percentage agricultural land use, 2004), they were selected for all three of the multimetric scoring solutions, and their inclusion as indicator metrics for biological assessment studies is widespread in the literature (Barbour and others, 1999). Furthermore, the information content that can be gathered from these two metrics as related to species presence or absence, species loss, and linkages to stream biodiversity make them important components in the evaluation of both rural and urban stream systems.

Individual metrics provide specific information on stream attributes and often are used as indicators for developing stream restoration guidelines or management goals. However, some metrics do not respond the same way in every watershed and stream type, or in regions outside the geographic area where they were originally developed. One example is the MBI goal of 4.5 or less for development of TMDLs in the Mill Creek watershed. This metric, which was originally developed in Illinois, relies on family-level tolerances of stream taxa, with values less than 4.51 indicating no adverse effects from excess nutrients or low dissolved oxygen levels (Davenport and Kelly, 1983). Kansas considers this metric appropriate for aquatic-life evaluations because Illinois has a very similar macroinvertebrate sampling protocol for evaluating stream quality. Even though this metric responded to relative stream conditions at Johnson County sites, it does not consider overall species diversity or effects on individual functional groups of macroinvertebrates. Specifically, some taxa included in the index (unionid mollusks, crayfish, non-insect invertebrates) may be less commonly encountered at smaller headwater stream sites, such as those upstream sites on Cedar, Kill, and Mill Creeks, thus affecting evaluation results. For this reason, the MBI goal of 4.5 or less may be an unrealistic guideline for developing TMDLs in some watersheds of Johnson County. An integrated score containing many metrics known to respond to environmental variables may be a better approach than relying on targets or goals for specific metrics.

Summary and Conclusions

Macroinvertebrate samples were collected at 15 selected stream sites representing 11 different watersheds in Johnson County, Kansas, in 2003 and 2004. Data were collected to assess biological conditions as part of a larger study to characterize water quality of Johnson County streams and provide comprehensive information for municipalities in developing effective water-quality management plans. Comparable data from an additional seven sites (one in Johnson County, Kansas, and six in adjacent downstream Cass and Jackson Counties in Missouri), collected and analyzed as part of a separate study, also were evaluated. The results of this study can be used to develop water-quality management strategies and to establish current information for comparing future conditions and changes at individual sites and within the watersheds being studied. In addition, the data can help direct water-quality measures required by National Pollutant Discharge Elimination System (NPDES) permits and the State total maximum daily load (TMDL) program.

Relative biological conditions in Johnson County streams were evaluated by: (1) examining community composition and relative abundance of resident aquatic macroinvertebrate communities, (2) scoring, ranking, and grouping the sites using combinations of macroinvertebrate metrics, (3) describing statistical relations between macroinvertebrate results and environmental variables, (4) assigning stream sites to impairment categories on the basis of ability to support aquatic life, (5) evaluating the effects of urbanization on macroinvertebrate communities, (6) identifying sites with the lowest levels of biological impacts due to human disturbance, (7) comparing data from Johnson County sites to published data from selected downstream sites in Missouri, and (8) providing an initial evaluation of the suitability of additional macroinvertebrate metrics that have potential for bioassessments in urban streams. Samples were collected using Kansas Department of Health and Environment (KDHE) protocol. Individual metric values and various multimetric scores were evaluated.

Values for 22 metrics resulting from both 2003 and 2004 sampling periods were calculated. Ten of those metrics were selected for combination because they are used in the State water-quality assessment for determining aquatic-life-support status, they demonstrated a distinct visual response pattern among the sites, or they were chosen by statistical analysis as the best metrics for correctly placing sites into meaningful groups. Environmental data, including land-use data and water- and sediment-quality data, also were used in correlation analyses and principal component analysis to evaluate relations between macroinvertebrate metrics and variables that may affect them. An environmental effects score was developed to relate environmental variables to macroinvertebrate site scores.

Among the three dominant orders of insects that normally are associated with streams (Ephemeroptera, Plecoptera, and Trichoptera; EPT), most sites contained abundances of between 10 and 50 percent of the total number of organisms, and the total number of taxa ranged from 0 to 11 species at all sites. In general, most of the rural sites included in this study contained a diversity of aquatic macroinvertebrates, with good representation of the insect orders normally associated with healthy communities such as mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera), dragonflies and damselflies (Odonata), and riffle beetles (Coleoptera: Elmidae). Several of the rural sites in Johnson County, including the reference site on Captain Creek, both Kill Creek sites, the two upstream Blue River sites, and the two Cedar Creek sites contained at least 23 taxa in 2003 and more than 40 taxa in 2004. In contrast, the more urban sites had none or very few EPT taxa and were dominated by pollution-tolerant organisms such as leeches [Hirudinea: *Mooreobdella microstoma*

(Moore)], planarians (Platyhelminthes: Turbellaria), Oligochaeta worms (Annelida: Oligochaeta), and midges in the *Cricotopus* and Orthocladius groups (Diptera: Chironomidae). These sites included the two Indian Creek sites downstream from discharges of municipal wastewater treatment facilities (WWTFs).

Each sampling site in the study was evaluated on the basis of KDHE's defined categories of aquatic-life support. The State evaluation used the average of four metric values—Macroinvertebrate Biotic Index (MBI), Kansas Biotic Index (KBI–NO), EPT taxa richness (EPTRich), and EPT abundance (%EPT)—to score sites and place them into one of three support categories. Captain Creek (the State reference site) and the upstream sites on Cedar, Kill, and Mill Creeks were the only sites in Johnson County assigned scores indicating full support of aquatic-life use for any of the individual metrics in either sampling year. However, no sites had an average score that would have met the fully supporting category in 2003 or 2004. Captain Creek had the highest average score of the four KDHE metrics in both 2003 and 2004, yet did not score high enough to fall into the fully supporting category. Ten of the 16 Johnson County sites scored in the nonsupporting category for both years, and these included eight of the urban sites and six sites receiving wastewater discharge. Most rural sites were partially supporting, whereas most of the urban sites in Johnson County were assigned a nonsupporting status in one or both years. The data indicate that the EPTRich metric had the most negative effect on the aquatic-life-support status results.

Several water-quality variables were significantly correlated with macroinvertebrate community metrics. Variables associated with land use and nonpoint contamination [percentage impervious surface, percentage urban land, percentage agricultural land, total concentration of polycyclic aromatic hydrocarbons (PAHs) in streambed sediment] generally had the strongest relations with 10-metric macroinvertebrate scores. Although point-source contributions may have substantial effects on the basis of proximity to the site, land use (and the corresponding nonpoint contributions) had the most substantial effect on overall macroinvertebrate communities in Johnson County.

The environmental effects score was calculated for 15 of the 16 Johnson County stream sites using data for percentage impervious surface, total nitrogen in stream water, and total PAHs in streambed sediment. The continuum in the amount of land-use-related adverse effects ranged from mostly urban sites negatively affected by wastewater treatment facility (WWTF) discharges, urban with no WWTF discharge, mixed urban and rural, rural with WWTF discharge, to rural sites. Sites less than 3 mi downstream from WWTF discharges (the two Indian Creek sites) and sites with no WWTF discharge but with large impervious surface areas (Tomahawk and Turkey Creeks) consistently scored and ranked among sites with the highest levels of biological impacts.

Results indicate that site rankings using environmental factors and the 10-metric site scores were strongly correlated, indicating that multimetric macroinvertebrate indices derived from screening-level protocols (KDHE) such as those used in this study can provide a meaningful measurement of site quality on the basis of the cumulative effects of multiple environmental variables. Similar sites were grouped together according to 10-metric scores and level of adverse environmental effects. Sites that consistently scored among those with the lowest levels of biological impacts included the two upstream Blue River sites, the two Cedar Creek sites, and the two Kill Creek sites, which demonstrated conditions similar to that of the State reference site on Captain Creek. In contrast, Johnson County sites on Indian Creek and downstream sites on the Blue River and Brush Creek in Missouri ranked among the most impacted. Turkey Creek in Johnson County also was grouped with the most-impacted sites. The diversity of macroinvertebrate communities, the levels of biological impacts, and the site rankings generated in this study generally reflected a gradient in the overall degree of adverse effects related to predominant land-use factors upstream from the sampling sites.

Both of the upstream Blue River sites in Johnson County consistently scored among the highest quality sites even though KDHE aquatic-life-use support guidelines identified both sites as having some level of impairment. Both Blue River sites are still surrounded by primarily rural land use and contain a high diversity of macroinvertebrates dominated by clean-water organisms. These results indicate that in Johnson County there is a remaining segment of the Blue River system that has a biological condition comparable to the least-impacted sites that were included in this study. Even though urban development has moved progressively upstream in this watershed over the last 20 years, these two sites presently are located upstream from most urban development.

The downstream Blue River sites and Brush Creek site in Missouri consistently scored among sites with the highest levels of biological impacts based on individual metric values and multimetric scores. The Missouri sites are affected by several WWTF discharges that enter both directly downstream from the Kansas State line and through tributaries such as Indian Creek. The most downstream Blue River site in Missouri has multiple potential source of contaminants, including WWTF discharge from all upstream sources and tributaries, channelization for flood control, industrial discharges, and cumulative urban runoff, in addition to being located downstream from the confluence with Brush Creek.

In general, the different rating methods used to evaluate relative biological quality of sites in this study yielded similar ranks for most of the sites except the KDHE aquatic-life-use support method. The data indicated that an integrated macroinvertebrate score that includes appropriate metrics developed as a grading system for relative stream quality, although meaningless by itself, is a useful tool for measuring overall biological conditions for streams located in rapidly developing landscapes such as Johnson County, Kansas. Several individual metrics included in this study including MBI, KBI-NO, total taxa richness (TRich), and EPT richness (EPTRich) appear to have potential as indicators of relative biological impacts as related to changing environmental conditions and the degree of urbanization in Johnson County. Some commonly used metrics did not show a clear response pattern, including percentage Chironomidae (%Chir), percentage COP (*Cricotopus, Orthocladius, Paratrissocladius*) midges (%COP), percentage filterers (%Fil), percentage filtering Trichoptera (%FT), and percentage dominant taxon (PDT). One possible reason for this is that many commonly used macroinvertebrate metrics have not been subjected to validation or rigorous evaluation procedures for use in assessing effects on urban stream systems or for use with data generated from specific sampling protocols.

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Appendixes

Appendix 1. List of macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.

[--, not identified]

Phylum	Class	Order	Family	Subfamily	Genus	Taxa reported as
Cnidaria	Hydrozoa	Hydroida	Hydridae	--	*Hydra*	*Hydra sp.*
Platyhelminthes	Turbellaria	--	--	--	--	Turbellaria
Nematoda	--	--	--	--	--	Nematoda
Nematomorpha	Gordioida	--	--	--	--	Gordioida
Bryozoa	--	--	--	--	--	Bryozoa
Mollusca	Gastropoda	--	--	--	--	Gastropoda
Mollusca	Gastropoda	Mesogastropoda	Hydrobiidae	--	--	Hydrobiidae
Mollusca	Gastropoda	Basommatophora	Ancylidae	--	--	Ancylidae
Mollusca	Gastropoda	Basommatophora	Ancylidae	--	*Ferrissia*	*Ferrissia sp.*
Mollusca	Gastropoda	Basommatophora	Lymnaeidae	Lymnaeinae	*Fossariad*	*Fossaria sp.*
Mollusca	Gastropoda	Basommatophora	Physidae	Physinae	*Physa*	*Physa sp.*
Mollusca	Gastropoda	Basommatophora	Physidae	Physinae	*Physella*	*Physella sp.*
Mollusca	Gastropoda	Basommatophora	Planorbidae	--	--	Planorbidae
Mollusca	Gastropoda	Basommatophora	Planorbidae	--	*Gyraulus*	*Gyraulus sp.*
Mollusca	Gastropoda	Basommatophora	Planorbidae	--	*Micromenetus*	*Micromenetus dilatatus* (Gould)
Mollusca	Gastropoda	Basommatophora	Planorbidae	--	*Planorbella*	*Planorbella sp.*
Mollusca	Bivalvia	--	--	--	--	Bivalvia
Mollusca	Bivalvia	Veneroida	Corbiculidae	--	*Corbicula*	*Corbicula sp.*
Mollusca	Bivalvia	Veneroida	Sphaeriidae	--	--	Sphaeriidae
Mollusca	Bivalvia	Veneroida	Sphaeriidae	Pisidiinae	*Pisidium*	*Pisidium sp.*
Mollusca	Bivalvia	Veneroida	Sphaeriidae	Sphaeriinae	*Musculium*	*Musculium sp.*
Mollusca	Bivalvia	Veneroida	Sphaeriidae	Sphaeriinae	*Sphaerium*	*Sphaerium sp.*
Annelida	Oligochaeta	--	--	--	--	Megadrile
Annelida	Oligochaeta	Lumbriculida	Lumbriculidae	--	--	Lumbriculidae
Annelida	Oligochaeta	Tubificida	Naididae	--	--	Naididae
Annelida	Oligochaeta	Tubificida	Naididae	--	*Dero*	*Dero sp.*
Annelida	Oligochaeta	Tubificida	Tubificidae	--	--	Tubificidae
Annelida	Oligochaeta	Tubificida	Tubificidae	--	*Branchiura*	*Branchiura sowerbyi (*Beddard)
Annelida	Oligochaeta	Enchytraeida	Enchytraeidae	--	--	*Enchytraeidae*
Annelida	Hirudinea	--	--	--	--	Hirudinea

Appendix 1. List of macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.—Continued

[--, not identified]

Phylum	Class	Order	Family	Subfamily	Genus	Taxa reported as
Annelida	Hirudinea	Rhynchobdellae	Glossiphoniidae	--	*Helobdella*	*Helobdella sp.*
Annelida	Hirudinea	Rhynchobdellae	Glossiphoniidae	--	*Helobdella*	*Helobdella stagnalis* (Linnaeus)
Annelida	Hirudinea	Rhynchobdellae	Glossiphoniidae	--	*Placobdella*	*Placobdella rnate* (Verrill)
Annelida	Hirudinea	Rhynchobdellae	Piscicolidae	--	--	Piscicolidae
Annelida	Hirudinea	Arhynchobdellae	Erpobdellidae	--	--	Erpobdellidae
Annelida	Hirudinea	Arhynchobdellae	Erpobdellidae	--	--	*Mooreobdella microstoma* (Moore)
Arthropoda	Arachnida	--	--	--	--	Acari
Arthropoda	Malacostraca	Decapoda	Cambaridae	--	--	Cambaridae
Arthropoda	Malacostraca	Decapoda	Cambaridae	Cambarinae	*Orconectes*	*Orconectes sp.*
Arthropoda	Malacostraca	Isopoda	Asellidae	--	*Caecidotea*	*Caecidotea sp.*
Arthropoda	Malacostraca	Isopoda	Asellidae	--	*Lirceus*	*Lirceus sp.*
Arthropoda	Malacostraca	Amphipoda	Crangonyctidae	--	*Crangonyx*	*Crangonyx sp.*
Arthropoda	Malacostraca	Amphipoda	Hyalellidae	--	*Hyalella*	*Hyalella azteca* (Saussure)
Arthropoda	Insecta	Collembola	--	--	--	Collembola
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	--	*Leptophlebia*	*Leptophlebia sp.*
Arthropoda	Insecta	Ephemeroptera	Ephemeridae	--	*Hexagenia*	*Hexagenia sp.*
Arthropoda	Insecta	Ephemeroptera	Caenidae	--	*Caenis*	*Caenis sp.*
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	--	*Tricorythodes*	*Tricorythodes sp.*
Arthropoda	Insecta	Ephemeroptera	Baetidae	--	*Acerpenna*	*Acerpenna pygmaea* (Hagen)
Arthropoda	Insecta	Ephemeroptera	Baetidae	--	*Baetis*	*Baetis intercalaris McDunnough*
Arthropoda	Insecta	Ephemeroptera	Baetidae	--	*Fallceon*	*Fallceon quilleri* (Dodds)
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	--	--	Heptageniidae
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	--	Stenacron	*Stenacron sp.*
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	--	Stenacron	*Stenacron interpunctatum* (Say)
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	--	*Stenonema*	*Stenonema sp.*
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	--	*Stenonema*	*Stenonema femoratum* (Say)
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	--	*Stenonema*	*Stenonema terminatum* (Walsh)
Arthropoda	Insecta	Odonata	Calopterygidae	--	*Calopteryx*	*Calopteryx maculata* (Beauvois)
Arthropoda	Insecta	Odonata	Calopterygidae	--	*Hetaerina*	*Hetaerina americana* (Fabricius)
Arthropoda	Insecta	Odonata	Coenagrionidae	--	--	Coenagrionidae

Appendix 1. List of macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.—Continued

[--, not identified]

Phylum	Class	Order	Family	Subfamily	Genus	Taxa reported as
Arthropoda	Insecta	Odonata	Coenagrionidae	--	*Argia*	*Argia sp.*
Arthropoda	Insecta	Odonata	Coenagrionidae	--	*Argia*	*Argia apicalis* (Say)
Arthropoda	Insecta	Odonata	Coenagrionidae	--	*Argia*	*Argia plana Calvert*
Arthropoda	Insecta	Odonata	Coenagrionidae	--	*Argia*	*Argia translata Hagen*
Arthropoda	Insecta	Odonata	Coenagrionidae	--	*Enallagma*	*Enallagma sp.*
Arthropoda	Insecta	Odonata	Coenagrionidae	--	*Ischnura*	*Ischnura sp.*
Arthropoda	Insecta	Odonata	Aeshnidae	--	*Basiaeschna*	*Basiaeschna janata* (Say)
Arthropoda	Insecta	Odonata	Aeshnidae	--	*Nasiaeschna*	*Nasiaeschna pentacantha* (Rambur)
Arthropoda	Insecta	Odonata	Corduliidae	--	*Epitheca*	*Epitheca princeps Hagen*
Arthropoda	Insecta	Odonata	Corduliidae	--	*Somatochlora*	*Somatochlora sp.*
Arthropoda	Insecta	Odonata	Libellulidae	--	--	Libellulidae
Arthropoda	Insecta	Odonata	Libellulidae	--	*Libellula*	*Libellula sp.*
Arthropoda	Insecta	Odonata	Libellulidae	--	*Plathemis*	*Plathemis lydia* (Drury)
Arthropoda	Insecta	Plecoptera	Capniidae	Capniinae	*Allocapnia*	*Allocapnia sp.*
Arthropoda	Insecta	Plecoptera	Capniidae	Capniinae	*Allocapnia*	*Allocapnia vivipara* (Claassen)
Arthropoda	Insecta	Plecoptera	Perlidae	--	--	Perlidae
Arthropoda	Insecta	Plecoptera	Perlidae	--	Perlesta	Perlesta sp.
Arthropoda	Insecta	Plecoptera	Perlodidae	--	--	Perlodidae
Arthropoda	Insecta	Plecoptera	Perlodidae	Isoperlinae	*Isoperla*	*Isoperla sp.*
Arthropoda	Insecta	Hemiptera	Belostomatidae	Belostomatinae	*Belostoma*	*Belostoma flumineum* (Say)
Arthropoda	Insecta	Hemiptera	Corixidae	Corixinae	*Palmacorixa*	*Palmacorixa sp.*
Arthropoda	Insecta	Hemiptera	Corixidae	Corixinae	*Sigara*	*Sigara sp.*
Arthropoda	Insecta	Hemiptera	Corixidae	Corixinae	*Trichocorixa*	*Trichocorixa sp.*
Arthropoda	Insecta	Hemiptera	Gerridae	Gerrinae	*Aquarius*	*Aquarius sp.*
Arthropoda	Insecta	Hemiptera	Notonectidae	--	*Notonecta*	*Notonecta sp.*
Arthropoda	Insecta	Hemiptera	Nepidae	--	*Ranatra*	*Ranatra nigra Herrich-Schaeffer*
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalinae	*Corydalus*	*Corydalus cornutus* (Linnaeus)
Arthropoda	Insecta	Megaloptera	Sialidae	--	*Sialis*	*Sialis sp.*
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptilinae	*Hydroptila*	*Hydroptila sp.*
Arthropoda	Insecta	Trichoptera	Rhyacophilidae	--	*Rhyacophila*	*Rhyacophila sp.*

Appendix 1. List of macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.—Continued

[--, not identified]

Phylum	Class	Order	Family	Subfamily	Genus	Taxa reported as
Arthropoda	Insecta	Trichoptera	Rhyacophilidae	--	*Rhyacophila*	*Rhyacophila lobifera Betten*
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsychinae	*Cheumatopsyche*	*Cheumatopsyche spp.*
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsychinae	*Hydropsyche*	*Hydropsyche sp.*
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsychinae	*Hydropsyche*	*Hydropsyche betteni Ross*
Arthropoda	Insecta	Trichoptera	Polycentropodidae	Polycentropodinae	--	Cernotina/Polycentropus sp.
Arthropoda	Insecta	Trichoptera	Phryganeidae	Phryganeinae	*Ptilostomis*	*Ptilostomis sp.*
Arthropoda	Insecta	Trichoptera	Limnephilidae	Limnephilinae	*Pycnopsyche*	*Pycnopsyche sp.*
Arthropoda	Insecta	Trichoptera	Helicopsychidae	--	*Helicopsyche*	*Helicopsyche borealis* (Hagen)
Arthropoda	Insecta	Lepidoptera	--	--	--	Lepidoptera
Arthropoda	Insecta	Coleoptera	--	--	--	Coleoptera
Arthropoda	Insecta	Coleoptera	Carabidae	--	--	Carabidae
Arthropoda	Insecta	Coleoptera	Dytiscidae	Colymbetinae	*Agabus*	Agabus sp. 1
Arthropoda	Insecta	Coleoptera	Dytiscidae	Colymbetinae	*Agabus*	Agabus sp. 2
Arthropoda	Insecta	Coleoptera	Dytiscidae	Hydroporinae	--	Hydroporini sp. 1
Arthropoda	Insecta	Coleoptera	Dytiscidae	Hydroporinae	--	Hydroporini sp. 2
Arthropoda	Insecta	Coleoptera	Dytiscidae	Hydroporinae	*Neoporus*	*Neoporus sp.*
Arthropoda	Insecta	Coleoptera	Gyrinidae	--	*Dineutus*	*Dineutus assimilis* (Kirby)
Arthropoda	Insecta	Coleoptera	Gyrinidae	--	*Gyrinus*	*Gyrinus sp.*
Arthropoda	Insecta	Coleoptera	Haliplidae	--	*Peltodytes*	*Peltodytes sp.*
Arthropoda	Insecta	Coleoptera	Staphylinidae	--	--	Staphylinidae
Arthropoda	Insecta	Coleoptera	Hydrophilidae	--	*Cymbiodyta*	*Cymbiodyta sp.*
Arthropoda	Insecta	Coleoptera	Hydrophilidae	--	*Enochrus*	*Enochrus sp.*
Arthropoda	Insecta	Coleoptera	Hydrophilidae	--	*Tropisternus*	*Tropisternus sp.*
Arthropoda	Insecta	Coleoptera	Hydrophilidae	--	*Tropisternus*	*Tropisternus lateralis* (Fabricus)
Arthropoda	Insecta	Coleoptera	Scirtidae	--	--	Scirtidae
Arthropoda	Insecta	Coleoptera	Dryopidae	--	*Helichus*	*Helichus basalis LeConte*
Arthropoda	Insecta	Coleoptera	Dryopidae	--	*Helichus*	*Helichus lithophilus* (Germar)
Arthropoda	Insecta	Coleoptera	Elmidae	--	*Dubiraphia*	*Dubiraphia sp.*
Arthropoda	Insecta	Coleoptera	Elmidae	--	*Stenelmis*	*Stenelmis sp. 1*
Arthropoda	Insecta	Coleoptera	Elmidae	--	*Stenelmis*	*Stenelmis sp. 2*

Appendix 1. List of macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.—Continued

[--, not identified]

Phylum	Class	Order	Family	Subfamily	Genus	Taxa reported as
Arthropoda	Insecta	Coleoptera	Elmidae	--	*Stenelmis*	*Stenelmis sexlineata Sanderson*
Arthropoda	Insecta	Diptera	--	--	--	Nematocera
Arthropoda	Insecta	Diptera	Chironomidae	--	--	Chironomidae sp. A
Arthropoda	Insecta	Diptera	Chironomidae	--	--	Chironomidae sp. B
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	--	Chironominae
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	--	Chironomini
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	--	*Phaenopsectra/Tribelos sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Axarus*	*Axarus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	Chironomus	Chironomus sp.
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Cryptochironomus*	*Cryptochironomus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Cryptotendipes*	*Cryptotendipes sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Dicrotendipes*	*Dicrotendipes sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Glyptotendipes*	*Glyptotendipes sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Microtendipes*	*Microtendipes sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Paralauterborniella*	*Paralauterborniella nigrohalterale* (Malloch)
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Parachironomus*	*Parachironomus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Paracladopelma*	*Paracladopelma sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Paratendipes*	*Paratendipes sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Phaenopsectra*	*Phaenopsectra sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Polypedilum*	*Polypedilum sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Stictochironomus*	*Stictochironomus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Tribelos*	*Tribelos sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Pseudochironomus*	*Pseudochironomus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	--	*Tanytarsini*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	--	*Micropsectra/Tanytarsus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Cladotanytarsus*	*Cladotanytarsus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Micropsectra*	*Micropsectra sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Paratanytarsus*	*Paratanytarsus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Rheotanytarsus*	*Rheotanytarsus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae	*Tanytarsus*	*Tanytarsus sp.*

Appendix 1. List of macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.—Continued

[--, not identified]

Phylum	Class	Order	Family	Subfamily	Genus	Taxa reported as
Arthropoda	Insecta	Diptera	Chironomidae	Diamesinae	*Diamesa*	*Diamesa sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	--	*Orthocladiinae*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	--	*Cricotopus/Orthocladius spp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Corynoneura*	*Corynoneura sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Cricotopus*	*Cricotopus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Cricotopus*	*Cricotopus bicinctus group sp. 1*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Cricotopus*	*Cricotopus bicinctus group sp. 2*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Cricotopus*	*Cricotopus (Isocladius) sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Diplocladius*	*Diplocladius cultriger Kieffer*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Eukiefferiella*	*Eukiefferiella sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Hydrobaenus*	*Hydrobaenus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Limnophyes*	*Limnophyes sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Nanocladius*	*Nanocladius sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Parakiefferiella*	*Parakiefferiella sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Parametriocnemus*	*Parametriocnemus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Paraphaenocladius*	*Paraphaenocladius sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Paratrichocladius*	*Paratrichocladius sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Psectrocladius*	*Psectrocladius sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Rheocricotopus*	*Rheocricotopus sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Thienemanniella*	*Thienemanniella sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae	*Tvetenia*	*Tvetenia sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	--	Tanypodinae
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	*Natarsia*	*Natarsia sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	--	Pentaneurini
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	--	*Thienemannimyia gp.*
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	*Ablabesmyia*	*Ablabesmyia sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	*Procladius*	*Procladius sp.*
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	*Zavrelimyia*	*Zavrelimyia sp.*
Arthropoda	Insecta	Diptera	Simuliidae	--	--	Simuliidae
Arthropoda	Insecta	Diptera	Simuliidae	--	*Simulium*	*Simulium sp. 1*

Appendix 1. List of macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.—Continued

[--, not identified]

Phylum	Class	Order	Family	Subfamily	Genus	Taxa reported as
Arthropoda	Insecta	Diptera	Simuliidae	--	*Simulium*	*Simulium sp. 2*
Arthropoda	Insecta	Diptera	Tipulidae	--	--	Tipulidae
Arthropoda	Insecta	Diptera	Tipulidae	Tipulinae	*Tipula*	Tipula sp.
Arthropoda	Insecta	Diptera	Tipulidae	Limoniinae	*Hexatoma*	*Hexatoma sp.*
Arthropoda	Insecta	Diptera	--	--	--	Brachycera
Arthropoda	Insecta	Diptera	Empididae	--	--	Empididae
Arthropoda	Insecta	Diptera	Empididae	Clinocerinae	*Clinocera*	*Clinocera sp.*
Arthropoda	Insecta	Diptera	Stratiomyidae	Stratiomyinae	*Stratiomys*	*Stratiomys sp.*
Arthropoda	Insecta	Diptera	Tabanidae	--	--	Tabanidae
Arthropoda	Insecta	Diptera	Tabanidae	--	*Tabanus*	*Tabanus sp.*

Appendix 2. List of the four most dominant macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.

Site identifier (fig. 2)	Stream site	Four most dominant taxa 2003
		Kansas
BL3	Blue River near Stanley (Highway 69)	*Caenis sp., Stenonema sp., Cricotopus/Orthocladius spp., Hydrobaenus sp.*
BL5	Blue River at Kenneth Road	*Hyalella azteca, Caenis sp., Stenonema sp., Cricotopus/Orthocladius spp.*
IN3a	Indian Creek at College Blvd.	Turbellaria, *Musculium* sp., Naididae, *Mooreobdella microstoma*
IN6	Indian Creek at State Line Road	Naididae, *Cheumatopsyche spp., Chironomus sp., Cricotopus bicinctus*
TO2	Tomahawk Creek near 111th Street	*Stenacron sp., Argia sp., Cheumatosyche spp., Cricotopus/Orthocladius spp.*
TU1	Turkey Creek at 67th Street	*Argia sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp., Thienemannimyia gp.*
MI1	Mill Creek at 127th Street	*Stenacron sp., Stenonema sp., Cricotopus/Orthocladius spp., Thienemannimyia gp.*
MI4	Mill Creek at 87th Street Lane	*Physella sp., Corbicula sp., Argia sp., Cheumatopsyche spp.*
MI7	Mill Creek at Johnson Drive	*Argia sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp., Hydrobaenus sp.*
CE1	Cedar Creek at Old Highway 56	*Lirceus sp., Stenonema sp., Cricotopus/Orthocladius spp., Hydrobaenus sp.*
CE6	Cedar Creek near DeSoto (83rd Street)	*Stenacron sp., Stenonema sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp.*
KI5	Kill Creek at 135th Street	*Stenonema sp., Allocapnia sp., Cricotopus/Orthocladius spp., Hydrobaenus sp.*
KI6b	Kill Creek at 95th Street	Tubificidae, *Cricotopus/Orthocladius spp., Hydrobaenus sp., Simulium sp.*
BI1	Big Bull Creek near Edgerton Road	*Stenacron sp., Argia sp., Cheumatosyche spp., Cricotopus/Orthocladius spp.*
CA1	Captain Creek at 119th Street	*Fossaria sp., Allocapnia sp., Stenelmis sp., Hydrobaenus sp.*
		Kansas and Missouri (Wilkison and others, 2005)
BL2b	Blue River at Blue Ridge Blvd Extension	*Physella sp., Stenacron sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp.*
BL7	Blue River near Kansas City, MO (Bannister Road)	*Stenacron sp., Argia sp., Cheumatosyche spp, Hydrobaenus sp.*
BL8	Blue River at Blue Parkway	*Corbicula sp., Stenacron sp., Cheumatopsyche spp., Simulium sp.*
BL13	Blue River at Stadium Drive	*Corbicula sp*., Naididae, *Stenacron sp., Cheumatopsyche spp.*
IN1b	Indian Creek at Highway 69	*Physella sp., Calopteryx sp., Argia sp., Cheumatopsyche spp.*
BR12	Brush Creek at Elmwood Avenue	*Physella sp.,* Naididae, *Helobdella sp., Glyptotendipes sp.*
GR19	South Fork Grand River near Freeman	*Stenacron sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp., Simulium sp.*

Appendix 2. List of the four most dominant macroinvertebrate taxa collected at stream-sampling sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri, 2003 and 2004.—Continued

Site identifier (fig. 2)	Stream site	Four most dominant taxa
		2004
	Kansas	
BL3	Blue River near Stanley (Highway 69)	*Stenacron sp., Stenonema sp., Cricotopus/Orthocladius spp., Simulium sp.*
BL5	Blue River at Kenneth Road	*Crangonyx sp., Stenonema sp., Cricotopus/Orthocladius spp., Simulium sp.*
IN3a	Indian Creek at College Blvd.	Turbellaria, Naididae, *Mooreobdella microstoma, Argia sp.*
IN6	Indian Creek at State Line Road	Naididae, *Cheumatopsyche spp., Cricotopus/Orthocladius spp., Cricotopus bicinctus*
TO2	Tomahawk Creek near 111th Street	*Cheumatopsyche spp., Cricotopus/Orthocladius spp., Thienemannimyia gp., Simulium sp.*
TU1	Turkey Creek at 67th Street	*Physa sp., Morreobdella microstoma, Cricotopus/Orthocladius spp., Thienemannimyia gp.*
MI1	Mill Creek at 127th Street	*Argia sp., Ischnura sp., Thienemannimyia gp., Simulium sp.*
MI4	Mill Creek at 87th Street Lane	Naididae, *Argia sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp.*
MI7	Mill Creek at Johnson Drive	*Hyalella azteca, Argia sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp.*
CE1	Cedar Creek at Old Highway 56	*Stenonema sp., Cricotopus/Orthocladius spp., Hydrobaenus sp., Simulium sp.*
CE6	Cedar Creek near DeSoto (83rd Street)	*Physa sp., Stenacron sp., Argia sp., Cricotopus/Orthocladius spp.*
KI5	Kill Creek at 135th Street	*Physa sp., Caenis sp., Stenonema sp., Cricotopus/Orthocladius spp.*
KI6b	Kill Creek at 95th Street	*Stenacron sp., Stenonema sp., Cricotopus/Orthocladius spp., Simulium sp.*
BI1	Big Bull Creek near Edgerton Road	*Stenacron sp., Cricotopus/Orthocladius spp., Hydrobaenus sp., Thienemannimyia gp.*
CA1	Captain Creek at 119th Street	*Leptophlebia sp., Stenonema sp., Allocapnia sp., Hydrobaenus sp.*
	Kansas and Missouri (Wilkison and others, 2005)	
BL2b	Blue River at Blue Ridge Blvd Extension	Naididae, *Argia sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp.*
BL7	Blue River near Kansas City, MO (Bannister Road)	Tubificidae, *Morreobdella microstoma, Argia sp., Cheumatopsyche spp.*
BL8	Blue River at Blue Parkway	*Stenacron sp., Argia sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp.*
BL13	Blue River at Stadium Drive	*Corbicula sp., Stenacron sp., Cheumatopsyche spp., Chironomus sp.*
IN1b	Indian Creek at Highway 69	*Physella sp., Morreobdella microstoma, Chironomus sp., Thienemannimyia gp.*
BR12	Brush Creek at Elmwood Avenue	*Physa sp.*, Naididae, Tubificidae, *Chironomus sp.*
GR19	South Fork Grand River near Freeman	*Stenonema sp., Cheumatopsyche spp., Cricotopus/Orthocladius spp., Simulium sp.*

Appendix 3. Macroinvertebrate metric values for 15 stream-sampling sites in Johnson County, Kansas, and 7 selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), calculated for 2003 and 2004.

[MBI, Macroinvertebrate Biotic Index; KBI–NO, Kansas Biotic Index; EPT, Ephemeroptera, Plecoptera, and Trichoptera; COP, *Cricotopus, Orthocladius, and Paratrissocladius*; <, less than]

Site identifier (fig. 2)	Stream site	General land classification[1]	Benthic macroinvertebrate metric value									
			MBI		KBI–NO		EPT taxa richness		EPT abundance (percent)		Total taxa richness	
			2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
			Kansas									
BL3	Blue River near Stanley (Highway 69)	Rural	5.47	5.22	2.71	2.68	6	9	24.7	32.8	42	56
BL5	Blue River at Kenneth Road	Rural	5.27	5.36	2.78	2.84	7	10	26.5	32.0	47	52
IN3a	Indian Creek at College Blvd.	Urban	7.17	7.14	2.79	2.80	2	1	1.6	1.0	20	22
IN6	Indian Creek at State Line Road	Urban	7.68	8.12	3.76	3.50	1	2	12.0	7.0	24	26
TO2	Tomahawk Creek near 111th Street	Urban	5.72	6.10	3.29	3.38	5	2	19.9	12.1	29	25
TU1	Turkey Creek at 67th Street	Urban	5.94	6.44	3.19	3.35	3	2	14.2	3.8	24	29
MI1	Mill Creek at 127th Street	Urban	4.71	5.98	3.32	2.94	4	3	53.0	2.8	24	22
MI4	Mill Creek at 87th Street Lane	Urban	5.46	6.27	2.36	3.32	6	5	27.0	22.8	21	22
MI7	Mill Creek at Johnson Drive	Urban	5.83	5.77	3.17	3.21	5	5	22.3	23.1	35	30
CE1	Cedar Creek at Old Highway 56	Rural	5.02	5.43	2.35	2.50	4	8	35.9	30.0	23	47
CE6	Cedar Creek near DeSoto (83rd Street)	Rural	5.55	6.00	3.10	3.10	6	7	31.2	17.6	40	50
KI5	Kill Creek at 135th Street	Rural	4.87	5.49	2.42	2.85	4	9	36.7	26.5	29	47
KI6b	Kill Creek at 95th Street	Rural	5.83	5.15	2.90	2.81	6	7	11.8	35.6	36	46
BI1	Big Bull Creek near Edgerton Road	Rural	5.34	5.71	3.14	3.11	5	4	30.0	26.5	28	28
CA1	Captain Creek at 119th Street	Rural	4.02	4.98	1.61	2.23	3	11	47.7	36.5	24	55
			Kansas and Missouri Missouri (Wilkison and others, 2005)									
BL2b	Blue River at Blue Ridge Blvd Extension	Urban	5.36	6.12	3.17	3.19	6	4	45.5	20.6	29	37
BL7	Blue River near Kansas City, MO (Bannister Road)	Urban	5.68	6.71	2.91	2.92	4	3	37.1	19.9	23	22
BL8	Blue River at Blue Parkway	Urban	5.08	5.26	2.95	3.40	2	3	53.1	46.4	22	23
BL13	Blue River at Stadium Drive	Urban	5.70	7.11	3.23	3.74	2	4	47.5	26.9	21	26
IN1b	Indian Creek at Highway 69	Urban	6.18	6.68	2.70	3.25	5	4	17.6	8.0	25	34
BR12	Brush Creek at Elmwood Avenue	Urban	7.88	9.16	4.55	4.50	0	0	0	0	20	17
GR19	South Fork Grand River near Freeman	Rural	5.51	5.57	3.04	3.14	5	7	30.2	31.6	28	35

Appendix 3. Macroinvertebrate metric values for 15 stream-sampling sites in Johnson County, Kansas, and 7 selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), calculated for 2003 and 2004.—Continued

[MBI, Macroinvertebrate Biotic Index; KBI–NO, Kansas Biotic Index; EPT, Ephemeroptera, Plecoptera, and Trichoptera; COP, *Cricotopus, Orthocladius, and Paratrissocladius*; <, less than]

Site identi-fier (fig. 2)	Stream site	Benthic macroinvertebrate metric value									
		Chironomidae taxa richness		Percentage of Chironomidae		Percentage of filterers		Percentage of scrapers		Ratio of abundances EPT/Chironomidae	
		2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
				Kansas							
BL3	Blue River near Stanley (Highway 69)	8	15	33.8	29.2	7.1	13.0	29.8	15.8	0.7	1.1
BL5	Blue River at Kenneth Road	15	18	34.6	34.0	12.8	15.2	24.8	18.4	.8	.9
IN3a	Indian Creek at College Blvd.	6	6	6.1	13.0	12.6	9.6	1.6	1.4	.3	.1
IN6	Indian Creek at State Line Road	9	11	44.2	29.4	16.7	11.3	5.2	4.9	.3	.2
TO2	Tomahawk Creek near 111th Street	11	9	48.5	52.8	16.0	25.1	7.4	3.0	.4	.2
TU1	Turkey Creek at 67th Street	7	11	54.1	56.7	15.0	4.3	7.3	12.5	.3	.1
MI1	Mill Creek at 127th Street	10	10	29.7	40.5	10.4	14.0	10.8	2.8	1.8	.1
MI4	Mill Creek at 87th Street Lane	2	8	4.5	43.6	26.6	25.3	16.2	9.5	6.0	.5
MI7	Mill Creek at Johnson Drive	14	11	49.6	40.7	12.9	22.6	18.8	11.8	.4	.6
CE1	Cedar Creek at Old Highway 56	7	18	27.6	32.7	6.9	14.8	41.9	28.3	1.3	.9
CE6	Cedar Creek near DeSoto (83rd Street)	12	19	35.7	38.2	19.0	12.6	19.0	12.2	.9	.5
KI5	Kill Creek at 135th Street	14	15	46.4	38.0	10.1	12.7	38.3	17.1	.8	.7
KI6b	Kill Creek at 95th Street	9	13	48.6	25.8	15.9	21.2	26.4	21.2	.2	1.4
BI1	Big Bull Creek near Edgerton Road	10	11	26.8	45.1	22.2	20.4	12.1	22.6	1.1	.6
CA1	Captain Creek at 119th Street	3	17	24.8	26.1	4.7	9.5	23.4	23.7	1.9	1.4
				Kansas and Missouri (Wilkison and others, 2005)							
BL2b	Blue River at Blue Ridge Blvd Extension	5	16	21.2	40.9	21.2	19.8	21.6	13.5	2.1	.5
BL7	Blue River near Kansas City, MO (Bannister Road)	7	10	24.9	25.3	31.8	21.5	14.3	8.6	1.5	.8
BL8	Blue River at Blue Parkway	10	10	17.9	21.1	55.8	29.4	6.3	1.0	3.0	2.2
BL13	Blue River at Stadium Drive	6	11	11.0	42.3	54.2	27.5	3.4	2.2	4.3	.6
IN1b	Indian Creek at Highway 69	7	11	16.2	35.7	10.6	20.1	27.3	12.6	1.1	.2
BR12	Brush Creek at Elmwood Avenue	6	7	35.9	29.8	2.5	4.6	9.6	7.3	0	0
GR19	South Fork Grand River near Freeman	8	13	23.6	31.6	41.7	35.2	13.2	11.9	1.3	1.0

Appendix 3. Macroinvertebrate metric values for 15 stream-sampling sites in Johnson County, Kansas, and 7 selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), calculated for 2003 and 2004.—Continued

[MBI, Macroinvertebrate Biotic Index; KBI–NO, Kansas Biotic Index; EPT, Ephemeroptera, Plecoptera, and Trichoptera; COP, *Cricotopus, Orthocladius, and Paratrissocladius*; <, less than]

Site identifier (fig. 2)	Stream site	Benthic macroinvertebrate metric value									
		Ratio of abundances of scrapers/filterers		Percentage of COP midges		Percentage of Oligochaeta		Ratio of abundances EPT/Oligochaeta		Percentage of Ephemeroptera	
		2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
		Kansas									
BL3	Blue River near Stanley (Highway 69)	4.2	1.2	8.6	10.3	3.0	2.8	8.2	11.9	20.7	20.2
BL5	Blue River at Kenneth Road	1.9	1.2	12.4	12.7	2.6	1.6	10.3	19.5	24.4	23.0
IN3a	Indian Creek at College Blvd.	.1	.1	.3	8.9	40.0	29.8	0	0	.3	0
IN6	Indian Creek at State Line Road	.3	.4	0	20.2	20.6	44.7	.6	.2	0	.3
TO2	Tomahawk Creek near 111th Street	.5	.1	28.1	32.7	2.2	2.0	9.2	6.0	10.8	.5
TU1	Turkey Creek at 67th Street	.5	2.9	23.2	26.4	2.8	2.4	5.0	1.6	.4	0
MI1	Mill Creek at 127th Street	1.0	.2	7.6	3.3	1.6	4.2	33.0	.7	50.2	2.3
MI4	Mill Creek at 87th Street Lane	.6	.4	0	34.9	.5	10.0	60.0	2.3	2.7	1.7
MI7	Mill Creek at Johnson Drive	1.5	.5	32.8	27.1	5.9	4.1	3.8	5.7	12.1	8.1
CE1	Cedar Creek at Old Highway 56	6.1	1.9	12.4	7.2	0	.9	0	33.5	25.3	16.6
CE6	Cedar Creek near DeSoto (83rd Street)	1.0	1.0	19.0	20.2	4.1	5.0	7.6	3.5	19.0	9.9
KI5	Kill Creek at 135th Street	3.8	1.4	18.1	15.9	1.2	2.9	30.3	9.3	20.6	19.2
KI6b	Kill Creek at 95th Street	1.7	1.0	25.0	10.2	5.0	3.8	2.4	9.3	7.3	25.8
BI1	Big Bull Creek near Edgerton Road	.5	1.1	16.7	11.9	.8	1.3	38.5	20.0	19.5	19.5
CA1	Captain Creek at 119th Street	5.0	2.5	3.7	3.7	4.2	6.2	11.3	5.9	.5	14.9
		Kansas and Missouri (Wilkison and others, 2005)									
BL2b	Blue River at Blue Ridge Blvd Extension	1.0	.7	16.7	16.3	1.4	8.7	33.7	2.4	28.8	7.5
BL7	Blue River near Kansas City, MO (Bannister Road)	.4	.4	7.3	10.2	7.8	15.6	4.8	1.3	11.8	6.5
BL8	Blue River at Blue Parkway	.1	0	.9	8.2	1.3	3.6	39.7	12.9	13.8	29.4
BL13	Blue River at Stadium Drive	.1	.1	4.2	3.3	11.9	9.9	4.0	2.7	11.9	12.6
IN1b	Indian Creek at Highway 69	2.6	.6	5.1	4.0	1.4	1.5	12.7	5.3	8.8	2.0
BR12	Brush Creek at Elmwood Avenue	3.9	1.6	0	4.0	31.7	48.7	0	0	14.1	14.7
GR19	South Fork Grand River near Freeman	.3	.3	14.5	21.3	1.2	2.5	24.3	12.8	14.0	15.0

Appendix 3. Macroinvertebrate metric values for 15 stream-sampling sites in Johnson County, Kansas, and 7 selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), calculated for 2003 and 2004.—Continued

[MBI, Macroinvertebrate Biotic Index; KBI–NO, Kansas Biotic Index; EPT, Ephemeroptera, Plecoptera, and Trichoptera; COP, *Cricotopus, Orthocladius, and Paratrissocladius*; <, less than]

Site identifier (fig. 2)	Stream site	Benthic macroinvertebrate metric value									
		Percentage of filtering Trichoptera		Percentage of *Tanytarsini* midges		Percentage of intolerant organisms (MBI<6)		Percentage of intolerant organisms (KBI<3)		Percentage of dominant taxon	
		2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Kansas											
BL3	Blue River near Stanley (Highway 69)	0	4.3	0	0.8	47.5	53.2	55.3	43.2	15.7	8.7
BL5	Blue River at Kenneth Road	1.3	4.1	.4	.8	48.9	47.2	41.7	40.6	15.4	12.7
IN3a	Indian Creek at College Blvd.	1.3	1.0	0	0	45.0	41.4	35.7	44.1	38.1	28.1
IN6	Indian Creek at State Line Road	12.0	6.7	0	.3	19.2	12.9	10.3	13.4	24.5	39.1
TO2	Tomahawk Creek near 111th Street	9.1	11.6	.4	0	36.7	28.1	21.1	13.4	28.1	25.1
TU1	Turkey Creek at 67th Street	13.8	3.8	.4	0	32.9	21.2	14.7	12.5	25.2	22.6
MI1	Mill Creek at 127th Street	2.8	.5	1.2	1.4	60.5	42.3	17.8	29.2	39.8	16.7
MI4	Mill Creek at 87th Street Lane	18.5	21.2	0	0	84.0	34.9	64.7	15.2	43.2	34.4
MI7	Mill Creek at Johnson Drive	10.2	14.9	0	1.4	37.3	41.8	32.0	17.0	32.8	27.1
CE1	Cedar Creek at Old Highway 56	0	3.6	.5	1.8	56.0	46.6	65.9	49.5	23.5	13.0
CE6	Cedar Creek near DeSoto (83rd Street)	12.3	6.1	1.1	3.8	45.9	36.3	27.4	28.1	19.0	20.2
KI5	Kill Creek at 135th Street	0	2.0	1.6	6.5	39.8	43.4	60.2	30.1	20.6	15.1
KI6b	Kill Creek at 95th Street	0	4.2	1.4	.4	21.4	50.7	37.8	44.6	25.0	12.7
BI1	Big Bull Creek near Edgerton Road	10.5	7.1	.8	3.5	55.1	35.7	25.1	24.7	16.7	11.9
CA1	Captain Creek at 119th Street	0	4.6	.9	.4	58.6	55.0	87.9	66.2	46.3	10.8
Kansas and Missouri (Wilkison and others, 2005)											
BL2b	Blue River at Blue Ridge Blvd Extension	16.7	13.1	.9	1.6	60.1	34.1	26.7	20.0	18.5	15.9
BL7	Blue River near Kansas City, MO (Bannister Road)	25.3	13.4	0	0	56.0	40.0	35.4	40.0	21.2	16.7
BL8	Blue River at Blue Parkway	39.3	16.5	.4	3.1	66.2	61.2	19.5	11.8	39.3	29.4
BL13	Blue River at Stadium Drive	35.6	14.3	0	.6	66.3	36.1	9.1	8.9	35.6	23.6
IN1b	Indian Creek at Highway 69	8.8	5.5	.5	.5	54.3	30.3	48.4	14.8	21.3	14.1
BR12	Brush Creek at Elmwood Avenue	0	0	0	0	8.2	2.7	.8	0	31.3	35.1
GR19	South Fork Grand River near Freeman	16.9	12.3	0	2.9	43.3	39.7	21.2	20.8	19.4	20.9

Appendix 3. Macroinvertebrate metric values for 15 stream-sampling sites in Johnson County, Kansas, and 7 selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005), calculated for 2003 and 2004.—Continued

[MBI, Macroinvertebrate Biotic Index; KBI–NO, Kansas Biotic Index; EPT, Ephemeroptera, Plecoptera, and Trichoptera; COP, *Cricotopus, Orthocladius, and Paratrissocladius;* <, less than]

Site identifier (fig. 2)	Stream site	Benthic macroinvertebrate metric value			
		Percentage of EP		Shannon-Wiener Diversity Index	
		2003	2004	2003	2004
	Kansas				
BL3	Blue River near Stanley (Highway 69)	21.2	23.7	3.3	3.6
BL5	Blue River at Kenneth Road	25.2	26.2	3.3	3.4
IN3a	Indian Creek at College Blvd.	.3	0	1.9	2.3
IN6	Indian Creek at State Line Road	0	.3	2.4	2.2
TO2	Tomahawk Creek near 111th Street	10.8	.5	2.7	2.6
TU1	Turkey Creek at 67th Street	.4	0	2.3	2.5
MI1	Mill Creek at 127th Street	50.2	2.3	2.1	2.5
MI4	Mill Creek at 87th Street Lane	2.7	1.7	2.0	2.2
MI7	Mill Creek at Johnson Drive	12.1	8.1	2.6	2.7
CE1	Cedar Creek at Old Highway 56	32.3	21.1	2.4	3.3
CE6	Cedar Creek near DeSoto (83rd Street)	19.0	10.3	3.0	3.3
KI5	Kill Creek at 135th Street	36.7	24.5	2.5	3.4
KI6b	Kill Creek at 95th Street	11.4	31.4	2.7	3.3
BI1	Big Bull Creek near Edgerton Road	19.5	19.5	2.7	2.9
CA1	Captain Creek at 119th Street	47.7	29.5	2.0	3.5
	Kansas and Missouri (Wilkison and others, 2005)				
BL2b	Blue River at Blue Ridge Blvd Extension	28.8	7.5	2.6	3.0
BL7	Blue River near Kansas City, MO (Bannister Road)	11.8	6.5	2.7	2.6
BL8	Blue River at Blue Parkway	13.8	29.4	2.2	2.5
BL13	Blue River at Stadium Drive	11.9	12.6	2.2	2.6
IN1b	Indian Creek at Highway 69	8.8	2.0	2.6	3.0
BR12	Brush Creek at Elmwood Avenue	0	0	2.0	2.1
GR19	South Fork Grand River near Freeman	12.0	18.9	2.7	2.8

[1]Urban sites have greater than 32 percent urban land use and greater than 10 percent impervious surface.

Appendix 4. Sampling-site rankings based on proportional scaling of metric values for three multimetric combinations in 2003 and 2004, for sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005).

[n, number of sites; --, not applicable]

Site identifier (fig. 2)	2003 site rankings						2004 site rankings					
	Johnson County sampling sites (n = 15)			All sampling sites (n = 22)			Johnson County sampling sites (n = 15)			All sampling sites (n = 22)		
	5-metric combination	6-metric combination	10-metric combination	5-metric combination	6-metric combination	10-metric combination	5-metric combination	6-metric combination	10-metric combination	5-metric combination	6-metric combination	10-metric combination
Kansas												
BL3	3	2	4	3	3	4	4	5	4	4	5	4
BL5	2	4	2	2	4	2	5	4	5	5	4	5
IN3a	14	14	14	19	20	21	12	13	14	18	18	20
IN6	15	15	15	21	21	20	14	14	15	20	19	21
TO2	12	12	12	14	14	15	15	15	13	21	22	19
TU1	13	13	13	17	17	18	9	9	11	10	11	16
MI1	11	11	8	12	13	9	11	12	10	15	16	14
MI4	10	9	10	13	12	13	13	11	12	17	15	17
MI7	8	8	11	10	10	12	10	10	9	12	12	11
CE1	7	3	5	7	2	5	3	2	2	3	2	3
CE6	6	7	6	6	7	6	6	7	7	6	6	7
KI5	1	1	1	1	1	1	2	3	3	2	3	2
KI6b	4	5	7	4	5	7	7	6	6	7	7	6
BI1	9	10	9	11	11	10	8	8	8	9	8	8
CA1	5	6	3	5	6	3	1	1	1	1	1	1
Kansas and Missouri (Wilkison and others, 2005)												
BL2b	--	--	--	8	9	8	--	--	--	11	10	10
BL7	--	--	--	16	16	16	--	--	--	14	14	15
BL8	--	--	--	18	18	17	--	--	--	16	17	12
BL13	--	--	--	22	22	19	--	--	--	19	20	18
IN1b	--	--	--	9	8	11	--	--	--	13	13	13
BR12	--	--	--	20	19	22	--	--	--	22	21	22
GR19	--	--	--	15	15	14	--	--	--	8	9	9

Appendix 5. Sampling-site rankings based on percentile site scoring for three multimetric combinations in 2003 and 2004 for sites in Johnson County, Kansas, and selected sites in Cass and Jackson Counties, Missouri (Wilkison and others, 2005).

[n, number of sites; --, not applicable]

Site identifier (fig. 2)	2003 site rankings						2004 site rankings					
	Johnson County sampling sites (n = 15)			All sampling sites (n = 22)			Johnson County sampling sites (n = 15)			All sampling sites (n = 22)		
	5-metric combi-nation	6-metric combi-nation	10-metric combi-nation	5-metric combi-nation	6-metric combi-nation	10-metric combi-nation	5-metric combi-nation	6-metric combi-nation	10-metric combi-nation	5-metric combi-nation	6-metric combi-nation	10-metric combi-nation
Kansas												
BL3	3	2.5	3.5	5.5	3.5	4	3.5	4	2.5	3.5	4.5	2
BL5	3	2.5	2	5.5	6.5	2	5.5	4	2.5	5.5	4.5	2
IN3a	14.5	14.5	14.5	19.5	19.5	19	12	12	11.5	20	20.5	20
IN6	14.5	14.5	14.5	21	21	21	13.5	13.5	15	17	16	21
TO2	11.5	12	11.5	12.5	13.5	15	15	15	13	22	22	18
TU1	13	13	13	16	17	18	10.5	10	11.5	14	13	15
MI1	9	10	9.5	12.5	12	12.5	10.5	11	10	14	16	14
MI4	9	8.5	9.5	14	13.5	12.5	13.5	13.5	14	17	16	18
MI7	9	8.5	11.5	11	10.5	12.5	9	9	9	10.5	11.5	10
CE1	7	6.5	3.5	9.5	9	4	1.5	1.5	2.5	1.5	1	2
CE6	3	5	5	2.5	3.5	6.5	5.5	7	8	5.5	6.5	8
KI5	3	2.5	1	2.5	2	1	3.5	4	6	1.5	2.5	5.5
KI6b	3	2.5	6	1	1	4	7.5	7	5	7	6.5	5.5
BI1	11.5	11	8	9.5	10.5	8.5	7.5	7	7	8.5	8	7
CA1	6	6.5	7	5.5	6.5	8.5	1.5	1.5	2.5	3.5	2.5	4
Kansas and Missouri (Wilkison and others, 2005)												
BL2b	--	--	--	5.5	6.5	6.5	--	--	--	10.5	9.5	11.5
BL7	--	--	--	16	15.5	17	--	--	--	17	16	16
BL8	--	--	--	19.5	19.5	16	--	--	--	14	16	13
BL13	--	--	--	22	22	20	--	--	--	20	20.5	18
IN1b	--	--	--	8	6.5	10	--	--	--	12	11.5	11.5
BR12	--	--	--	18	18	22	--	--	--	20	19	22
GR19	--	--	--	16	15.5	12.5	--	--	--	8.5	9.5	9

Appendix 6. Environmental variables used to develop environmental effects scores for 15 sampling sites in Johnson County, Kansas, 2003 and 2004.

[mg/L, milligrams per liter; PAHs, polycyclic aromatic hydrocarbons; µg/mg, micrograms per milligram; <, less than]

Site identifier (fig. 2)	Stream and location	Impervious surface (percent)	Impervious surface, proportionally scaled	Total nitrogen in water samples (mg/L)[1]	Total nitrogen, proportionally scaled	Total PAHs in sediment samples (µg/mg)[1]	Total PAHs, proportionally scaled	Environmental effects score
BL3	Blue River near Stanley (Highway 69)	3.1	96.1	0.57	96.1	11	99.9	292
BL5	Blue River at Kenneth Road	3.5	95.0	.59	95.9	30	99.7	291
IN3a	Indian Creek at College Blvd	28.7	26.9	14	1.0	8,270	17.4	45
IN6	Indian Creek at State Line Road	27.6	29.9	13	13.8	9,917	1.0	45
TO2	Tomahawk Creek at 111th Street	21.6	46.3	1.3	91.2	5,127	48.8	186
TU1	Turkey Creek at 67th Street	38.3	1.0	.90	93.8	2,463	75.4	170
MI1	Mill Creek at 127th Street	34.2	12.1	.82	94.4	2,134	78.7	185
MI4	Mill Creek at 87th Street Lane	20.9	48.0	6.1	57.6	1,600	84.0	190
MI7	Mill Creek at Johnson Drive	15.0	63.9	1.5	89.7	1,471	85.3	239
CE1	Cedar Creek at Old Highway 56	9.6	78.6	1.5	89.8	2,063	79.4	248
CE6	Cedar Creek near DeSoto (83rd Street)	6.1	88.2	2.2	84.6	91	99.1	272
KI5	Kill Creek at 135th Street	4.7	91.7	.74	94.9	<50	100.0	287
KI6b	Kill Creek at 95th Street	3.9	93.9	.60	95.9	423	95.8	286
BI1	Big Bull Creek near Edgerton Road	2.4	98.1	1.2	91.8	15	99.9	290
CA1	Captain Creek at 119th Street	1.7	100.0	<.05	100.0	24	99.8	300

[1]Average of two samples.

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For more information concerning the research described in this report, contact:

U.S. Geological Survey
4821 Quail Crest Place
Lawrence, KS 66049
(785) 842-9909
http://ks.water.usgs.gov

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