Prepared in cooperation with the city of Independence, Missouri, Water Pollution Control Department

Water-Quality Trends of Urban Streams in Independence, Missouri, 2005–18

Scientific Investigations Report 2020–5130

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

Cover. Outflow from a bridge culvert on Crackerneck Creek at Selsa Road in Independence, Missouri, after a storm event.

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U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2021

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Suggested citation:
Barr, M.N., and Kalkhoff, S.J., 2021, Water-quality trends of urban streams in Independence, Missouri, 2005–18: U.S. Geological Survey Scientific Investigations Report 2020–5130, 57 p., https://doi.org/10.3133/sir20205130.

ISSN 2328-0328 (online)

Acknowledgments

The authors would like to acknowledge the support and assistance received from staff at the city of Independence, Missouri, Department of Water Pollution Control during the study period. The knowledge and support of the staff were critical in the project development and evolution and in the investigation of the results.

The authors would like to acknowledge the U.S. Geological Survey staff who collected the physical samples and maintained equipment at the sites; whose tireless efforts and enthusiasm to capture storm events regardless of the day or hour, were fundamental for recording and documenting reliable science. The authors also would like to acknowledge all U.S. Geological Survey staff who assisted in the data compilation, interpretation, and production of this document and its findings; whose attention to detail and quality of data greatly benefit the text, illustrations, and tables presented in this report.

Contents

Figures

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
milliliter (mL)	0.033814	fluid ounce (oz)
milliliter (mL)	0.002113	pint (pt)
milliliter (mL)	0.001057	quart (qt)
milliliter (mL)	0.002642	gallon (gal)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg)	2,205	pound avoirdupois (lb)

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

$$°F = (1.8 \times °C) + 32.$$

Supplemental Information

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

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

A water year is the 12-month period from October 1 through September 30 and designated by the calendar year in which it ends (water year 2019 is the period beginning October 1, 2018, and ending September 30, 2019).

Abbreviations

CFU/100 mL	colony forming units per 100 milliliters
E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
FIB	fecal indicator bacteria
GIS	geographic information system
LOADEST	Load Estimator (a FORTRAN program for estimating constituent loads in streams and rivers)
MS4	municipal separate storm sewer system
NLCD	National Land Cover Database
NURP	Nationwide Urban Runoff Program
ortho-P	dissolved orthophosphate as phosphorus
PARMA	periodic autoregressive moving average
p-value	probability value
SCR	secondary contact recreation
SSC	suspended-sediment concentration
SSL	suspended-sediment load
TDS	total dissolved solids
TN	total nitrogen
TP	total phosphorus
TON	total organic nitrogen
USGS	U.S. Geological Survey
WBC–B	whole-body contact class B
WRTDS	Weighted Regressions on Time, Discharge, and Season
WRTDS–K	Weighted Regressions on Time, Discharge, and Season-Kalman filter

Water-Quality Trends of Urban Streams in Independence, Missouri, 2005–18

By Miya N. Barr and Stephen J. Kalkhoff

Abstract

The U.S. Geological Survey and the city of Independence, Missouri, Water Pollution Control Department has studied the water quality and ecological condition of urban streams within Independence since 2005. Selected physical properties, nutrients, chloride, fecal indicator bacteria (*Escherichia coli* and total coliform), total dissolved solids, and suspended-sediment concentration data for base-flow and stormflow samples were used to document temporal trends in concentrations and flow-weighted concentrations; and annual loads were computed and investigated for selected nutrients, chloride, and suspended sediment. The six study sites included in this report are located on five urban streams: Rock Creek, a tributary in the city that drains to the Missouri River; three tributaries of the Little Blue River within the city (East Fork Little Blue River, Adair Creek, and Spring Branch Creek); and two sites on the main stem of the Little Blue River (one upstream from the city and one downstream from the three tributaries).

Many factors such as population, land use, and climate, and combinations of these factors contributed to the significant changes in the concentrations and transport of nutrients, chloride, fecal indicator bacteria, and suspended sediment in the urban streams within Independence. The population of Independence and the amount of developed land in the urban watersheds remained unchanged during the 2005–18 study. Differences were noted in precipitation and in streamflow during the study. Annual precipitation and streamflow were separated into two time periods within the study—period 1 (2006–10), having greater annual streamflow and precipitation, and period 2 (2011–18), having about 30 percent lower annual streamflow and less precipitation. Streamflow was an important factor in the transport of nitrogen, phosphorus, chloride, and suspended sediment from the urban watersheds. Changes in data collection methodology during the study period and improvements to the city stormwater and wastewater infrastructure also could have contributed to some of the trends. Between 2009 and 2015, more than 35 million dollars of improvements were made to stormwater and wastewater infrastructure within the city. These improvements, such as additional sewage overflow holding tanks, removal of septic tanks, and improved and expanded sanitary sewer lines and storm overflows, also could have affected the decreased nutrients and fecal indicator bacteria trends among the urban streams in the study area.

Models were used for analyzing streamflow-related variability in constituent concentrations and loads to determine if the water quality changed significantly during the study period. Trends in concentration data at four sites were analyzed using a statistical package called R–QWTREND and trends in load data were analyzed at six sites using a statistical package called Weighted Regressions on Time, Discharge, and Season-Kalman filter (WRTDS–K); both developed by the U.S. Geological Survey and publicly available for use.

Statistically significant trends in flow-weighted nutrient concentrations and loads generally were downward during the study period. The only nutrient compound with a statistically significant upward trend in flow-weighted concentration was dissolved orthophosphate as phosphorus at the Rock Creek site and the upstream site on the Little Blue River. A statistically significant downward trend in annual dissolved ammonia load was identified at the downstream Little Blue River site. A significant upward linear trend in annual orthophosphate as phosphorus load was identified on Adair Creek.

A statistically significant upward trend in dissolved chloride concentrations was identified at the downstream Little Blue River site. Road salt application near the site during the winter could have resulted in higher concentrated runoff during wet weather conditions. Annual chloride loads significantly decreased in Adair Creek and Spring Branch Creek. The mean annual chloride load transported in the drier (2011–18) period 2 was significantly less than during the wetter (2006–10) period 1, indicating that trends in precipitation runoff are an important factor in trends in annual transport of chloride.

Statistically significant downward trends in flow-weighted fecal indicator bacteria *Escherichia coli* (*E. coli*) population densities were noted for Rock Creek and the downstream site on the Little Blue River. However, no trend was identified in E. coli population density at the upstream Little Blue River site. The downward trend in E. coli population density at the downstream site could be a result of decreased streamflow and precipitation over the study period, storage of fecal indicator bacteria in the Little Blue River streambed within the study area, die-off of fecal indicator bacteria during travel from upstream to downstream, changes in the sample

collection methodology, improvements to the city's stormwater and wastewater infrastructures, or a combination of these factors.

The statistically significant downward trend in suspended-sediment concentration identified at the upstream Little Blue River site could be affected by the decreased streamflow and precipitation during the study period, by changes in sampling methods within the study period, and by the decrease in construction and urban land development upstream from the city.

No statistically significant change was indicated in the annual suspended-sediment load transported from Independence to the Little Blue River during the study period. More than one-half the suspended sediment transported in the Little Blue River originated in the watershed upstream from Independence.

The Little Blue River and many of its tributaries that drain Independence have been designated as recreational waters classified for whole-body contact class B and secondary contact recreation, and some have been listed as impaired for *E. coli* by the Missouri Department of Natural Resources from urban runoff and storm sewers. Observations were made among the available *E. coli* population density data for both Little Blue River sites to further understand water-quality conditions over the study period. Both Little Blue River sites had similar medians and geometric means for the recreational season (April through October) and during the full study period, both of which are greater than the regulatory population density for both recreational classes. The Little Blue River drainage area nearly doubles in size from the upstream to downstream site; therefore, the consistent geometric mean and median of *E. coli* population densities at the upstream and downstream Little Blue River sites could be primarily due to the larger volume of streamflow creating a dilution effect. Other possible factors could be storage of fecal indicator bacteria in stream bed sediments, die-off of fecal indicator bacteria during transport, improvements to the city's wastewater and stormwater infrastructure, changes to sampling methodology, or a combination of these factors. Specific sources of the *E. coli* are currently (2019) unknown.

Introduction

The U.S. Geological Survey (USGS) and the city of Independence, Missouri, Water Pollution Control Department, began a cooperative study in June 2005 to characterize and evaluate the water quality and ecological condition of urban streams within Independence (fig. 1). The quantities and sources of pollutants were characterized to better understand the processes that affect water quality and its effect on aquatic life in Independence streams. The data collected assisted the city of Independence in fulfilling its National Pollution Discharge Elimination System permit requirements for the municipal separate storm sewer system (MS4). An MS4 is a system of conveyances that include man-made channels, pipes, tunnels, and storm drains, as well as surface streets, catch basins, curbs, gutters, and ditches that discharge into waters of the United States (U.S. Environmental Protection Agency, 2018). The monitoring of an MS4 is mandated by Federal and State Government regulations. For Independence to meet the conditions for its MS4 permit and to design effective strategies to reduce contaminant discharges to streams, information about the source and nature of contaminants identified in receiving streams was initially needed. As a result of this study, a network of monitoring sites was installed and instrumented to measure streamflow and select water-quality constituents and to automatically collect stormwater samples. Collection of water-quality data in urban streams in Independence continued through 2018 resulting in a dataset that can be used to evaluate the progress of applied best management practices and to establish a baseline by which the effectiveness of current (2019) and future best management practices can be measured.

Previous Investigations

The U.S. Environmental Protection Agency (EPA) led the Nationwide Urban Runoff Program (NURP) research project between 1979 and 1983 (U.S. Environmental Protection Agency, 1983), and one of the study sites was on Rock Creek, an urban stream in Independence, Mo. (fig. 1). The NURP study concluded that urban runoff was the cause of much pollution nationwide, and the goals of the Clean Water Act would not be met if action was not taken (U.S. Environmental Protection Agency, 1983). During the initial phase (1991–92) of the National Pollution Discharge Elimination System permit process, the water quality of base flow and stormflow was evaluated in five urban streams within Independence (Schalk, 1994).

In June 2005, the USGS began to collect and analyze base-flow and stormflow samples from selected streams within the city limits of Independence. The objective of water-quality monitoring was to characterize and assess contaminant sources, concentrations, loads, and yields of various constituents from tributaries receiving inflow from within the MS4 boundary and to determine each constituent's contribution to the overall water quality and ecological condition of the Little Blue River (fig. 1). From June 2005 through December 2008, data were collected from four sampling sites (sites 1, 5, 6, and 8; fig. 1). The data consisted primarily of stormflow runoff samples with less frequent base-flow sampling and a small suite of selected constituents (Christensen and others, 2010). From 2009 through 2014, five sampling sites (sites 2, 3, 4, 7, and 9; fig. 1) were included with an increased number of base-flow samples and additional constituents to develop a more robust dataset. Loads were computed for selected constituents collected from the nine sites (Niesen and Christensen, 2015). Data collected from 2007 through 2011 were used to evaluate the ecological health of Independence streams (Christensen

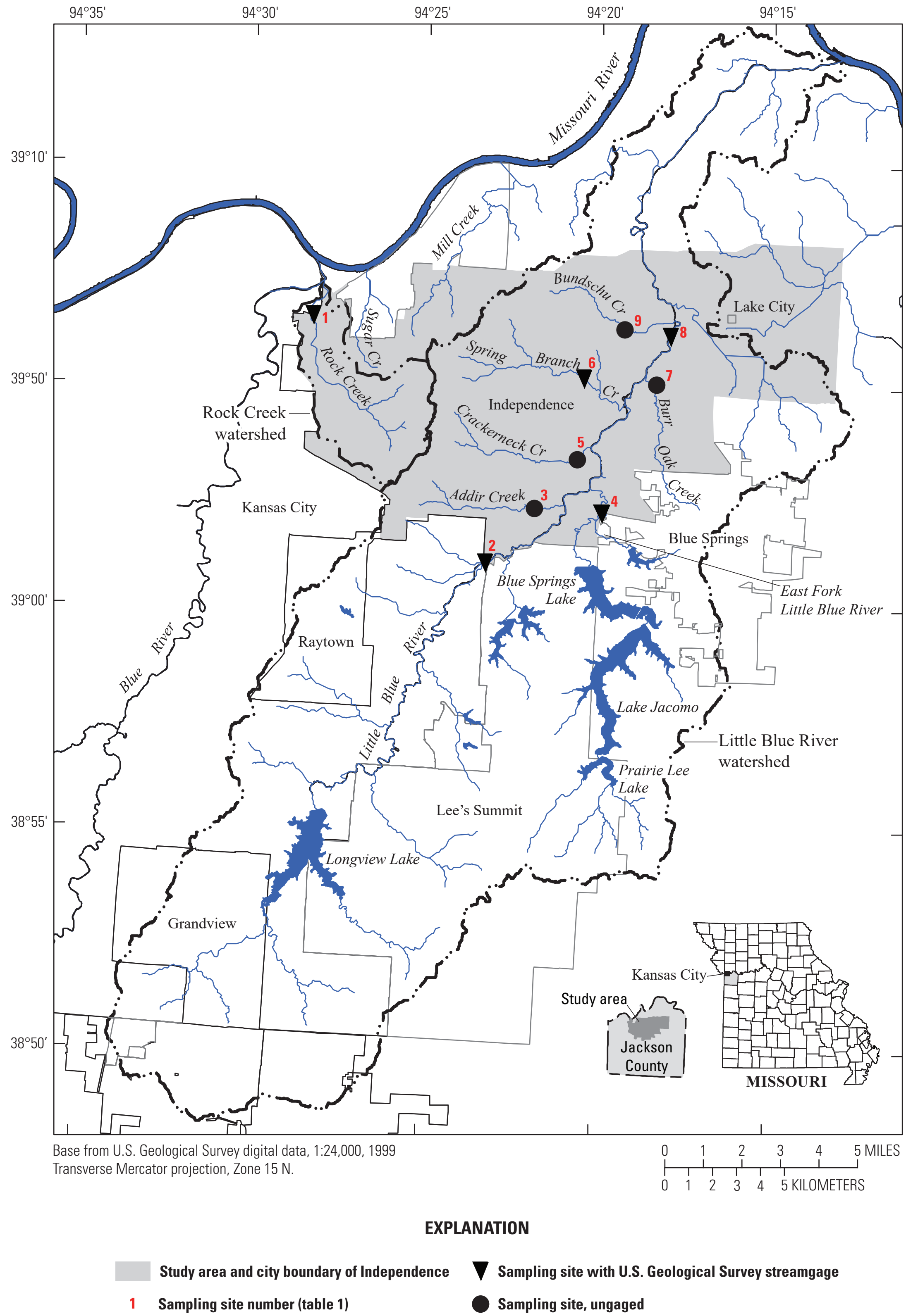


Figure 1. The Little Blue River watershed, sampling sites, study area location, and political boundaries for Independence, Missouri, and surrounding cities. Modified from Niesen and Christensen (2015).

and Krempa, 2013). Concentrations, loads, and yields of *Escherichia coli* (*E. coli*) and microbial source tracking from 2008 through 2015 have been used to examine potential sources of *E. coli* within the MS4 and sources entering and leaving the city through the Little Blue River (Bushon and others, 2017). Results indicated no statistically significant difference between *E. coli* loads entering the MS4 and *E. coli* loads leaving the MS4.

Storm and Wastewater Infrastructure Improvements

During 2009, the city of Independence signed a consent decree with the U.S. Department of Justice and the EPA to improve stormwater and wastewater infrastructures during a 5-year period at an estimated cost of about $35 million (U.S. Department of Justice, 2009). Major improvements were made to the Rock Creek Wastewater Treatment Plant. The improvements included upgraded pump stations and installation of two new holding tanks, each with 2.5-million-gallon capacity, increasing the plant's storage capacity to 10 million gallons. The increased storage capacity minimized the risk of untreated sanitary sewer overflow into streams during extreme weather or periods of increased sanitary use. Sanitary sewer lines in Rock Creek, Sugar Creek, and Mill Creek watersheds were upgraded, and sanitary lines in the Burr Oak Creek watershed area were expanded (fig. 1). At least 43 septic tanks were removed, and the properties were connected to sanitary sewer lines in the Bundschu Creek watershed (fig. 1). Improvements and additional sewer lines also were added to the Adair Creek watershed (fig. 1).

Purpose and Scope

The purpose of this report is to present trends in water quality in relation to changes in precipitation, streamflow, population, and land use in urban streams using data collected by USGS staff from 2005 through 2018 as part of an ongoing, cooperative study with the Independence Water Pollution Control Department. Selected physical properties, nutrients, chloride, fecal indicator bacteria (FIB; such as *E. coli* and total coliform), total dissolved solids (TDS), and suspended-sediment concentration (SSC) data for base-flow and stormflow samples were used to document temporal trends in concentrations and flow-weighted concentrations; annual loads were computed and investigated for selected nutrients, chloride, and suspended sediment. Concentration and annual-load trends presented are based on discrete surface water-quality data collected from January 2006 through December 2018. Annual loads are estimated from discrete water-quality data and daily streamflow data. The methods used to analyze trends and loads differ from previous investigations (Christensen and others, 2010; Niesen and Christensen, 2015) and are discussed in the "Methods" section of this report.

Description of Study Area

The city of Independence, Mo., is east of Kansas City in Jackson County (fig. 1). The sites within the study cover about 288 square kilometers (km^2) of total drainage area within the city limits of Independence (fig. 1; table 1).

About two-thirds of Independence is drained by the Little Blue River and its tributaries, and most of these streams flow generally northward to the Missouri River (fig. 1). Of the total drainage area of the Little Blue River at its confluence with the Missouri River (580 km^2; Ellis, 2018), about 160 km^2, or roughly 28 percent, is within Independence (fig. 1; table 1). The Little Blue River within Independence is monitored as part of the MS4 between the sites Little Blue River at Lee's Summit Road in Independence, Mo. (site 2) and Little Blue River near Lake City, Mo. (site 8; fig. 1). The largest tributary to the Little Blue River is the East Fork Little Blue River. Both the Little Blue River and East Fork Little Blue River have sizable parts of their drainage area upstream from Independence (fig. 1). The Little Blue River drains an area of 476 km^2 (site 8) of which 254 km^2 or 43 percent is upstream from Independence (fig. 1; table 1). The East Fork Little Blue River (site 4) drains an area of 89.1 km^2, most of which is upstream of Independence (fig. 1; table 1). Adair Creek, Crackerneck Creek, and Spring Branch Creek are tributaries of the Little Blue River and drain the west-central part of Independence (fig. 1). Rock Creek drains northwest from Independence and flows north, discharging directly to the Missouri River (fig. 1).

Some of the streams in Independence have stream classifications designated by the State of Missouri (Missouri Department of Natural Resources, 2019a). The Little Blue River and East Fork Little Blue River are classified by the State of Missouri as Class P (perennial) streams suitable for whole-body contact class B (WBC–B) and secondary contact recreation (SCR). Burr Oak Creek is a Class-C stream, meaning the stream has perennial pools that may not flow during periods of drought and has designated uses including WBC–B and SCR. The remaining streams in Independence are currently (2019) unclassified. Within Independence, the streams are mostly channelized. The reach of the Little Blue River is listed in the Missouri Code of State Regulations (10 CSR 20–7) as a metropolitan no discharge stream, meaning no municipal effluent can be discharged directly into the stream (Missouri Department of Natural Resources, 2019a).

Population and Land Use

The population of the city of Independence increased rapidly from 1940 through the 1960s (fig. 2). The population increased from about 16,000 in 1940 to about 112,000 in 1970. The population has been relatively constant since 1970, increasing less than 1 percent per decade to about 117,000 in 2018 (U.S. Census Bureau, 2020). The number of households in Independence during 2014–18 was 48,166, and the population per square mile was about 581 people per square kilometer in 2010 (U.S. Census Bureau, 2020).

Table 1. Study site information for urban sites within Independence, Missouri.

[Shading indicates sites not used in trend analysis because available data did not meet minimum requirements for models. USGS, U.S. Geological Survey; ddmmss, degrees/minutes/seconds; km², square kilometer; mi², square mile; --, no data available]

Site number (fig. 1)	USGS site name	USGS site number	Latitude (ddmmss)	Longitude (ddmmss)	Drainage area[1] Above site[2] (km²)	Drainage area[1] Above site[2] (mi²)	Drainage area[1] Within Independence (km²)	Drainage area[1] Within Independence (mi²)	Period of streamflow record used in report	Period of water-quality sampling used in report
1	Rock Creek at Kentucky Road in Independence, Missouri	06893620	390643	0942820	24.6	9.4	26.1	10.1	July 2005–December 2018	June 2005–December 2018
2	Little Blue River at Lee's Summit Road in Independence, Missouri	06893820	390102	0942314	254	98.4	1.3	0.5	October 2009–December 2018	December 2009–December 2018
3	Adair Creek at Independence, Missouri	06893830	390216	0942148	13.3	5.1	14.2	5.5	October 2008–January 2018	July 2008–December 2018
4	East Fork Little Blue River near Blue Springs, Missouri	06893890	390132	0942037	89.1	34.4	10.1	3.9	June 2007–September 2007, November 2009–December 2018	December 2009–December 2018
5	Crackerneck Creek at Selsa Road in Independence, Missouri	06893940	390322	0942041	12.9	5.0	17.6	6.8	July 2005–September 2008	June 2005–September 2008, March 2010–December 2018
6	Spring Branch Creek at Holke Road in Independence, Missouri[3]	06893970	390518	0942036	21.7	8.4	27.7	10.7	July 2005–December 2018	June 2005–December 2018
7	Burr Oak Creek at Independence, Missouri	06893990	390510	0941832	21.0	8.1	17.1	6.6	March 2010–November 2011	March 2010–December 2018
8	Little Blue River near Lake City, Missouri	06894000	390602	0941801	476	195	161	62.1	October 2004–December 2018	June 2005–December 2018
9	Bundschu Creek at North Little Blue Parkway in Independence, Missouri	390617094190201	390617	0941902	10.1	3.9	12.7	4.9	--	January 2012–December 2018

[1]Drainage areas were obtained using USGS StreamStats application, accessed February 3, 2020, at https://streamstats.usgs.gov/ss/.

[2]Drainage area above site incorporate the area upstream from the streamgage and sampling location.

[3]Spring Branch Creek streamgage moved downstream approximately 1,500 feet to Missouri State Highway 78 bridge on August 15, 2007, because of sedimentation at the original location on Holke Road.

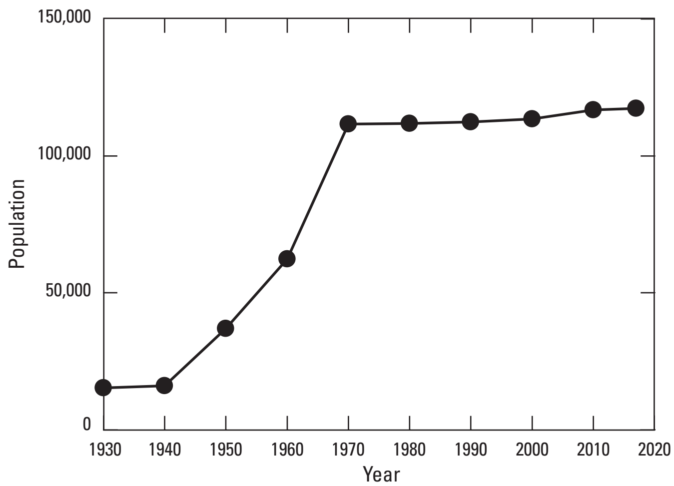


Figure 2. Population of Independence, Missouri, from 1930 through 2018. Data from U.S. Census Bureau (2020).

Land use of watersheds upstream from and draining Independence have been classified primarily as developed land and comprise about 46 to about 94 percent of the total area (table 2). Developed land types such as open space, low-, medium-, and high-intensity (table 2) refer to residential, commercial, and industrial uses and are classified based on percent imperviousness (Yang and others, 2018). Percentages of developed areas of watersheds draining the city range from about 70 to about 94 percent and have remained similar from 2006 to 2016 (table 2). The percentage of developed areas within Independence are greater than the percentage of developed area in watersheds upstream from Independence (table 2). The total percentage of developed areas in watersheds upstream from Independence were nearly equal to the total of all other identified land uses (grassland, forest, cultivated crops, open water, wetlands, and barren; table 2).

Undeveloped areas of Independence (grassland, forest, cultivated crops, open water, wetlands, and barren) cover a much smaller area than the developed areas (table 2). The western part of Independence is primarily urbanized, whereas the eastern and northern parts of the city are characterized by large tracts of undeveloped land, including grasslands, forests, and cultivated croplands, with some new residential construction on what had previously been vacant and agricultural-zoned land (fig. 3). The total percentage of undeveloped area in watersheds draining Independence range from about 6 to 27 percent and have remained similar from 2006 through 2016 (table 2).

Land use within the Little Blue River watershed upstream from and within Independence had minimal changes from 2006 through 2016. The largest land-use change within the entire watershed was a decrease in cultivated crops that was offset mainly by increases in forest, and low-, and medium-, intensity development (table 2). The percentage of each watershed upstream from Independence that was developed remained unchanged at about 50 percent for the Little Blue River and about 46 percent for the East Fork Little Blue River (table 2).

Precipitation and Streamflow

Since 1940, annual precipitation in northwestern Missouri (fig. 4) has ranged from 54 to 144 centimeters (cm) (Midwestern Regional Climate Center, 2019). Although no long-term trend is indicated, annual precipitation (fig. 4) decreased from 105 cm in period 1 (2006–10) to 93 cm/yr in period 2 (2011–18). The 30-year (1981–2010) mean annual precipitation for northwestern Missouri is 99.4 cm. During period 1, mean annual precipitation was greater than the 30-year mean, and during period 2, mean annual precipitation was less than the 30-year mean (Midwestern Regional Climate Center, 2019). During the study period (2006–18), the wettest year was 2008 followed by 2015, and the driest year was 2012 followed by 2006 (fig. 4). The 30-year mean annual precipitation for Independence is 110.9 cm (43.67 inches) (Midwestern Regional Climate Center, 2019).

Although precipitation values remained relatively constant (fig. 4), differences in the mean annual streamflow and annual low streamflow at the Little Blue River near Lake City, Mo. (site 8, streamgage 06894000) can be identified by observing the central tendency (LOESS smooth line) with time from 1949 through 2018 (fig. 5; U.S. Geological Survey, 2019). Mean annual streamflow (fig. 5) increased substantially during a period of rapid population growth (fig. 2) from the 1950s through the 1970s, indicating that urbanization in Independence and upstream in the Little Blue River watershed affected the streamflow. Urbanization and its increase in impermeable surfaces and stormwater drainage potentially caused larger amounts of rainfall runoff to flow to rivers and streams. No wastewater treatment plants or discharge points from plants are along the reach of the Little Blue River, because this stream is designated as a no discharge stream (Missouri Department of Natural Resources, 2019a). Mean annual streamflow has remained constant during the period of minimal population increases from 1980 to 2018 (fig. 5).

Low flow in the Little Blue River also increased during the period of rapid population growth (figs. 2, 5). The annual 7-day minimum streamflow increased from less than 0.1 cubic meter per second (m^3/s) in the 1950s to more than 0.4 m^3/s in the 1970s (fig. 5). The substantial decrease in minimum flow during the 1980s (fig. 5) most likely resulted from completion of the large reservoirs on the upper Little Blue River and East Fork Little Blue River. The dams on the East Fork Little Blue River were completed in 1936 (Prairie Lee Lake [fig. 1]; Heimann, 1995) and 1986 (Blue Springs Lake [fig. 1]; Rouse, 2004), whereas the dam on the Little Blue River (Longview Lake [fig. 1]) was completed in 1985 (Jackson County Parks and Recreation, 2019). About one-half, or 292 square kilometers (km^2), of the drainage area of the Little Blue River watershed is regulated by reservoirs.

Table 2. Land use in urban watersheds in Independence, Missouri.

[Land-use data from National Land Cover Database, 2006 and 2016 (Multi-Resolution Land Characteristics Consortium, 2020). USGS, U.S. Geological Survey; km^2, square kilometer; the sum of all land use categories may not equal 100 percent because of rounding.]

Site number (fig. 1)	USGS site number	Stream name	Drainage area (km^2)	Year	Land use, percent of watershed									
					Developed				Grassland	Forest	Cultivated crops	Open water	Wetlands	Barren
					Open space	Low intensity	Medium intensity	High intensity						
Watersheds upstream from Independence														
2	06893820	Little Blue River	254	2006	19.9	20.9	6.04	2.27	21.5	15.9	10.7	2.19	0.38	0.13
				2016	18.2	21.1	6.85	2.81	23.4	19.3	5.68	2.14	0.34	0.18
4	06893890	East Fork Little Blue River	89.1	2006	16.4	20.8	7.34	1.48	17.4	18.8	7.96	9.19	0.40	0.16
				2016	14.9	21.4	7.94	1.65	17.1	22.4	5.31	8.97	0.29	0.13
Watersheds draining Independence														
1	06893620	Rock Creek	24.6	2006	27.7	51.9	10.4	4.12	0.84	4.91	0.11	0.00	0.02	0.00
				2016	27.4	51.8	10.5	4.16	1.21	4.83	0.00	0.00	0.00	0.01
3	06893830	Adair Creek	13.3	2006	16.5	47.4	17.5	9.25	2.38	5.21	1.18	0.07	0.00	0.54
				2016	16.6	48.2	18.3	9.83	2.12	4.43	0.09	0.24	0.26	0.01
6	06893970	Spring Branch Creek	21.7	2006	26.4	31.8	9.57	2.55	8.00	15.3	6.15	0.15	0.12	0.06
				2016	26.5	32.3	9.87	2.61	8.63	16.9	2.97	0.06	1.30	0.02
Little Blue River near Lake City, Missouri														
8	06894000	Little Blue River	476	2006	18.8	21.4	7.74	2.11	15.1	20.5	11.9	1.35	1.07	0.02
				2016	17.5	22.2	8.78	2.31	15.3	23.4	7.79	1.30	1.30	0.12

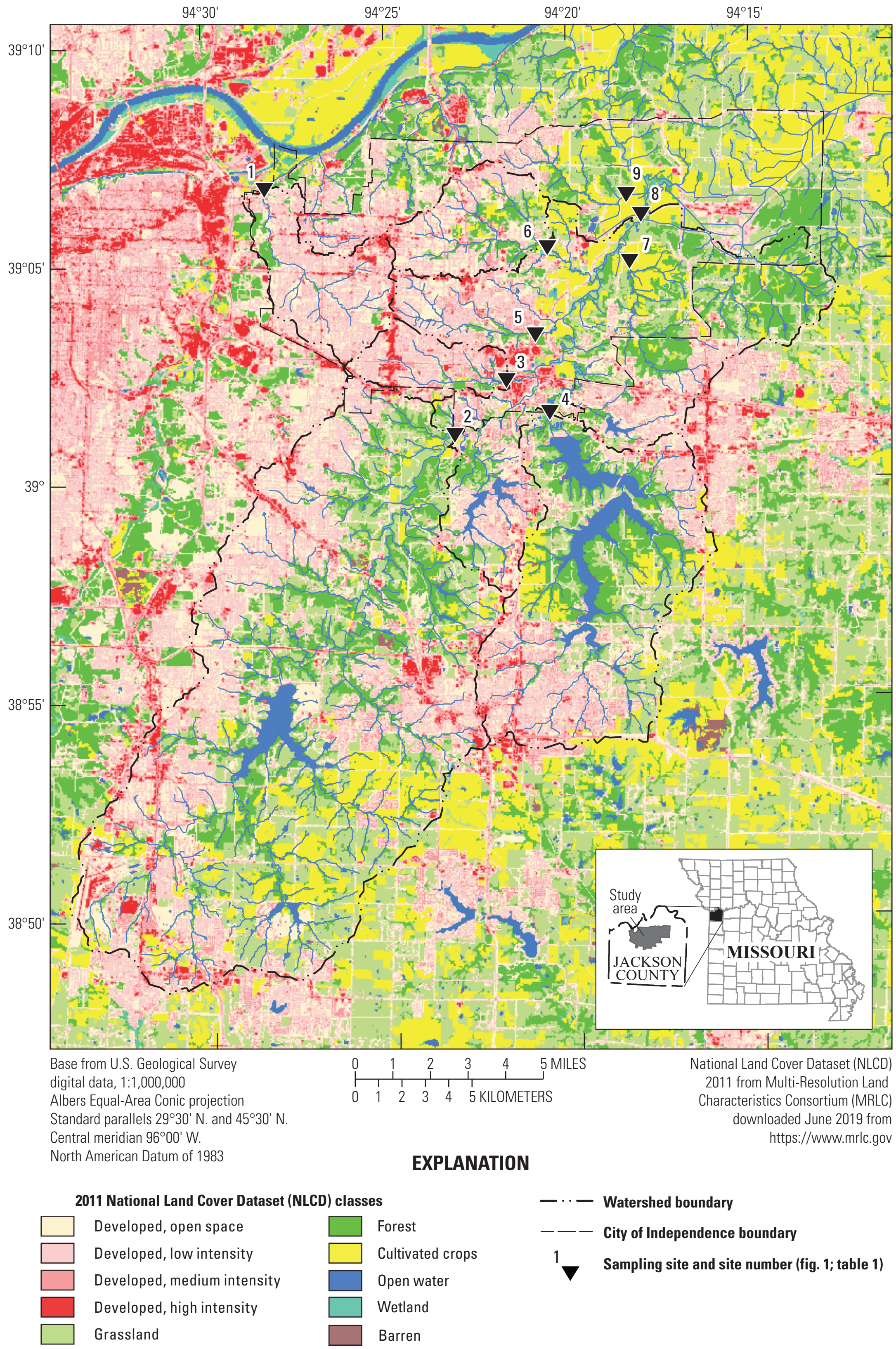


Figure 3. Land use/land cover in the Little Blue River Watershed and adjacent watersheds within Independence, Missouri.

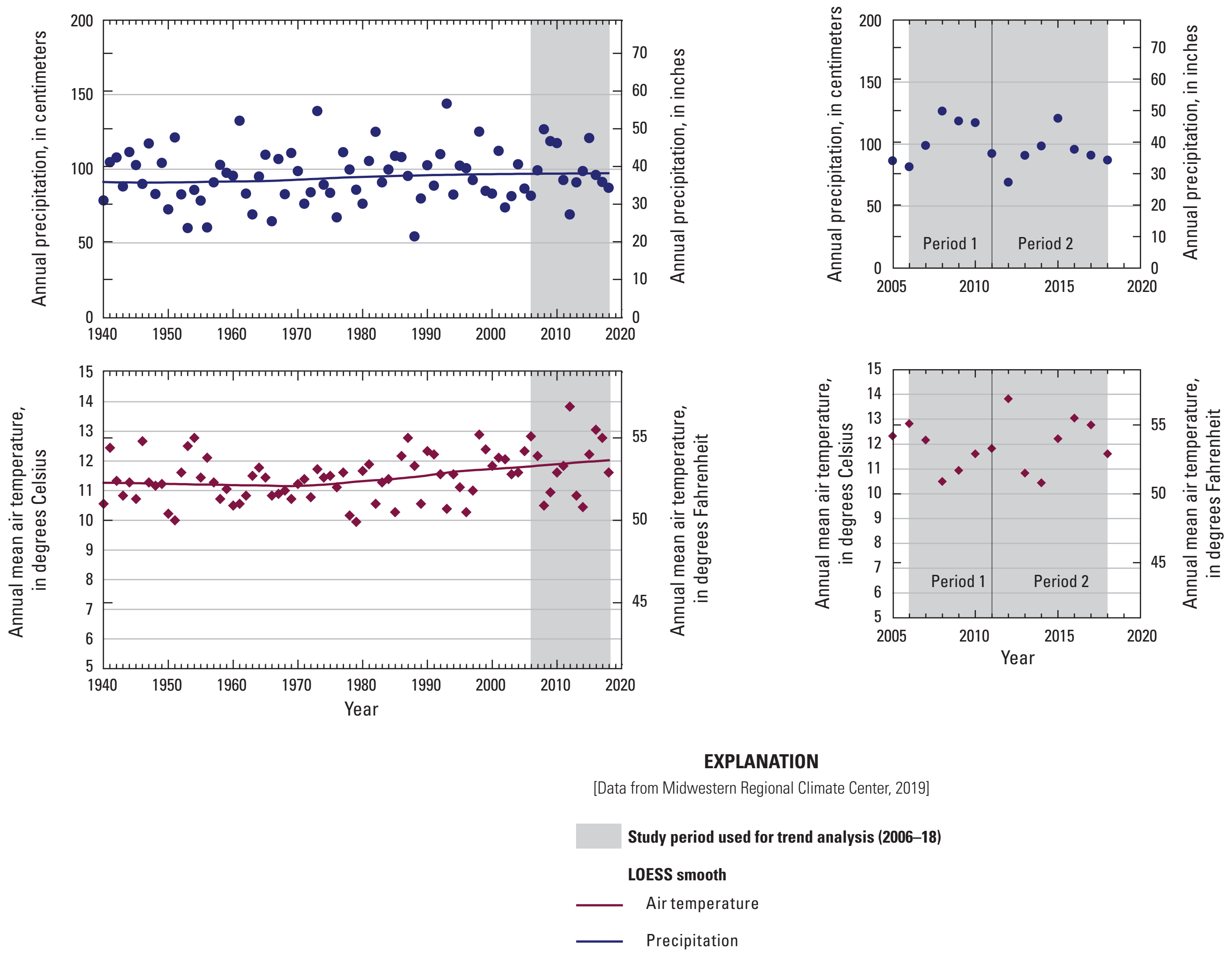


Figure 4. Annual mean precipitation and air temperature in northwestern Missouri in relation to long-term trends, 2006–18.

Annual maximum flows in the Little Blue River have remained relatively constant at less than 200 m^3/s since 1949 (fig. 5). Exceptional flow events were in 1977 and 1982 when flow in the Little Blue River near Lake City, Mo., peaked at 413 and 784 m^3/s, respectively (U.S. Geological Survey, 2019). The next two greatest annual maximum flows were during the study period. The third-greatest annual maximum flow since 1949 was 297 m^3/s in 2007, and the fourth-greatest annual maximum flow was 267 m^3/s in 2017.

Slightly lower air temperatures reducing evapotranspiration and more precipitation generating more runoff (fig. 4) probably were contributing factors that resulted in greater annual streamflow in the Little Blue River during period 1 (2006–10) than in period 2 (2011–18; fig. 5). The mean annual streamflow in the Little Blue River near Lake City, Mo. (site 8), was greater during period 1 (5.97 m^3/s) than during period 2 (3.97 m^3/s; fig. 5). Mean annual flow was not significantly (p greater than 0.05, Wilcoxon rank-sum test) different between the two periods, likely due to the large variability during period 1 (fig. 5).

Streamflow in the Little Blue River is affected by reservoirs at Longview Lake on the main stem of the Little Blue River and at Prairie Lee Lake, Lake Jacomo, and Blue Springs Lake on the East Fork Little Blue River (fig. 1). Longview Lake and Blue Springs Lake reservoirs are most immediately upstream from Independence on the Little Blue River and East Fork Little Blue River, respectively, and both reservoirs affect base flow. Low-flow releases from Longview Lake are maintained at a minimum of about 0.20 m^3/s, but low-flow releases are not maintained from Blue Springs Lake (Christensen and others, 2010).

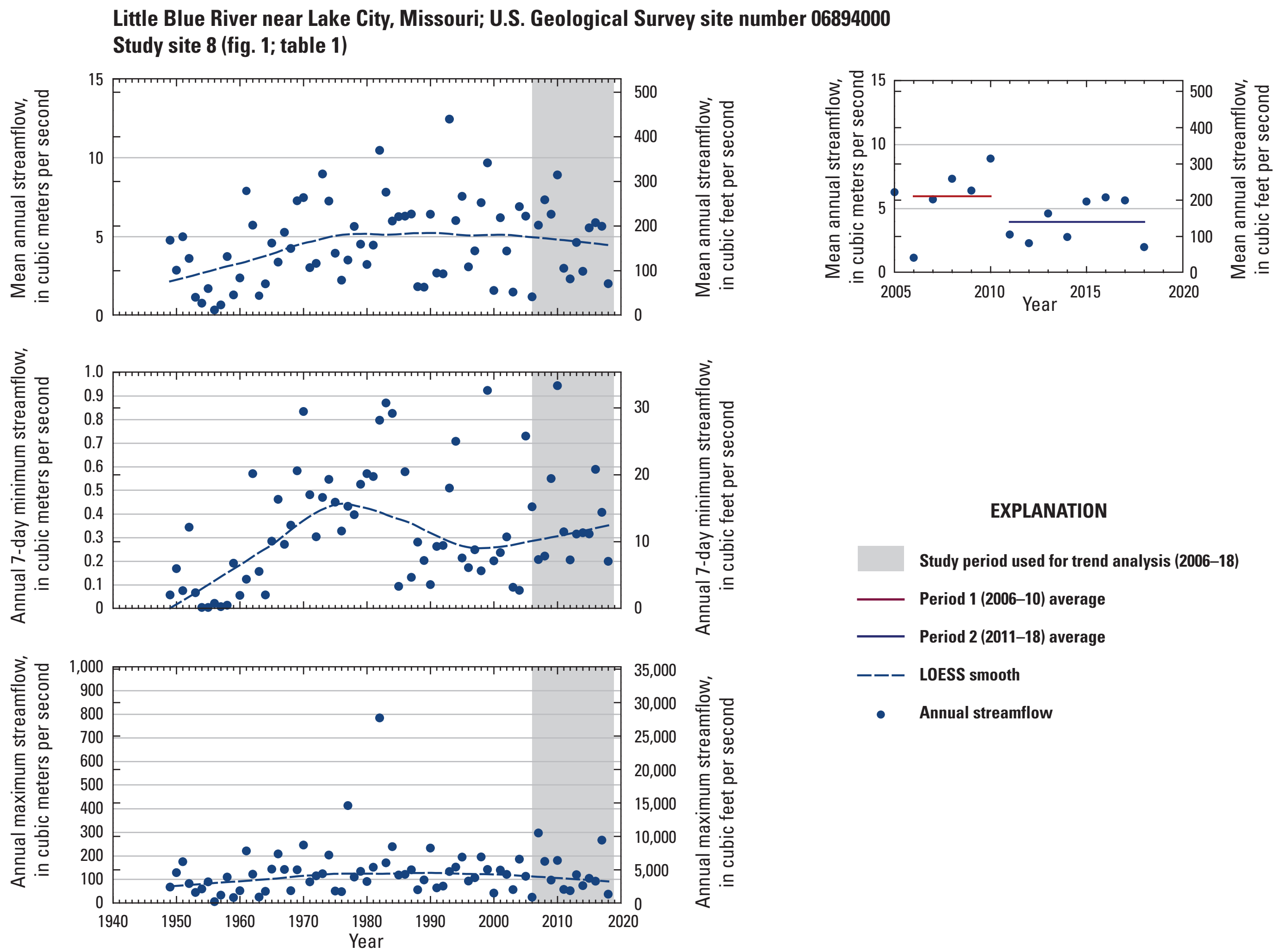


Figure 5. Streamflow conditions from 2006–18 in relation to long-term streamflow conditions in the Little Blue River near Lake City, Missouri (streamgage 06894000; U.S. Geological Survey, 2019).

Methods

Various data obtained within the study period were used to evaluate trends in concentrations and loads for selected constituents at select sites. Not all constituents analyzed or sites within the study area were applicable for trend evaluations because of the length of time in which data were collected, periods of no data collection within the dataset, or other reasons that did not fit criteria for the models used.

Water-Quality and Streamflow Data

The hydrologic monitoring network within Independence consists of USGS streamgages and ungaged sampling sites, which both have varied data collection periods during the length of the study (table 1). Other streamgages have periodically been operated within Independence, through the NURP study (U.S. Environmental Protection Agency, 1983) and through the USGS streamgaging network in 1992 and 1993 (Schalk, 1994). Since 2005, water-quality samples have been collected from 11 sites in the Little Blue River watershed that are representative of Independence's contribution to the water quality of the Little Blue River and to streams that drain developed areas of Independence that receive streamflow from the MS4. Of these 11 sampling sites, the 9 sites that are currently (2019) active since 2015 are listed in table 1; 6 of these 9 sites were used in the analyses in this report. Sampling sites, sampling intervals, and constituents collected were based on MS4 permit requirements as well as the city's stormwater management plan.

As the regulatory requirements and management plans changed throughout the years, the study objectives also changed to meet the needs of the city. From 2005 through 2008, four sites (sites 1, 5, 6, and 8; table 1) were selected for stormwater and base-flow samples. Stormflow samples were collected four times per year (seasonally) and one base-flow sample was collected per year. The next phase of the study

(2009–14) had a sampling plan of four stormwater samples collected at six sites (sites 1, 2, 3, 4, 6, and 8) seasonally, an additional two stormflow samples collected at three ungaged sites (sites 5, 7, and 9) per year, and two base-flow samples collected at all nine sites each year. To help characterize changes in constituent concentrations and bacteria population densities across various streamflows, the study was modified to monthly sampling at all nine sites from 2015 through 2019. The monthly sample collections were during the recreational period (April through October) for the nine sites. During the nonrecreational period, two base-flow samples were collected at the original six sites (sites 1, 2, 3, 4, 6, and 8). From 2015 through 2018, two stormwater samples were collected at four sites (sites 1, 2, 6, and 8) each year. Some sites used in the study have changed to more-suitable upstream or downstream locations or were discontinued depending on the project objectives and scope (table 1).

Data from four study sites that had at least 10 years of streamflow and periodic water-quality samples were used for trend analysis (sites 1, 2, 3, and 8). Some of the water-quality constituents that are required by the MS4 permit for analysis and other select constituents with consistent datasets were selected for concentration and load trends, when applicable. These constituents are as follows: the physical properties of water temperature, specific conductance, pH, and dissolved oxygen; the nitrogen species total nitrogen (TN), total organic nitrogen (TON), dissolved ammonia as nitrogen (hereinafter referred to as ammonia), total ammonia plus organic nitrogen as nitrogen, and dissolved nitrate plus nitrite as nitrogen (hereinafter referred to as nitrate plus nitrite); the phosphorus species dissolved orthophosphate as phosphorus (ortho-P) and total phosphorus (TP); dissolved chloride; FIB (*E. coli* and total coliform); TDS; and suspended sediment. The TN values are not analytically derived concentrations but are the sum of dissolved nitrate plus nitrite, ammonia, and other organic nitrogen concentrations.

Surface-water-quality samples were collected during the study using approved USGS methods documented in U.S. Geological Survey (2006). For example, samples were collected by using equal-width increment or grab sampling methods for base-flow samples and by using automated samplers for stormflow collections. Further details of data collection techniques used for this study have previously been discussed by Christensen and others (2010), Christensen and Krempa (2013), Niesen and Christensen (2015), and Bushon and others (2017). All water-quality and streamflow data used in trend analyses are available online from the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2019) using the USGS site numbers in table 1.

Trend Analysis

Changes, or trends, in the water quality in urban streams in Independence, Mo., were evaluated by documenting changes in selected physical properties; concentrations of total and dissolved nutrients, dissolved chloride, TDS, and suspended sediment; and population densities of FIB transported from each watershed. Trends were investigated for the various constituent concentrations at four urban stream sites (sites 1, 2, 3, and 8) and constituent loads were computed and investigated at six urban stream sites (sites 1, 2, 3, 4, 6, and 8). To compute annual results, both concentration and load trend analysis datasets contained samples collected from January 2006 through December 2018.

Analysis of Concentration Trends

A statistical time-series model developed by the USGS was used for analyzing complex, flow-related trends in water-quality constituents. The model is used for parametric statistical inferences and uses maximum likelihood estimation to determine complex trends, flow-related variability, and seasonal serial correlation. The model is operated using a publicly available software package called R–QWTREND (Vecchia, 2005; Vecchia and Nustad, 2020). This package is a collection of functions written in R, a free, open-source language used for statistical and graphical interpretations and computations (R Development Core Team, 2019). An advantage to using this particular model for trend analyses is the ability to model serial correlation among observations and to model complex trends during different times as well as different directions, such as upward or downward, within the analysis period. The R–QWTREND also can identify and remove variability in streamflow to compute a flow-averaged trend and flow-weighted annual concentrations to represent trends that would have occurred if flow conditions were the same for each year in the time period. The software package also identifies and removes potential step trends in datasets. The step trends are the result of the compiled data being collected by various agencies and methods, or the data being processed by various laboratory methods (Vecchia and Nustad, 2020).The R–QWTREND requires a complete record of daily mean streamflow measured at the same streamgage as the discrete water-quality samples are collected. Water-quality data from sites 1, 2, 3, and 8 representing three watersheds met the model criteria of a minimum of 60 discrete samples collected during a 10-year period, with four or more samples collected per year as required for model estimates with low bias. The model also can interpret censored data, but no more than 25 percent of the dataset can be censored. Analyses can be performed with datasets that do not meet the minimum criteria, but the model errors could be highly biased (Vecchia and Nustad, 2020) and should be interpreted with caution. An example of commands used to run the R–QWTREND model for the study is in figure 1.1.

The specific time-series model used to reduce model error because of serial correlation such as periodic or seasonal correlation is called a periodic autoregressive moving average (PARMA) model. The PARMA model within R–QWTREND filters the serial correlation and is available in three model options described further in Vecchia and

Nustad (2020) to adjust for error that vary in model parameter estimates. Outliers are defined within the model parameters of R–QWTREND as an observation with an absolute value of the standardized residual from the trend model that is larger than 3.5 in absolute value (Vecchia and Nustad, 2020). Any data exceeding the outlier range were flagged within the model steps for review and either were removed or corrected in the original dataset used for the trend analysis. All outliers removed from the trend analyses for each site and constituent are documented in table 1.2.

The R–QWTREND program uses Gaussian maximum likelihood estimation to fit the model parameters, chooses the best trend model, and determines the significance levels (probability [*p*]-values) associated with the trends (Vecchia, 2000; Vecchia and Nustad, 2020). For this study, results were compared with all nested model results (null [no trend] and 1-period trend), and statistically significant trends were identified when the probability value (*p*-value) was less than 5 percent ($\alpha = 0.05$). Nested models also can be compared against 2-period trends, but because of the shorter analysis period available for this study, 2-period trend models were not determined as significant compared to the 1-period trend models. Therefore, 2-period trend models were not used. Generalized likelihood ratio tests were used to determine if the 1-period trend model was a significantly better fit than the null-trend model by the computed *p*-value (Vecchia and Nustad, 2020). Example output information from a best-fit model are listed in table 1.1 and are shown in figure 1.2. The magnitude of upward trends and downward trends was expressed as a percentage change in concentration between the beginning and ending years; the annual model-fitted median concentrations for beginning and ending years of the trend period also were reported.

Statistical Procedures

Select constituents were analyzed for significant differences among sites using Tukey's nonparametric, multiple comparison test (Helsel and others, 2020). If sites were not significantly different, meaning the attained significance level, or *p*-value, was greater than 0.05, the sites were noted with the same letter. If left-censored data (reported as less than a method reporting limit) were included in the dataset used, these data were set to one-half the smallest method detection level reported within the study period (Helsel and others, 2020). For calculated parameters such as TN and TON, all censored values were set to the smallest censored value in the dataset. Estimated values were used as the value reported. One outlier was removed for site 6 because all results reported for the sample collected on May 3, 2006, were flagged with value qualifiers, indicating the results were affected by unknown contamination.

Summary statistics were computed for select constituents at the four sites used in the concentration trends analyses (table 1.3). In addition to routine, descriptive statistics such as minimum, maximum, mean, and median values, the number and percentage of censored values within a constituent's observed value dataset also were provided. These summary statistics were necessary for proper model selection and evaluation within R–QWTREND.

Analysis of Load Trends

Annual loads of selected nutrients, dissolved chloride, and suspended sediment for 2006–18 were estimated by the Weighted Regressions on Time, Discharge, and Season-Kalman filter (WRTDS–K) model described in Zhang and Hirsch (2019). The WRTDS–K model was used to estimate loads for all nitrogen and phosphorus compounds and suspended sediment. Research by Lee and others (2019) showed that the WRTDS–K model results in more accurate estimates of annual loads for many constituents than Load Estimator (LOADEST; Runkel and others, 2004). Based on this research, the WRTDS–K model was the first choice for estimating annual nitrogen and phosphorus species, chloride, and suspended-sediment loads (SSLs). The WRTDS–K model, which is an updated version of the Weighted Regressions on Time, Discharge, and Season (WRTDS; Hirsch and De Cicco, 2015) model, accounts for the autocorrelation of residuals using a first-order autoregressive model and provides more accurate estimates of annual loads (Zhang and Hirsch, 2019). Daily mean streamflow and constituent concentrations from the analysis of periodic water-quality samples are input into the WRTDS–K model to estimate daily loads. Daily loads were summed to obtain annual loads. Optimal correlation coefficients for the nitrogen species (0.95), TP (0.875), ortho-P (0.875), chloride (0.90), and suspended sediment (0.90) determined according to Zhang and Hirsch (2019) were used in the WRTDS–K model. Estimated annual loads of TN, TON, ammonia, nitrate plus nitrite, TP, ortho-P, chloride, and suspended sediment computed using WRTDS–K for this report are listed in tables 2.1 and 2.2.

Annual loads of *E. coli* were not computed for this report, because the WRTDS–K model can only estimate mass (in kilograms) and not populations (colonies of *E. coli*). Other modeling tools such as LOADEST also do not have a means for computation of a population density load, as the results are not a mass. Previous single-day load estimations for *E. coli* presented in Bushon and others (2017) were directly computed for a specific sampling date using daily mean flow and mean *E. coli* density. Because samples analyzed for population density of *E. coli* were not collected daily, or even monthly in most of the study period, estimation of annual mean *E. coli* loads with single-sample load computation would not be a valid representation of temporal and spatial changes within *E. coli* population density loads for the study period and, therefore, could be misinterpreted.

Comparisons of Model Estimates

Earlier estimates of annual loads of nitrate plus nitrite, ammonia, TON, TN, TP, chloride and suspended sediment in urban Independence streams used the LOADEST model (Runkel and others, 2004) to estimate annual loads transported in urban streams in Independence (Christensen and others, 2010; Niesen and Christensen, 2015). To provide a comparison to the previous LOADEST model calculations, the dataset used by Niesen and Christensen (2015) also was analyzed using the WRTDS–K model, and a comparison of the two model results for site 8 is shown in figure 6. The difference in the results between these two models using the same datasets at site 8 are summarized in tables 3.1 and 3.2. Although varying from year to year, the mean difference between the annual loads from the LOADEST and WRTDS–K models is less than 20 percent. The annual load estimate from the WRTDS–K model is generally greater than the LOADEST models for the nitrogen and phosphorus species and generally less than the LOADEST model estimate for chloride and suspended sediment (tables 3.1, 3.2). The percentage difference in annual load estimates for the nitrogen species and TP tended to decrease as mean annual streamflow increased. The differences between the LOADEST and WRTDS–K estimated annual chloride loads were unrelated to mean annual streamflow. The SSL estimates from the LOADEST model became substantially greater than from the WRTDS–K model as annual streamflow increased.

Statistical Procedures

Two nonparametric trend tests were used to quantify trends in annual loads in streams in Independence. The Mann-Kendall test was used to determine if the study period had a monotonic trend, and the Wilcoxon rank-sum test (Helsel and others, 2020) was used to understand the significance of differences between constituent load and yield during period 1 (2006–10) and period 2 (2011–18). Nonparametric statistics were used because annual load datasets were small and could not be assumed to be normally distributed.

Land-Use Data

Land-use data for the Independence-area urban watersheds were extracted from the National Land Cover Database (NLCD) satellite imagery database (appendix 4). NLCD data are geographic information system (GIS) coverages with 30-meter pixels classified by land cover largely based on Landsat imagery. NLCD coverages for 2006 and 2016 were used to bracket the study period to document land cover changes in individual watersheds. The boundaries of these watersheds were delineated using the USGS StreamStats web-based watershed mapping tool (Ellis, 2018). NLCD pixels falling within watershed boundary polygons were tallied by land-use category using the GIS software ArcGIS, and total and fractional areas of each land-use category within individual watersheds were calculated from this pixel tabulation. Land use in the NLCD coverage is classified into 20 major land-cover classes. To simplify analysis, similar NLCD classifications were grouped together into 10 categories (appendix 4). In the modified classification used for this report, forest

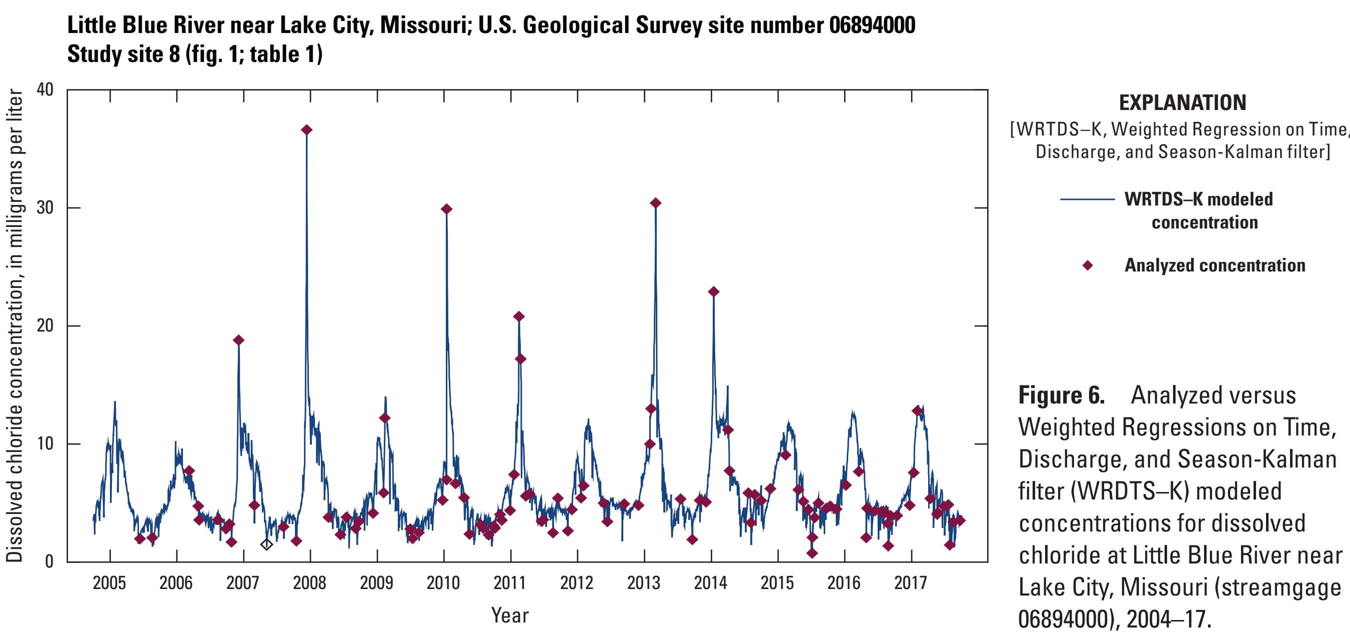


Figure 6. Analyzed versus Weighted Regressions on Time, Discharge, and Season-Kalman filter (WRDTS–K) modeled concentrations for dissolved chloride at Little Blue River near Lake City, Missouri (streamgage 06894000), 2004–17.

includes the deciduous, evergreen, and mixed forest NLCD classifications; grassland includes the shrub/scrub, grassland/herbaceous, and pasture/hay classifications; and wetlands includes woody and emergent herbaceous wetlands. Because the study area contains large amounts of urban areas, all four "developed" categories were retained.

Water-Quality Trends in Concentrations and Loads

Available data collected from January 2006 through December 2018 for 15 water-quality physical properties and constituent concentrations were analyzed for trends at four study sites (sites 1, 2, 3, and 8). Summary statistics used to assist in selection of the best-fit models are available in table 1.3. Statistically significant, flow-weighted concentration trends are presented in table 3 as percentage change and magnitude of change for annual geometric mean and annual flow-weighted mean concentrations for each of the four sites. All available data for 2006–18 (full study period) were used that fit the requirements of the various trend models used in the study. If more than one site had a statistically significant trend for a select constituent, the flow-weighted trend was plotted, and the sites were indicated on a location map.

In addition to using the full period, a fixed period set as 2010–17 was selected to compare trends among the four sites (table 4). Although this period was the longest period of consistent data collection for all four sites, the period does not meet the minimum criteria of 10 years for the R–QWTREND model to predict low-biased trends. Caution, therefore, should be used in interpreting such trends because of the increased risk for error (Vecchia and Nustad, 2020).

Load trends were analyzed to document changes in transport into Independence and transport from urban streams within Independence. The annual load contribution from the Little Blue River within Independence, including its monitored tributaries (sites 3 and 6) was calculated as the difference in annual load at site 8 from the sum of the annual load entering the city at site 2 on the Little Blue River and at site 4 on the East Fork Little Blue River. The annual loads within Independence also included loads flowing directly to the Missouri River from Rock Creek (site 1).

Trends in Physical Properties

Select physical properties analyzed for trends in concentrations during the study period are water temperature, dissolved oxygen, specific conductance, and pH. These physical properties, which are measurements in the field, can assist in the understanding of the current conditions of a stream at the time of sampling. Many constituents are dependent on water temperature and can degrade or react at certain temperatures. Particular fish species also can thrive within certain ranges of water temperature better than other species. Dissolved oxygen is important to aquatic life for survival. Lower concentrations of dissolved oxygen can be an indicator of higher concentrations of suspended particulates and organic material in the stream that can limit light and algal photosynthesis or increase demand for dissolved oxygen through oxidation of reduced organic material. The solubility of dissolved oxygen in water also decreases with increasing temperature. Specific conductance is the measurement of dissolved ions in the water and the ability of dissolved ions to carry an electrical charge or current, at a specified temperature.

The collection of physical properties provided datasets that met the requirements of the model analyses; however, few trends were identified. When trends were investigated for each site within the full period of record as listed in table 3, site 1 had a statistically significant trend in pH (upward, table 3), and site 2 had a statistically significant trend in dissolved oxygen (downward, fig. 7). Site 8 had statistically significant trends in water temperature (upward, table 3), dissolved oxygen (downward, fig. 7), and specific conductance (upward, table 3).

Trends in Nutrient Concentrations and Loads

The nutrients nitrogen and phosphorus are essential for plant and animal nutrition, but if excessive concentrations of nutrients are present in water bodies, the nutrients can cause water-quality concerns such as algal blooms, fish kills, and taste and odor issues in drinking water sources. Nutrient concentrations reflected in TN, TON, total ammonia plus organic nitrogen as nitrogen, nitrate plus nitrite, TP, and ortho-P were analyzed at four sites (sites 1, 2, 3, and 8). Ammonia data did not meet the minimum criteria for model requirements at the four sites because ammonia was not consistently sampled until 2013, but data were included in the summary statistics (table 1.3).

Trends in TN concentrations were investigated using the full period of available data for each site, and results indicated statistically significant downward, single-period trends at all four sites (table 3; fig. 8). The largest percentage change in the annual flow-weighted mean concentration from beginning year to end year was at site 8 with 46.9 percent (table 3). Although sites 1, 2, and 3 had varying lengths of trend periods, each site had consistent changes in annual flow-weighted mean concentrations (about 23–30 percent decrease, table 3) from the beginning to end of the period of data for each site. The TN concentrations were highest at site 1 (table 3), but the downward trend in TN could be a result of infrastructure improvements in the Rock Creek watershed.

Using the full period of data for each site, concentrations of TON had a downward trend at all sites, and all trends were significant except at site 3 (table 3; fig. 9). Site 1 had the largest percentage change in flow-weighted concentration (56.4 percent) during the site's trend period (table 3). The decrease in TON at site 1 could be a result of infrastructure improvements within the Rock Creek watershed. Downstream

Table 3. Summary of trend results based on data collected during 2006–18 for select physical properties and chemical constituents at selected sites having data meeting trend model criteria.

[Bold font indicates statistically significant (p-value less than 0.05) trend results. Shading indicates no results are presented because minimum data requirements were not met or because more than 25 percent of the data were censored, or model error. USGS, U.S. Geological Survey; --, no data available; ME, model error; MRNM, minimum data requirements not met]

Site number (fig. 1)	USGS site number (table 1)	Best-fit trend model	Trend period	Percent change	*p*-value	Trend direction	Annual geometric mean concentration for start year	Annual geometric mean concentration for end year	Annual flow-weighted mean concentration for start year	Annual flow-weighted mean concentration for end year
Water temperature, in degrees Celsius										
1	06893620	Null	2006–18	--	--	--	--	--	--	--
2	06893820	Single period	2010–18	6.8	0.08910	Up	10.7	10.2	19.4	15.1
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	14.6	0.01920	**Up**	9.9	11.2	ME	ME
Dissolved oxygen, in milligrams per liter										
1	06893620	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
2	06893820	**Single period**	2010–18	11.6	0.00020	**Down**	9.8	8.2	9.5	8.5
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	8.3	0.00080	**Down**	9.3	8.7	9.6	8.9
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius										
1	06893620	Null	2006–18	--	--	--	--	--	--	--
2	06893820	Single period	2010–18	8.1	0.10380	Up	471	564	410	516
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	15.2	0.00380	**Up**	453	524	445	458
pH, in standard units										
1	06893620	**Single period**	2006–18	4.0	0.00020	**Up**	7.59	7.91	7.61	7.95
2	06893820	Null	2010–18	--	--	--	--	--	--	--
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	Null	2006–18	--	--	--	--	--	--	--
Total nitrogen, in milligrams per liter										
1	06893620	**Single period**	2006–18	29.8	0.00160	**Down**	2.41	1.56	3.54	2.79
2	06893820	**Single period**	2010–18	28.5	0.00160	**Down**	0.81	0.79	2.68	2.20
3	06893830	**Single period**	2009–17	23.2	0.01790	**Down**	0.861	0.737	1.10	1.02
8	06894000	**Single period**	2006–18	46.9	0.00004	**Down**	1.15	0.67	2.01	2.26

Table 3. Summary of trend results based on data collected during 2006–18 for select physical properties and chemical constituents at selected sites having data meeting trend model criteria.—Continued

[Bold font indicates statistically significant (p-value less than 0.05) trend results. Shading indicates no results are presented because minimum data requirements were not met or because more than 25 percent of the data were censored, or model error. USGS, U.S. Geological Survey; --, no data available; ME, model error; MRNM, minimum data requirements not met]

Site number (fig. 1)	USGS site number (table 1)	Best-fit trend model	Trend period	Percent change	*p*-value	Trend direction	Annual geometric mean concentration for start year	Annual geometric mean concentration for end year	Annual flow-weighted mean concentration for start year	Annual flow-weighted mean concentration for end year
Total organic nitrogen, in milligrams per liter										
1	06893620	**Single period**	2006–18	56.4	0.00190	**Down**	0.529	0.243	1.96	1.68
2	06893820	**Single period**	2010–18	36.1	0.00070	**Down**	0.526	0.391	2.47	1.51
3	06893830	Single period	2009–17	18.5	0.10600	Down	0.479	0.460	0.690	0.563
8	06894000	**Single period**	2006–18	52.6	0.00009	**Down**	0.523	0.324	1.07	1.34
Dissolved ammonia as nitrogen, in milligrams per liter										
1	06893620	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
2	06893820	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
3	06893830	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
8	06894000	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
Total ammonia plus organic nitrogen as nitrogen, in milligrams per liter										
1	06893620	**Single period**	2006–18	46.3	0.00200	**Down**	0.72	0.373	2.60	2.62
2	06893820	**Single period**	2010–18	33.1	0.00030	**Down**	0.65	0.537	3.95	1.71
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	Null	2006–18	--	--	--	--	--	--	--
Dissolved nitrate plus nitrite as nitrogen, in milligrams per liter										
1	06893620	Null	2006–18	--	--	--	--	--	--	--
2	06893820	Null	2010–18	--	--	--	--	--	--	--
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	33.9	0.01550	**Down**	0.349	0.224	0.479	0.356
Total phosphorus, in milligrams per liter										
1	06893620	**Single period**	2006–18	34.3	0.01490	**Down**	0.279	0.175	0.728	0.743
2	06893820	Null	2010–18	--	--	--	--	--	--	--
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	49.6	0.00120	**Down**	0.137	0.089	0.393	0.786

Table 3. Summary of trend results based on data collected during 2006–18 for select physical properties and chemical constituents at selected sites having data meeting trend model criteria.—Continued

[Bold font indicates statistically significant (p-value less than 0.05) trend results. Shading indicates no results are presented because minimum data requirements were not met or because more than 25 percent of the data were censored, or model error. USGS, U.S. Geological Survey; --, no data available; ME, model error; MRNM, minimum data requirements not met]

Site number (fig. 1)	USGS site number (table 1)	Best-fit trend model	Trend period	Percent change	*p*-value	Trend direction	Annual geometric mean concentration for start year	Annual geometric mean concentration for end year	Annual flow-weighted mean concentration for start year	Annual flow-weighted mean concentration for end year
Dissolved orthophosphate as phosphorus, in milligrams per liter										
1	06893620	**Single period**	2006–18	15.3	0.00790	**Up**	0.088	0.100	0.102	0.121
2	06893820	**Single period**	2010–18	79.1	0.00050	**Up**	0.016	0.038	0.209	0.642
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	Single period	2006–18	18.1	0.07360	Down	0.041	0.032	0.075	0.081
Dissolved chloride, in milligrams per liter										
1	06893620	**Null**	2006–18	--	--	--	--	--	--	--
2	06893820	Null	2010–18	--	--	--	--	--	--	--
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	41.1	0.00010	**Up**	46.1	56.7	46.8	46.6
Escherichia coli, in colony forming units per 100 milliliters										
1	06893620	**Single period**	2006–18	66.4	0.01040	**Down**	940	380	316,000	1,600,000
2	06893820	Null	2010–18	--	--	--	--	--	--	--
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	88.3	0.00009	**Down**	230	60	16,400	20,400
Total coliform, in colony forming units per 100 milliliters										
1	06893620	Null	2006–18	--	--	--	--	--	--	--
2	06893820	Null	2010–18	--	--	--	--	--	--	--
3	06893830	Single period	2009–17	91.2	0.19660	Up	2,600	10,700	52,000	280,000
8	06894000	Null	2006–18	--	--	--	--	--	--	--
Total dissolved solids, in milligrams per liter										
1	06893620	Null	2006–18	--	--	--	--	--	--	--
2	06893820	Null	2010–18	--	--	--	--	--	--	--
3	06893830	Null	2009–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2006–18	19.0	0.00090	**Up**	294	323	293	275
Suspended-sediment concentration, in milligrams per liter										
1	06893620	Null	2006–18	--	--	--	--	--	--	--
2	06893820	**Single period**	2010–18	63.1	0.00210	**Down**	72.3	24	808	155
3	06893830	Single period	2009–17	19.4	0.33450	Down	41.3	28.5	121.0	51.7
8	06894000	Null	2006–18	--	--	--	--	--	--	--

Table 4. Summary of trend results based on a fixed period during 2010–17 for select physical properties and chemical constituents at selected sites having data meeting trend model criteria.

[Bold font indicates statistically significant (p-value less than 0.05) trend results. Shading indicates no results are presented because minimum data requirements were not met or because more than 25 percent of the data were censored, or model error. USGS, U.S. Geological Survey; --, no data available; ME, model error; MRNM, minimum data requirements not met]

Site number (fig. 1)	USGS site number (table 1)	Best-fit trend model	Trend period	Percent change	*p*-value	Trend direction	Annual geometric mean concentration for start year	Annual geometric mean concentration for end year	Annual flow-weighted mean concentration for start year	Annual flow-weighted mean concentration for end year
				Water temperature, in degrees Celsius						
1	06893620	Single period	2010–17	37.1	0.0395	Up	8.1	10.8	14.2	23.5
2	06893820	**Single period**	2010–17	11.4	0.0249	**Up**	10.1	10.3	ME	ME
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--
				Dissolved oxygen, in milligrams per liter						
1	06893620	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
2	06893820	**Single period**	2010–17	12.0	0.0003	**Down**	9.8	8.4	9.9	8.1
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--
				Specific conductance, in microsiemens per centimeter at 25 degrees Celsius						
1	06893620	Null	2010–17	--	--	--	--	--	--	--
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Single period	2010–17	3.18	0.3671	Up	499	511	461	381
				pH, in standard units						
1	06893620	ME	ME	ME	ME	ME	ME	ME	ME	ME
2	06893820	**Single period**	2010–17	1.3	0.0009	**Up**	7.8	7.9	7.8	7.9
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--
				Total nitrogen, in milligrams per liter						
1	06893620	Single period	2010–17	15.4	0.0813	Down	1.620	1.770	2.610	5.020
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Single period	2010–17	5.8	0.5109	Up	0.711	0.739	0.961	1.043
8	06894000	**Single period**	2010–17	21.9	0.0278	**Down**	1.066	0.761	2.196	1.575

Table 4. Summary of trend results based on a fixed period during 2010–17 for select physical properties and chemical constituents at selected sites having data meeting trend model criteria.—Continued

[Bold font indicates statistically significant (p-value less than 0.05) trend results. Shading indicates no results are presented because minimum data requirements were not met or because more than 25 percent of the data were censored, or model error. USGS, U.S. Geological Survey; --, no data available; ME, model error; MRNM, minimum data requirements not met]

Site number (fig. 1)	USGS site number (table 1)	Best-fit trend model	Trend period	Percent change	*p*-value	Trend direction	Annual geometric mean concentration for start year	Annual geometric mean concentration for end year	Annual flow-weighted mean concentration for start year	Annual flow-weighted mean concentration for end year
Total organic nitrogen, in milligrams per liter										
1	06893620	Null	2010–17	--	--	--	--	--	--	--
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2010–17	35.1	**0.0127**	Down	0.686	0.344	2.283	1.726
Dissolved ammonia as nitrogen, in milligrams per liter										
1	06893620	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
2	06893820	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
3	06893830	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
8	06894000	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM	MRNM
Total ammonia plus organic nitrogen as nitrogen, in milligrams per liter										
1	06893620	Null	2010–17	--	--	--	--	--	--	--
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--
Dissolved nitrate plus nitrite as nitrogen, in milligrams per liter										
1	06893620	Single period	2010–17	8.4	0.2310	Down	0.938	0.868	0.900	0.830
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	**Single period**	2010–17	45.8	0.0442	Up	0.155	0.136	0.351	0.268
8	06894000	Single period	2010–17	8.6	0.3639	Down	0.290	0.210	0.419	0.282
Total phosphorus, in milligrams per liter										
1	06893620	Single period	2010–17	28	0.1882	Up	0.110	0.216	0.289	0.776
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--

Table 4. Summary of trend results based on a fixed period during 2010–17 for select physical properties and chemical constituents at selected sites having data meeting trend model criteria.—Continued

[Bold font indicates statistically significant (p-value less than 0.05) trend results. Shading indicates no results are presented because minimum data requirements were not met or because more than 25 percent of the data were censored, or model error. USGS, U.S. Geological Survey; --, no data available; ME, model error; MRNM, minimum data requirements not met]

Site number (fig. 1)	USGS site number (table 1)	Best-fit trend model	Trend period	Percent change	*p*-value	Trend direction	Annual geometric mean concentration for start year	Annual geometric mean concentration for end year	Annual flow-weighted mean concentration for start year	Annual flow-weighted mean concentration for end year
Dissolved orthophosphate as phosphorus, in milligrams per liter										
1	06893620	Null	2010–17	--	--	--	--	--	--	--
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--
Dissolved chloride, in milligrams per liter										
1	06893620	Null	2010–17	--	--	--	--	--	--	--
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--
Escherichia coli, in colony forming units per 100 milliliters										
1	06893620	Null	2010–17	--	--	--	--	--	--	--
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	**Single period**	2010–17	**76**	**0.0010**	**Down**	479	70	186,000	13,400
Total coliform, in colony forming units per 100 milliliters										
1	06893620	Null	2010–17	--	--	--	--	--	--	--
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Single period	2010–17	38.4	0.3262	Up	8,200	11,300	7,000,000	4,000,000
8	06894000	Null	2010–17	--	--	--	--	--	--	--
Total dissolved solids, in milligrams per liter										
1	06893620	Single period	2010–17	15.4	0.2254	Up	424	401	362	276
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--
Suspended-sediment concentration, in milligrams per liter										
1	06893620	Single period	2010–17	71.1	0.0600	Up	91	121	488	2,300
2	06893820	Null	2010–17	--	--	--	--	--	--	--
3	06893830	Null	2010–17	--	--	--	--	--	--	--
8	06894000	Null	2010–17	--	--	--	--	--	--	--

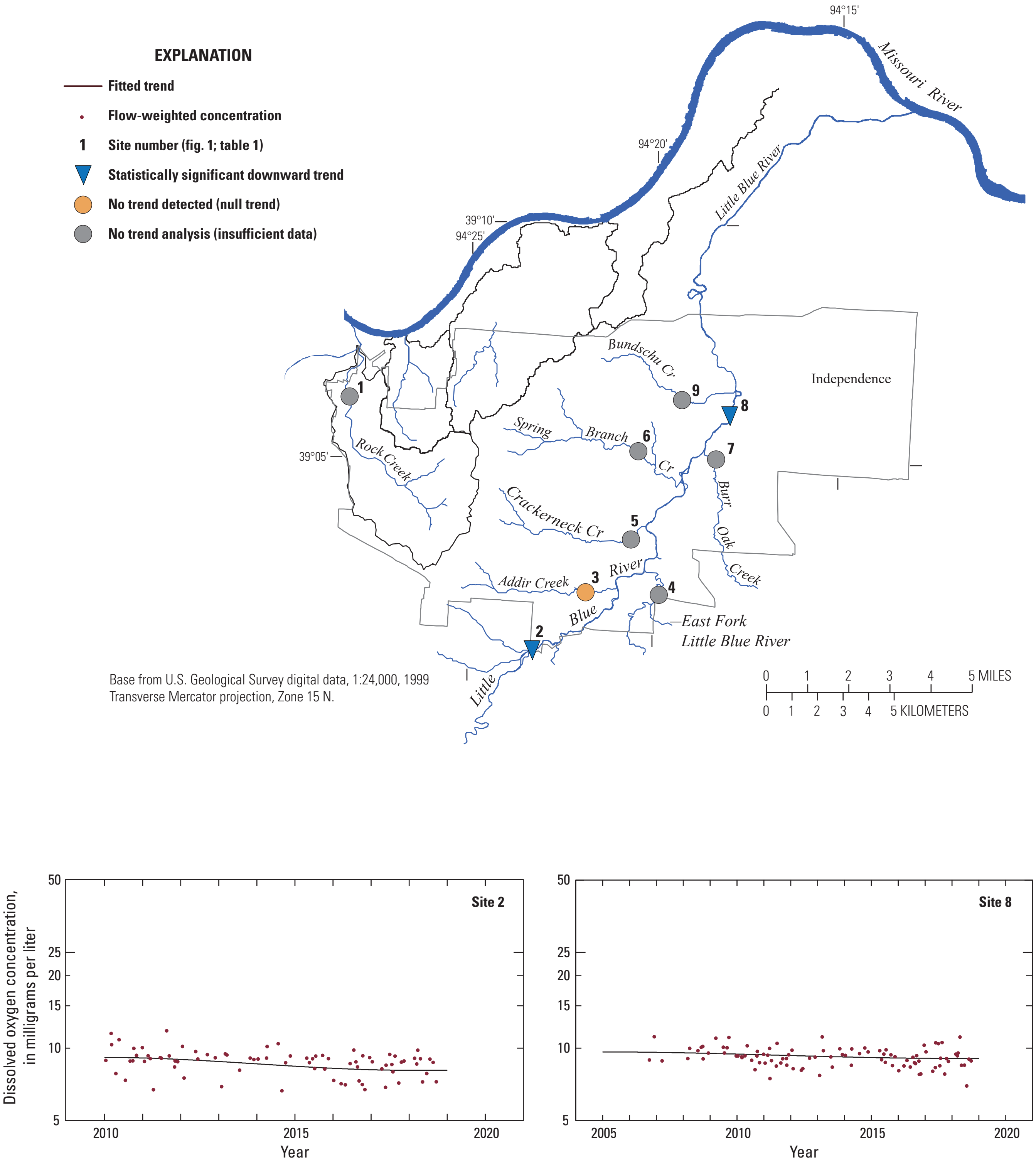


Figure 7. Location map and graphs of sites with statistically significant trends in flow-weighted dissolved oxygen concentrations from 2006 through 2018.

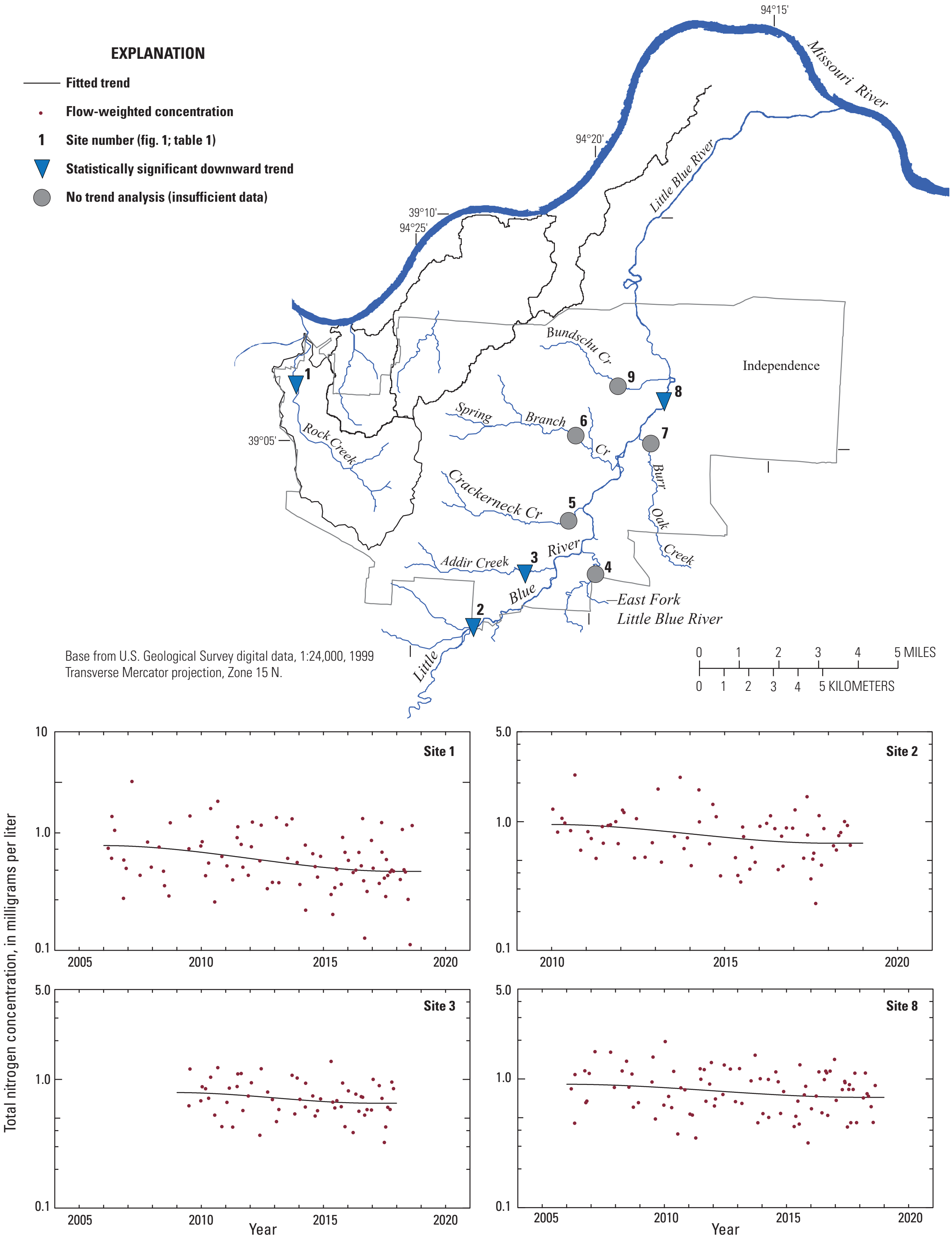


Figure 8. Location map and graphs of sites with statistically significant trends in flow-weighted total nitrogen concentrations from 2006 through 2018.

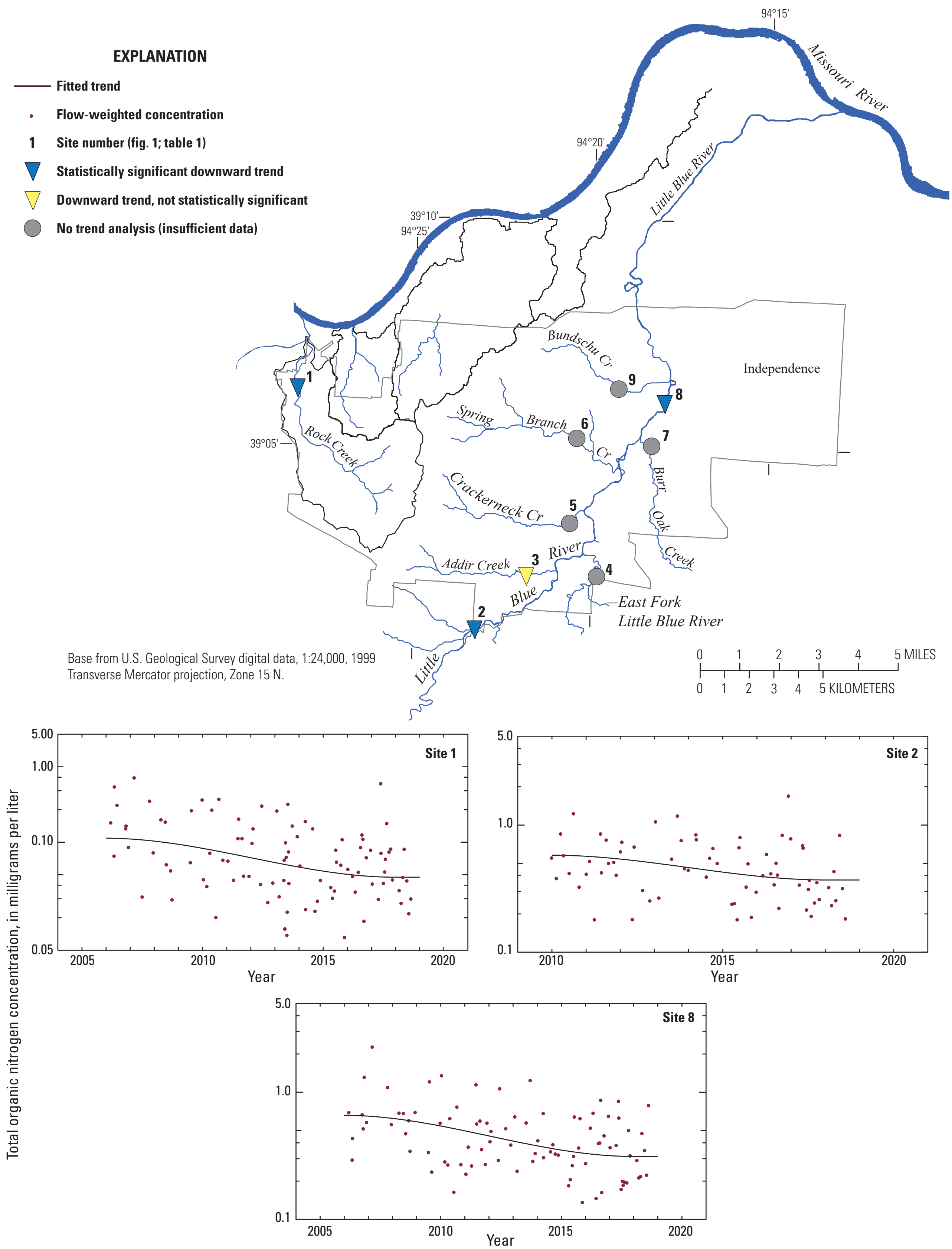


Figure 9. Location map and graphs of sites with statistically significant trends in flow-weighted total organic nitrogen concentrations from 2006 through 2018.

downward trends were noted on the Little Blue River for sites 2 and 8, with the larger decrease observed in the downstream site 8 (fig. 9).

The remainder of nutrient constituents investigated for trend analyses had fewer statistically significant trends. Downward trends were identified at sites 1 and 2 for total ammonia plus organic nitrogen as nitrogen (fig. 10). Only one statistically significant trend was identified in flow-weighted nitrate plus nitrite concentrations at site 8 (table 3). The TP concentrations showed statistically significant downward trends at sites 1 and 8 (fig. 11), but flow-weighted, annual concentrations increased from first year to the end year in the analysis period (table 3). The increase in flow-weighted concentrations may be a result of a change in sampling from the beginning of the study, which targeted stormflow conditions, to a more consistent and hydrologically dynamic sampling program implemented in 2015.

The only nutrient constituent with an upward trend was flow-weighted ortho-P concentrations at sites 1 and 2 (fig. 12). Ortho-P is commonly detected in fertilizers, residential detergents, and organic waste in sewage and effluent (U.S. Environmental Protection Agency, 2019). Of the various forms of phosphorus, ortho-P is more readily available for biological consumption. The percentage change of annual flow-weighted mean ortho-P concentrations was smaller at site 1 (15.3 percent) than at site 2 (79.1 percent; table 3). The cause of increased flow-weighted ortho-P concentrations at these sites is not apparent. The upstream area has had some land-use change during the study period, with slight increases (1 percent or less) in developed low-, medium-, and high-intensity land use from 2006 through 2016 (table 2). The greatest difference in land-use changes upstream from the MS4 (site 2) was cultivated croplands, which decreased by about 50 percent, and forest land, which increased by 3.4 percent from 2006 through 2016 (table 2).

A study performed in urban watersheds of St. Paul, Minnesota (not shown; Hobbie and others, 2017), determined that excess nitrogen and phosphorus inputs to watersheds were from residential sources but occurred in different ways. The study indicates nitrogen concentrations in surface waters were reduced by intake from the atmosphere and increased contamination in groundwater, and increased phosphorus concentrations were transported from impervious surfaces and storm drains to surface waters. Results from this study indicated that in urban areas across the Nation, consistent sources of nutrients were predominantly from residential lawn fertilizers, yard waste (grass clippings and leaf litter), and pet waste. The upward trend in flow-weighted ortho-P concentrations at site 2 could be attributed to residential practices similarly described in the St. Paul study, particularly in the areas with increased residential development, as well as the increase in forested areas upstream from Independence.

Significant downward trends were identified in flow-weighted TN and TON concentrations at site 8 within the full (2006–18) period (table 3) and the fixed (2010–17) period (table 4). Although the results from the fixed period warrant using with caution because of the datasets not meeting the minimum criteria for the model, analysis of the fixed period allowed for trend comparison within more of the latter part of the study when samples were collected representing a greater range in streamflow conditions and seasons. The significant downward flow-weighted trends in the full period of available data and the fixed period at site 8 may indicate that downward trends are not necessarily a result of an environmental change such as land use, precipitation, or streamflow, but perhaps indicate the effect from changes in sampling methodology during the study. The consistent downward trends in the full period of available data and the fixed period also may be indicative of improved wastewater and stormwater management practices within the MS4 boundaries.

Annual loads of nitrogen species were computed for TN, TON, ammonia, and nitrate plus nitrite, of which only ammonia had a statistically significant trend (table 5). Results indicated a small nonstatistically significant decrease in the annual TN load transported from the Little Blue River and its tributaries from 2006 through 2018 (tables 2.1, 2.2). During the full study period, the small downward trend in annual TN loads was correlated with annual streamflow and was generally not a monotonic trend, but rather a step trend from the wetter first period (2006–10) to the drier second period (2011–18).

The annual TN load transported in the Little Blue River within Independence, Missouri (downstream from sites 2 and 4 and upstream from site 8), was about 109,100 kilograms (kg; table 6). The annual TN load transported from Independence at site 1 was about 42,300 kg (table 7). A large part of the nitrogen in the Little Blue River (72 percent) and in Rock Creek (69 percent) transported from within Independence was in the form of TON (tables 6, 7). Ammonia made up the smallest part of the TN load transported from Independence in the Little Blue River (0.6 percent) and Rock Creek (about 2 percent). The Little Blue River within Independence contributed a mean of 43 percent of the TN, 41 percent of the TON, 34 percent of the nitrate plus nitrite, and 15 percent of the ammonia load identified at site 8 (table 6). The TN load at sites 1, 2, 3, 6, and 8 decreased from period 1 (2006–10) to period 2 (2011–18) for all nitrogen species except ammonia at site 3 (table 7).

In contrast to the TN, nitrate plus nitrite and TON loads remained relatively constant, and ammonia loads transported from the Little Blue River Watershed at site 8 decreased significantly through the 2006–18 study period (table 5, fig. 13). The ammonia loads decreased about 7 percent per year. Although there was a significant decreasing linear trend, the significantly smaller loads during the drier 2011–18 period (fig. 13) affected the overall 2006–18 trend in ammonia load, and the overall trend could be reduced to a step trend (p-value of 0.04, Wilcoxon rank-sum test) between the first (2006–10) and second (2011–18) study periods. The downward trend in ammonia loads was due to smaller amounts of ammonia originating from within Independence as the ammonia load entering Independence at site 2 and site 4 remained constant. The

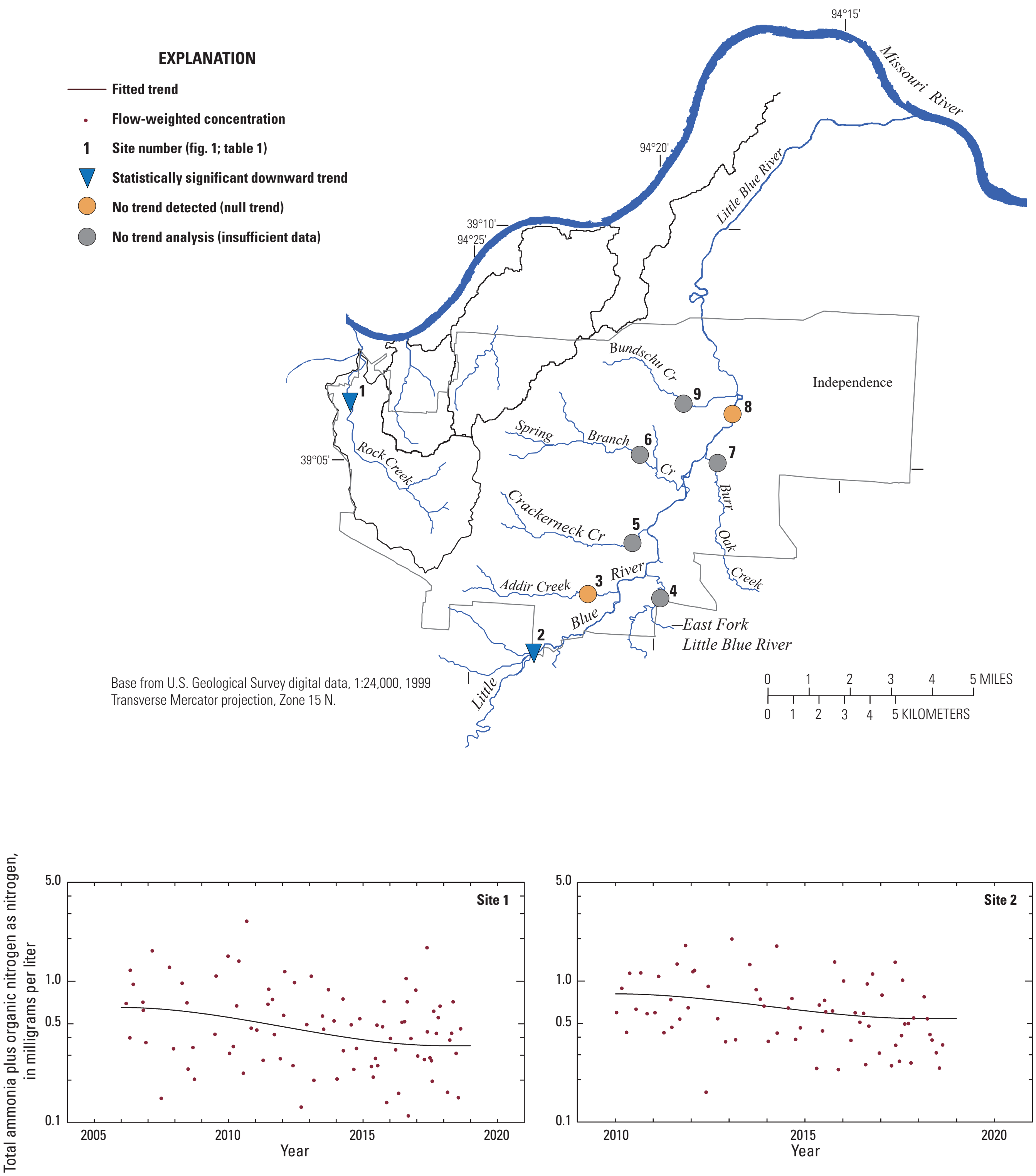


Figure 10. Location map and graphs of sites with statistically significant trends in flow-weighted total ammonia plus organic nitrogen as nitrogen concentrations from 2006 through 2018.

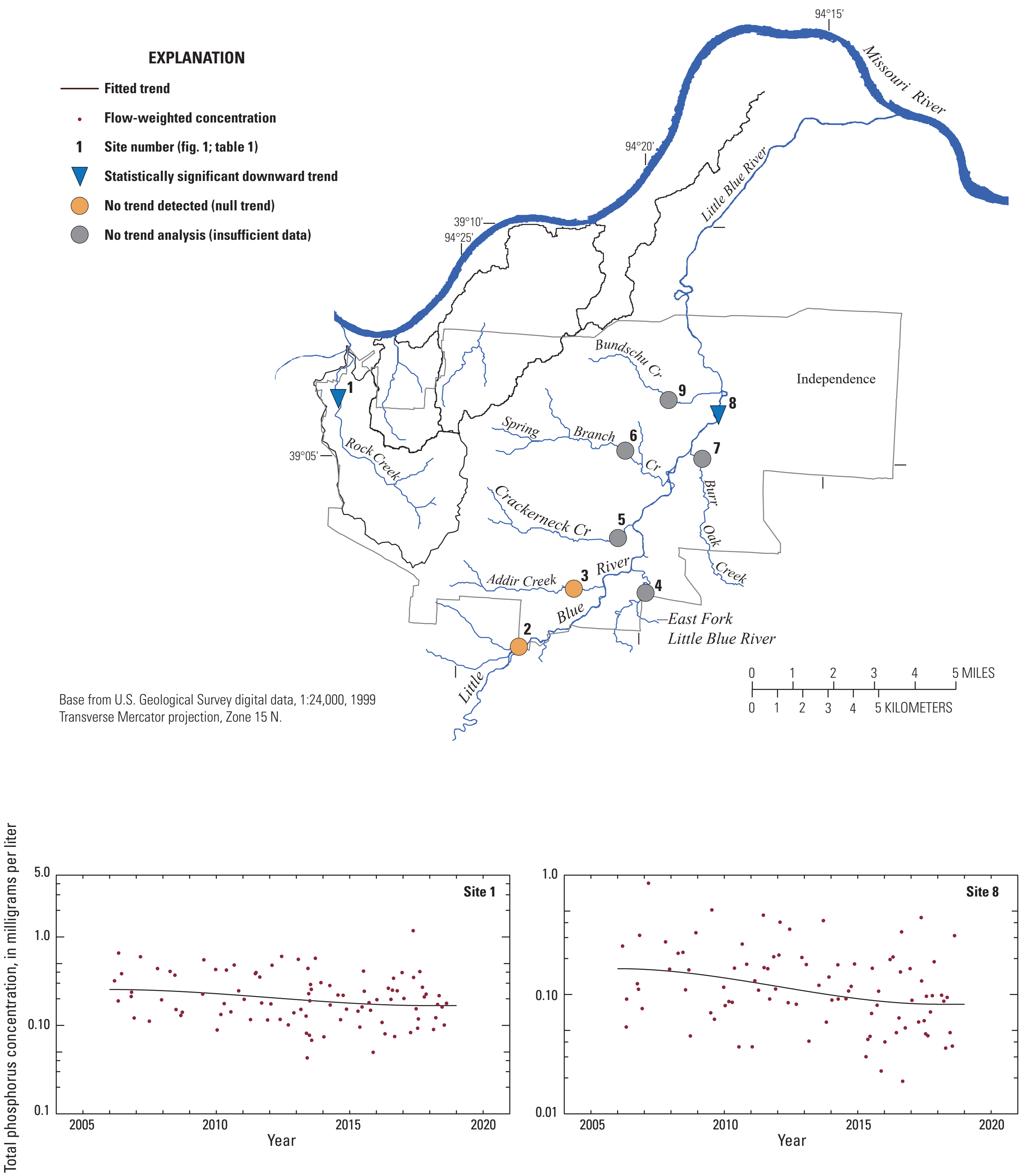


Figure 11. Location map and graphs of sites with statistically significant trends in flow-weighted total phosphorus concentrations from 2006 through 2018.

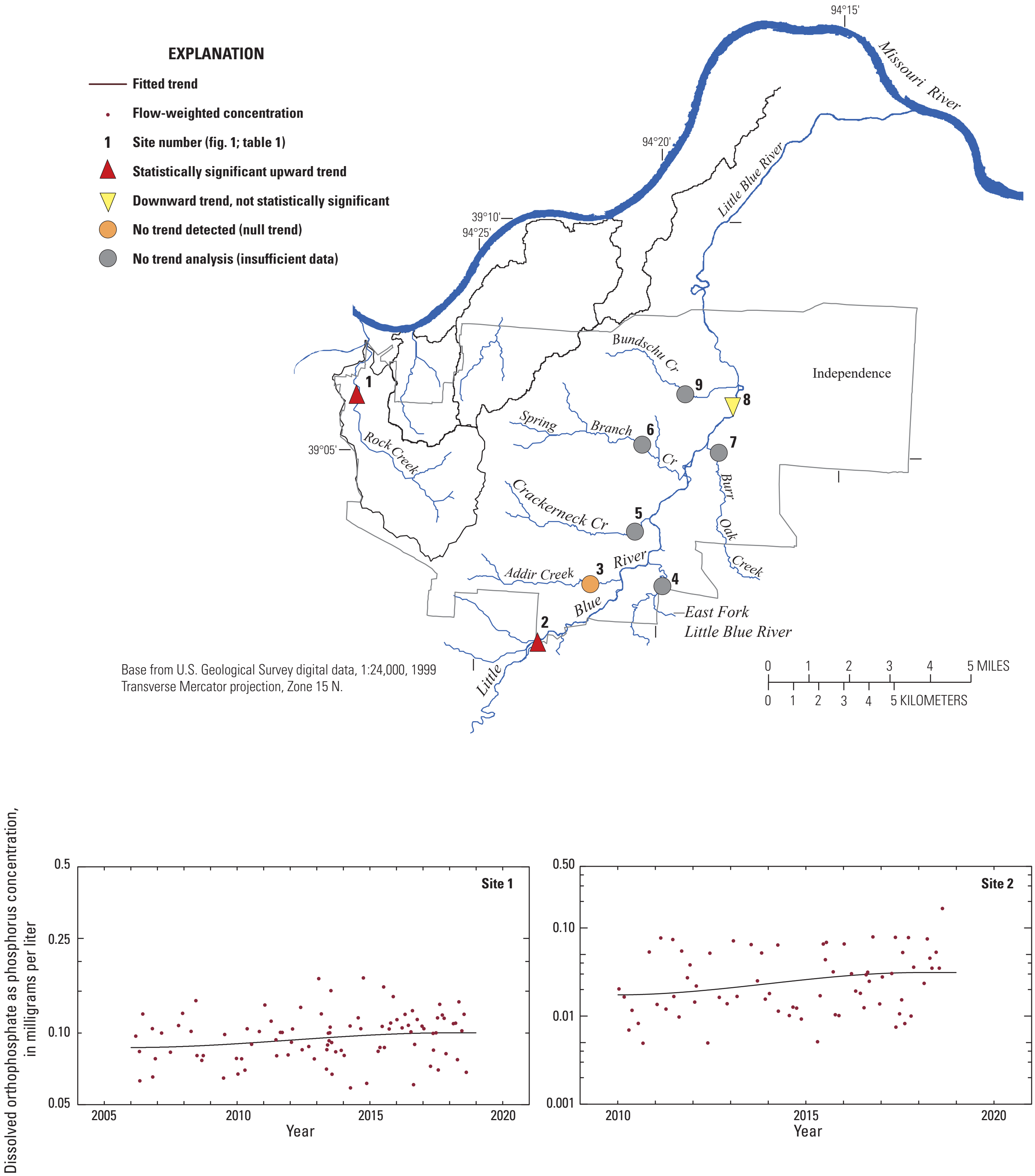


Figure 12. Location map and graphs of sites with statistically significant trends in dissolved ortho-phosphate as phosphorus concentrations from 2006 through 2018.

Table 5. Trends in loads for selected water-quality constituents transported in urban streams in Independence, Missouri.

[Statistically significant trend shown as “L” linear or “S” step trend. Direction of trend shown as (+) upward trend or (-) downward trend; N, nitrogen; P, phosphorus; --, no trend identified; USGS, U.S. Geological Survey.]

Site number (fig. 1)	Watershed	Period of trend	Streamflow	Total nitrogen	Total organic nitrogen	Dissolved ammonia as N	Dissolved nitrate plus nitrite as N	Dissolved ortho-phosphate as P	Total phosphorus	Dissolved chloride	Suspended sediment
Watersheds upstream from Independence											
2	Little Blue River	2010–18	--	--	--	--	--	--	--	--	--
4	East Fork Little Blue River	2010–18	--	--	--	--	--	--	--	--	--
Watersheds draining Independence											
1	Rock Creek	2006–18	--	--	--	--	--	--	--	--	--
3	Adair Creek	2009–17	--	--	--	--	--	(+)L	--	(-)L,S	--
6	Spring Branch Creek	2006–18	--	--	--	--	--	--	--	(-)L,S	--
Little Blue River near Lake City, Missouri (USGS site number 06894000; downstream from sampled watersheds draining Independence)											
8	Little Blue River	2006–18	--	--	--	(-)L,S	--	--	--	--	--

Table 6. Mean annual nitrogen load and yield at selected sites in the Little Blue River watershed, 2011–18.

[mm/day, millimeter per day; m^3/s, cubic meter per second; hec, hectare; kg, kilogram; kg/hec, kilogram per hectare; --, no data available]

Runoff (mm/day)	Streamflow (m^3/s)	Drainage area (hec)	Total nitrogen		Total organic nitrogen		Dissolved ammonia, as N		Dissolved nitrate plus nitrite, as N	
			Load (kg)	Yield (kg/hec)	Load (kg)	Yield (kg/hec)	Load (kg)	Yield (kg/hec)	Load (kg)	Yield (kg/hec)
Little Blue River at Lee's Summit Road in Independence, Missouri (site 2; fig. 1)										
0.72	2.13	25,434	125,381	4.93	97,847	3.85	3,005	0.12	27,970	1.10
East Fork Little Blue River near Blue Springs, Missouri (site 4; fig. 1)										
0.64	0.66	8,910	17,789	2.00	15,630	1.75	955	0.11	2,825	0.32
Little Blue River within Independence, Missouri[1]										
0.72	1.17	13,313	109,106	8.20	78,218	5.88	675	0.05	16,156	1.21
Little Blue River near Lake City, Missouri (site 8; fig.1)										
0.72	3.97	47,656	252,276	5.29	191,696	4.02	4,634	0.10	46,951	0.99

[1]The Little Blue River within Independence is the area downstream from sites 2 and 4 and upstream from site 8 (fig. 1).

Table 7. Mean annual loads in urban streams in Independence, Missouri, for two hydrologic periods.

[Period 1 is during 2006–10. Period 2 is during 2011–18. Constituent loads are in kilograms. m^3/s, cubic meter per second; N, nitrogen; P, phosphorus; --, no data available]

Period	Number of years	Streamflow (m^3/s)	Total nitrogen	Total organic nitrogen	Dissolved ammonia, as N	Dissolved nitrate plus nitrite, as N	Total phosphorus	Dissolved orthophosphate, as P	Dissolved chloride	Suspended sediment
Rock Creek at Kentucky Road in Independence, Missouri (site 1; fig. 1)										
1	5	0.209	27,440	22,227	738	5,397	7,009	705	304,787	6,410,711
2	8	0.154	14,852	10,245	323	3,996	4,085	589	201,370	3,735,928
Little Blue River at Lee's Summit Road in Independence, Missouri (site 2; fig. 1)										
1	1	4.81	377,969	430,064	3,828	64,105	121,154	5,570	6,744,349	--
2	8	2.13	125,381	97,847	3,005	27,970	36,669	4,515	3,115,744	32,304,822
Adair Creek at Independence, Missouri (site 3; fig. 1)										
1	2	0.210	7,325	5,167	292	1,536	1,235	88	830,262	803,372
2	8	0.448	5,957	4,405	504	1,167	1,040	180	443,704	565,679
East Fork Little Blue River near Blue Springs, Missouri (site 4; fig. 1)										
1	0	--	--	--	--	--	--	--	--	--
2	8	0.659	17,789	15,630	955	2,825	3,234	160	937,635	1,210,236
Spring Branch Creek at Holke Road in Independence, Missouri[1] (site 6; fig. 1)										
1	5	0.263	30,343	26,495	502	4,821	12,209	796	707,521	15,807,745
2	8	0.174	17,078	11,609	337	3,359	5,944	608	361,849	6,940,399
Little Blue River near Lake City, Missouri (site 8; fig. 1)										
1	5	5.90	560,305	507,781	12,885	89,596	240,019	11,906	8,142,037	82,167,557
2	8	3.97	252,276	191,696	4,634	46,951	93,364	7,568	6,194,957	55,716,374

[1]Spring Branch Creek streamgage moved downstream approximately 1,500 feet to Missouri State Highway 78 bridge on August 15, 2007, because of sedimentation at the original location on Holke Road.

ammonia reduction within Independence occurred in Spring Branch Creek (table 2.1) and potentially in other unmonitored urban streams.

As with nitrogen, there were small but nonstatistically significant decreases in the loads of TP and ortho-P transported from the Little Blue River and its tributaries from 2006 through 2018. The downward trends were caused by reduced streamflow from period 1 to period 2 that are reflected in larger period-1 mean annual loads compared to period-2 mean annual loads (table 7). The annual TP loads at site 6 and site 3, streams draining the city, also generally decreased in relation to annual streamflow, but the trends were not statistically significant. An exception to the overall downward trends in phosphorus transport was a significant upward linear trend in annual ortho-P load at site 3 on Adair Creek (table 5). The annual ortho-P load from Adair Creek increased from less than 100 kg in 2009 to more than 200 kg in 2017 (table 2.2). Overall, TP transported to the Little Blue River from the city of Independence constituted about 57 percent of the annual TP load at downstream site 8 during the 2011–18 period. The ortho-P load originating from Independence is only 19 percent of the ortho-P load at site 8. An additional 6,800 kg of TP, of which 652 kg is ortho-P, is transported annually from site 1.

Trends in Chloride and Total Dissolved Solids Concentrations and Loads

Of the major ions collected as part of the MS4 permit requirements, dissolved chloride had the largest dataset and fit the minimum criteria for using R–QWTREND for determining trends in the concentrations. Chloride can come from various sources such as salts (applied to roadways during the winter for snow and ice removal), water treatments (water softeners), sewage, and fertilizers (Kelly and others, 2010).When trends were investigated by using the full period of available record for each site, a null or no trend was identified at three sites, and only site 8 had a significant trend (table 3). The trend at site 8 was upward, with a 41.1 percent increase in annual flow-weighted mean concentrations from 2006 through 2018 (table 3). Land-use changes (table 2) indicate small increases (about 1 percent or less) in developed low-, medium-, and high-intensity at site 8; however, increased road salt application near the site during the winter could have resulted in higher concentrated runoff during wet weather conditions.

The TDS concentrations were analyzed at sites 1, 2, 3, and 8 to identify if more trends were present in major ions that may not have had a large enough dataset to analyze individually. Significant trends in major ions can be from naturally occurring events but also can be effects of urbanization. When each site was analyzed by using the full period of available data, a significant upward TDS trend—similar to chloride—was indicated at site 8, with an increase in annual flow-weighted mean concentration of 19 percent (table 3).

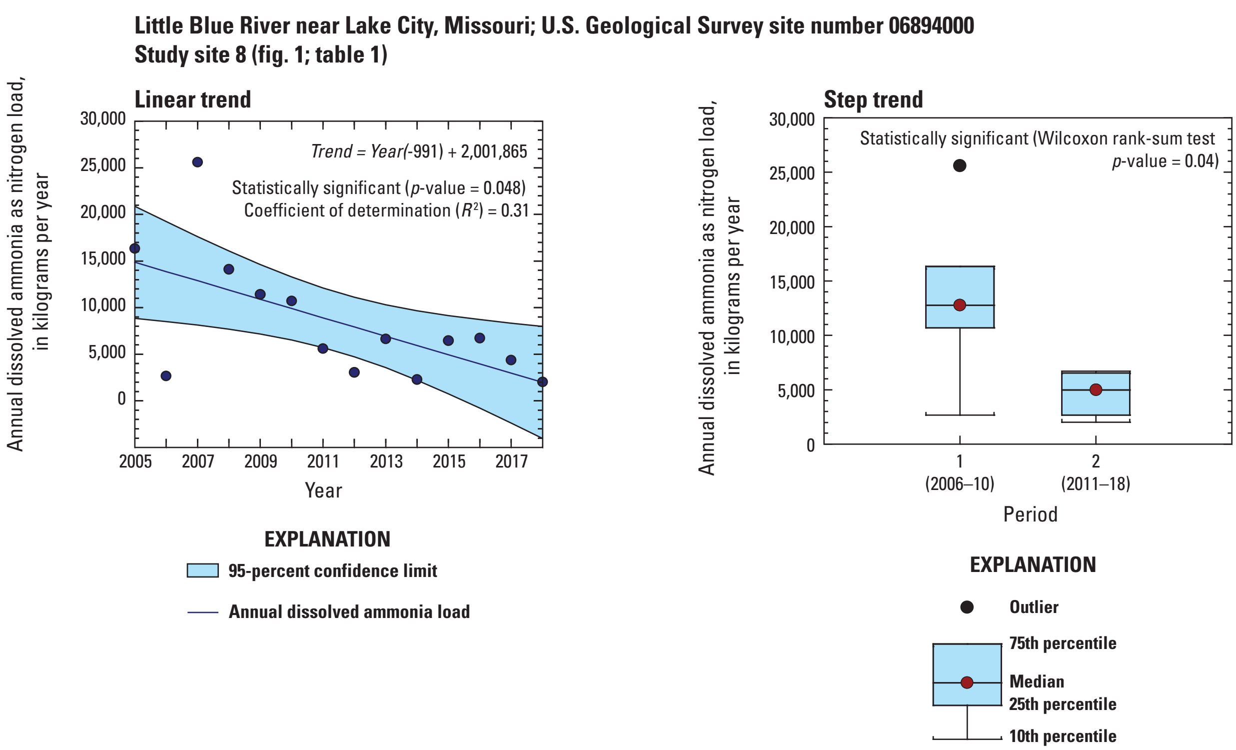


Figure 13. Significant trends in annual dissolved ammonia loads at the Little Blue River near Lake City, Missouri, 2006–18.

No statistically significant change was indicated in the annual chloride load transported from the Little Blue River during the 2006–18 study period (table 5). However, with the exception of a dry 2006, annual chloride loads at the downstream Little Blue River site (site 8) were greater than 6,000,000 kg during the first 5 years of the study and decreased to less than 4,000,000 kg by the end of the study period (table 2.2). Annual chloride loads transported by Adair Creek (site 3) and Spring Branch Creek (site 6) significantly (*p*-value greater than 0.05) decreased during the period that chloride loads were monitored (table 5). The mean chloride load at sites 3 and 6 decreased by nearly half from the wetter period 1 to the drier period 2 (table 7). Annual chloride loads at site 6 significantly (*p*-value greater than 0.05) decreased from 929,763 kg in 2007 to 166,184 kg in 2018 (table 2.2). Although there was a significant linear decrease at site 6, the mean chloride load transported in the drier (2011–18) period 2 was significantly (*p*-value greater than 0.05, Wilcoxon rank-sum test) less than the chloride load transported during the wetter (2006–11) period 1 (table 7). These values indicate that trends in precipitation runoff are important factors in trends in annual transport of chloride from two of Independence's urban watersheds. For the study period, samples were collected primarily during the recreational period (April through October) until 2014; limited data were available during the winter (November through February) when road salt application typically occurs.

A small decrease in chloride loads also was indicated on Rock Creek (site 1), which transported chloride originating from Independence directly to the Missouri River (table 7). The annual mean chloride load at site 1 decreased about 34 percent from period 1 to period 2 (table 7), but the decrease was not statistically significant (table 5).

Trends in Fecal Indicator Bacteria Population Density

The FIB, such as *E. coli* and total coliform, are bacteria found in the intestines of warm-blooded animals and humans and can contain disease-causing organisms. These bacteria are measured to indicate the possible human-health risks of fecal contamination in urban and rural streams. Some urban and rural sources of FIB contamination include sewage overflows from older or failing infrastructure during heavy rainfall; improper connections between storm and sanitary sewer systems; leaking sanitary sewer lines and septic systems; and more traditional nonpoint sources such as livestock, domestic animals, wildlife, and biosolid spreading as fertilizer on agricultural land (Bushon and others, 2017). In urban areas during rainfall, bacteria density can increase in surface waters through runoff from impervious surfaces such as parking lots, roads, and roofs (Mallin and others, 2000). Increases in FIB densities during storm events can be indicative of stormwater runoff processes delivering contaminants from urban and rural sources. During the study period, FIB have been analyzed extensively by various methods. The Little Blue River and some of its tributaries upstream from and within Independence have been listed by the Missouri Department of Natural Resources (2018) as impaired for *E. coli* contamination from urban runoff and sewer sources. Characterization of the fecal contamination was identified previously as multiple nonhuman as well as some human sources and loads of *E. coli*. Population densities were determined to have no statistically significant differences between upstream from the city boundaries and downstream from the city boundaries (Bushon and others, 2017). The previous conclusions of *E. coli* density loads and yields performed in Bushon and others (2017) were not extrapolated or confirmed during the current (2019) study.

Trends in FIB population densities were investigated at four sites using the full period of record available for each site. Statistically significant downward trends were noted for sites 1 and 8 with 66.4 and 88.3 percent change, respectively, in annual flow-weighted mean population densities from 2006 through 2018 (table 3; fig. 14). The annual geometric mean concentration of *E. coli* population density decreased during the trend period, but the flow-weighted annual mean population density increased from 2006 through 2018 for sites 1 and 8. The changes in data collection methodology during the period of record could have affected the annual flow-weighted mean densities because samples were collected primarily during stormflow events for most of the study (2006–13). From 2014 through 2018, samples were collected with more temporal and spatial variance to gain more data within various streamflow conditions, which also increased the number of samples per year. Improvements within the MS4 to stormwater and wastewater infrastructure also could be a result of the downward trends in FIB population densities, particularly for site 1.

The *E. coli* densities at sites 2 and 8 on the Little Blue River support conclusions in Bushon and others (2017) that FIB concentrations were not significantly different from upstream (site 2) to downstream (site 8) of the MS4 area and have remained unchanged during the study period. The upstream Little Blue River site (site 2) had a null trend for the full period of data, which indicates no statistically significant changes in *E. coli* population density from 2010 through 2018 upstream from the MS4 boundary. Site 8 had a statistically significant downward trend in available data from 2006 through 2018. Streamflow in the Little Blue River increases downstream as the drainage area increases by nearly 50 percent from site 2 to site 8 (table 1). Because the trends predicted with R–QWTREND are flow adjusted, the effect of streamflow is held constant throughout the time period modeled. The downward trend of *E. coli* population density at site 8 could be a result of dilution from increased streamflow volume downstream, the decrease in streamflow and precipitation during the study period, storage of FIB in the Little Blue River streambed within the MS4, die-off of FIB during travel from upstream to downstream, infrastructure improvements within the MS4 boundary, changes in the sample collection methodology as described previously, or a combination of these factors.

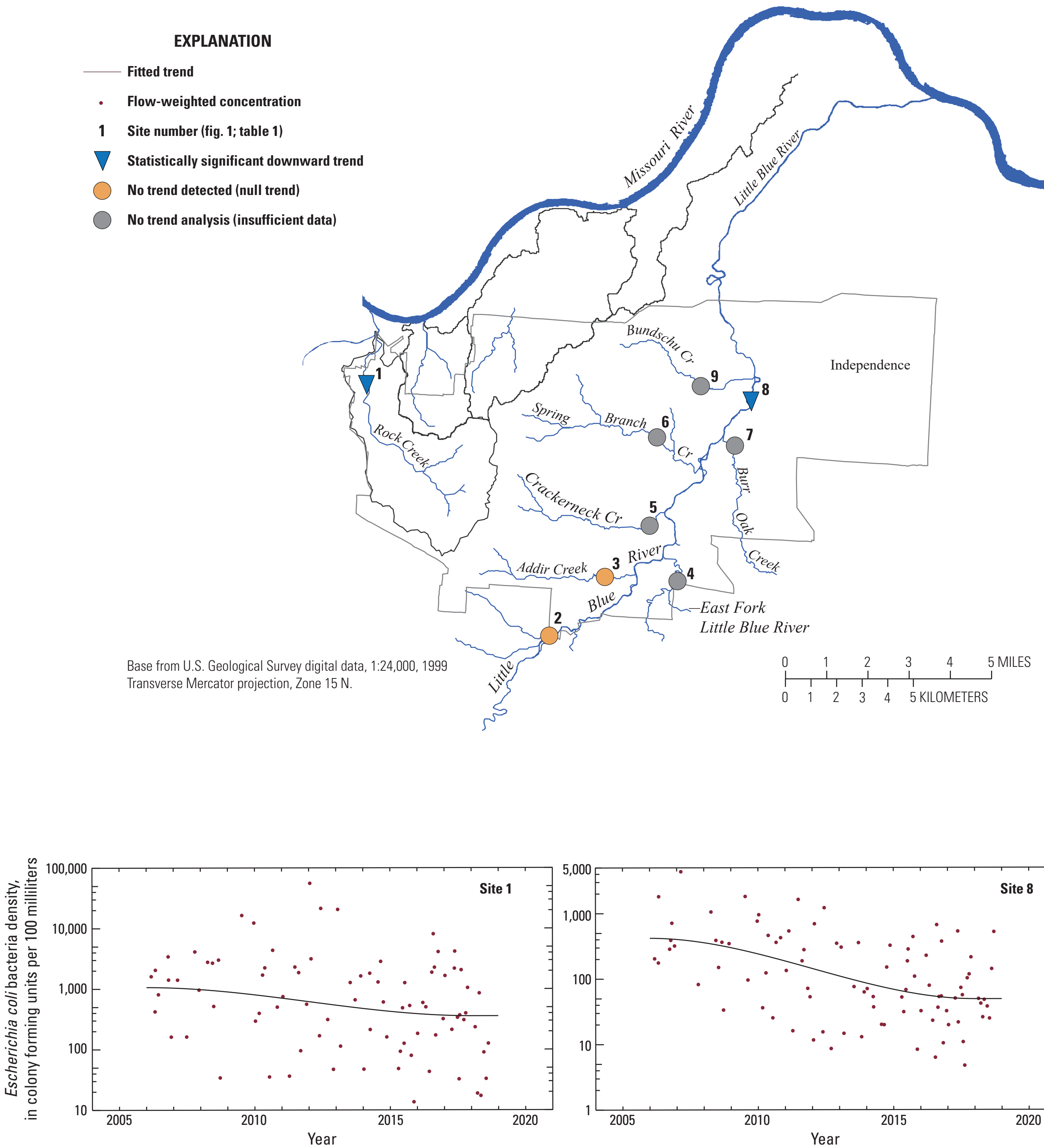


Figure 14. Location map and graphs of sites with statistically significant trends in flow-weighted *Escherichia coli* bacteria densities from 2006 through 2018.

Trends in Suspended-Sediment Concentrations and Loads

Sediment is noted as one of the most common pollutants in streams across the Nation, causing damage to aquatic habitat as well as drinking water and recreational issues (U.S. Environmental Protection Agency, 2017). Sediment in suspension can be the primary pollutant or carry other pollutants such as nutrients, organic materials, pathogens, and trace elements. A statistically significant downward trend in SSC was identified at site 2 with a 63.1 percent change in annual flow-weighted mean concentration during the full period of available data (table 3). The downward trend in SSC at site 2 could be affected by the decreased streamflow and precipitation during the study period, by changes in sampling methods within the study period, and by the decrease in construction and urban land development upstream from the MS4 boundary.

No statistically significant change was indicated in the annual SSL transported from the Little Blue River near Lake City, Missouri (site 8) during the 2006–18 study period (table 5). However, with the exception of a dry 2006, annual SSLs at site 8 were about 80,000,000 kg or greater in the first 5 years of the study and were less than 82,000,000 kg during the last 8 years of the study (table 2.2). The annual mean SSL for site 8 was about 82,200,000 kg during the wetter period 1 (2006–10) and was about 55,700,000 kg during the drier period 2 (2011–18; table 7).

During period 2 (2011–18), the annual mean SSL transported from the Little Blue River at site 8 was about 55,700,000 kg (table 7). The combined annual mean SSL during period 2 transported from Spring Branch Creek (site 6) and Adair Creek (site 3) and potentially from other monitored and unmonitored streams in Independence that discharge into the Little Blue River was about 7,510,000 kg (table 7). This combined annual SSL mean is about 13 percent of the total SSL transported by the Little Blue River at site 8. The Little Blue River upstream from Independence (site 2) and the upstream portion of the East Fork Little Blue River (site 4), contributed a combined mean annual SSL of about 33,500,000 kg during period 2; about 60 percent of the mean annual SSL in the Little Blue River at site 8 (55,716,374; table 7). Suspended-sediment yield from the East Fork Little Blue River at site 4 was an order of magnitude less than from the Little Blue River at site 2 (table 2.2). About an additional 3,740,000 kg (1,520 kilograms per hectare) of sediment were transported from Independence by Rock Creek (site 1) during period 2 (table 7).

Observations in Concentrations by Land-Use and Water-Quality Criteria

Select constituents were compared among six of the urban study sites to determine if the concentration distributions were statistically similar and to see how concentrations compared to State regulatory criteria and two agricultural sites (fig. 15). Data used in the comparison ranged from October 2005 through September 2018 to represent water years 2006 through 2018. A water year is the 12-month period from October 1 through September 30 and designated by the calendar year in which it ends. Sites 1, 2, 3, 4, 6, and 8 were included in the analyses, as well as two sites in predominantly agricultural watersheds in northern Missouri—Medicine Creek near Harris, Missouri (USGS site number 06899950) and Grand River near Sumner, Missouri USGS site number 06902000) (fig. 15; U.S. Geological Survey, 2019). These sites were chosen because they are in northern Missouri near the study area, have a different land use than the study area, and had monthly data available for the select constituents during the comparison period. The Medicine Creek site has a drainage area of 497 km^2, which is similar to the area known as the Little Blue River within Independence. The Grand River site has a much larger drainage area (17,800 km^2) than any of the urban streams, but the site was chosen because of its long period of nutrient data and because the site was part of a stormflow-event sampling project for suspended sediment. If constituent concentrations were not significantly different (p-value less than 0.05), the sites were grouped by the same letter in figure 15, which were obtained by the Tukey's test. Some sites were grouped with more than one letter, indicating similar medians in concentrations among multiple sites. If one site had a unique letter, the site was statistically different from any other site.

The water quality of urban streams in Independence and two nearby agricultural rivers indicate many similarities. Median dissolved oxygen concentrations, water temperature, and *E. coli* densities were similar among all sites (fig. 15). Sites 1 and 3 had more statistically similar constituents among all the sites—mostly among the physical properties. Specific conductance, nitrate plus nitrite, and TN concentrations at site 1 were significantly different from other sites. Differences between urban and agriculture sites were that agricultural sites generally had lower water temperature, ammonia, and chloride median concentrations than the urban sites and had higher dissolved oxygen and SSC (only one agricultural comparison site had SSC data) median concentrations than the urban sites (fig. 15).

State and Federal regulatory requirement for the protection of aquatic life or human contact are shown in comparison with all available data in figure 15. The Clean Water Commission of the Missouri Department of Natural Resources implemented a minimum dissolved oxygen requirement of 5 milligrams per liter (mg/L) for waters designated as warm-water fishery, and water temperature maximum criteria of about 32.2 degrees Celsius (Missouri Department of Natural Resources, 2019a; fig. 15). The Little Blue River has been designated as a warm-water fishery stream as part of other provisional aquatic life limits. The State of Missouri falls within the EPA Region 7, which in 2005 established benchmark criteria for nutrients in regional streams (Missouri Department of Natural Resources, 2019b). These benchmarks are for TN

(0.9 mg/L; fig. 15) and TP (0.075 mg/L; fig. 15). Additionally, the State also has standards for chloride (230 mg/L), which are part of the EPA concentration limits for chronic toxicity of aquatic life of (Missouri Department of Natural Resources, 2019a; fig. 15).

The Little Blue River and many of its tributaries that drain Independence have been designated as recreational waters classified for WBC–B and SCR. As a result of urban runoff and storm sewers, some of these designated streams have been listed as impaired for *E. coli* on the Missouri Department of Natural Resources 2018 Section 303(d) Listed Waters (Missouri Department of Natural Resources, 2018). Five streams—Rock Creek, Spring Branch Creek, East Fork Little Blue River, Burr Oak Creek, and Little Blue River—were listed as impaired for *E. coli* in 2018. Geometric means of available samples during the recreational season (April through October) are greater than the regulatory colony density requirement of 206 colony forming units per 100 milliliters (CFU/100 mL) for WBC–B and 1,134 CFU/100 mL for SCR (fig. 15; Missouri Department of Natural Resources, 2019a). The geometric mean of all samples for the period of available data for each site is less than the SCR at sites 2, 3, 4, and 8 (fig. 15). Boxplots of *E. coli* population density (fig. 15) show similar (within one order of magnitude) medians and geometric means for the recreational season (April through October) and all available data for both Little Blue River sites (sites 2 and 8). The Little Blue River drainage area nearly doubles in size from site 2 (254 km^2) to site 8 (476 km^2; table 1); therefore, the consistent *E. coli* population densities at site 2 and 8 is primarily because of the increased volume of streamflow, which creates a dilution effect (fig. 15). It is possible that FIB may be settling out of suspension during transportation downstream and incubate in storage in streambed sediments. It is also possible that FIB have a high die-off rate during transportation downstream. The improvements to the city’s MS4 wastewater and stormwater infrastructure, as well as the modifications to the sampling methods during the study period, also could have reduced FIB population density transported in the Little Blue River between the study sites. Specific sources of *E. coli* in the Little Blue River and its tributaries are currently (2019) unknown. Previous microbial source tracking investigations documented in Bushon and others (2017) characterized some sources within the Little Blue River and some of its tributaries during stormwater runoff collected from June 2008 through October 2014 from human, canine, and ruminant markers.

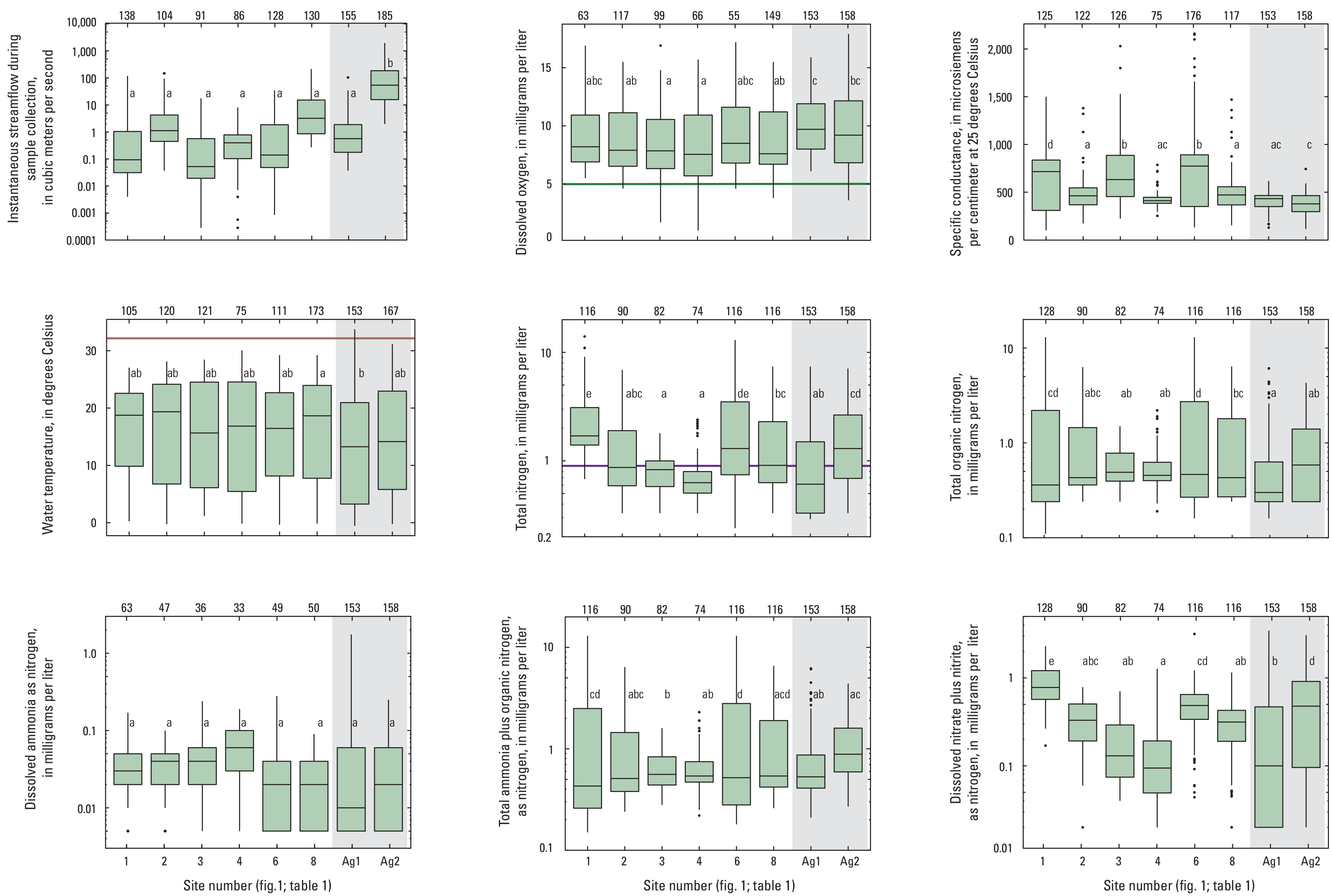
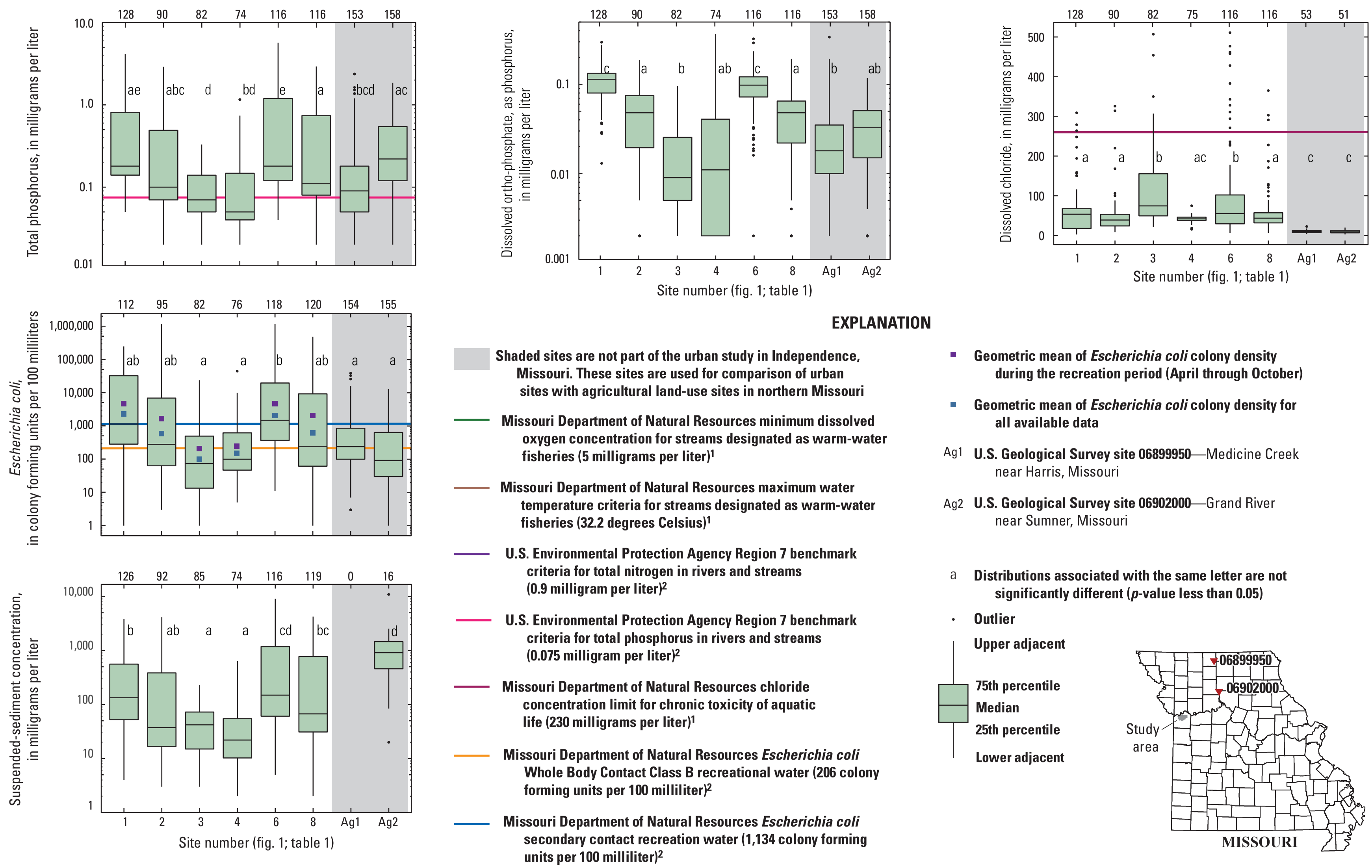


Figure 15. Boxplots of selected physical properties, nutrients, chloride, fecal indicator bacteria, and suspended-sediment concentrations at select Independence, Missouri, urban and northern Missouri agricultural sites and State of Missouri water-quality criteria, October 2005 through September 2018.



[1]Missouri Department of Natural Resources, 2019a, Rules of Department of Natural Resources, Division 20—Clean Water Commission, Chapter 7—Water quality: Missouri Department of Natural Resources, Code of State Regulations, 10 CSR 20–7, p. 54–131, accessed September 2019 at https://www.sos.mo.gov/adrules/csr/current/10csr/10csr.asp#10-20.

[2]Missouri Department of Natural Resources, 2019b, EPA Region 7 nutrient benchmarks—Streams: accessed November 13, 2019, at https://dnr.mo.gov/env/wpp/wqstandards/docs/rtag_region7_benchmarks.pdf.

Figure 15. Boxplots of selected physical properties, nutrients, chloride, fecal indicator bacteria, and suspended-sediment concentrations at select Independence, Missouri, urban and northern Missouri agricultural sites and State of Missouri water-quality criteria, October 2005 through September 2018.—Continued

Summary and Conclusions

The U.S. Geological Survey and the city of Independence, Missouri, Water Pollution Control Department began a cooperative study in June 2005 that continued through 2018 to characterize and evaluate the water quality and ecological condition of urban streams within Independence. Collection of water-quality data has resulted in a dataset that can be used to evaluate the progress of applied best management practices and to establish a baseline by which the effectiveness of current (2019) and future best management practices can be measured. This report presents trends in water quality in relation to changes in precipitation, streamflow, population, and land use among urban streams using data collected by U.S. Geological Survey staff from 2005 through 2018. Selected physical properties, nutrients, chloride, fecal indicator bacteria [FIB; such as *Escherichia coli* (*E. coli*) and total coliform], total dissolved solids (TDS), and suspended-sediment concentration (SSC) data for base-flow and stormflow samples were used to document temporal trends in concentrations and flow-weighted concentrations; and annual loads were computed and investigated for selected nutrients, chloride, and suspended sediment.

The Little Blue River drains a watershed of 580 square kilometers (km^2), of which about 160 km^2, or roughly 28 percent, is within Independence, and flows generally northward, discharging into the Missouri River. The Little Blue River within Independence is monitored as part of the city's municipal separate storm sewer system at two sites: upstream from the city and downstream from three of its tributaries. The largest tributary to the Little Blue River is the East Fork Little Blue River. Adair Creek and Spring Branch Creek also are tributaries that drain Independence. An additional study site is located on Rock Creek, which is not a tributary of the Little Blue River, but drains the northwest portion of the city to the Missouri River. The Little Blue River is regulated with the State of Missouri as a metropolitan no discharge stream, meaning no municipal effluent can be directly discharged into the stream.

Population and land use in the study area indicated no significant changes during the study. However, results indicated differences in precipitation and streamflow, which were identified as two periods within the study—period 1 (2006–10) and period 2 (2011–18). Slightly lower air temperatures and more precipitation probably were contributing factors that resulted in greater annual streamflow in the Little Blue River during the first period (2006–10) than in the second period (2011–18). The differences in annual precipitation and streamflow between the two periods also were identified in trends of annual loads of some constituents.

Trends in the measurements of physical properties; the concentrations of total and dissolved nutrients, dissolved chloride, total dissolved solids, and suspended sediment; and population densities of FIB were investigated at four urban stream sites. The concentration trends were performed using a statistical time-series modeling package developed by the U.S. Geological Survey called R–QWTREND, and has the ability to model serial correlation among observations, and can model complex trends during different times as well as different directions. Annual loads of selected nutrients, dissolved chloride, and suspended sediment were estimated using the Weighted Regressions on Time, Discharge, and Season-Kalman filter (WRTDS–K) model at six urban stream sites. Both R–QWTREND and WRTDS–K are publicly available software packages written in R, a free, open-source language used for statistical and graphical interpretations and computations. Trend analysis datasets for both concentration and load trends contained samples collected from January 2006 through December 2018.

Statistically significant trends in flow-weighted nutrient concentrations generally were downward during the study period. A statistically significant downward trend in flow-weighted total nitrogen concentration was indicated at all four sites, and the Rock Creek site had the highest concentrations. Flow-weighted concentrations of total organic nitrogen were indicated as statistically significant downward trends at all sites except the Adair Creek site. Downward trends also were identified at the Rock Creek site and the upstream site on the Little Blue River for total ammonia plus organic nitrogen as nitrogen; and one statistically significant downward trend was identified in flow-weighted concentrations of dissolved nitrate plus nitrite as nitrogen. Downward total phosphorus trends were statistically significant at the Rock Creek site and the downstream site on the Little Blue River. The downward trend in annual flow-weighted nutrient concentrations could be from a change in sampling program from a targeted stormwater collection effort to a more hydrologically diverse sampling program or from improvements to storm and wastewater infrastructure within the various watersheds within the city, or both. The only nutrient compound with a statistically significant upward trend was dissolved orthophosphate as phosphorus. This upward trend was indicated at the Rock Creek site and the upstream site on the Little Blue River.

The only statistically significant trend in annual loads of nitrogen species was identified for dissolved ammonia transported from the Little Blue River watershed at the downstream Little Blue River site. Although there was a significant downward linear trend, ammonia made up the smallest part of the total nitrogen load transported from Independence in the Little Blue River. Independence contributed a mean of 43 percent of the total nitrogen, 41 percent of the total organic nitrogen, 34 percent of the nitrate plus nitrite as nitrogen, and 15 percent of the dissolved ammonia load identified at the Little Blue River downstream site. The total nitrogen load decreased from period 1 (2006–10) to period 2 (2011–18) at all six sites for all nitrogen species except dissolved ammonia at the Adair Creek site.

As with nitrogen, there were nonstatistically significant decreases in the loads of total phosphorus and orthophosphate as phosphorus transported from the Little Blue River and its tributaries from 2006 through 2018. The downward trends were caused by reduced streamflow during study period 2 (2011–18) that are reflected in larger period-1 annual loads compared to period-2 mean annual loads. An exception to the overall downward trends in nutrient transport was a significant upward linear trend in annual orthophosphate as phosphorus load at the Adair Creek site, which increased from less than 100 kg in 2009 to more than 200 kg in 2017. Overall, the total phosphorus transported to the Little Blue River from the city of Independence constituted about 57 percent of the annual total phosphorus load at the downstream Little Blue River site during the 2011–18 period.

A statistically significant upward trend in dissolved chloride concentrations was identified at the downstream Little Blue River site. The annual flow-weighted mean concentrations increased by about 41 percent from 2006 through 2018. Land-use changes indicate small increases (about 1 percent or less) in developed low-, medium-, and high-intensity; however, increased road salt application near the site during the winter could have resulted in higher concentrated runoff during wet weather conditions.

Annual chloride loads significantly decreased at the Adair Creek and Spring Branch Creek sites during the study period. The decrease in chloride load at the two sites was nearly half from the wetter period 1 (2006–10) to the drier (2011–18) period 2. Annual chloride loads at site 6 decreased from 929,763 kg in 2007 to 166,184 kg in 2018. The mean annual chloride load transported in the drier period 2 was significantly less than during the wetter period 1, indicating that trends in precipitation runoff are an important factor in trends in annual transport of chloride. For the study period, samples were collected primarily during the recreational period (April through October) until 2014; limited data were available during the winter (November to February) when road salt application typically occurs.

Statistically significant downward trends in FIB *E. coli* population densities were noted for the Rock Creek site and the downstream site on the Little Blue River. The annual geometric mean concentration of *E. coli* population density decreased during the trend period, but the flow-weighted annual mean population density increased from 2006 through 2018 for the two sites. The changes in data collection methodology during the period of record could have affected the annual flow-weighted mean densities because samples were collected primarily during stormflow events for most of the study (2006–13). Since 2014, samples were collected with more temporal and spatial variance to gain more data within various streamflow conditions, which also increased the number of samples per year. The downward trends in FIB population densities could also be a result of improvements within the MS4 to stormwater and wastewater infrastructure, particularly for the Rock Creek site.

The *E. coli* densities at both Little Blue River sites supports conclusions in previous studies that FIB concentrations were not significantly different from upstream to downstream from the MS4 area and have remained unchanged during the study period. No trend was indicated in *E. coli* population density at the upstream site on the Little Blue River, but a statistically significant downward trend was identified at the downstream site on the Little Blue River. The change in *E. coli* density downstream could be a result of dilution from increased streamflow volume downstream, a decrease in streamflow and precipitation during the study period, storage of FIB in the Little Blue River streambed within the study area, die-off of FIB during travel from upstream to downstream changes in the sample collection methodology, improvements to the MS4 stormwater and wastewater infrastructures, or a combination of these factors.

A statistically significant downward trend in suspended-sediment concentration was identified at the upstream Little Blue River site with a 63.1 percent change during the study period. This trend could be affected by the decreased streamflow and precipitation during the study period, by changes in sampling methods within the study period, and by the decrease in construction and urban land development upstream from the city.

No statistically significant change was indicated in the annual suspended-sediment load (SSL) transported from the Little Blue River during the 2006–18 study period. With the exception of a dry 2006, the annual mean SSL at the downstream Little Blue River site during the first 5 years of the study was greater than the annual mean SSL during the last 8 years of the study. The annual mean SSL transported from the Little Blue River at the downstream site was about 82,200,000 kg during the wetter period 1 (2006–10) and was about 55,700,000 kilograms during period 2 (2011–18). About 13 percent of the total SSL transported in the Little Blue was transported from Spring Branch Creek and Adair Creek. About 60 percent of the total upstream contribution during period 2 (2011–18) originated in the Little Blue River watershed upstream from Independence.

The Little Blue River and many of its tributaries that drain Independence have been designated as recreational waters classified for whole-body contact class B and secondary contact recreation, and some of these designated streams have been listed as impaired for *E. coli* by the Missouri Department of Natural Resources from urban runoff and storm sewers. Observations were made among the available *E. coli* population density data for both Little Blue River sites to further understand water-quality conditions over the study period. Both Little Blue River sites had similar medians and geometric means for the recreational season (April through October) and for all available data during the study period, both of which are greater than the regulatory population density for both recreational classes. The Little Blue River drainage area nearly doubles in size from the upstream site (254 km^2) to the downstream site (476 km^2); therefore, the consistent *E. coli* population densities at the upstream and downstream Little Blue River sites is primarily because of the larger volume of streamflow, which creates a dilution effect. Other possible factors include storage of FIB in streambed sediments, die-off of FIB during transport, improvements to the city's wastewater and stormwater infrastructure, the changes to sampling methodology, or a combination of these factors. Specific sources of the *E. coli* are currently (2019) unknown. Previous microbial source tracking investigations characterized *E. coli* sources within the Little Blue River and some of its tributaries during stormwater runoff collected from June 2008 through October 2014 from human, canine, and ruminant markers.

Climate changes, particularly precipitation and streamflow conditions, contributed to the changes identified in the concentrations of nutrients, chloride, fecal indicator bacteria, and sediment as well as the constituent loads transported in urban streams. During the full study period, annual streamflow for period 2 (2011–18) was about 30 percent less than for period 1 (2006–10). This result is reflected in the smaller nutrient, dissolved chloride, and SSLs transported from the urban streams and from the Little Blue River. The amount of developed land and the population in the Independence urban watersheds remained unchanged during the 2006–18 study period and, thus, had little effect on the downward trend in transport.

Changes in data collection methodology during the study period and improvements to the city stormwater and wastewater infrastructure could also have contributed to some of the identified trends. Stormflow events were targeted with limited base-flow samples in the first period, with more samples collected annually across various streamflow conditions as well as seasons in the second period. For both periods, samples were collected during the recreational season from April through October, with limited samples collected during the winter. Between 2009 and 2015, more than 35 million dollars of improvements were made to stormwater and wastewater infrastructure within the city. These improvements, such as additional sewage overflow holding tanks, removal of septic tanks, and improved and expanded sanitary sewer lines and storm overflows, also could have resulted in the downward nutrients and FIB trends among the urban streams in the study area.

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Appendixes 1–4

Appendix 1. Documentation of Concentration Trends for Urban Streams in Independence, Missouri, Analyzed Using R–QWTREND

This appendix contains examples of the steps and processes used to analyze and produce flow-weighted trends in concentration data (available for download at https://doi.org/10/13133/sir20205130). A series of code (fig. 1.1*A*) using R software (R Development Team, 2019) shows an example of how all datasets were produced and prepared for use with R–QWTREND (Vecchia and Nustad, 2020). Additional code shows examples of how models were produced (fig. 1.1*B*) and the outputs of the results (fig. 1.2; table 1.1). Outliers that were identified and removed from datasets presented in the report also are documented (table 1.2). This appendix also contains an Excel spreadsheet of the summary statistics (table 1.3) for selected physical properties and chemical constituents at select sites in Independence, Missouri (available for download at https://doi.org/10/13133/sir20205130.

Table 1.1. Example of generic numerical model output of annual trend results (QWMODOUTANN) from R–QWTREND.

[dyr, decimal year for midpoint of calendar year; agmc, estimated annual geometric mean concentration, in milligrams per liter; tagmc, estimated trend in annual geometric mean concentration; fvrP10, 10th percentile of flow-related variability; fvr90, 90th percentile of the flow-related variability; amflow, annual mean streamflow, in cubic feet per second; afwac, annual flow-weighted average concentration, in milligrams per liter; tafwac, trend in annual flow-weighted average concentration; aflux, annual flux, in metric tons (1,000 kilograms) per day; taflux, trend in annual flux.]

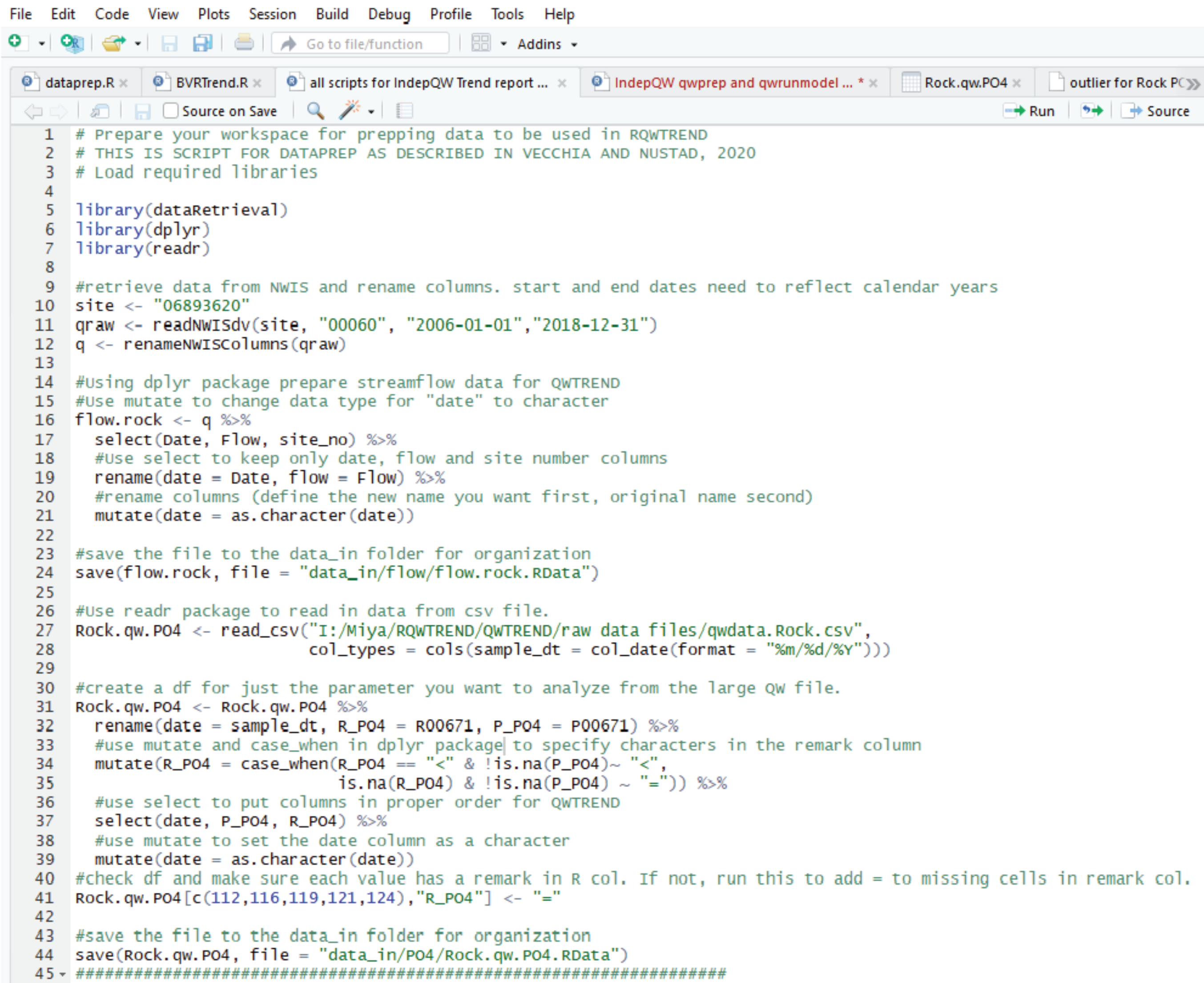
dyr	agmc	tagmc	frvP10	frvP90	amflow	afwac	tafwac	aflux	taflux
2006.49	0.088	0.087	0.049	0.126	2.432	0.102	0.102	0.001	0.002
2007.49	0.088	0.088	0.047	0.128	6.421	0.095	0.102	0.001	0.002
2008.49	0.087	0.089	0.048	0.121	9.586	0.103	0.103	0.002	0.002
2009.49	0.088	0.09	0.05	0.122	9.635	0.101	0.105	0.002	0.002
2010.49	0.092	0.092	0.05	0.129	8.707	0.105	0.106	0.002	0.002
2011.49	0.093	0.093	0.053	0.129	5.843	0.105	0.108	0.002	0.002
2012.49	0.097	0.095	0.052	0.141	2.651	0.101	0.110	0.001	0.002
2013.49	0.096	0.096	0.052	0.137	4.804	0.103	0.112	0.001	0.002
2014.49	0.098	0.098	0.057	0.135	4.162	0.123	0.114	0.001	0.002
2015.49	0.098	0.099	0.055	0.139	8.156	0.122	0.115	0.002	0.002
2016.49	0.101	0.100	0.056	0.139	7.207	0.119	0.116	0.002	0.002
2017.49	0.102	0.101	0.061	0.141	6.989	0.132	0.117	0.002	0.002
2018.49	0.100	0.101	0.056	0.141	5.331	0.121	0.117	0.002	0.002

Table 1.2. Outliers identified and removed from datasets during trend analysis of urban streams in Independence, Missouri, using R–QWTREND.

[USGS, U.S. Geological Survey; site number in parenthesis was used for the study]

USGS site name	Sample date	Outlier value
Water temperature, in degrees Celsius		
Little Blue River at Lee's Summit Road in Independence, Missouri (site 2)—USGS site number 06893820	1/13/2010	0.1
Little Blue River at Lee's Summit Road in Independence, Missouri (site 2)—USGS site number 06893820	11/18/2014	0.1
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	12/5/2006	1.0
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	1/14/2010	0.1
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	1/14/2014	0.2
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	11/20/2014	1.1
Dissolved oxygen, in milligrams per liter		
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	8/26/2014	3.8
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius		
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	12/5/2006	1,070
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	12/11/2007	1,470
pH, in standard units		
Rock Creek at Kentucky Road in Independence, Missouri (site 1)—USGS site number 06893620	4/2/2014	6.9
Little Blue River at Lee's Summit Road in Independence, Missouri (site 2)—USGS site number 06893820	4/3/2014	6.7
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	3/18/2011	6.7
Dissolved orthophosphate, in milligrams per liter		
Rock Creek at Kentucky Road in Independence, Missouri (site 1)—USGS site number 06893620	9/1/2010	0.013
Dissolved chloride, in milligrams per liter		
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	12/5/2006	188
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	12/11/2007	366
Total dissolved solids (mg/L)		
Little Blue River near Lake City, Missouri (site 8)—USGS site number 06894000	12/11/2007	802

A




```
# Prepare your workspace for prepping data to be used in RQWTREND
# THIS IS SCRIPT FOR DATAPREP AS DESCRIBED IN VECCHIA AND NUSTAD, 2020
# Load required libraries

library(dataRetrieval)
library(dplyr)
library(readr)

#retrieve data from NWIS and rename columns. start and end dates need to reflect calendar years
site <- "06893620"
qraw <- readNWISdv(site, "00060", "2006-01-01","2018-12-31")
q <- renameNWISColumns(qraw)

#Using dplyr package prepare streamflow data for QWTREND
#Use mutate to change data type for "date" to character
flow.rock <- q %>%
  select(Date, Flow, site_no) %>%
  #Use select to keep only date, flow and site number columns
  rename(date = Date, flow = Flow) %>%
  #rename columns (define the new name you want first, original name second)
  mutate(date = as.character(date))

#save the file to the data_in folder for organization
save(flow.rock, file = "data_in/flow/flow.rock.RData")

#Use readr package to read in data from csv file.
Rock.qw.PO4 <- read_csv("I:/Miya/RQWTREND/QWTREND/raw data files/qwdata.Rock.csv",
                        col_types = cols(sample_dt = col_date(format = "%m/%d/%Y")))

#create a df for just the parameter you want to analyze from the large QW file.
Rock.qw.PO4 <- Rock.qw.PO4 %>%
  rename(date = sample_dt, R_PO4 = R00671, P_PO4 = P00671) %>%
  #use mutate and case_when in dplyr package to specify characters in the remark column
  mutate(R_PO4 = case_when(R_PO4 == "<" & !is.na(P_PO4)~ "<",
                           is.na(R_PO4) & !is.na(P_PO4) ~ "=")) %>%
  #use select to put columns in proper order for QWTREND
  select(date, P_PO4, R_PO4) %>%
  #use mutate to set the date column as a character
  mutate(date = as.character(date))
#check df and make sure each value has a remark in R col. If not, run this to add = to missing cells in remark col.
Rock.qw.PO4[c(112,116,119,121,124),"R_PO4"] <- "="

#save the file to the data_in folder for organization
save(Rock.qw.PO4, file = "data_in/PO4/Rock.qw.PO4.RData")
###################################################################
```

Figure 1.1. Script file containing series of code used with R–QWTREND. *A*, for creating a dataset; *B*, for setting up initial workspace and running R–QWTREND.

B

File Edit Code View Plots Session Build Debug Profile Tools Help

Go to file/function Addins

BVRTrend.R | IndepQW qwprep and qwrunmodel ... * | outlier for Rock PO4

Source on Save Run

```
1  ######################################################################
2  # Preparing your workspace for running R-QWTREND
3  # THIS SCRIPT IS FOR PRODUCING TREND MODELS AS DESCRIBED IN VECCHIA AND NUSTAD, 2020
4  # Load required libraries (tuncnorm, survival, and splines)
5  library("truncnorm")
6  library("survival")
7  library("splines")
8  #
9  # Set the pathname for QWTrend2018V4 folder
10 QWModPath <-  "I:/Miya/RQWTREND/QWTREND/"
11 
12 #  Create the functions prepQWdata, runQWmodel, and plotQWdata
13 #
14 source(paste(QWModPath,"prepQWdataV4.txt",sep=""))
15 source(paste(QWModPath,"runQWmodelV4.txt",sep=""))
16 source(paste(QWModPath,"plotQWtrendV4.txt",sep=""))
17 
18 #prep the qw and flow files to run the model
19 RockQWP <- prepQWdata(Rock.qw.PO4,flow.rock,2006,2018)
20 regmods
21 
22 # examine the data and note the outliers, if any
23 # replace outlier cells with missing values using command below and rerun prepQWdata again (lines 20-21).
24 Rock.qw.PO4[c(31),"P_PO4"] <- NA
25 
26 #run NULL model and review the .txt and .pdf file
27 runQWmodel(RockQWP,"PO4")
28 #run for a single monotonic trend.
29 runQWmodel(RockQWP,"PO4",monxx="2006x2018", runname = ".tnd")
30 #simpler monotonic trend.keep track of the different runs so they don't overwrite by changing runname.
31 runQWmodel(RockQWP,"PO4", monxx="2006x2018", modnum = 2, runname = ".tnd2")
32 
33 #after review and computing best fit, rerun the best model with full output and graphical output
34 runQWmodel(RockQWP, "PO4", monxx="2006x2018", modnum = 3,runname = ".best", fullout=T)
35 
36 #save  .pdf and .txt files of best-fit model to data_out folder for organization
37 #also copy the QWMODOUT files for annual results and paste into something useable like Excel.
38 save(RockQWPPO4.best.pdf, file = "data_out/PO4/RockQWPPO4.best.pdf")
39 save(RockQWPPO4.best.txt, file = "data_out/PO4/RockQWPPO4.best.txt")
```

Figure 1.1. Script file containing series of code used with R–QWTREND. *A*, for creating a dataset; *B*, for setting up initial workspace and running R–QWTREND.—Continued

A

```
****************
** -2lnLik = -497.89
**     AIC = -455.89
**   ecode = 1
**  modnum = 3

**  Parameter estimates

     Variable   CV(log)   SE(log)  Pvalue   CV(pct)
       int    -1.0299   0.0103   0.00000       NA
      xcos1   -0.1593   0.0130   0.00000   -30.71
      xsin1   -0.1459   0.0131   0.00000   -28.53
      xcos2    0.0123   0.0125   0.34907     2.87
      xsin2   -0.0714   0.0102   0.00004   -15.16
       falt   -0.0424   0.0420   0.33653    -1.91
       famt   -0.1009   0.0324   0.01105    -7.54
     famtsq    0.0889   0.0432   0.06676     9.39
       fast   -0.0062   0.0137   0.66348    -0.59
    fastxmt    0.0702   0.0372   0.08890     5.41
```

```
****************
** -2lnLik = -506.22
**     AIC = -462.22
**   ecode = 2
**  modnum = 3

**  Parameter estimates

     Variable   CV(log)   SE(log)  Pvalue   CV(pct)
          int   -1.0276   0.0095  0.00000       NA
        xcos1   -0.1461   0.0126  0.00000   -28.57
        xsin1   -0.1487   0.0123  0.00000   -28.99
        xcos2    0.0104   0.0115  0.38660     2.42
        xsin2   -0.0761   0.0096  0.00001   -16.07
         falt   -0.0095   0.0402  0.81738    -0.43
         famt   -0.0565   0.0324  0.10881    -4.29
       famtsq    0.0297   0.0436  0.50932     3.04
         fast    0.0022   0.0127  0.86864     0.21
      fastxmt    0.0563   0.0339  0.12461     4.32
    m2006x2018    0.0619   0.0191  0.00789    15.32
```

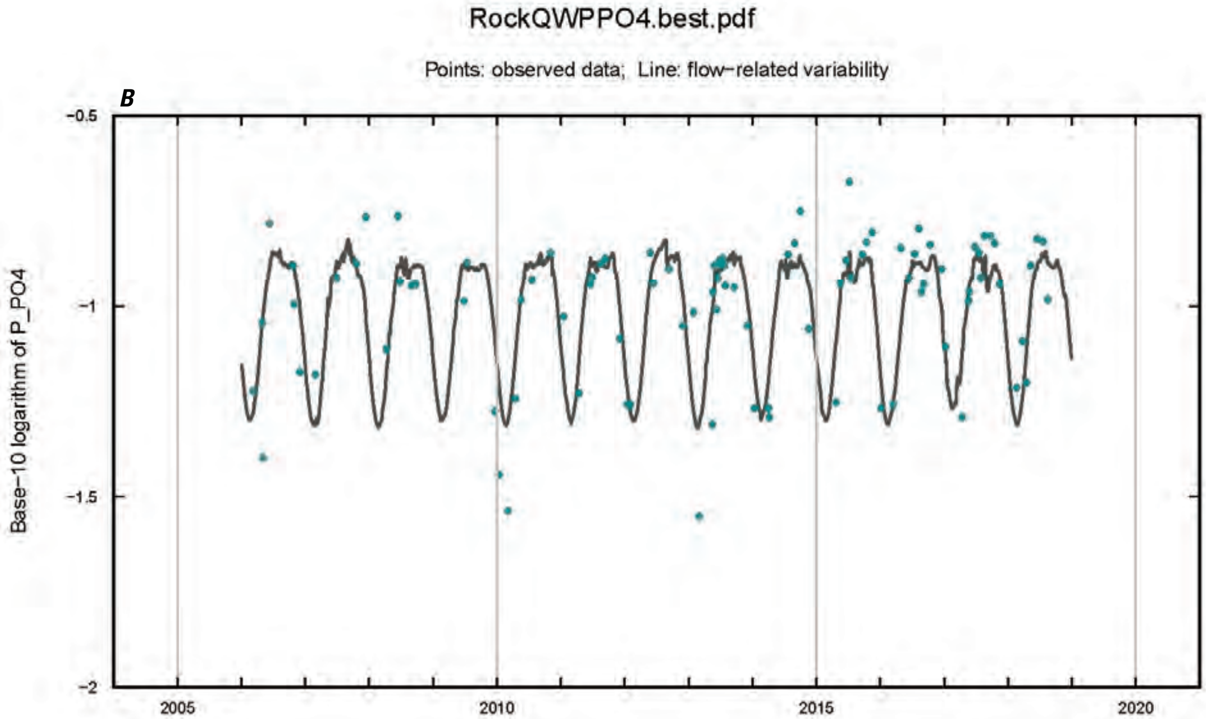
EXPLANATION

[left, null model; right, single monotonic trend]

–2lnLik—Minus two times the natural logarithm of the maximized likelihood function
AIC—Penalized likelihood value (not used in analysis)
ecode—Error code from nonlinear optimization program
modnum—Model number (Vecchia and Nustad, 2020)
CV(log)—Estimated coefficient value
SE(log)—Approximate standard error of estimated coefficient
Pvalue—Approximate probability value of coefficient
CV(pct)—Estimated coefficient value expressed as a percentage

int—Intercept
xcos1—Cosine with period 1 year
xsin1—Sine with period 1 year
xcos2—Cosine with period 6 months
xsin2—Sine with period 6 months
falt—Long-term flow anomaly
famt—Midterm flow anomaly
famtsq—Square of midterm flow anomaly
fast—Short-term flow anomaly
fastxmt—Product of short-term and midterm flow anomalies
m2006x2018—Monotonic trend from 2006 to 2018

Figure 1.2. Output from runQWmodel for orthophosphate as phosphorus concentration data for the RockQWP dataset (fig. 1.1*B*) for a single monotonic trend *A*, maximum likelihood estimation results from text file; *B*–*K*, full graphical output.



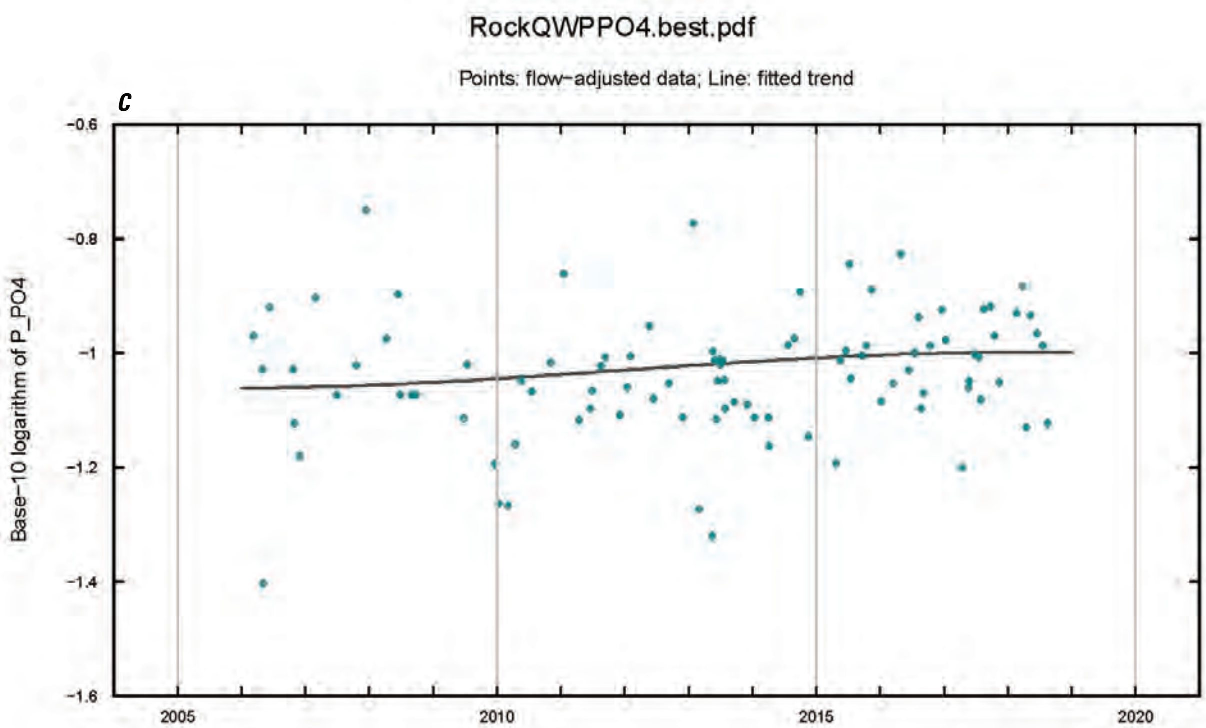
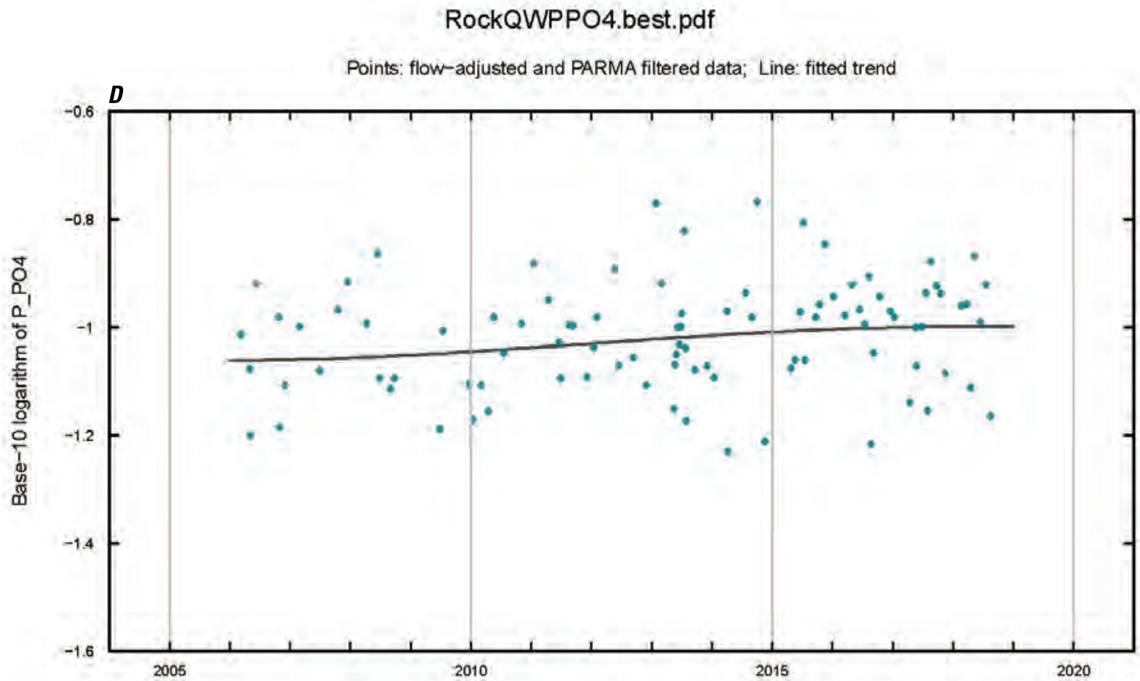
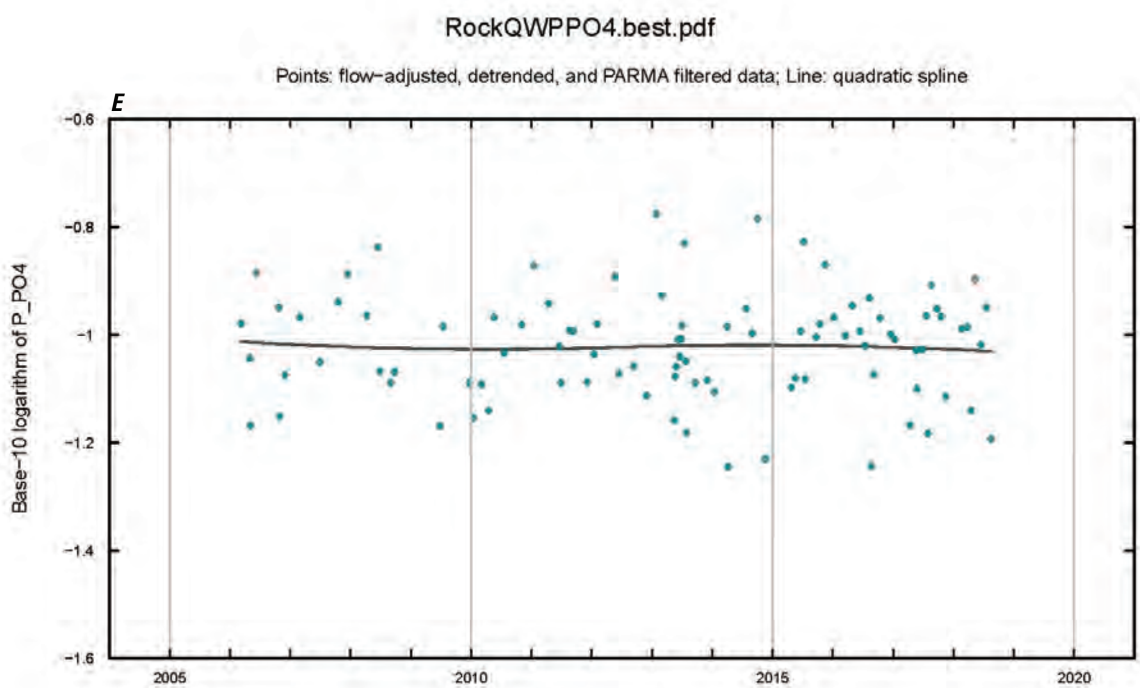


Figure 1.2. Output from runQWmodel for orthophosphate as phosphorus concentration data for the RockQWP dataset (fig. 1.1*B*) for a single monotonic trend *A*, maximum likelihood estimation results from text file; *B*–*K*, full graphical output.—Continued

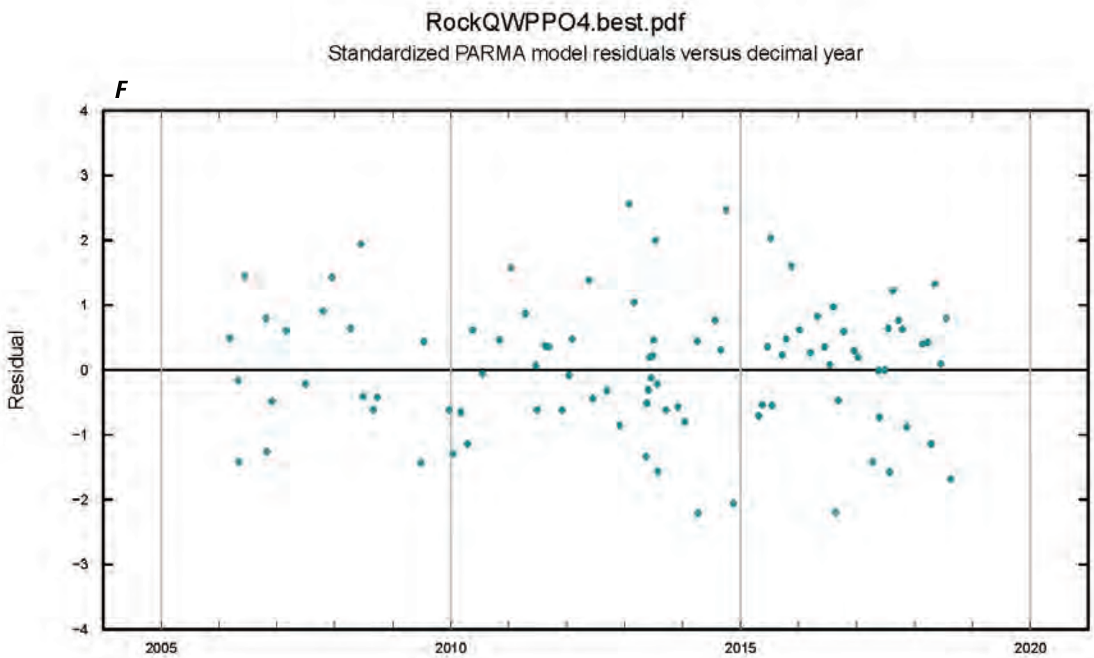


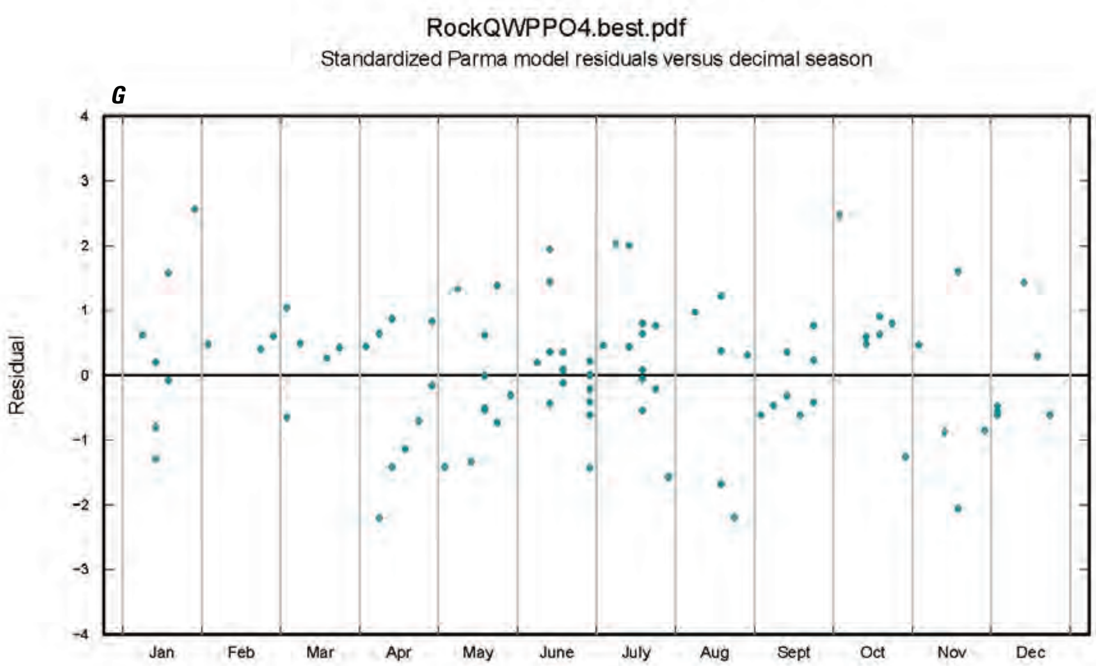


EXPLANATION

PARMA—Periodic autoregressive moving average

Figure 1.2. Output from runQWmodel for orthophosphate as phosphorus concentration data for the RockQWP dataset (fig. 1.1*B*) for a single monotonic trend *A*, maximum likelihood estimation results from text file; *B*–*K*, full graphical output.—Continued

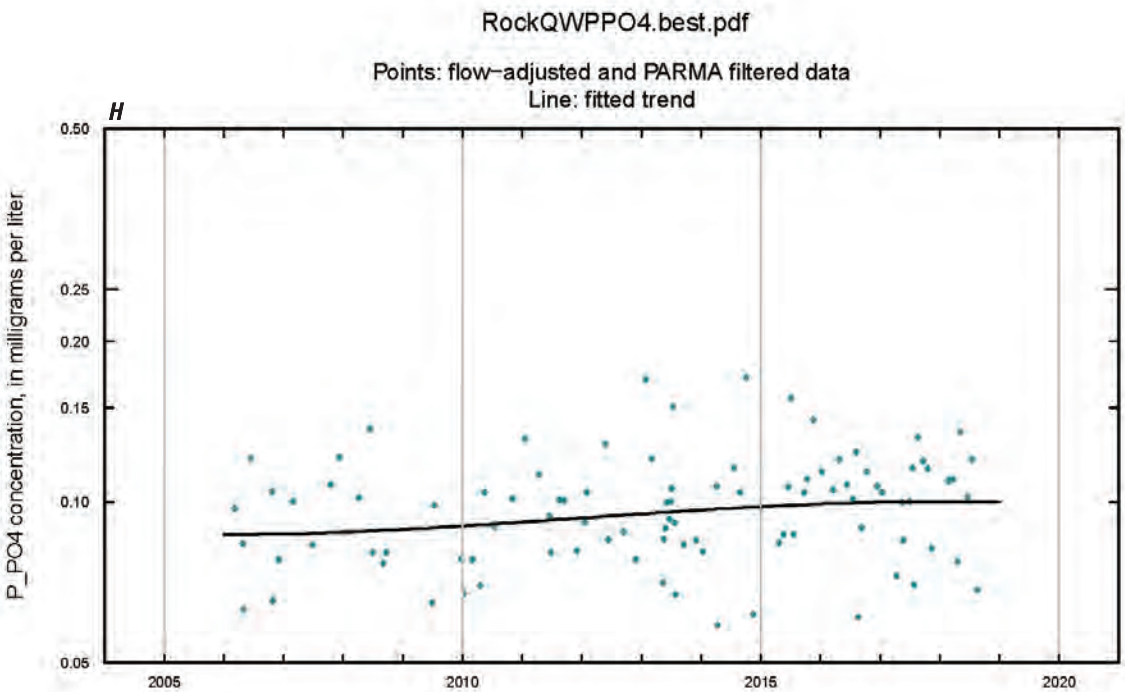


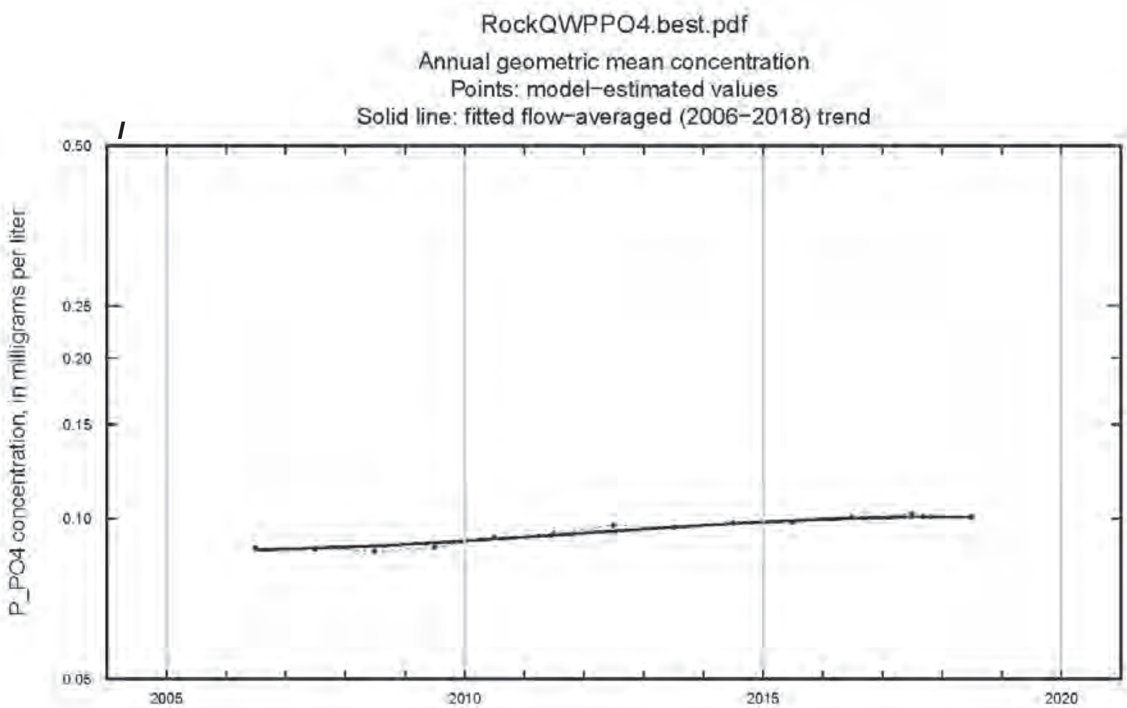


EXPLANATION

PARMA—Periodic autoregressive moving average

Figure 1.2. Output from runQWmodel for orthophosphate as phosphorus concentration data for the RockQWP dataset (fig. 1.1*B*) for a single monotonic trend *A*, maximum likelihood estimation results from text file; *B*–*K*, full graphical output.—Continued

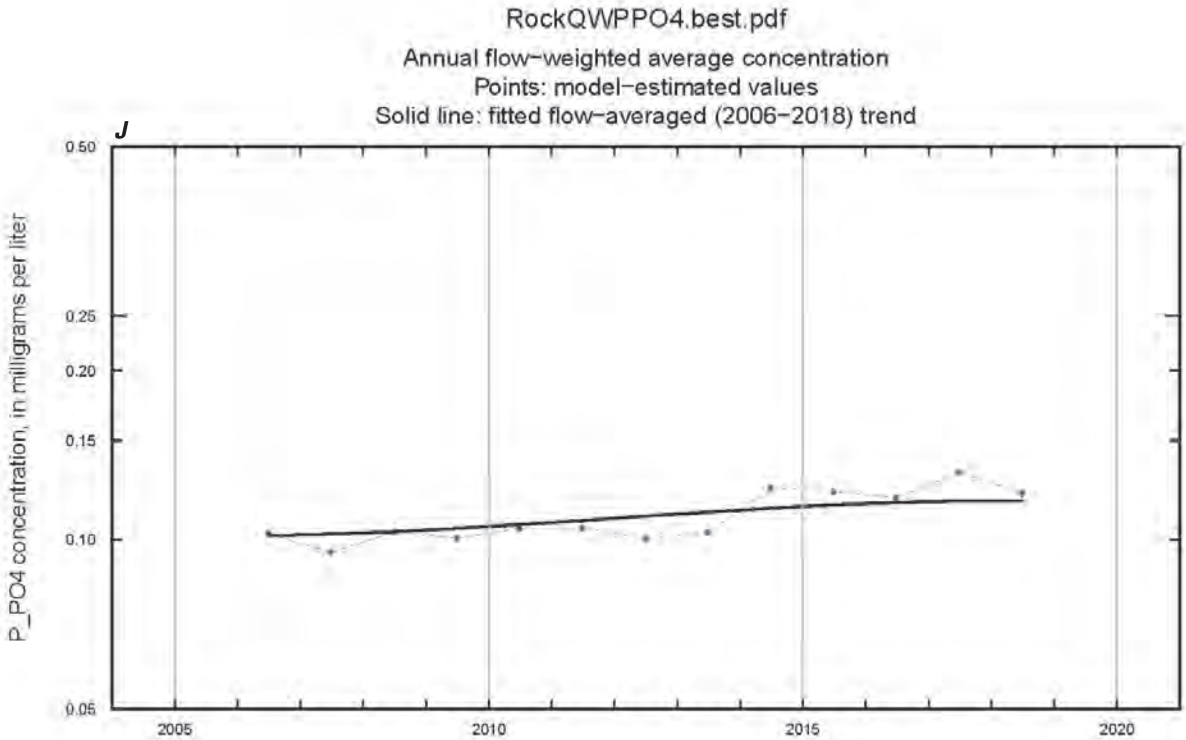




EXPLANATION

PARMA—Periodic autoregressive moving average

Figure 1.2. Output from runQWmodel for orthophosphate as phosphorus concentration data for the RockQWP dataset (fig. 1.1*B*) for a single monotonic trend *A*, maximum likelihood estimation results from text file; *B*–*K*, full graphical output.—Continued



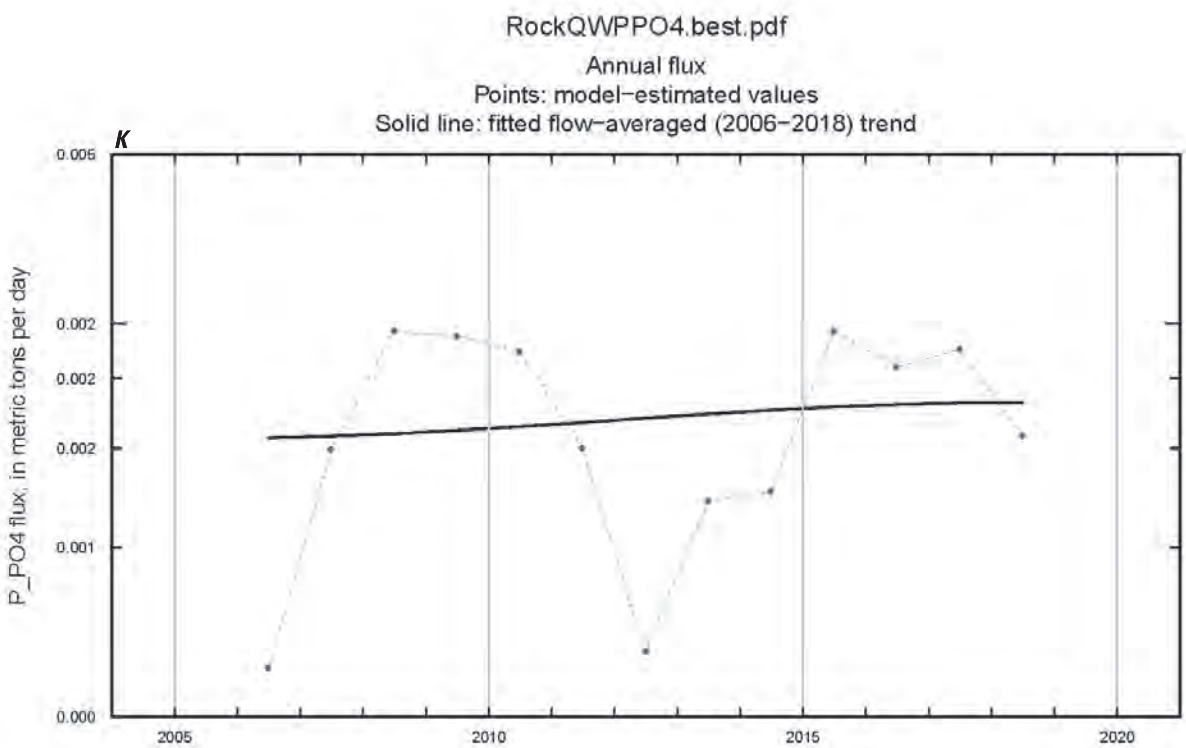


Figure 1.2. Output from runQWmodel for orthophosphate as phosphorus concentration data for the RockQWP dataset (fig. 1.1*B*) for a single monotonic trend *A*, maximum likelihood estimation results from text file; *B*–*K*, full graphical output.—Continued

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Appendix 2. Estimated Mean Annual Concentration, Load, and Yield for Selected Constituents in Urban Streams in Independence, Missouri

Mean annual loads of selected nutrients, dissolved chloride, and suspended sediment were estimated for selected urban streams in Independence, Missouri, from January 2006 through December 2018 using the Weighted Regressions on Time, Discharge, and Season-Kalman filter (WRTDS–K) model as described by Zhang and Hirsch (2019), and the data are presented in an Excel spreadsheet (tables 2.1 and 2.2) (available for download at https://doi.org/10/13133/sir20205130).

References Cited

Zhang, Q., and Hirsch, R.M., 2019, River water-quality concentration and flux estimation can be improved by accounting for serial correlation through an autoregressive model: Water Resources Research, v. 55, no. 11, p. 9705–9723, accessed November 2019 at https://doi.org/10.1029/2019WR025338.

Appendix 3. Annual Load Estimates Using Regression and Weighted Regressions on Time, Discharge, and Season-Kalman Filter (WRTDS–K) Models

Estimates of annual loads of total nitrogen, total organic nitrogen, dissolved ammonia, and dissolved nitrate plus nitrite as nitrogen (table 3.1), total phosphorous, chloride, and suspended sediment (table 3.2) in selected urban streams in Independence, Missouri, were computed for this report using the Weighted Regressions on Time, Discharge, and Season-Kalman filter (WRTDS–K) model (Zang and Hirsch, 2019). In a previous study (Niesen and Christensen, 2015), annual loads of these constituents at the same urban streams were computed using the LOADEST model (Runkel and others, 2004). This appendix contains an Excel spreadsheet (available for download at https://doi.org/10.3133/sir20205130) that compares the results from both studies, as well as the differences between the two models while using the same datasets.

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Appendix 4. Reclassification of the National Land Cover Database Land Cover in Urban Watersheds in Independence, Missouri

Land cover information extracted from the National Land Cover Database (NLCD) satellite imagery database was used to determine changes in land use during the period of the study (2005 through 2018). This appendix contains an Excel spreadsheet (available for download at https://doi.org/10.3133/sir20205130) that lists the 20 classes of coverage used by the NLCD (Yang and others, 2018) and lists the grouping of certain classes used in this report (table 4.1).

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Table 4.1. Reclassification of the National Land Cover Database land cover in urban watersheds in Independence, Missouri.

[Land cover from Yang and others, 2018. NLCD, National Land Cover Database; --, no data]

NLCD key	NLCD land cover	Reclassified key	Reclassified land cover
11	Open water	11	Open water
21	Developed open space	21	Developed open space
22	Developed low intensity	22	Developed low intensity
23	Developed medium intensity	23	Developed medium intensity
24	Developed high intensity	24	Developed high intensity
31	Barren land	31	Barren land
41	Deciduous forest	40	Forest
42	Evergreen forest	40	Forest
43	Mixed forest	40	Forest
51	Dwarf scrub	50	Grassland
52	Shrub/scrub	50	Grassland
71	Grassland/herbaceous	50	Grassland
81	Pasture/hay	50	Grassland
82	Cultivated croplands	82	Cultivated croplands
90	Woody wetlands	90	Wetlands
95	Emergent herbaceous wetlands	90	Wetlands
12	Perennial ice/snow	--	Land cover was not present and was not used
72	Sedge/herbaceous	--	Land cover was not present and was not used
73	Lichens	--	Land cover was not present and was not used
74	Moss	--	Land cover was not present and was not used

For more information about this publication, contact:
Director, USGS Central Midwest Water Science Center
1400 Independence Road
Rolla, MO 65401
573–308–3667
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Publishing support provided by the
Rolla Publishing Service Center

Barr and Kalkhoff—**Water-Quality Trends of Urban Streams in Independence, Missouri, 2005–18**—SIR 2020–5130

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20205130