Prepared in cooperation with the Johnson County Stormwater Management Program

Assessment of Water-Quality Constituents Monitored for Total Maximum Daily Loads in Johnson County, Kansas, January 2015 through December 2018

Scientific Investigations Report 2021–5041

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

Cover: Storm-event runoff at the Blue River near Stanley, Kansas, U.S. Geological Survey monitoring site, July 27, 2017. **Inset:** Storm-event runoff at the Turkey Creek at Antioch, Overland Park, Kansas, U.S. Geological Survey monitoring site, October 9, 2018. **Back cover:** Storm-event runoff at the Mill Creek Johnson Drive, Shawnee, Kansas, U.S. Geological Survey monitoring site, October 7, 2018; photography by Brianna Leiker, U.S. Geological Survey.

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton, short (2,000 pounds)	0.9072	metric ton (t)

Datum

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

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

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

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

Concentrations of nitrogen species in water are given in milligrams per liter as nitrogen (mg/L–N).

Concentrations of phosphorus species in water are given in milligrams per liter as phosphorus (mg/L–P).

Total nitrogen is the sum of total Kjeldahl nitrogen (U.S. Geological Survey parameter code 00625, also known as total ammonia plus organic nitrogen) and dissolved nitrate plus nitrite (U.S. Geological Survey parameter code 00631).

Escherichia coli densities are given in most probable number per 100 milliliters (MPN/100 mL) or colony forming units per 100 milliliters (CFU/100 mL).

Abbreviations

BMP	best management practice
CFU	colony forming unit
E. coli	*Escherichia coli*
EWI	equal-width increment
JCWQL	Johnson County Water Quality Laboratory
KDHE	Kansas Department of Health and Environment
NWQL	National Water Quality Laboratory
RPD	relative percent difference
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TSS	total suspended solids
USGS	U.S. Geological Survey
WWTF	wastewater treatment facility

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Abstract

Stormwater discharges from municipalities are regulated by provisions in the Clean Water Act of 1972 to protect the Nation's water resources from harmful pollutants. In 2014, the Kansas Department of Health and Environment issued new stormwater discharge permits for 17 municipalities in Johnson County, Kansas, in the northeastern part of the State. The county is largely suburban and has 20 municipalities within 22 watersheds. Municipalities in Johnson County are required to implement stormwater management programs that reduce discharges of pollutants, protect water quality, and satisfy applicable water-quality regulations.

In 2015, the U.S. Geological Survey, in cooperation with the Johnson County Stormwater Management Program, began a 4-year monitoring program designed to meet new stormwater monitoring requirements for some municipalities in Johnson County. Additional data were collected to evaluate the usefulness of continuous water-quality monitoring and different sampling methods in assessing changes in water quality. Twelve of the 22 watersheds in the county were within the sampling network for this project.

Discrete water-quality samples were collected at 25 stream sites and 2 lake sites using passive, grab, and equal-width increment sampling methods. Samples at all sites were analyzed for nutrients, *Escherichia coli* bacteria, total suspended solids, and suspended-sediment concentration. Ninety-nine percent of storm-event samples and 98 percent of low-flow samples were less than the Kansas Surface Water Quality Standard for nitrate plus nitrite. Eight percent of storm-event samples and 100 percent of low-flow samples were less than the total suspended solids screening value of 50 milligrams per liter. Passive samples generally had higher concentrations when compared to equal-width increment and grab samples, and grab samples and equal-width increment samples generally had similar concentrations.

Continuous water-quality data were collected at one site. Ordinary least squares regression analysis was used to relate continuous (15-minute) water-quality sensor measurements to discretely sampled constituent concentrations at one site.

Numerous factors affect water quality in urban runoff. Urban areas have many possible contaminant sources, including municipal and industrial wastewater discharges, stormwater runoff from impervious surfaces, and failing infrastructure. A better understanding of these factors can inform future monitoring efforts, leading to datasets that are representative of storm runoff and can be used to detect differences between sites and over time.

Introduction

Stormwater discharges from municipalities are regulated by provisions in the Clean Water Act of 1972 (33 U.S.C. 1251 et seq.) to protect the Nation's water resources from harmful pollutants. Kansas municipalities with populations greater than 10,000 or within an urban area (as defined by the U.S. Census Bureau [2018]) are required to obtain stormwater discharge permits from the Kansas Department of Health and Environment (KDHE) to ensure that they are in compliance with State and Federal regulations for protecting water quality, including the U.S. Environmental Protection Agency's National Pollutant Discharge Elimination System (https://www.epa.gov/npdes; Kansas Department of Health and Environment, 2013). In 2014, the KDHE issued new stormwater discharge permits for 17 municipalities (not shown) in Johnson County, Kansas, in the northeastern part of the State (fig. 1). The county is largely suburban and has 20 municipalities within 22 watersheds (hydrologic unit code 12; Seaber and others, 1987). Twelve of the 22 watersheds in the county were within the sampling network for this project. Municipalities in Johnson County are required to implement stormwater management programs that reduce discharges of pollutants, protect water quality, and satisfy applicable water-quality regulations (Kansas Department of Health and Environment, 2016b). These requirements apply to all small municipal separate storm sewer systems in the county.

Nine of the 17 stormwater discharge permits also mandate that municipalities in Johnson County monitor water quality relative to water-quality impairments, total maximum daily loads (TMDLs) designated by the KDHE, or

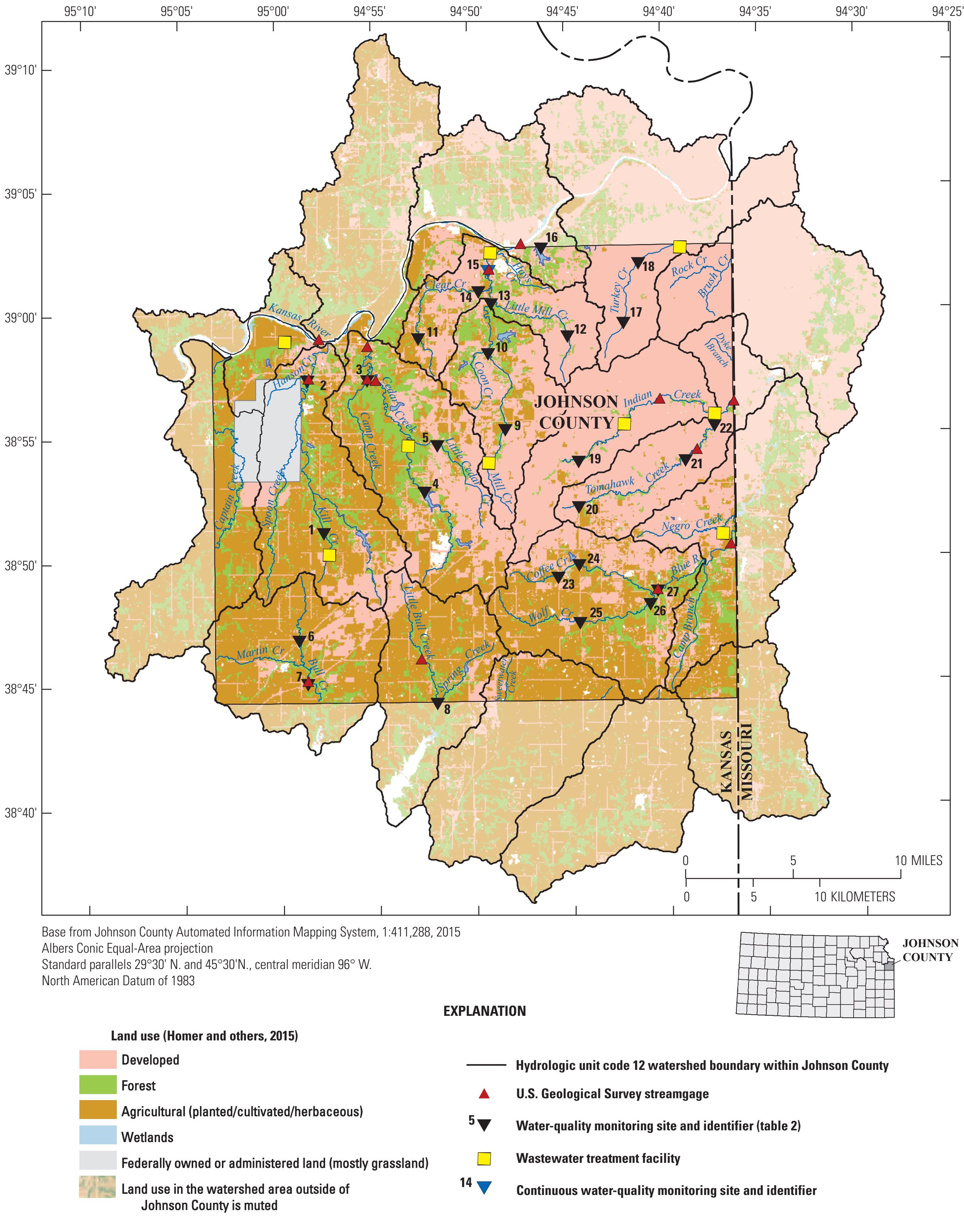

Figure 1. Study area, Johnson County, northeast Kansas.

both. Section 303(d) of the Clean Water Act requires States to identify water bodies with impaired water quality and the pollutants causing the impairments. A TMDL is the maximum amount of a pollutant allowed in a waterbody while still meeting water-quality standards (Kansas Department of Health and Environment, 2016a). TMDLs are developed for each impairment-causing pollutant to determine reduction targets and management plans for reducing pollutants. In 2014, 13 streams and 2 lakes in Johnson County had designated water-quality impairments, TMDLs with monitoring requirements, or both (table 1; Kansas Department of Health and Environment, 2012). The 13 streams and Lake Olathe (site 4, fig. 1) had designated water-quality impairments and TMDLs, and Quivira Lake (site 16, fig. 1) had only designated water-quality impairments. In Johnson County, water-quality impairments are primarily caused by excessive nutrients, sediment, and (or) bacteria (Kansas Department of Health and Environment, 2012).

The stormwater discharge permits with designated TMDLs require municipalities to install pollutant source controls, implement best management practices (BMPs), and monitor the effectiveness of the source controls and BMPs in achieving goals for pollution reduction (Kansas Department of Health and Environment, 2016b). Monitoring required by the permits is intended to assess change in the target waterbody resulting from BMP implementation through stormwater management programs (Kansas Department of Health and Environment, 2013). At a minimum, municipalities are required to collect grab samples at stream locations entering and leaving their jurisdictional areas during the rising stage of four runoff events annually, generally between March 1 and October 31. Qualifying runoff events are defined as those resulting from at least 0.5 inch of precipitation during a 24-hour period.

In 2015, the U.S. Geological Survey (USGS), in cooperation with the Johnson County Stormwater Management Program, began a 4-year monitoring program designed to meet stormwater monitoring requirements for municipalities in Johnson County including sampling frequency and sampling conditions described in stormwater discharge permits. Additional data were collected to evaluate the usefulness of continuous water-quality monitoring and different sampling methods in assessing changes in water quality. The municipal-boundary based monitoring program used during 2015–18 was replaced with a watershed-based program in 2019.

Purpose and Scope

The purpose of this report is to describe results of the 4-year monitoring program implemented in 2015 by the USGS, in cooperation with the Johnson County Stormwater Management Program, to help municipalities monitor water-quality constituents regulated by TMDLs and to evaluate the utility of the monitoring data in assessing water-quality improvements. Additional continuous and method-comparison data were collected to help evaluate the utility of different monitoring approaches in assessing water-quality changes. Nationally, the methods and results presented in this report can provide perspective and guidance for future investigations studying water-quality constituents monitored for TMDLs and for investigations comparing water-quality monitoring approaches.

Throughout the 4-year monitoring program, discrete water-quality samples were collected at 25 stream sites and 2 lake sites and were analyzed for nutrients, *Escherichia coli* (*E. coli*) bacteria, total suspended solids (TSS), and suspended-sediment concentration. Samples were generally

Table 1. Municipalities, water bodies, and pollutants causing water-quality impairments in streams and lakes in Johnson County, Kansas.

Municipality	Waterbody (fig. 1)	Pollutant causing water-quality impairment
Gardner	Kill Creek	Bacteria
Johnson County (unincorporated)	Camp Creek	Sediment, bacteria, and nutrients
	Kill Creek	Sediment, bacteria, and nutrients
	Big Bull Creek	Nutrients
	Little Bull Creek	Nutrients
	Coffee Creek	Sediment, bacteria, and nutrients
	Wolf Creek	Sediment, bacteria, and nutrients
Lake Quivira	Quivira Lake	Nutrients
Leawood	Tomahawk Creek	Bacteria
Lenexa	Little Mill Creek	Sediment, bacteria, and nutrients
	Clear Creek	Sediment, bacteria, and nutrients
Merriam	Turkey Creek	Sediment, bacteria, and nutrients
Overland Park	Coffee Creek	Sediment, bacteria, and nutrients
	Wolf Creek	Sediment, bacteria, and nutrients
	Tomahawk Creek	Bacteria
Olathe	Mill Creek	Sediment, bacteria, and nutrients
	Little Cedar Creek	Bacteria
	Olathe Lake	Nutrients
Shawnee	Little Mill Creek	Sediment, bacteria, and nutrients
	Clear Creek	Sediment, bacteria, and nutrients

collected during the spring, summer, and early autumn (March 1 through October 31). Discrete water-quality samples collected at the two lake sites also were analyzed for chlorophyll. Continuous water-quality data (water temperature, specific conductance, pH, dissolved oxygen, turbidity, and nitrate plus nitrite) were collected at one of the stream sites to characterize variability and to provide a basis for comparison to discrete data.

Previous Studies

Several previous USGS studies have evaluated water quality in Johnson County (Lee and others, 2005; Wilkison and others, 2009; Lee and Ziegler, 2010; Graham and others, 2010, 2014; Rasmussen and others, 2012; Rasmussen and Gatotho, 2014; Rasmussen and Paxson, 2017). Lee and others (2005) investigated effects of land use and of point and nonpoint contaminant sources on streams using data collected from 2002 to 2004. Results indicated that the occurrence and magnitude of numerous potential water-quality contaminants originating from nonpoint sources were affected by land use and seasonality. Generally, stormwater samples had higher nutrient concentrations than base-flow samples in Johnson County streams except for samples from sites near wastewater treatment facility (WWTF) discharges.

Wilkison and others (2009) characterized water-quality and ecological character and trends in the metropolitan Blue River Basin between 1998 and 2007. Sites with increased urbanization typically had higher bacteria densities, and nonpoint-source runoff was almost entirely the source of bacteria loadings to the Blue River and Indian Creek.

Effects of wastewater effluent on receiving streams were assessed by Graham and others (2010) for the Blue River and by Graham and others (2014) for Indian Creek. In both studies, upgrades to WWTFs improved wastewater effluent quality, but the effluent still had negative effects on environmental and biological water-quality conditions at downstream sites. In the Blue River downstream from the WWTF, ecosystem functional stream health was not impaired during most of the year (Graham and others, 2010). In Indian Creek, wastewater effluent caused persistent adverse changes in functional stream health at sites immediately downstream from the WWTF effluent discharges, but some recovery to conditions similar to the urban site upstream from the WWTF occurred over a relatively short distance, about 6 miles (Graham and others, 2014).

Rasmussen and others (2012) described stream quality in Johnson County using the quality of aquatic biological communities between 2002 and 2010. Aquatic biological community quality was correlated with urban land use; the least-disturbed streams were in rural areas of the county. Percent impervious surface and percent urban land use were consistently highly negatively correlated with biological conditions. Density of stormwater outfall points next to streams was significantly negatively correlated with biological conditions. The fundamental factor causing decline in stream quality was consistently determined to be general urbanization, measured by impervious surface area or urban land use.

Rasmussen and Gatotho (2014) developed regression models for chloride, suspended-sediment concentration, total nitrogen, total phosphorus, and *E. coli* bacteria in five Johnson County watersheds using discrete and continuous water-quality data collected between 2003 and 2011. Streamflow conditions, amount of urbanization, and relative contributions from WWTFs and stormwater runoff in the watershed were important for estimating water quality.

Rasmussen and Paxson (2017) provided a preliminary assessment of this 4-year TMDL monitoring program using water-quality data collected from January 2015 through June 2016. They described valuable and limiting attributes of the monitoring program design and the program's efficacy in providing sufficient data to quantify changes in water quality resulting from implemented and planned BMPs.

Study Area

Johnson County has an area of 477 square miles (mi^2) in northeast Kansas (fig. 1), shares a State border with Missouri, and is part of the Kansas City metropolitan area (not shown). The water-quality network for this 4-year monitoring program consisted of 25 stream sites and 2 lake sites across Johnson County (sites 1–27; fig. 1; table 2). Sites in the water-quality network were selected to intersect municipal boundaries and to use established sampling sites from previous USGS studies for historical context. Site access, site conditions, and suitability for sampling also were considered. One site (Indian Creek at Pflumm Road; site 19, fig. 1, table 2) was removed from the network after the first year of data collection when that stream segment was not included in the final TMDL listing. Two sites (Kill Creek at 151st Street and Quivira Lake near Lake Quivira; sites 1 and 16, respectively, fig. 1, table 2) were added after the first year of data collection. All stream sites were at road or pedestrian bridges.

Land use varies from rural (agricultural) in the western part of the county to highly urbanized (developed) in the northeastern part of the county (fig. 1, table 3; Homer and others, 2015). The gray box in the northwestern corner of Johnson County (fig. 1) is the former Sunflower Army Ammunition Plant, which is owned by the U.S. Government and is currently (2021) mostly grassland. The county contains all or part of 22 watersheds, 12 of which were within the sampling network for this project. The sampled watersheds are the (Big) Bull Creek, Blue River, Cedar Creek (includes Camp Creek), Clear Creek, Indian Creek, Kansas River (Quivira Lake site), Kill Creek, Little Bull Creek, Little Mill Creek, Mill Creek, Tomahawk Creek, and Turkey Creek watersheds. Mean annual precipitation (1981–2010) is 40.9 inches; 83 percent (33.9 inches) of that precipitation occurred during the sampling period outlined in the permits, March 1 through October 31 (PRISM Climate Group, 2019).

Table 2. Water-quality monitoring sites in Johnson County, Kansas.

[Station data are from the National Water Information System database (U.S. Geological Survey, 2019b)]

Site number (fig. 1)	Station identification number	Station name	Drainage area, in square miles
1	385118094575700	Kill Creek at 151st Street near Gardner, Kansas	5.76
2	06892360	Kill Creek at 95th Street near DeSoto, Kansas	53.4
3	06892494	Camp Creek at 95th Street near DeSoto, Kansas	9.00
4	06892450	Olathe Lake near Olathe, Kansas	17.0
5	385445094514700	Little Cedar Creek at 119th Street, Olathe, Kansas	6.85
6	384656094590400	Big Bull Creek at 191st Street, Edgerton, Kansas	4.91
7	06914950	Big Bull Creek near Edgerton, Kansas (I–35)	28.7
8	384419094515600	Little Bull Creek near 215th Street, Johnson County, Kansas	16.6
9	385523094481500	Mill Creek near 114th Street, Olathe, Kansas	8.47
10	385827094490500	Mill Creek at 85th Street, Lenexa, Kansas	25.7
11	385906094524400	Clear Creek at 79th Street, Lenexa, Kansas	2.68
12	385908094445900	Little Mill Creek at 79th Street, Lenexa, Kansas	4.44
13	390026094485300	Little Mill Creek near Midland Road, Shawnee, Kansas	12.9
14	390056094493200	Clear Creek at Woodland Road, Shawnee, Kansas	10.9
15[a]	06892513	Mill Creek at Johnson Drive, Shawnee, Kansas	58.1
16	390242094461500	Quivira Lake near Lake Quivira, Kansas	4.52
17	385937094420300	Turkey Creek near 85th Street, Overland Park, Kansas	4.49
18	390201094411500	Turkey Creek at Antioch, Overland Park, Kansas	14.3
19	385403094443200	Indian Creek at Pflumm Road near Overland Park, Kansas	10.9
20	385213094443200	Tomahawk Creek at Pflumm Road, Overland Park, Kansas	1.65
21	385401094385600	Tomahawk Creek at Nall Avenue, Leawood, Kansas	18.1
22[b]	385539094372100	Tomahawk Creek near 111th Street, Johnson County, Kansas	23.4
23	384922094454000	Coffee Creek at Lackman Road, Olathe, Kansas	3.57
24	384951094443200	Coffee Creek at Pflumm Road, Johnson County, Kansas	7.55
25	384732094443200	Wolf Creek at Pflumm Road, Johnson County, Kansas	10.0
26[b]	384813094405300	Wolf Creek at 179th Street, Overland Park, Kansas	28.7
27	06893080	Blue River near Stanley, Kansas	46.0

[a]Indicates site with continuous water-quality monitors and method-comparison samples.

[b]Indicates sites with method-comparison samples.

Methods

The monitoring program was designed with the primary goal of meeting minimum sampling requirements for those municipalities with monitoring requirements as described in stormwater discharge permits. Sites were selected by the USGS and the Johnson County Stormwater Management Program with input from the KDHE. Because stormwater discharge permits are assigned to each municipality, emphasis for site selection was placed on municipal boundaries. TMDLs apply to stream segments within each municipality. Discrete water-quality samples were collected at 25 stream sites and 2 lake sites (fig. 1). Continuous (15-minute) water-quality data were collected at one of the stream sites (site 15). Streamflow data were collected at most of the stream sites. Precipitation amounts for the 24 hours preceding discrete sample collection was determined using data from the StormWatch website (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018). Additional method-comparison data were collected at three stream sites to describe possible limitations of the data required by the stormwater discharge permits. Surrogate regression models were developed to compute continuous concentrations and loads for constituents of interest at the continuous monitoring site.

Table 3. Land use and mean precipitation by watershed in Johnson County, Kansas.

[Land-use data are from Homer and others (2015); precipitation data are from PRISM Climate Group (2019)]

Watershed	Land use, in percent						Mean annual precipitation, in inches
	Developed	Planted/cultivated	Herbaceous	Forest	Water	Wetlands	
(Big) Bull Creek	15.5	75.9	0.9	6.2	0.7	0.4	40.5
Little Bull Creek	22.8	68.5	0.4	5.4	0.6	1.9	40.8
Blue River	26.6	59.7	1.4	10.3	1.2	0.3	41.5
Kill Creek	33.3	50.6	1.9	12.4	0.9	0.3	40.3
Cedar Creek[a]	35.1	40.7	2.7	18.3	1.3	0.4	40.6
Lake Quivira	62.0	5.7	4.0	20.8	6.0	0.7	40.5
Mill Creek[b]	64.3	20.0	2.2	11.2	0.8	0.2	40.6
Indian Creek[c]	92.1	4.7	0.4	2.4	0.1	0.2	40.9
Turkey Creek	97.8	0.4	0.1	1.3	0.0	0.1	40.4

[a]Includes Camp Creek.

[b]Includes Clear Creek and Little Mill Creek.

[c]Includes Tomahawk Creek.

Discrete Water-Quality Data Collection

Discrete water-quality samples were collected at 25 stream sites and 2 lake sites using passive, grab, and equal-width increment (EWI) sampling methods (U.S. Geological Survey, 2006). Passive samplers were installed at stream sites with the goal of collecting at least four storm-event samples each calendar year from each site during the rising limb of the hydrograph after 0.5-inch precipitation events. Storm-event samples were also collected from stream sites using grab samples. At Olathe Lake (site 4, fig. 1) and Quivira Lake (site 16, fig. 1), grab samples were collected after dry-weather (no rainfall) periods of at least 10 days. Lake sample collection was delayed to assess lake water quality resulting from storm runoff. One low-flow sample was collected annually at each site over a 2-day period of stable flow (no rainfall in the past 10 days) in late February or early March to identify sources other than storm runoff that may be contributing to contaminants in streams.

Passive sampling was the primary sample collection method used for this study. To construct the passive samplers, mounting tubes were attached to a carriage equipped with trolley wheels. Three Nalgene Storm Water Samplers were deployed in each carriage to collect an adequate volume of sample water for each passive sample. The carriage was lowered down an I-beam, resting at a fixed elevation that was submerged when stream stage (water elevation) increased. At most sites, the I-beam was vertical and spanned from the bridge deck to the streambed (fig. 2*B*); some sites had I-beams that were angled along the streambank (fig. 2*C*). The fixed elevation was expected to capture runoff generated from events producing at least 0.5 inch of rainfall in 24 hours. At two sites, Little Mill Creek at 79th Street (site 12, fig. 1) and Tomahawk Creek at Nall Avenue (site 21, fig. 1), secondary passive samplers were attached to T-posts in the streambed in 2018 after I-beams were removed from bridges or rendered unusable by stormflow.

During runoff events, water flowed through the collection funnel and filled the sample bottles. Once a sample bottle was full, the floating ball valve blocked the funnel opening and prevented further addition of ambient water to the sample water. Sample bottles were retrieved by hoisting the sampler carriage up to the bridge deck.

Passive sample bottles were collected and delivered to the laboratory as soon as practicable to ensure preservation or analysis within 24 hours of sample collection (American Public Health Association and others, 1995). The bottles in the passive sampler did not always fill consistently, and sample color sometimes differed between bottles. The field approach of this study did not allow for compositing and subsampling, and this is one of the limitations of the data. TSS and turbidity were analyzed from the first bottle, suspended sediment was analyzed from the second bottle, and bacteria and nutrients were analyzed from the third bottle.

Appropriate fixed elevations for passive samplers were determined based on historical rainfall and streamflow data from StormWatch (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018) and nearby existing USGS streamgages (fig. 1). StormWatch is a network of remote weather stations reporting real-time rainfall, stream stage, and (or) other data that are throughout the Kansas City metropolitan area (City of Overland Park, Kansas, 2020). Bolts were used as fixed elevation markers in each I-beam to ensure consistent sampler elevation after deployment. Because the

Figure 2. Water-quality sample collection. Photographs by the U.S. Geological Survey. *A*, Example of debris snag on I-beam that made passive sample collection impossible, Clear Creek at 79th Street (site 11, fig. 1). *B*, Continuous monitoring site Mill Creek at Johnson Drive (site 15, fig. 1). *C*, Angled sampler at Kill Creek at 151st Street (site 1, fig. 1). *D*, Hach Company Nitratax sensor (left) and Yellow Springs Instruments EXO2 multiparameter sonde (right). *E*, A variety of color is seen in sediment samples being shipped to the analyzing laboratory.

passive samplers were set at fixed elevations, samples were reliably collected on the rising limb of the hydrograph resulting from runoff events.

Discrete samples also were collected using grab sampling, dipping open containers into the stream or lake at a single point and time. During storm events, grab samples from streams were collected from the visual centroid of flow. Because of the relative ease and low cost of collection, grab samples are often the primary collection method used in municipal monitoring programs. Grab samples were used for data-collection method comparison at selected stream sites, in base-flow sampling at all sites, and to capture rising limbs during runoff events at stream sites where passive samplers had malfunctioned or been damaged. All lake site samples were collected as grab samples.

Finally, EWI collection methods (U.S. Geological Survey, 2006) were used to collect discrete data samples at three sites: Mill Creek at Johnson Drive, Tomahawk Creek near 111th Street, and Wolf Creek at 179th Street (sites 15, 22, and 26, respectively, fig. 1). These sites were selected for ease of access and because they represented different percentages of watershed development (table 3). EWI collection methods produce samples that are representative of the entire stream cross section. In addition to use in comparing discrete data-collection methods, at Mill Creek at Johnson Drive (site 15, fig. 1), data from EWI samples also were used to develop surrogate regression models (for example, Rasmussen and others, 2008, and Rasmussen and Gatotho, 2014) that compute concentrations of constituents of interest using continuously monitored data. For data-collection method comparison samples, grab and EWI samples were collected as near in time as possible (within 15 minutes) to the passive sample. The surrogate models were developed using only samples collected using EWI methods.

At all 27 sites in the monitoring network, discrete samples were analyzed for nutrients (dissolved phosphorus, total phosphorus, dissolved orthophosphate, dissolved nitrate plus nitrite, and total Kjeldahl nitrogen [TKN, also known as total ammonia plus organic nitrogen]), *E. coli*, and TSS. These analytes were commonly included in the 303(d) list of pollutants causing impairments in waterbodies in Johnson County (Kansas Department of Health and Environment, 2012; table 1) and requiring monitoring according to permits. Suspended sediment also was analyzed because it is more reliable than TSS for quantifying solids in natural water (Gray and others, 2000). An additional permit requirement for the Olathe Lake and Quivira Lake sites was the collection of chlorophyll samples. Not all sites were listed as impaired for all constituents (table 1), but all constituents were included for all sites to simplify sampling methods and to provide a more complete and consistent evaluation of pollutant occurrence.

Samples were primarily analyzed for nutrients and bacteria by the Johnson County Water Quality Laboratory (JCWQL) in Olathe, Kans., in accordance with standard methods (table 4). The USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, also analyzed samples for nutrients according to standard methods (table 4). For samples analyzed for nutrients by the NWQL, the USGS Kansas Water Science Center in Lawrence, Kans., analyzed *E. coli* densities (table 4). The USGS Iowa Sediment Laboratory in Iowa City, Iowa, analyzed suspended-sediment samples (table 4). The NWQL also analyzed the chlorophyll samples collected from Olathe Lake and Quivira Lake (table 4).

Method-comparison data were collected at Mill Creek at Johnson Drive (site 15, fig. 1), Tomahawk Creek near 111th Street (site 22, fig. 1), and Wolf Creek at 179th Street (site 26, fig. 1). For method comparison, at least two of the three sample types (passive, grab, and EWI) were collected nearly concurrently. Mill Creek at Johnson Drive (site 15, fig. 1) had the most comprehensive data-collection approach consisting of continuous water-quality data in addition to the passive, grab, and EWI samples.

USGS protocols and procedures (U.S. Geological Survey, variously dated) were followed for cleaning equipment, collecting field measurements and samples, and processing samples. Samples were delivered to and processed by the lab providing analysis for samples analyzed by the JCWQL and the USGS Iowa Sediment Laboratory. Samples were processed by the USGS Kansas Water Science Center in the science center's laboratory for samples analyzed by the NWQL. Data were routinely compiled, reviewed, and evaluated in accordance with USGS Kansas Water Science Center procedures (Rasmussen and others, 2014). Data were entered into the USGS National Water Information System database (U.S. Geological Survey, 2019b) and can be accessed from the database by using the station identification numbers in table 2.

Continuous Water-Quality Monitoring

At Mill Creek at Johnson Drive in Shawnee, Kans. (site 15, fig. 1), an existing streamgage and previous water-quality monitoring site (October 2002 to May 2009), a continuous, real-time multiparameter sonde, and a continuous, real-time nitrate sensor were deployed to evaluate water-quality variability and pollutant loading. Measurements from both instruments were recorded every 15 minutes and transmitted hourly. The Yellow Springs Instruments EXO2 multiparameter sonde measured water temperature, pH, dissolved oxygen, specific conductance, and turbidity (Yellow Springs Instruments, 2017) and was installed in October 2014. The nitrate sensor was a Hach Company Nitratax that measured nitrate plus nitrite (Hach Company, 2012) and was installed in November 2014. The Nitratax primarily measured nitrate because the nitrite concentration is generally considered negligible in most surface waters (Pellerin and others, 2013) and in Johnson County streams (Rasmussen and others, 2012).

Both monitors were operated according to standard USGS procedures (Wagner and others, 2006; Pellerin and others, 2013; Bennett and others, 2014). The continuous nitrate plus nitrite data have not been corrected for interference because the mean bias correction calculated according to Pellerin and others (2013) was positive 0.26 milligram per liter as nitrogen (mg/L–N), which is within the manufacturer-stated measuring error of the device: 3 percent of reading or plus or minus 0.5 mg/L–N, whichever is greater (Hach Company, 2012). Data from both monitors were entered into the USGS National Water Information System database (U.S. Geological Survey, 2019b).

Unit values may be missing from the record because of equipment malfunction, ice, or other factors. Over the study period, less than 7 percent of unit-value data were unavailable from the EXO2 monitor parameters (table 5). About 15 percent of data from the Nitratax were unavailable (table 5). Missing water-quality data were not estimated.

Streamflow Measurement and Estimation

Stream stage (also called gage height) was collected at all sites and used to determine the time of collection for the passive samplers and calculate streamflow. Streamflow data are required by the stormwater discharge permits and are used with concentration values to calculate loads. At existing USGS streamgages, stage and streamflow were measured and reported according to standard USGS procedures

Table 4. Laboratory method information for constituents analyzed in Johnson County, Kansas, 2015–18.

[JCWQL, Johnson County Water Quality Laboratory; NWQL, U.S. Geological Survey National Water Quality Laboratory; KSWSC, U.S. Geological Survey Kansas Water Science Center; IASED, U.S. Geological Survey Iowa Sediment Laboratory]

Constituent type	Method	Laboratory
Nutrients[1]	American Public Health Association and others (1995)	JCWQL
Nutrients	American Public Health Association and others (1995); Fishman and Friedman (1989); Patton and Truitt (1992, 2000); Fishman (1993); and Patton and Kryskalla (2011)	NWQL
Escherichia coli[1]	Standard Methods for the Examination of Water and Wastewater (2017)	JCWQL
Escherichia coli	Myers and others (2014)	KSWSC
Suspended sediment	Guy (1969)	IASED
Chlorophyll-*a* and pheophytin-*a*	Arar and Collins (1997)	NWQL

[1]Indicates primary analysis method and laboratory.

(Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015). At stream sites without existing USGS streamgages, streamflow was estimated based on static stage-discharge ratings developed for each site using the step-backwater methods as described in Bailey and Ray (1967), Davidian (1984), and Painter and Loving (2015). More detailed methods for stream stage and streamflow measurement and estimation are in appendix 1.

Precipitation Estimation

Precipitation data from the StormWatch website (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018) were used to determine if the precipitation threshold for the stormwater discharge permits (0.5 inch in 24 hours before sample collection) was met at either the precipitation gage closest to the monitoring site or at a precipitation gage upstream from the monitoring site. Preceding precipitation data for storm-event discrete samples are available in Leiker and others (2021).

Model Development and Computation of Loads

At one site, Mill Creek at Johnson Drive (site 15, fig. 1), ordinary least squares regression analysis was used to relate continuous (15-minute) water-quality sensor measurements to discretely sampled constituent concentrations. Surrogate regression models that define relations between *in situ* continuously measured parameters and laboratory-analyzed discrete data make possible continuous real-time estimates of particular constituents of interest. Models for total nitrogen, *E. coli*, TSS, and suspended sediment were developed to compute continuous estimates of constituent concentrations and loads and to compare variability documented using continuous data to variability documented using discrete data. The surrogate regression models and summary statistics are summarized

Table 5. Summary of continuous water-quality data from Mill Creek at Johnson Drive, Shawnee, Kansas, January 2015 through December 2018.

Water-quality parameter	Maximum	Minimum	Mean	Median	Percentage of missing unit values
Streamflow, in cubic feet per second	11,900	2.5	78.2	17.5	3.5
Water temperature, in degrees Celsius	33.4	0	15.3	15.9	2.2
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	4,800	86	926	869	4.0
pH, in standard units	9.0	7.2	8.0	8.0	4.9
Dissolved oxygen, in milligrams per liter	22.5	3.0	10.7	9.7	5.2
Turbidity, in formazin nephelometric units	1,310	0.5	18.5	6.4	6.4
Nitrate plus nitrite, in milligrams per liter as nitrogen	9.65	<0.1[a]	1.89	1.44	15.5

[a]Lower detection limit for Nitratax *plus* sc (Hach Company, 2012).

in table 6, and additional model development procedures, diagnostic plots, and summary statistics are provided in the model archive summaries (apps. 2–5). Only discrete sample data collected between March 2015 and October 2018 using the EWI method were used in regression analyses for model development.

Loads were estimated to provide an indication of mass transport of a constituent during a specified time. Continuous (15-minute) water-quality sensor measurements were first averaged into hourly values. The hourly mean water-quality sensor measurements were used to calculate the hourly mean concentration of each modeled constituent. The hourly mean concentration of each modeled constituent was multiplied by the hourly mean streamflow and a conversion factor to produce the hourly load. The models were developed for the selected analytes based on continuous measurements of turbidity, nitrate plus nitrite, and streamflow (apps. 2–5). Daily loads were calculated by summing hourly loads, and annual loads were calculated by summing daily loads.

There were periods of time in which hourly averaged water-quality sensor measurements were missing because of factors such as equipment malfunctions, ice, and backwater conditions. Because a load could not be calculated when continuous data were missing, streamflow, turbidity, and nitrate plus nitrite were estimated to fill in the gaps for load calculation purposes only. During periods of missing data lasting 5 hours or fewer, missing streamflow, turbidity, and nitrate plus nitrite values were estimated by interpolating between the measured values bracketing the missing period. During periods of missing streamflow data lasting more than 5 hours, the daily streamflow value was used as the hourly value for the whole day. In almost all cases (14 of 16 days), periods of missing streamflow data lasting more than 5 hours occurred during stable stream stage conditions; the lone exception is from May 28 to 29, 2016. During periods of missing turbidity and nitrate plus nitrite data lasting more than 5 hours during stable conditions, turbidity and nitrate plus nitrite were estimated by interpolating between the measured values bracketing the missing period only if deemed appropriate based on streamflow and other water-quality parameter data. If not appropriate, missing data were not estimated.

Estimating water-quality and streamflow data reduced the missing hourly loads of *E. coli*, TSS, and suspended sediment (which are calculated using only streamflow and turbidity data) from 5.5 percent to 1.7 percent. Most (511 of 595, 86 percent) missing loads occurred during stable conditions, and only 14 percent (*n*=84) of missing hourly loads occurred during runoff events with changing conditions. Specifically, 32 missing hourly loads were during much-above-normal (greater than 90th percentile) streamflow conditions, and the other 52 were during above-normal (between 76th and 90th percentiles) streamflow conditions. Annual loads of *E. coli*, TSS, and suspended sediment are likely a slight underestimate of actual loads, but this difference is assumed to be negligible because only 1.7 percent of data are missing, and an even smaller percentage of these were stormflows.

Estimating water-quality and streamflow data reduced the missing hourly loads of total nitrogen (which are calculated using streamflow, turbidity, and nitrate plus nitrite data) from 15.2 percent to 9.5 percent. About 32 percent (1,068 of 3,328) of missing hourly loads for total nitrogen occurred during runoff events with changing conditions. Of the 1,068 missing hourly loads that occurred during runoff events with changing conditions, 330 were during much-above-normal (greater than 90th percentile) streamflow conditions, 541 were during above-normal (between 75th and 90th percentiles) streamflow conditions, 193 were during normal (between 25th and 75th percentiles) streamflow conditions, 3 were during below-normal (between 10th and 25th percentiles) streamflow conditions, and 1 was during much-below-normal (less than 10th percentile) streamflow conditions. Because about 10 percent of hourly loads are missing, and most (871 of 1,068, 82 percent) were during high (greater than 75th percentile) streamflow conditions, the annual total nitrogen loads may underestimate actual loads.

Quality Assurance and Quality Control

Quality-assurance and quality-control methods and procedures followed USGS policies and USGS Kansas Water Science Center quality-assurance plans (U.S. Geological Survey, 2006; Rasmussen and others, 2014; Painter and Loving, 2015). The JCWQL provided the primary analyses and is accredited by The NELAC Institute (2016). Since 2002, the JCWQL has analyzed water-quality samples for USGS cooperative projects and has participated in the USGS standard reference sample program (U.S. Geological Survey, undated).

About 10 percent of all discrete samples collected were quality-control samples used to assess the integrity of the water-quality data analyzed in this report. Concurrent and sequential replicates collected using the same method were analyzed to determine bias and variability in sampling methods. During the study period, 26 replicate pairs were analyzed for nutrients, 20 replicate pairs were analyzed for *E. coli* bacteria, 29 replicate pairs were analyzed for TSS, and 25 replicate pairs were analyzed for suspended sediment (tables 7, 8).

For replicate sample pairs without left-censored data (concentrations or bacteria densities less than the reporting limit), relative percent difference (RPD) was used to evaluate differences between replicate samples (table 7). RPD is calculated by dividing the absolute difference between the replicate values by the mean of the replicate values and multiplying by 100. The mean and median RPD were largest for *E. coli* and smallest for nutrients. Median RPDs were acceptable to meet project objectives.

To evaluate replicate sample pairs with at least one left-censored result (less than the reporting limit), results were designated as either “matched” or “unmatched.” To “match,” either both results in the replicate pair were censored or one was uncensored and below the reporting limit of the other (for

Table 6. Surrogate regression models and summary statistics for estimating concentrations and densities of selected constituents using continuously measured parameters, Mill Creek at Johnson Drive in Shawnee, Kansas, 2015–18.

[Adj. R^2, adjusted coefficient of determination; RMSE, root mean square error; *n*, number of discrete samples used in model development; *TN*, total nitrogen, in milligrams per liter as nitrogen; *TBY*, continuous turbidity values, in formazin nephelometric units; NO_x, continuous nitrate values, in milligrams per liter as nitrogen; *ECB*, *Escherichia coli*, in most probable number per 100 milliliters or colony forming units per 100 milliliters; *TSS*, total suspended solids, in milligrams per liter; *SS*, suspended sediment, in milligrams per liter; --, not applicable]

Modeled constituent	Regression model	Adj. R^2	RMSE	Bias correction factor	Range of values in modeled dataset	Discrete samples			
						n	Range	Mean	Median
Total nitrogen (*TN*)	$TN = 0.00594 \times TBY + 1.26 \times NO_x + 0.0759$	0.906	0.574	--	0.13–12.29	32	0.9–9.7	2.8	2.2
E. coli (*ECB*)	$\log_{10}(ECB) = 1.34 \times \log_{10}(TBY) + 0.79$	0.830	0.468	1.56	1–48,539	34	3–36,000	5,205	450
Total suspended solids (*TSS*)	$\log_{10}(TSS) = 1.05 \times \log_{10}(TBY) + 0.339$	0.937	0.212	1.12	1–4,384	36	5–3,130	379	44
Suspended sediment (*SS*)	$\log_{10}(SS) = 1.09 \times \log_{10}(TBY) + 0.345$	0.912	0.258	1.18	1–6,239	35	1–3,640	453	66

Table 7. Summary of relative percentage difference for same-sampling-method replicate sample pairs without censored data.

[mg/L–N, milligram per liter as nitrogen; mg/L–P, milligram per liter as phosphorus; *E. coli*, *Escherichia coli*; MPN/100 mL, most probable number per 100 milliliters; CFU/100 mL, colony forming unit per 100 milliliters; mg/L, milligram per liter]

Constituent, unit	Total replicate pairs	Uncensored replicate pairs	Relative percent difference			
			Minimum	Maximum	Mean	Median
Total Kjeldahl nitrogen, in mg/L–N	26	18	0.0	66.7	21.3	14.4
Dissolved nitrate plus nitrite, in mg/L–N	26	18	0.0	94.7	18.9	7.6
Dissolved orthophosphate, in mg/L–P	26	6	4.1	19.7	15.1	16.9
Total phosphorus, in mg/L–P	26	16	0.0	80.0	23.8	11.0
E. coli, in MPN/100 mL or CFU/100 mL	20	16	18.8	143.8	53.0	41.3
Total suspended solids, in mg/L	29	19	0.0	136.8	36.5	18.2
Suspended-sediment concentration, in mg/L	25	25	0.0	90.9	24.6	22.2

Table 8. Summary of same-method replicate sample pair results with at least one left-censored result.

[*n*, number of replicate pairs; mg/L–N, milligram per liter as nitrogen; mg/L–P, milligram per liter as phosphorus; *E. coli*, *Escherichia coli*; MPN/100 mL, most probable number per 100 milliliters; CFU/100 mL, colony forming unit per 100 milliliters; mg/L, milligram per liter]

Constituent	*n*	Matched	Unmatched
Total Kjeldahl nitrogen, in mg/L–N	8	4	4
Dissolved nitrate plus nitrite, in mg/L–N	8	5	3
Dissolved orthophosphate, in mg/L–P	20	17	3
Total phosphorus, in mg/L–P	10	7	3
E. coli, in MPN/100 mL or CFU/100 mL	4	2	2
Total suspended solids, in mg/L	10	8	2

example, a value of less than 0.5 milligram per liter [mg/L] and a value of 0.29 mg/L). "Unmatched" pairs are those for which one value was censored and the uncensored value was greater than the reporting limit of the other (for example, a value of less than 15 mg/L and a value of 17 mg/L). Orthophosphate had the most replicate pairs with at least one censored result, and suspended sediment had none. There were generally more matched pairs than unmatched pairs (table 8).

Fourteen field blanks were collected at sampling sites, and one equipment blank was collected in the Kansas Water Science Center laboratory using sampling equipment unexposed to field conditions to identify and document possible sample contamination or bias caused by incomplete cleaning or sterilization (for bacteria samples) of sampling equipment, field collection methods, or sample analysis methods. Eighteen ambient blanks were collected at sampling sites using sampling equipment exposed to dry (no precipitation) field conditions for 2–16 days and analyzed to identify and document possible sample contamination or bias resulting from deployment of passive samplers before expected rainfall. A total of 33 blank samples (14 field blanks, 1 equipment blank, and 18 ambient blanks) were analyzed for nutrients and TSS, and 30 blank samples were analyzed for *E. coli* (table 9). No blank samples were analyzed for suspended sediment. Two blank samples had detections of TKN, seven blank samples had detections of dissolved nitrate plus nitrite, and two blank samples had detections of total phosphorus. No blank samples had detections of dissolved orthophosphate, *E. coli*, or TSS.

The 18 ambient blank samples exposed to sampling site conditions for 2–16 days had no detections of TSS, nutrients, or *E. coli* (table 10). Six of the 14 field blanks (which did not sit in the samplers) and the 1 equipment blank had detections of nitrate plus nitrite. The maximum value of nitrate plus nitrite detected in the field blanks was 0.28 mg/L; the other five field blanks and the one equipment blank detections were 0.07 mg/L or less.

Method-Comparison Replicate Samples

Nine method-comparison replicate sample sets were collected: six at Mill Creek at Johnson Drive (site 15, fig. 1), two at Tomahawk Creek near 111th Street (site 22, fig. 1), and one at Wolf Creek at 179th Street (site 26, fig. 1). Seven of the nine method-comparison replicate sample sets were collected during storm events, and the other two were collected during routine, low-flow conditions. For the sample sets collected during storm events, two were collected during the rising limb of the hydrograph, and five were collected during the falling limb of the hydrograph. Among the sample sets, there were nine comparisons between EWI and grab samples, three comparisons between EWI and passive samples, and three comparisons between passive and grab samples. The method-comparison sample size is small because time constraints caused collection of permit samples to be prioritized over collection of method-comparison samples.

Table 9. Summary of field blank, equipment blank, and ambient blank sample detections, by constituent.

[*n*, number of blank samples; Detections, number of blank samples with a detection; Max, maximum concentration detected; mg/L–N, milligram per liter as nitrogen; mg/L–P, milligram per liter as phosphorus; *E. coli*, *Escherichia coli*; MPN/100 mL, most probable number per 100 milliliters; CFU/100 mL, colony forming unit per 100 milliliters; mg/L, milligram per liter; --, not applicable]

Constituent	*n*	Detections	Max
Total Kjeldahl nitrogen, in mg/L–N	33	2	1.1
Dissolved nitrate plus nitrite, in mg/L–N	33	7	0.28
Dissolved orthophosphate, in mg/L–P	33	0	--
Total phosphorus, in mg/L–P	33	2	0.05
E. coli, in MPN/100 mL or CFU/100 mL	30	0	--
Total suspended solids, in mg/L	33	0	--

The RPD was calculated between all sample pairs in replicate sample sets. For example, if a sample set contained a passive, grab, and EWI sample, three RPDs were calculated: between the passive sample and grab sample results, between the grab sample and EWI sample results, and between the passive and EWI sample results. In method-comparison replicate samples, the median RPDs ranged from 7.7 to 31.3 percent (table 11).

Although the sample size was small, the method comparisons were informative. Concentrations between replicates were compared by plotting the replicate sample concentrations against each other by sampling method and comparing to a 1:1 line. Data points close to the 1:1 line had similar concentrations between replicates. Data points above the 1:1 line indicated that the sampling method on the vertical axis had a higher concentration than the sampling method on the horizontal axis, and data points below the 1:1 line indicated that the sampling method on the horizontal axis had a higher

Table 10. Summary of field blank, equipment blank, and ambient blank sample detections, by blank sample type.

[*n*, number of blank samples; Detections, number of blank samples with a detection; TKN, total Kjeldahl nitrogen; NO_2+NO_3, dissolved nitrate plus nitrite; Ortho-P, dissolved orthophosphate; TP, total phosphorus; ECB, *Escherichia coli*; TSS, total suspended solids]

Blank type	*n*	Detections					
		TKN	NO_2+NO_3	Ortho-P	TP	ECB	TSS
Ambient blank, sat in sampler 2–16 days	18	0	0	0	0	0	0
Field blank, collected at sampling site, did not sit in sampler	14	2	6	0	2	0	0
Equipment blank, collected in lab, did not sit in sampler	1	0	1	0	0	0	0

Table 11. Summary of relative percentage difference of replicate pairs with different sampling methods without censored data.

[*n*, number of replicate pairs; mg/L–N, milligram per liter as nitrogen; mg/L–P, milligram per liter as phosphorus; *E. coli*, *Escherichia coli*; MPN/100 mL, most probable number per 100 milliliters; CFU/100 mL, colony forming unit per 100 milliliters; mg/L, milligram per liter]

Constituent	*n*	Relative percent difference			
		Minimum	Maximum	Mean	Median
Total Kjeldahl nitrogen, in mg/L–N	17	0.0	49.2	15.3	9.5
Dissolved nitrate plus nitrite, in mg/L–N	17	0.0	18.6	8.2	7.7
Dissolved orthophosphate, in mg/L–P	10	0.0	28.2	11.2	8.9
Total phosphorus, in mg/L–P	17	0.0	48.8	16.8	11.4
E. coli, in MPN/100 mL or CFU/100 mL	13	3.7	58.8	19.6	19.2
Total suspended solids, in mg/L	15	1.5	63.8	26.1	20.4
Suspended-sediment concentration, in mg/L	14	0.4	83.4	30.1	31.3

concentration than the sampling method on the vertical axis. Replicate pairs with censored results were not included in the comparisons.

In the nine grab sample-EWI sample replicate comparisons, concentrations of nutrients (TKN, dissolved nitrate plus nitrite, dissolved orthophosphate, and total phosphorus), TSS, and suspended sediment were generally along the 1:1 line, signifying a similar concentration between replicates (figs. 3*A*, 3*B*). The largest differences were for TKN, but no bias for either sampling method was evident (fig. 3*A*). Densities of *E. coli* were generally along the 1:1 line at values less than 15,000 most probable number per 100 milliliters, but the two replicate sample sets above this value were farther from the 1:1 line, signifying dissimilar results between the two replicates (fig. 3*C*). Similar results between the two sampling methods indicate that the streams were generally well-mixed at the centroid of flow when the grab samples were collected.

In the three passive sample-EWI sample replicate comparisons, data points were generally above the 1:1 line for nutrients, TSS, suspended sediment, and *E. coli* (fig. 4), indicating that the densities in the passive sample was higher than the concentration in the EWI sample. This was especially evident in the TSS and suspended-sediment comparisons (fig. 4*B*). Concentrations may have been higher in passive samples because they were collected near the streambank, whereas EWI samples were collected at multiple points along the stream cross section and composited.

In the three passive sample-grab sample replicate comparisons, dissolved nutrient concentrations (nitrate plus nitrite and orthophosphate) were similar between replicates, and total nutrient concentrations (TKN and total phosphorus) were either similar between replicates or higher in the passive sample (fig. 5*A*). Concentrations of TSS, suspended sediment, and *E. coli* were always higher in the passive sample than the grab sample (figs. 5*B*, 5*C*). Concentrations may have been higher in passive samples because they were collected near the streambank, whereas grab samples were collected from the centroid of flow, generally near the middle of the stream.

Passive samples generally had higher concentrations when compared to EWI and grab samples, and grab samples and EWI samples generally had similar concentrations. Stream mixing dynamics may play a role in concentrations at the stream bank (passive samples), at the centroid of flow (grab samples), and composited across the whole stream (EWI samples).

Assessment of Discrete Water-Quality Constituents

To compare data between sites, concentration and load boxplots were created using storm-event samples collected using EWI, grab, and passive sampling methods. The 12 watersheds that are part of the sampling network were combined into 8 groups for data assessment. For left-censored (concentration below the reporting limit) storm samples, one-half of the laboratory reporting limit was used as the concentration for boxplot formation (U.S. Environmental Protection Agency, 1989). Low-flow concentrations are plotted on top of the boxplots for comparison purposes. There are no load boxplots for the two lake sites, Olathe Lake (site 4, fig. 1) and Quivira Lake (site 16, fig. 1). More samples were collected at Mill Creek at Johnson Drive (site 15, fig. 1) than all other sites because it was the location of the continuous water-quality monitors, and additional samples were required for model development and verification of continuous nitrate values, particularly at elevated sensor readings.

Nutrients

Median storm-event nitrate plus nitrite concentrations ranged from 0.3 to 4 mg/L (fig. 6*A*). The Kansas Surface Water Quality Standard for both nitrate (as N) and nitrate plus nitrite (as N) is 10 mg/L (Kansas Department of Health and Environment, 2017b). Ninety-nine percent (454 of 459) of storm-event samples and 98 percent (176 of 179) of low-flow samples were less than the Kansas Surface Water Quality Standard for nitrate plus nitrite. All samples that exceeded the standard were collected in the upper Mill Creek watershed, which has WWTFs upstream from the monitoring site (fig. 1) that could affect nutrient concentrations.

TKN was generally the more dominant nitrogen form compared to nitrate plus nitrite in both storm-event and low-flow samples (figs. 6, 7). In samples without a censored result for either constituent, 92 percent (419 of 456) of storm-event samples and 64 percent (65 of 102) of low-flow samples had higher concentrations of TKN than nitrate plus nitrite.

The U.S. Environmental Protection Agency ecoregion 40 reference condition for total nitrogen is 0.855 mg/L–N and is intended to “identify baseline conditions of surface waters that are minimally impacted by human activities” (U.S. Environmental Protection Agency, 2000a, 2000b). Less than 1 percent (4 of 459) of storm-event samples and 41 percent (73 of 179) of low-flow samples were less than the reference condition (fig. 8*A*). Median storm-event total nitrogen loads were generally between 0.1 and 10 tons per day as nitrogen (fig. 8*B*).

For samples without a censored result for either constituent, dissolved phosphorus generally dominated (more than 50 percent) total phosphorus in low-flow samples (31 of 36, 86 percent) but not in storm-event samples (26 of 264, 10 percent) (fig. 9). The reporting limit for dissolved orthophosphate, the biologically available form of phosphorus, was 0.004 or 0.05 mg/L depending on the analyzing laboratory. Dissolved orthophosphate concentrations were above the higher reporting limit (0.05 mg/L) in 55 percent (254 of 459) of storm samples and 22 percent (35 of 157) of low-flow samples (fig. 10). When dissolved orthophosphate concentrations were left-censored (below the reporting limit of 0.004 or 0.5 mg/L depending on the analyzing laboratory) in storm samples,

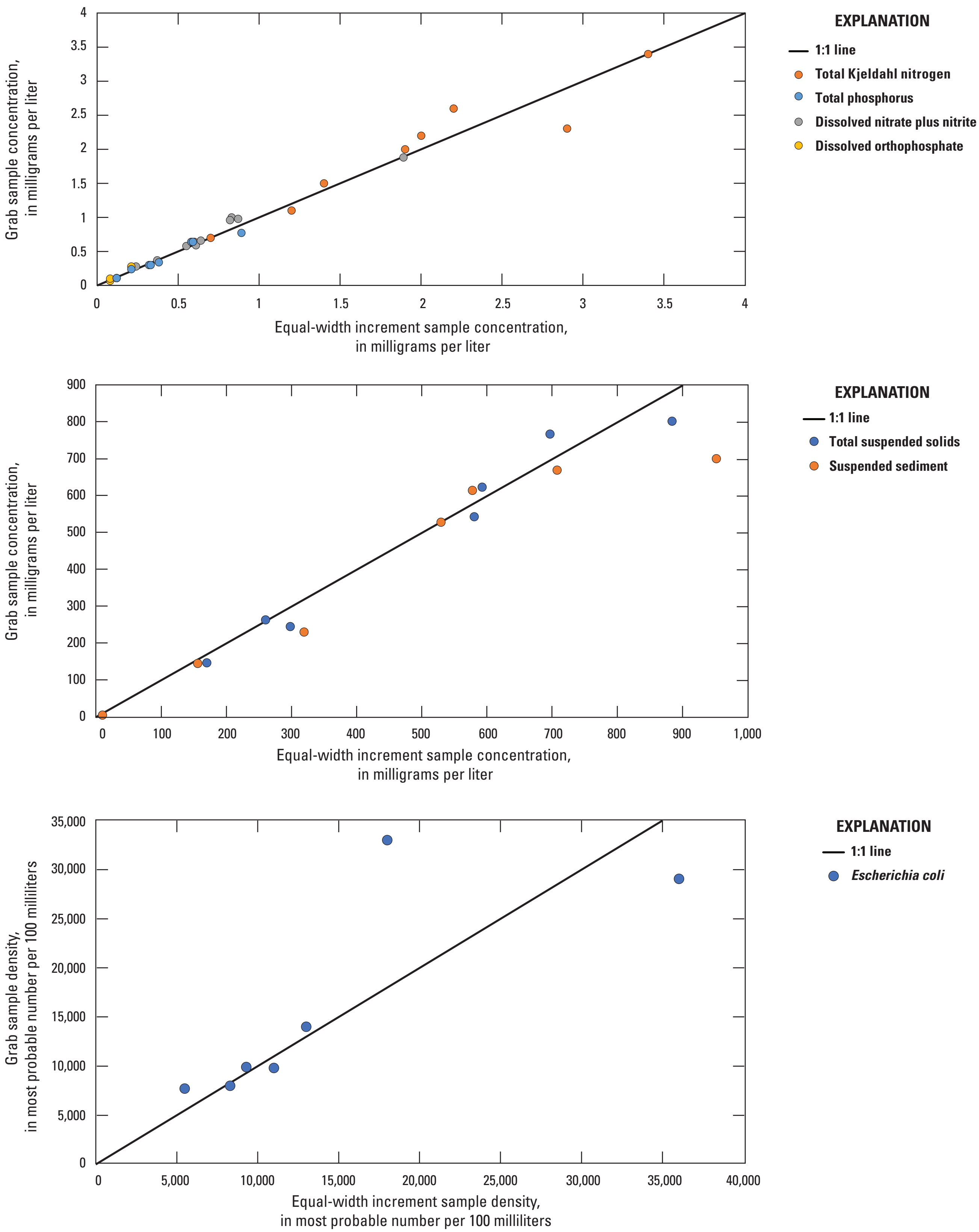

Figure 3. Comparisons of concentrations for nine grab sample and nine equal-width increment replicate samples from three sites in Johnson County, Kansas, 2015–16. *A*, Total Kjeldahl nitrogen, nitrate plus nitrite, orthophosphate, and total phosphorus. *B*, Total suspended solids and suspended sediment. *C*, *Escherichia coli*.

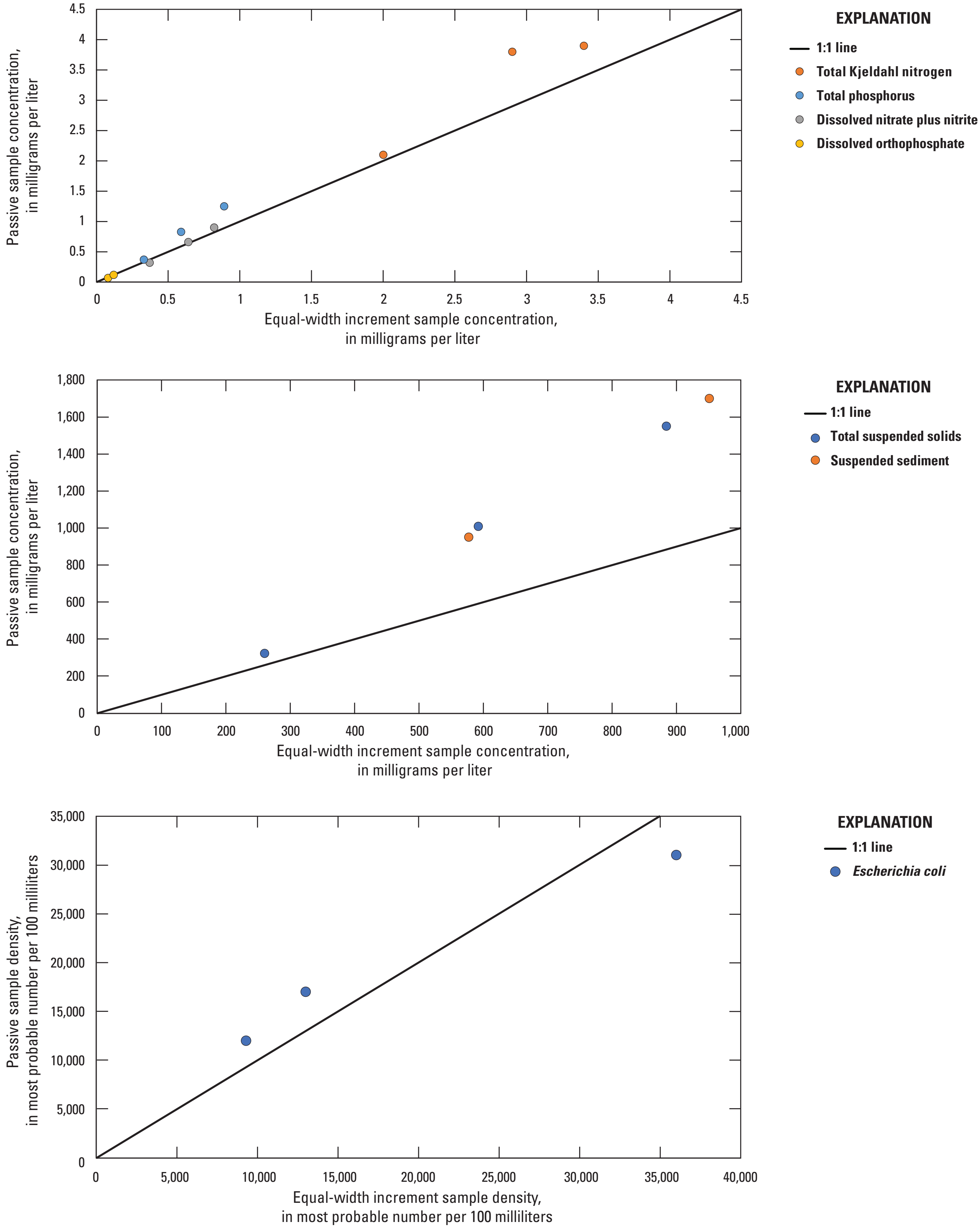

Figure 4. Comparisons of concentrations for three passive and three equal-width increment replicate samples from three sites in Johnson County, Kansas, 2015–16. *A*, Total Kjeldahl nitrogen, nitrate plus nitrite, orthophosphate, and total phosphorus. *B*, Total suspended solids and suspended sediment. *C*, *Escherichia coli*.

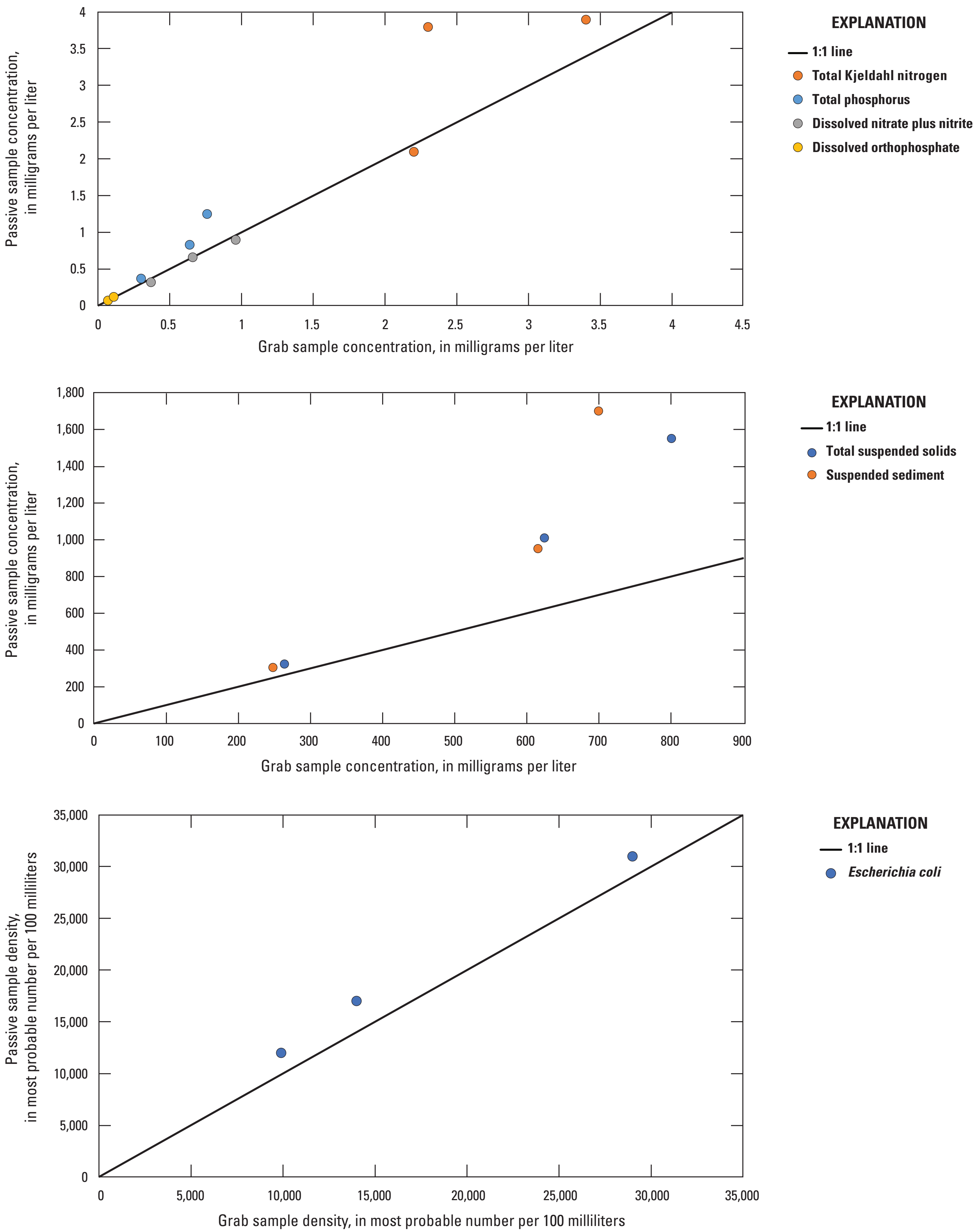

Figure 5. Comparisons of concentrations for three passive and three grab replicate samples from three sites in Johnson County, Kansas, 2015–16. *A*, Total Kjeldahl nitrogen, nitrate plus nitrite, orthophosphate, and total phosphorus. *B*, Total suspended solids and suspended sediment. *C*, *Escherichia coli*.

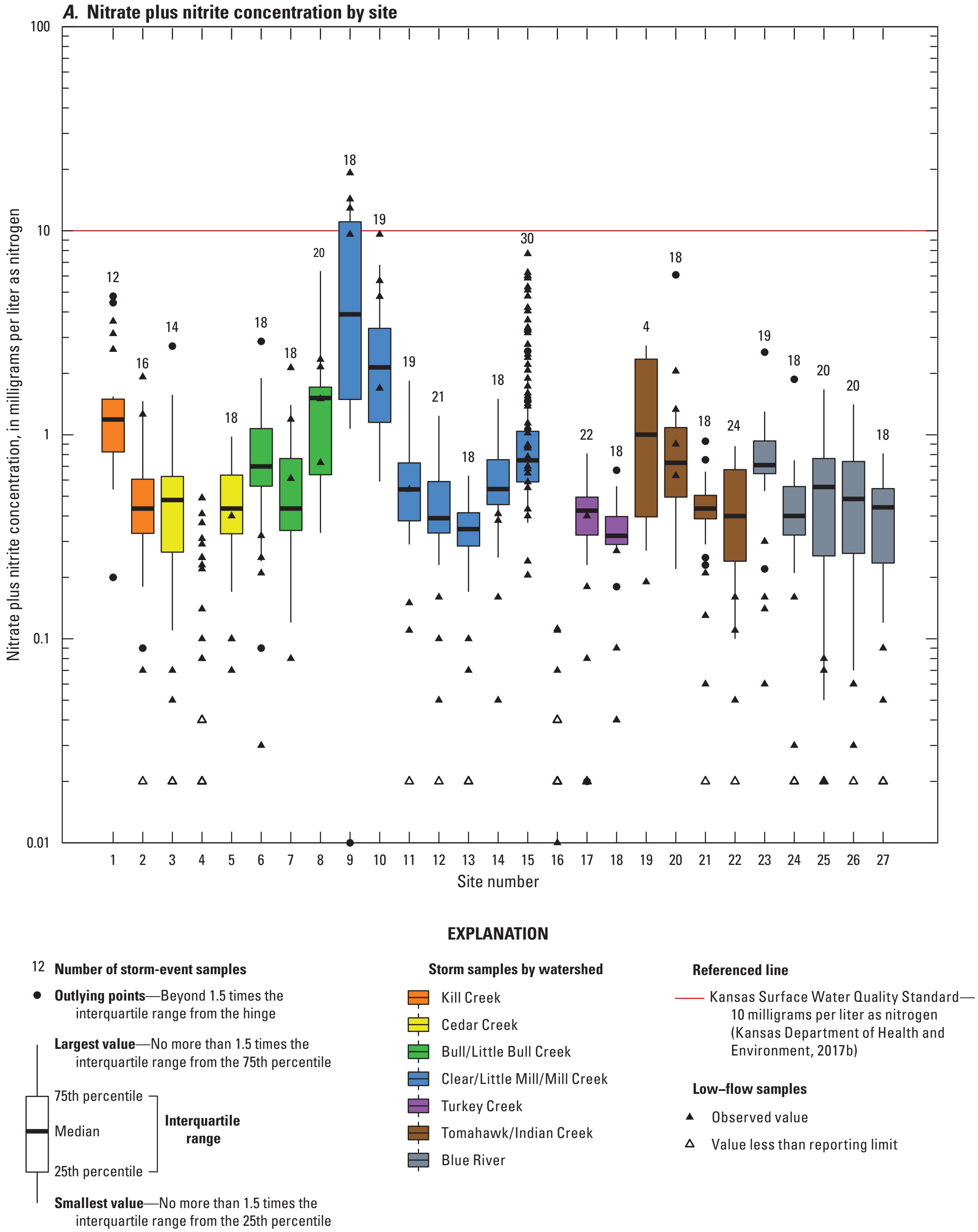

Figure 6. Nitrogen concentration in storm-event and low-flow samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Nitrate plus nitrite. *B*, Total Kjeldahl nitrogen.

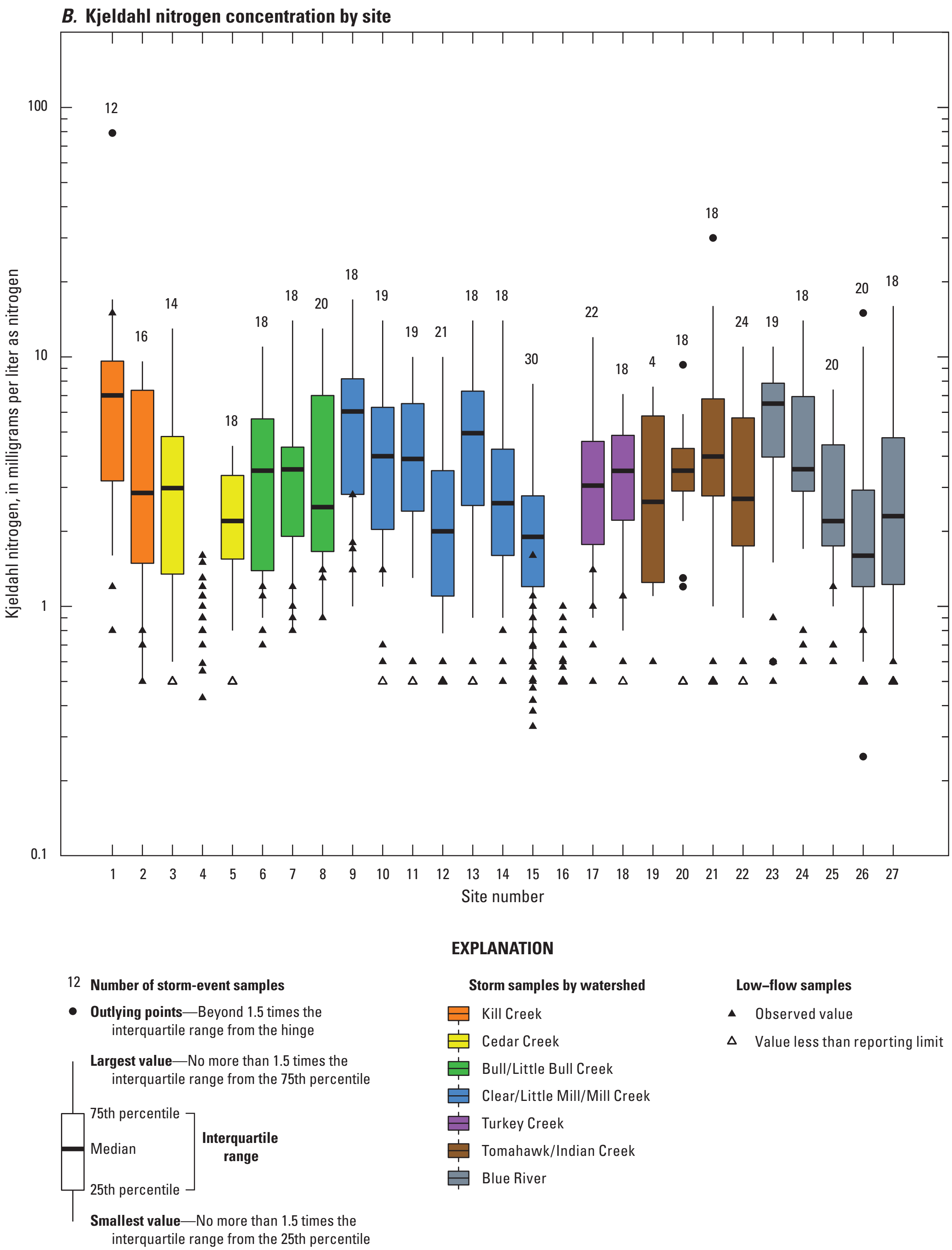

Figure 6. Nitrogen concentration in storm-event and low-flow samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Nitrate plus nitrite. *B*, Total Kjeldahl nitrogen.—Continued

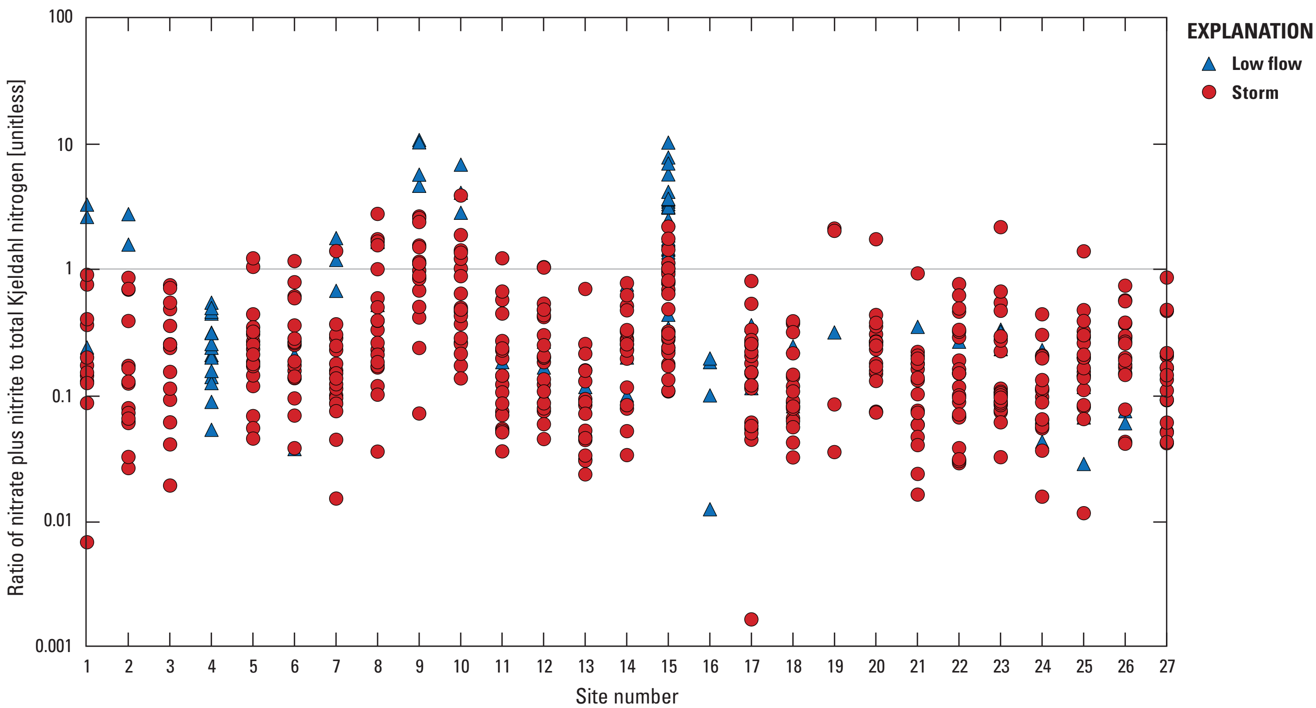

Figure 7. Ratio of nitrate plus nitrite to total Kjeldahl nitrogen in storm-event and low-flow samples without a censored result in either parameter at 27 sites in Johnson County, Kansas, 2015–18.

one-half of the reporting limit was used as the concentration for boxplot formation (U.S. Environmental Protection Agency, 1989).

Median storm-event total phosphorus concentrations ranged from 0.3 to 2.5 mg/L (fig. 11*A*) and median storm-event total phosphorus loads ranged from 0.6 to 3 tons per day (fig. 11*B*). There is not currently (2021) a numeric Kansas Surface Water Quality Standard for phosphorus, but according to the KDHE, “Conditions of full support [of aquatic biology] span total phosphorus levels of 0.031 mg/L to 0.215 mg/L” (Kansas Department of Health and Environment, 2017a, 2017b). Seventeen percent (76 of 459) of storm-event samples and 88 percent (138 of 157) of low-flow samples were less than 0.215 mg/L. The U.S. Environmental Protection Agency ecoregion 40 reference condition is 0.0925 mg/L (U.S. Environmental Protection Agency, 2000a). Three percent (16 of 459) of storm-event samples and 63 percent (99 of 157) of low-flow samples were less than the reference condition. The highest median dissolved orthophosphate and total phosphorus concentrations were in the upper Kill Creek watershed, which has WWTFs upstream from the monitoring site (fig. 1) that could affect nutrient concentrations.

Escherichia coli

Median storm-event *E. coli* densities were between 1,000 and 40,000 colony forming units per 100 milliliters (CFU/100 mL) (fig. 12*A*). Most streams in Johnson County are classified for primary contact recreation class B (publicly accessible streams not designated as swimming areas) or class C (streams with no public access) (U.S. Environmental Protection Agency, 2020; Kansas Department of Health and Environment, 2011). The Kansas Surface Water Quality Standards for *E. coli* during the recreation season (April 1 through October 31) are 262 CFU/100 mL for class-B stream segments and 427 CFU/100 mL for class-C stream segments (Kansas Department of Health and Environment, 2017b). These standards are based on the geometric mean of multiple samples throughout the recreation season, and the discrete samples collected in this study do not meet the sampling requirements set forth by the standards. However, as a basis for comparison, 1 percent (6 of 453) of storm-event samples were less than the class-B criteria and 3 percent (12 of 453) of storm-event samples were less than the class-C criteria for *E. coli* (fig. 12*A*). Ninety-two percent (137 of 149) of low-flow samples were less than the class-B criteria, and 95 percent (142 of 149) of low-flow samples were less than the class-C criteria. Median storm-event *E. coli* loads were between approximately 4,000 and 600,000 billion colony forming units per day (fig. 12*B*).

Total Suspended Solids and Suspended Sediment

Median storm-event TSS concentrations were generally between 200 and 3,000 mg/L (fig. 13*A*). Since 2008, the KDHE has used a screening value of

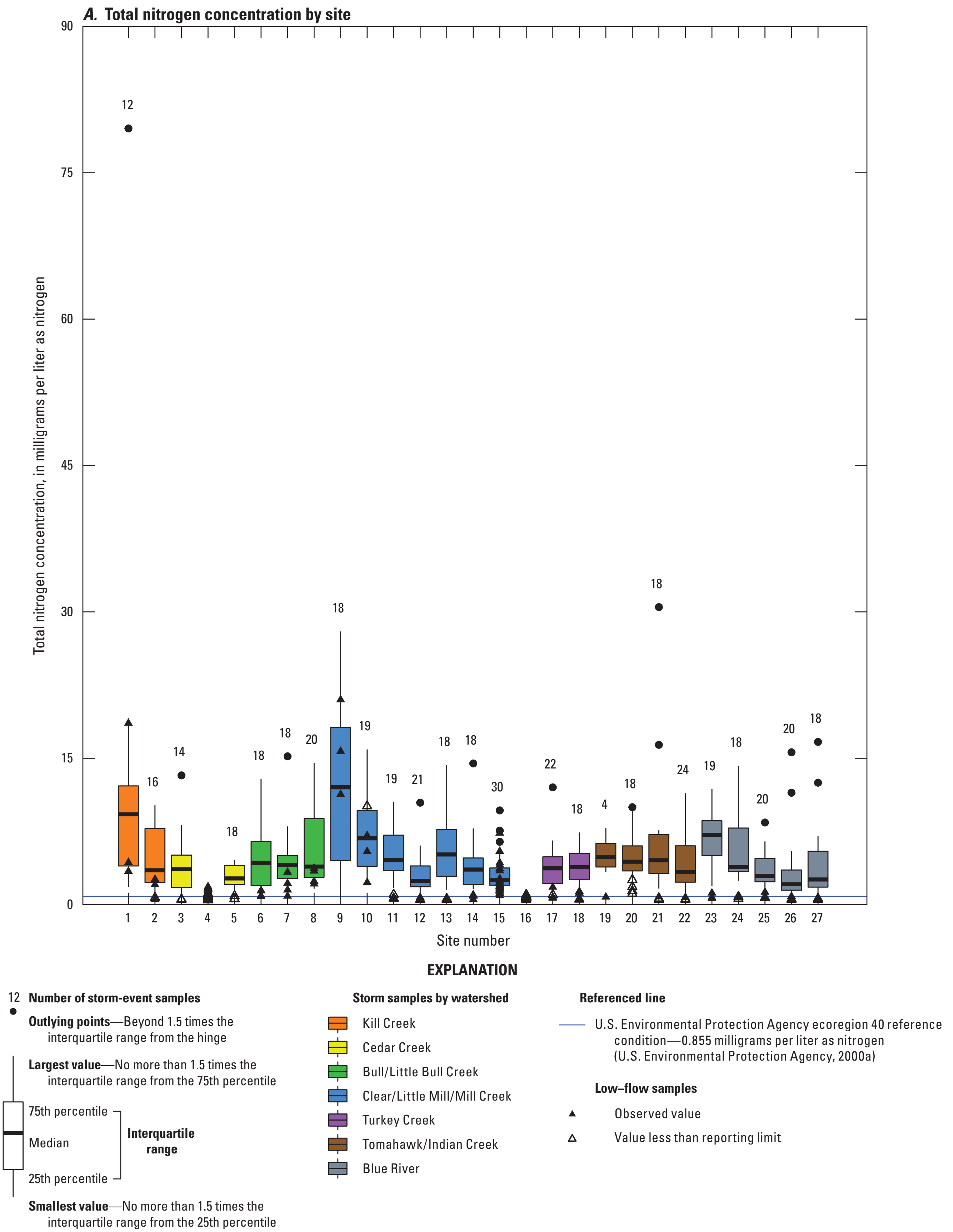

Figure 8. Total nitrogen in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.

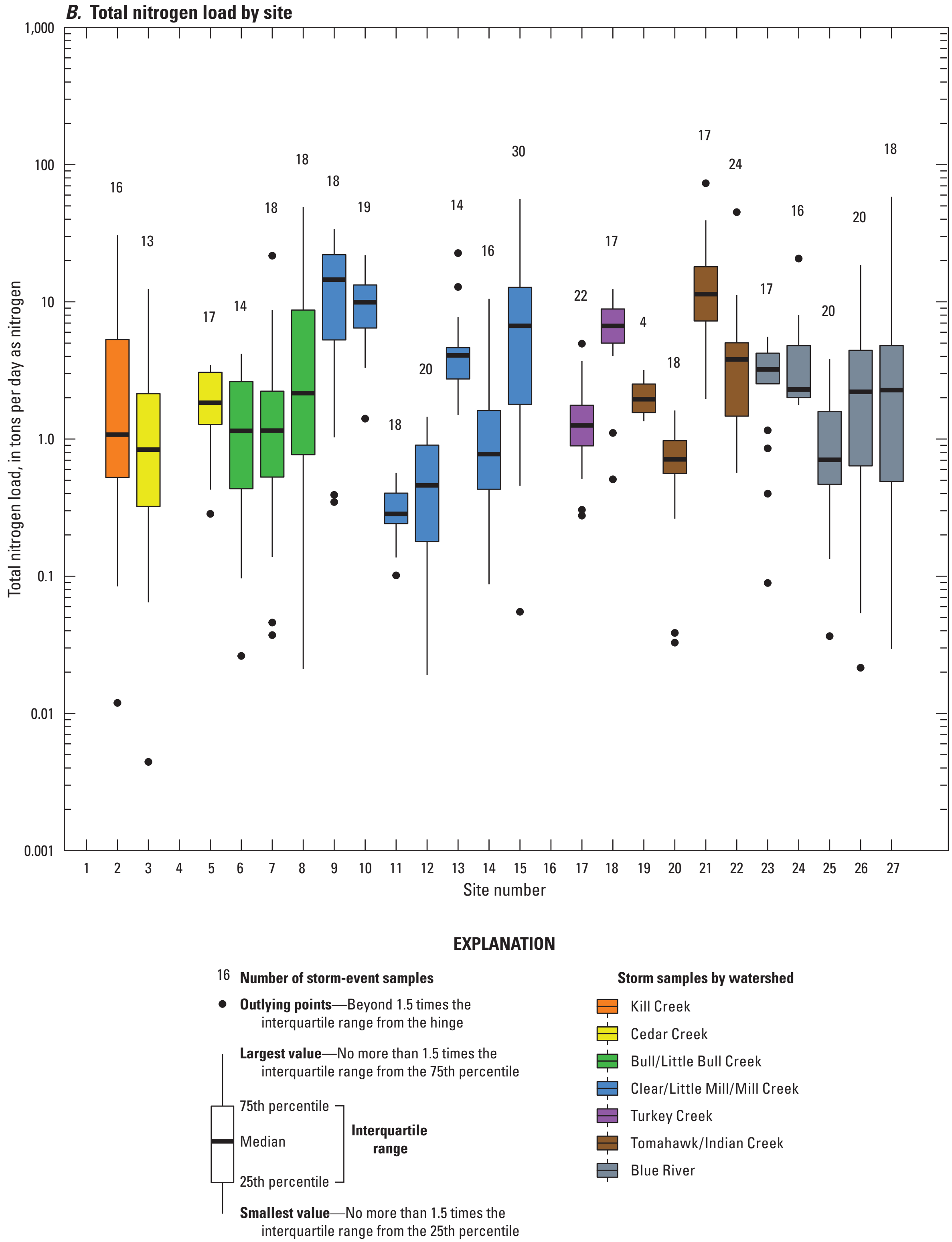

Figure 8. Total nitrogen in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.—Continued

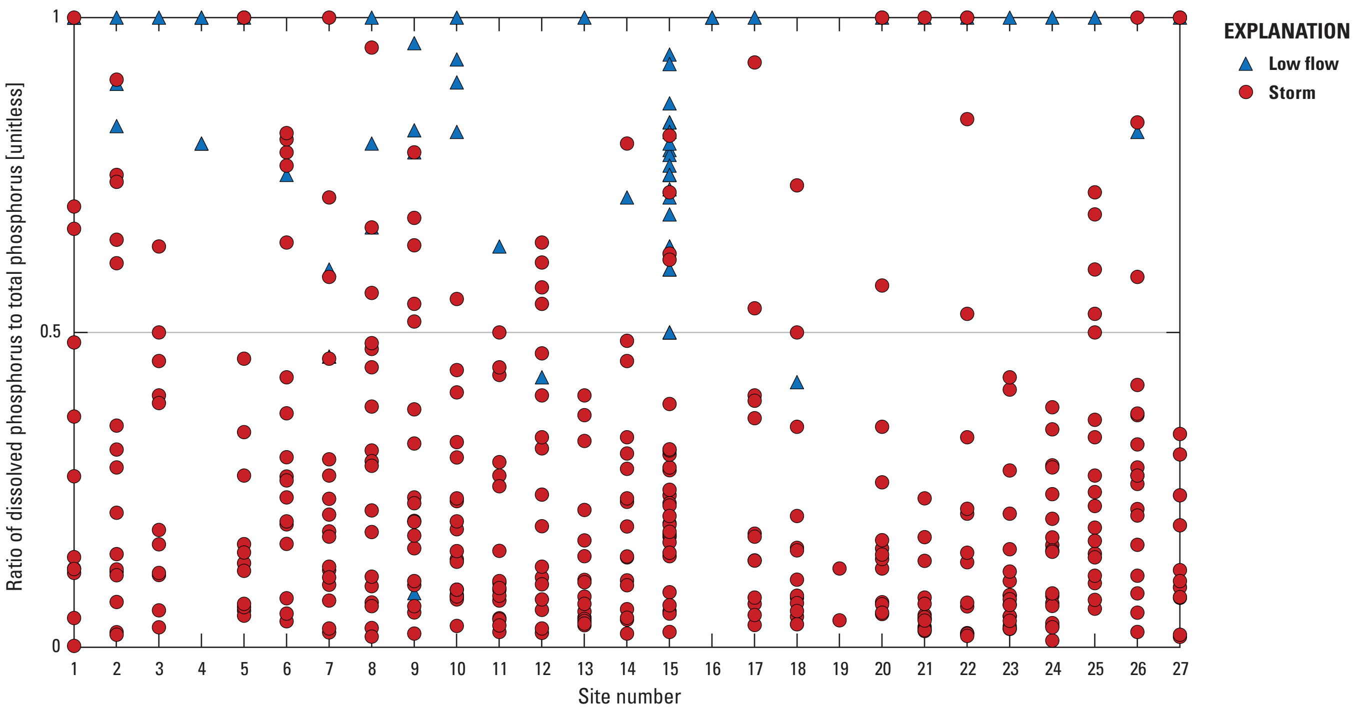

Figure 9. Ratio of dissolved phosphorus to total phosphorus in storm-event and low-flow samples without a censored result in either constituent at 27 sites in Johnson County, Kansas, 2015–18.

50 mg/L TSS to designate water bodies likely to fully support aquatic life uses (Kansas Department of Health and Environment, 2008). Eight percent (37 of 462) of storm-event samples and 100 percent (*n*=151) of low-flow samples were less than the screening value of 50 mg/L. Median storm-event TSS loads were between about 50 and 4,000 tons per day (fig. 13*B*).

Median storm-event suspended-sediment concentrations were generally less than 2,500 mg/L (fig. 14*A*). All eight watershed groups with a stream sampling site had at least one storm-event suspended-sediment concentration greater than 5,000 mg/L. Median storm-event suspended-sediment loads were between 10 and 5,000 tons per day (fig. 14*B*).

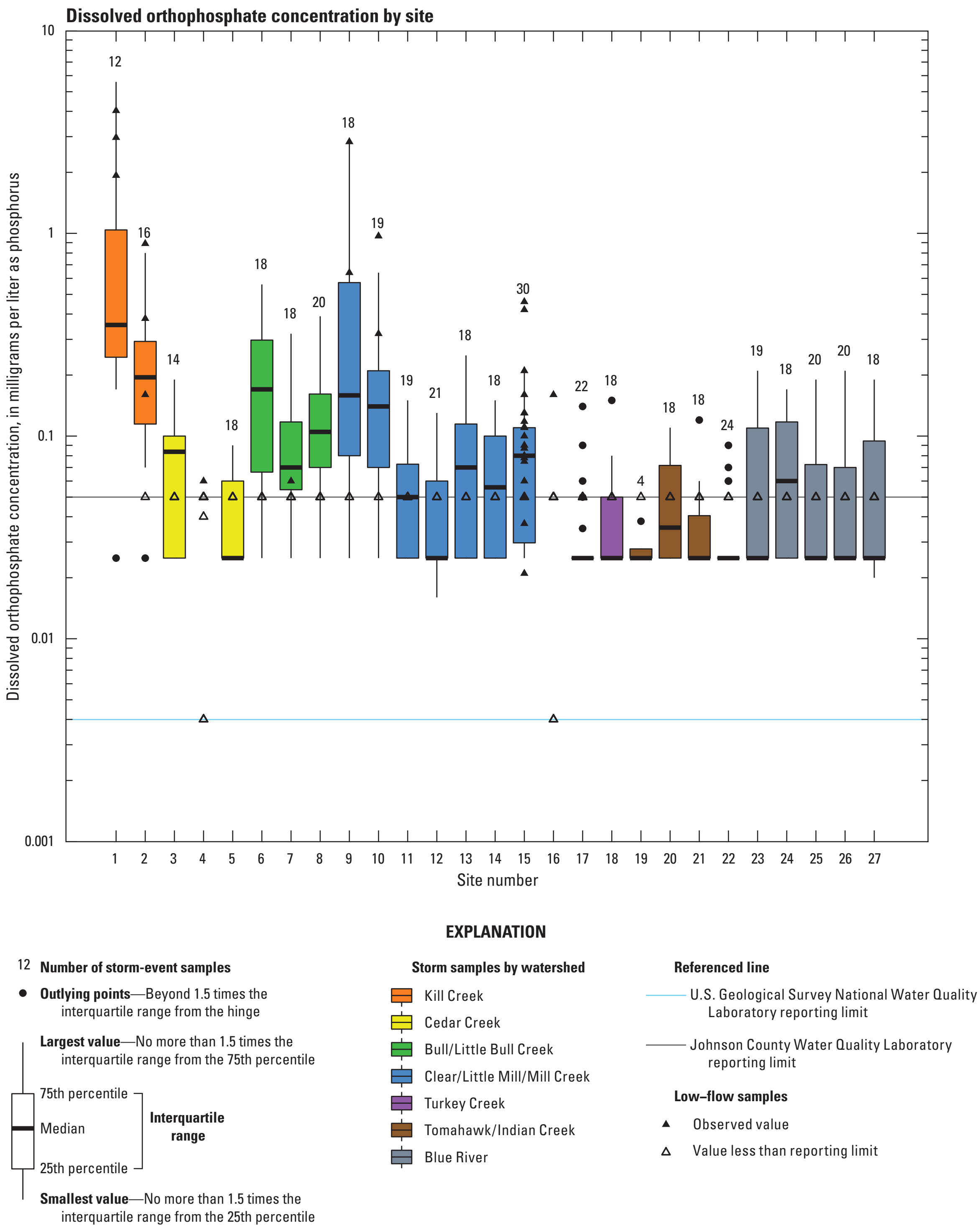

Figure 10. Concentrations of dissolved orthophosphate in storm-event and low-flow samples from 27 sites in Johnson County, Kansas, 2015–18.

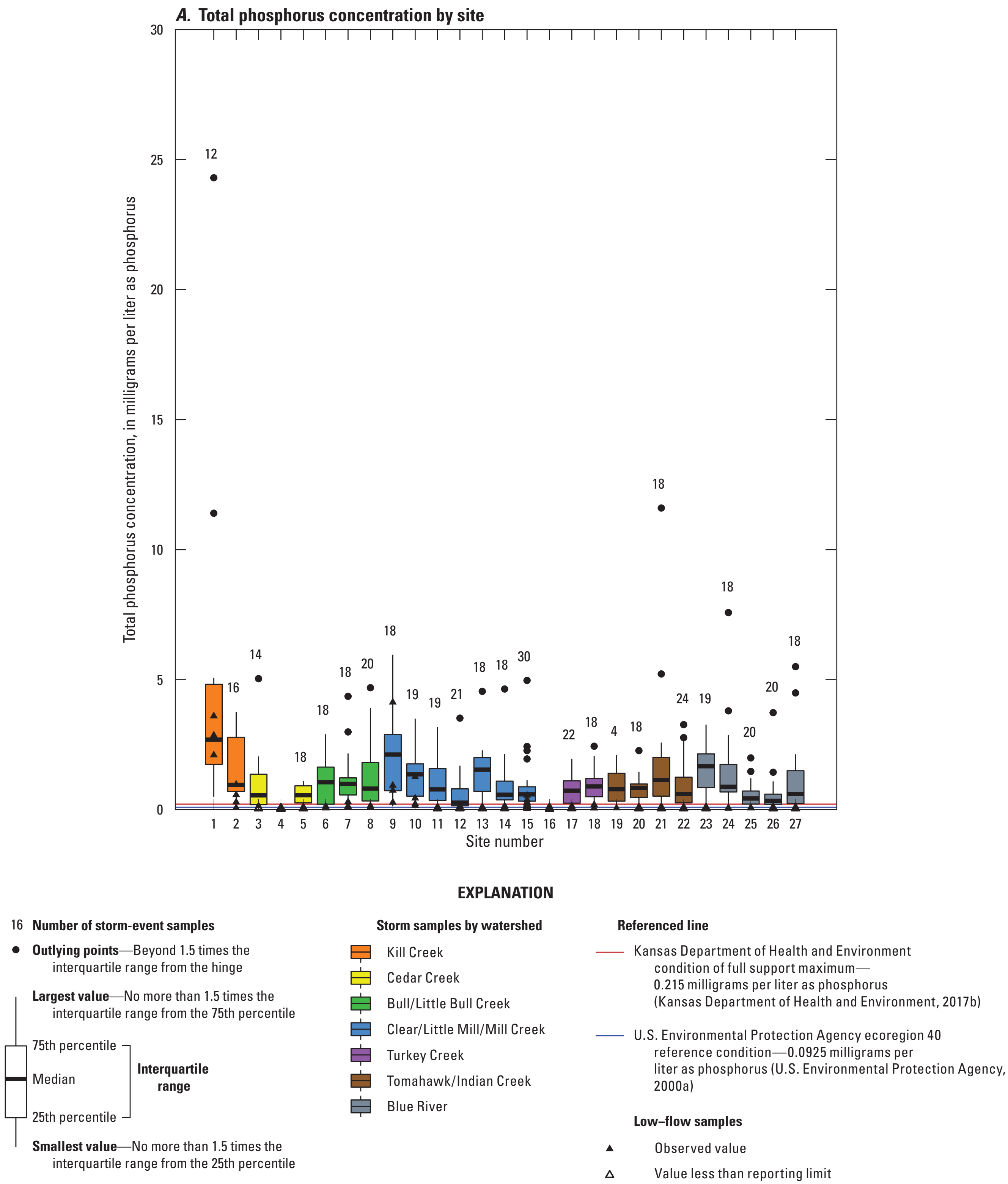

Figure 11. Total phosphorus in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.

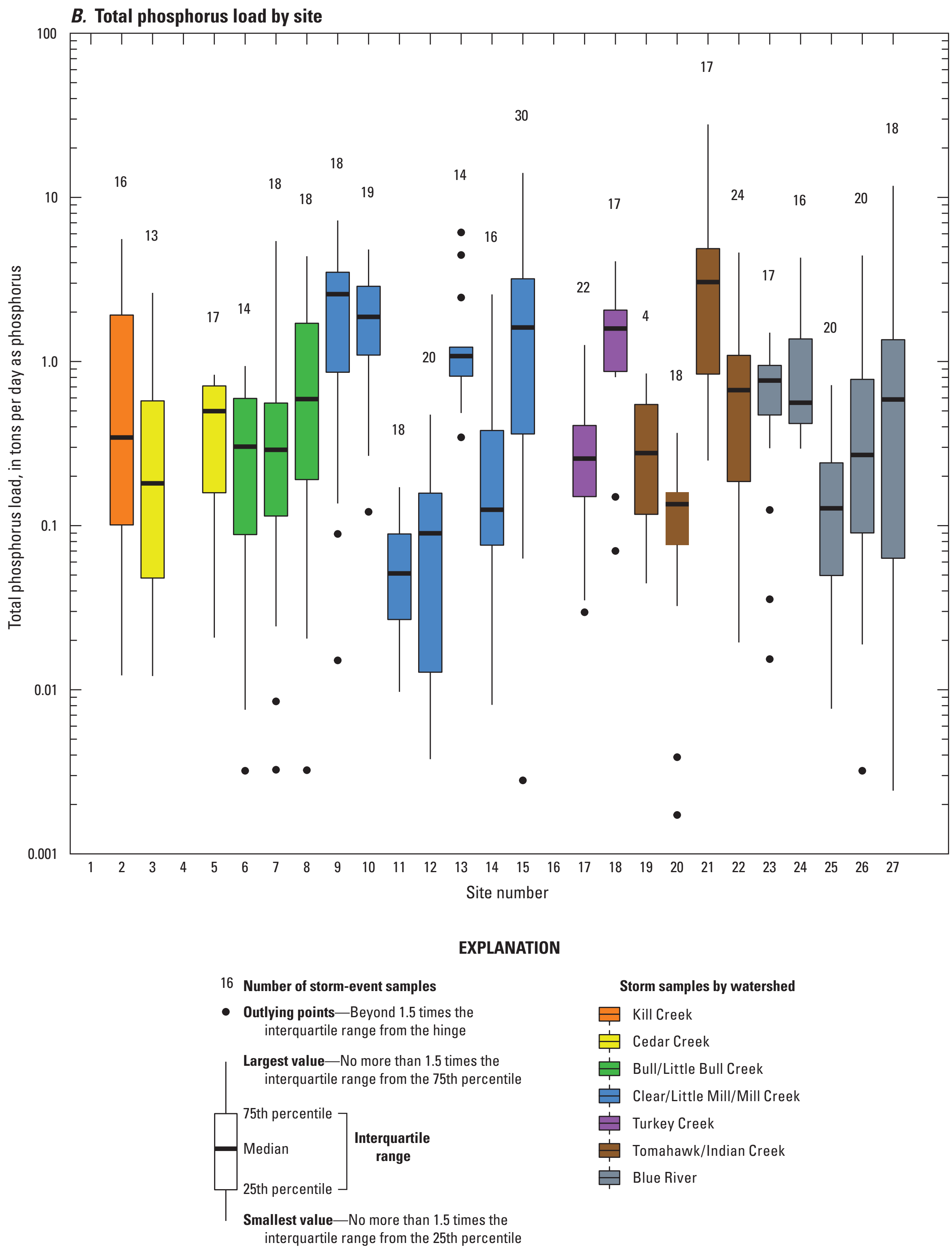

Figure 11. Total phosphorus in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.—Continued

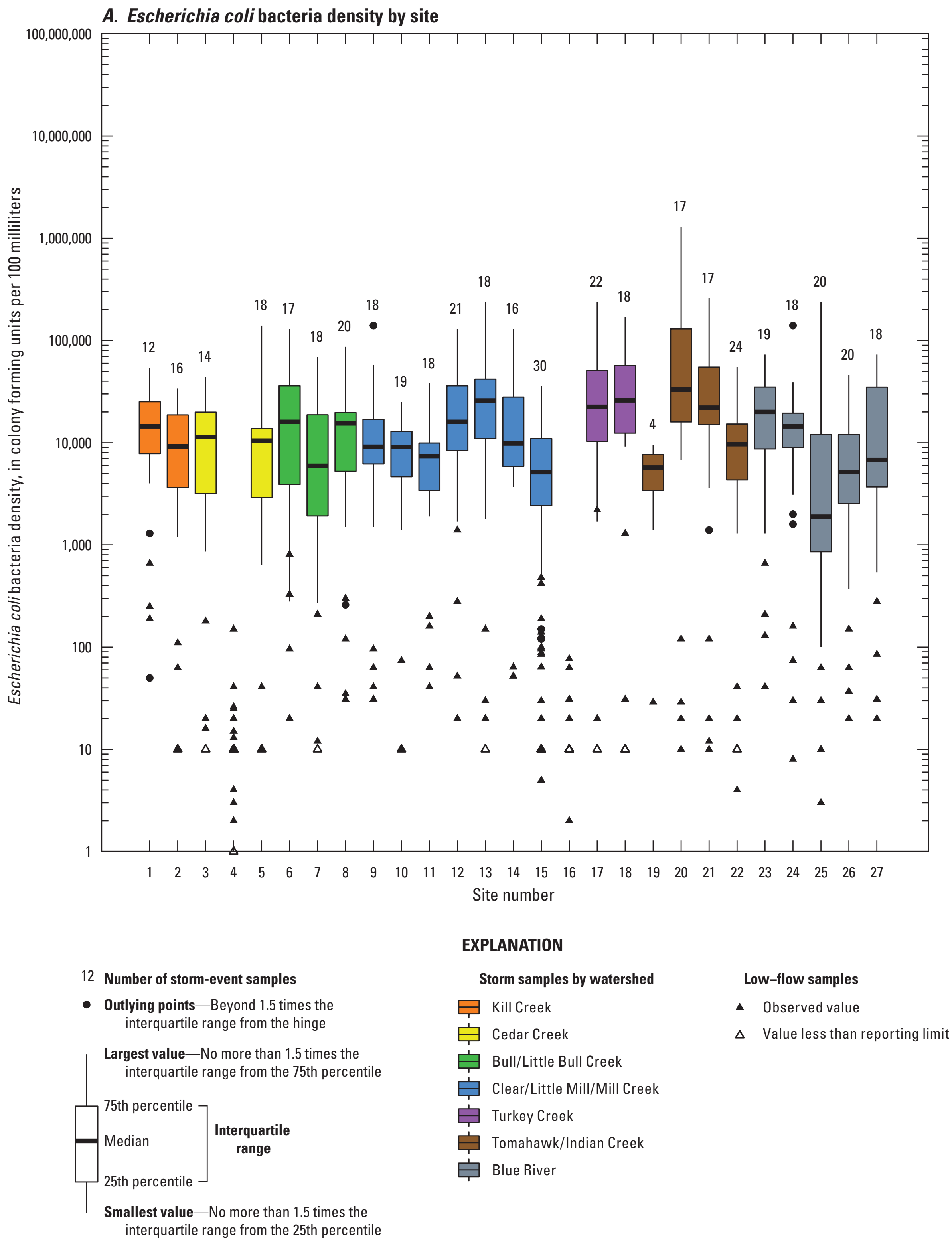

Figure 12. *Escherichia coli* in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Densities of storm-event and low-flow samples. *B*, Loads of storm-event samples only.

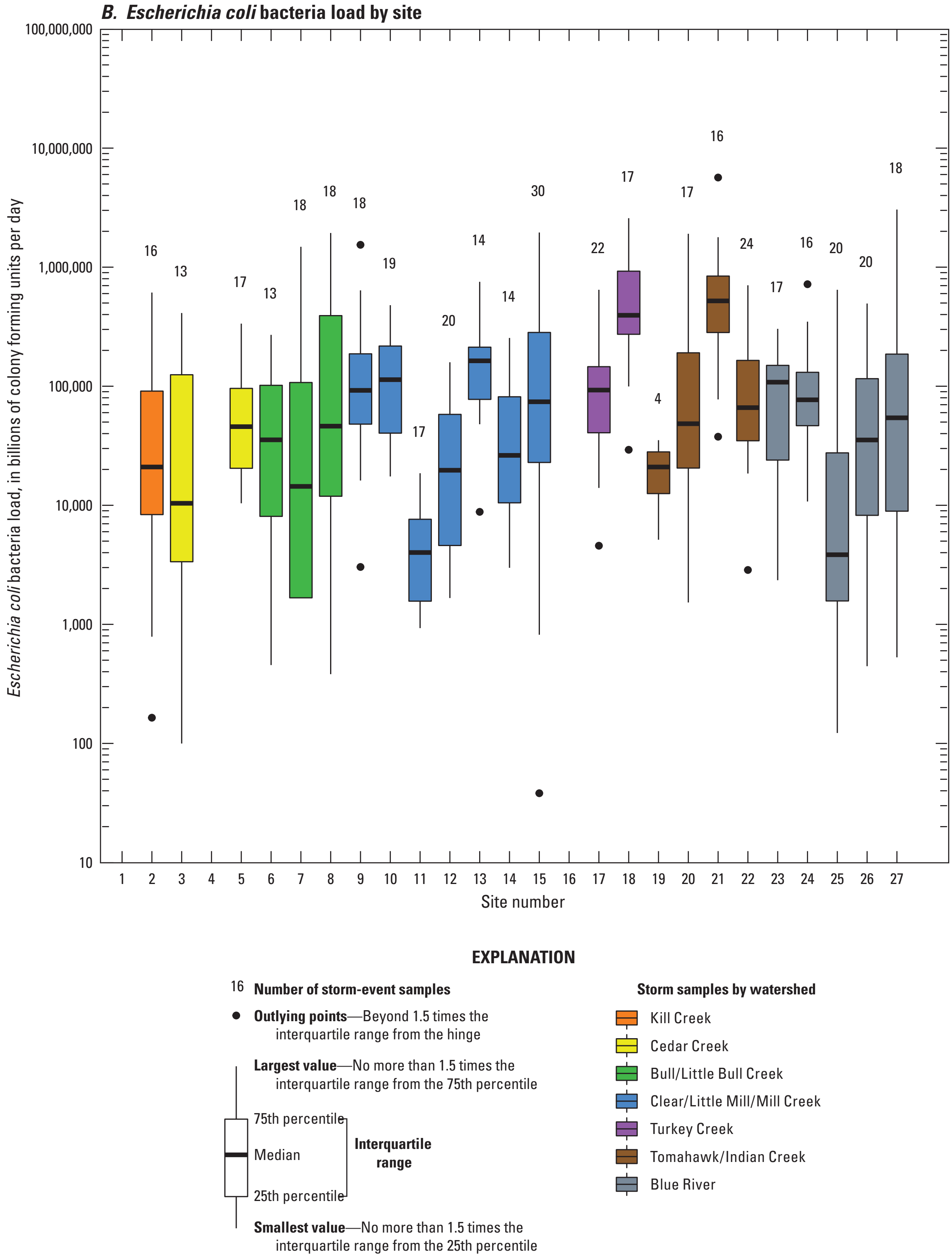

Figure 12. *Escherichia coli* in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Densities of storm-event and low-flow samples. *B*, Loads of storm-event samples only.—Continued

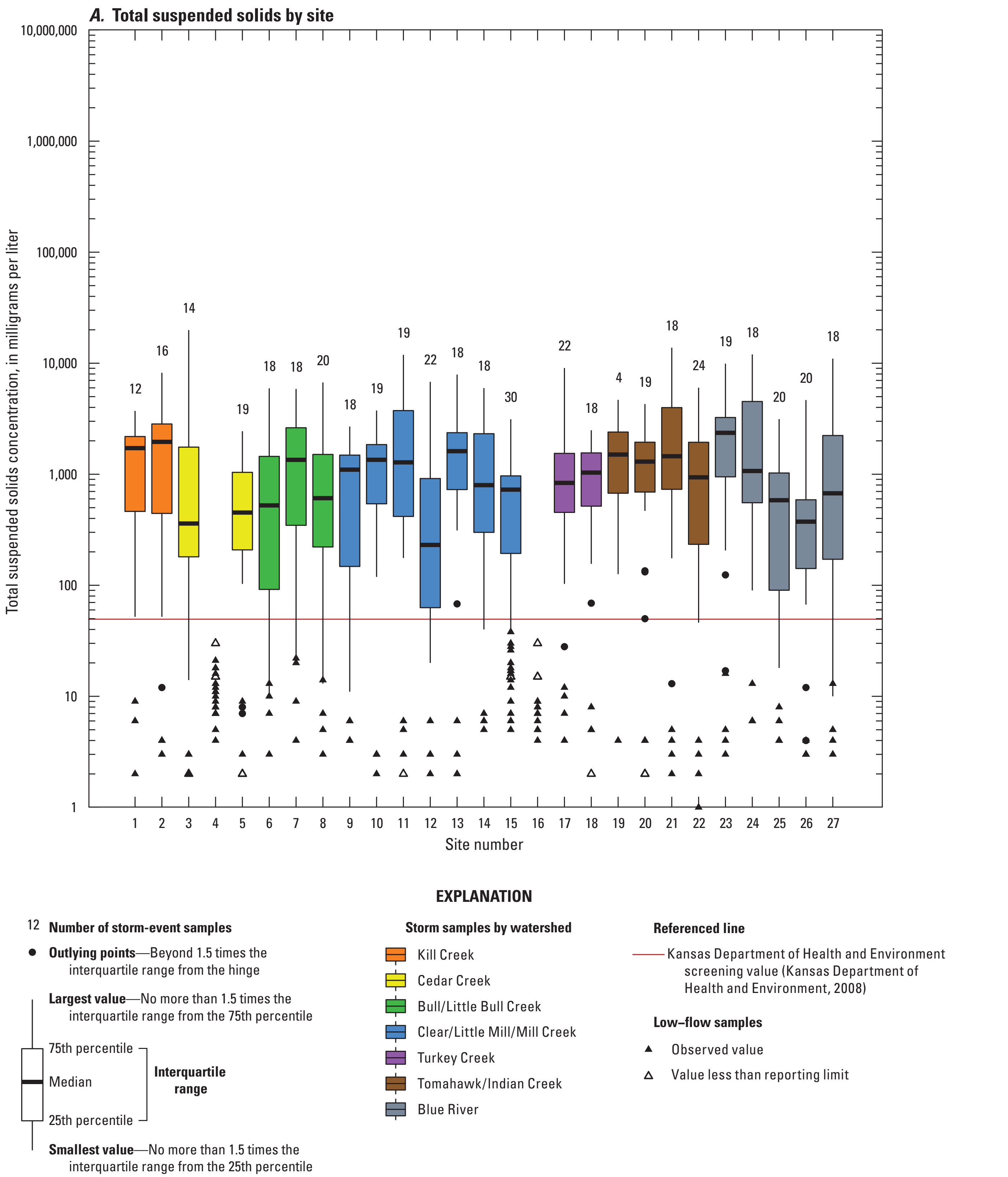

Figure 13. Total suspended solids in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.

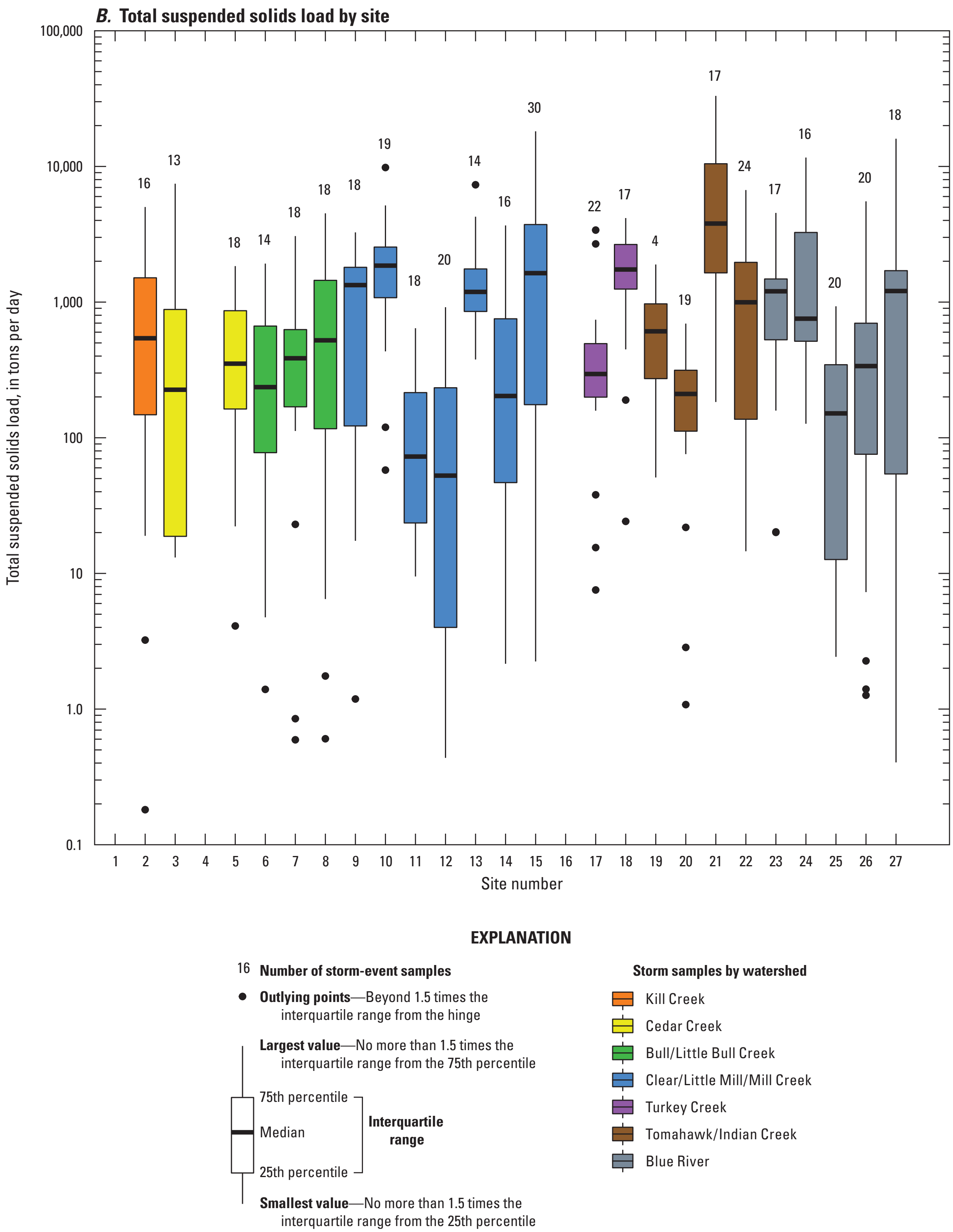

Figure 13. Total suspended solids in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.—Continued

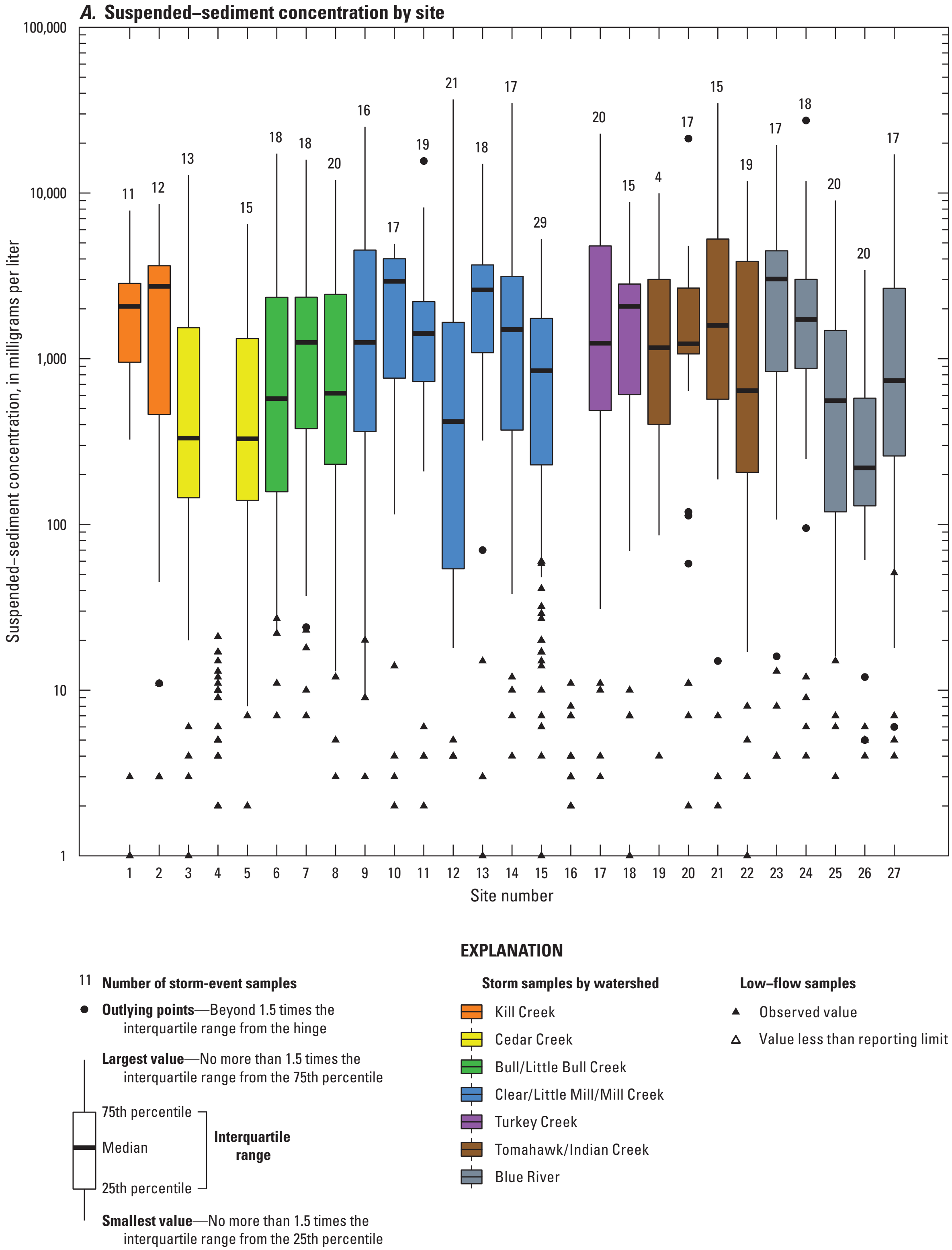

Figure 14. Suspended sediment in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.

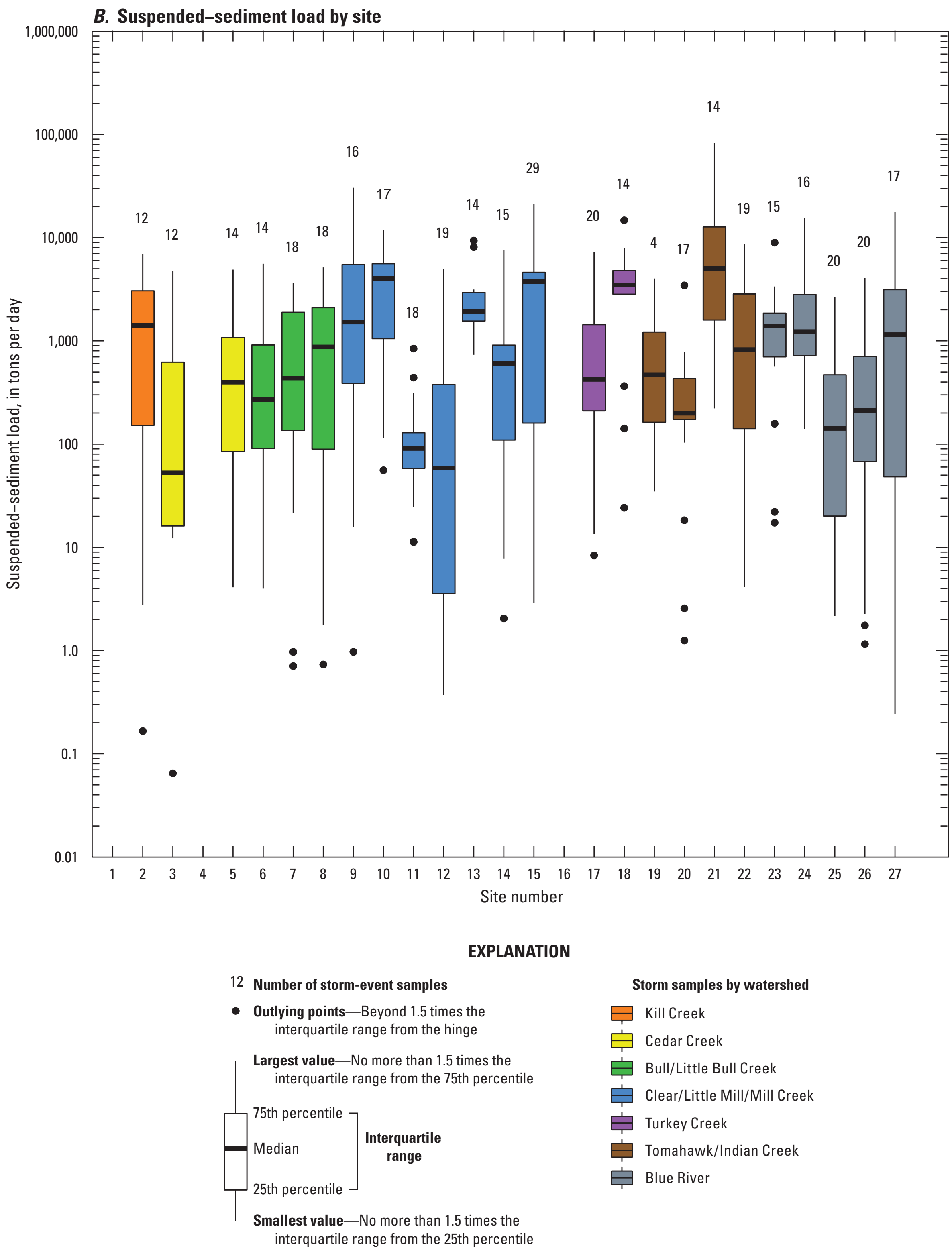

Figure 14. Suspended sediment in samples from 27 sites in Johnson County, Kansas, 2015–18. *A*, Concentrations of storm-event and low-flow samples. *B*, Loads of storm-event samples only.—Continued

Evaluation of Data Utility

The utility of data collected for this study were evaluated as described in this section of the report for continuous water-quality data and historical data comparisons. Environmental factors affecting sampling results and relevance of TMDLs also were used to evaluate data utility.

Continuous Water-Quality Data

At Mill Creek at Johnson Drive (site 15, fig. 1), continuous measurements of nitrate plus nitrite ranged from less than 0.1 to 9.65 mg/L and had a mean value of 1.89 mg/L and a median value of 1.44 mg/L (table 5, fig. 15). Over the study period, 83 discrete samples were collected at this site during storm-event and stable, low-flow conditions using EWI, grab, and passive sampling methods (data available in Leiker and others, 2021). Discrete sample values of nitrate plus nitrite ranged from 0.15 to 7.71 mg/L and had a mean value of 1.73 mg/L and a median value of 1.01 mg/L (data available in Leiker and others, 2021).

Discrete samples typically had lower nitrate plus nitrite concentrations than the closest continuous nitrate plus nitrite measurement (fig. 16) and had a mean bias of positive 0.26 mg/L–N in the continuous measurements calculated according to Pellerin and others (2013). The bias was calculated using only the 27 grab samples collected during stable (low-flow) conditions because grab samples were collected at the centroid of flow, where the Nitratax was located. Positive bias of ultraviolet sensor nitrate plus nitrite concentration can be caused by the presence of dissolved organic matter or suspended particles in the water column (Pellerin and others, 2013). Continuous data were not corrected for interference because the mean bias calculated according to Pellerin and others (2013), positive 0.26 mg/L–N, fell within the manufacturer-stated measuring error of the device: 3 percent of reading or plus or minus 0.5 mg/L–N, whichever is greater (Hach Company, 2012; Pellerin and others, 2013).

Absolute numerical difference between discrete-sample and sensor-measured nitrate plus nitrite ranged from 0.00 to 1.94 mg/L–N, and median absolute numeric differences between discrete-sample and sensor-measured nitrate plus nitrite ranged from 0.22 to 0.42 mg/L–N, depending on discrete sampling method (table 12). Median RPD between discrete-sample and sensor-measured nitrate plus nitrite was lowest in routine grab samples and highest in storm grab samples (table 12), but because of the previously discussed bias between discrete-sample and sensor-measured nitrate plus nitrite, it was not unexpected that RPDs were larger between discrete-sample and sensor-measured concentrations than for comparisons between two discrete-sample concentrations, for example the RPD values in table 7.

Concentrations of sensor-measured nitrate plus nitrite covered a wider range of values than concentrations in discrete samples. Capturing the range of conditions is necessary to better characterize and understand rapidly changing water quality. The wider range of values in the continuous dataset demonstrated that high and low extreme values can be missed when only discrete data are collected in a monitoring program. Continuous data can also demonstrate to what degree discrete samples are representative of site conditions. For example, using the surrogate regression model for TSS (app. 4), the corresponding turbidity value when TSS equals 50 mg/L (the KDHE screening value; Kansas Department of Health and Environment, 2008) would be 17.8 FNU at Mill Creek at Johnson Drive. The discrete dataset would indicate the screening value is exceeded at a higher frequency (68 percent of the time) than the continuous dataset (15 percent of the time) because of sampling frequency limitations and the monitoring program targeting storm-event samples because of stormwater discharge permit requirements. Continuous data provide a more comprehensive understanding of stream water quality than discrete sampling alone.

Historical Data Comparisons

Discrete water-quality data from sites in Johnson County where at least one sample was collected by the USGS and analyzed for at least one nutrient since 1994 were compared to data collected during this study. Historical data are available from the National Water Information System (U.S. Geological Survey, 2019b). Two sites, Kill Creek at 95th Street and Mill Creek at Johnson Drive, had robust (n>30) historical datasets (2003 through 2010 at the Kill Creek site and 2002 through 2010 at the Mill Creek site), consisting of low-flow and storm-event samples, to compare to data collected in this study. Six of the eight watershed groups in this study had historical data consisting of low-flow, storm-event, or both samples. The six watershed groups had between 13 and 222 historical samples before 2015. Differences between historical and current-study data were not immediately apparent, and statistically significant determinations were not possible due to the compositions of the datasets (app. 6).

Environmental Factors Affecting Sampling Results

Numerous factors affect water quality in urban runoff. Urban areas have many possible contaminant sources, including municipal and industrial wastewater discharges, stormwater runoff from impervious surfaces, and failing infrastructure. The ability of a precipitation event to produce runoff depends on a variety of factors including antecedent moisture conditions, land use (for example, percent impervious surfaces), precipitation intensity, and precipitation duration. Storm-event samples are intended to collect runoff from the basin, but if dry antecedent conditions lead to infiltration rather than runoff during precipitation events, the samples collected would be more representative of base flow than runoff. A few samples collected each year results in a dataset lacking the statistical

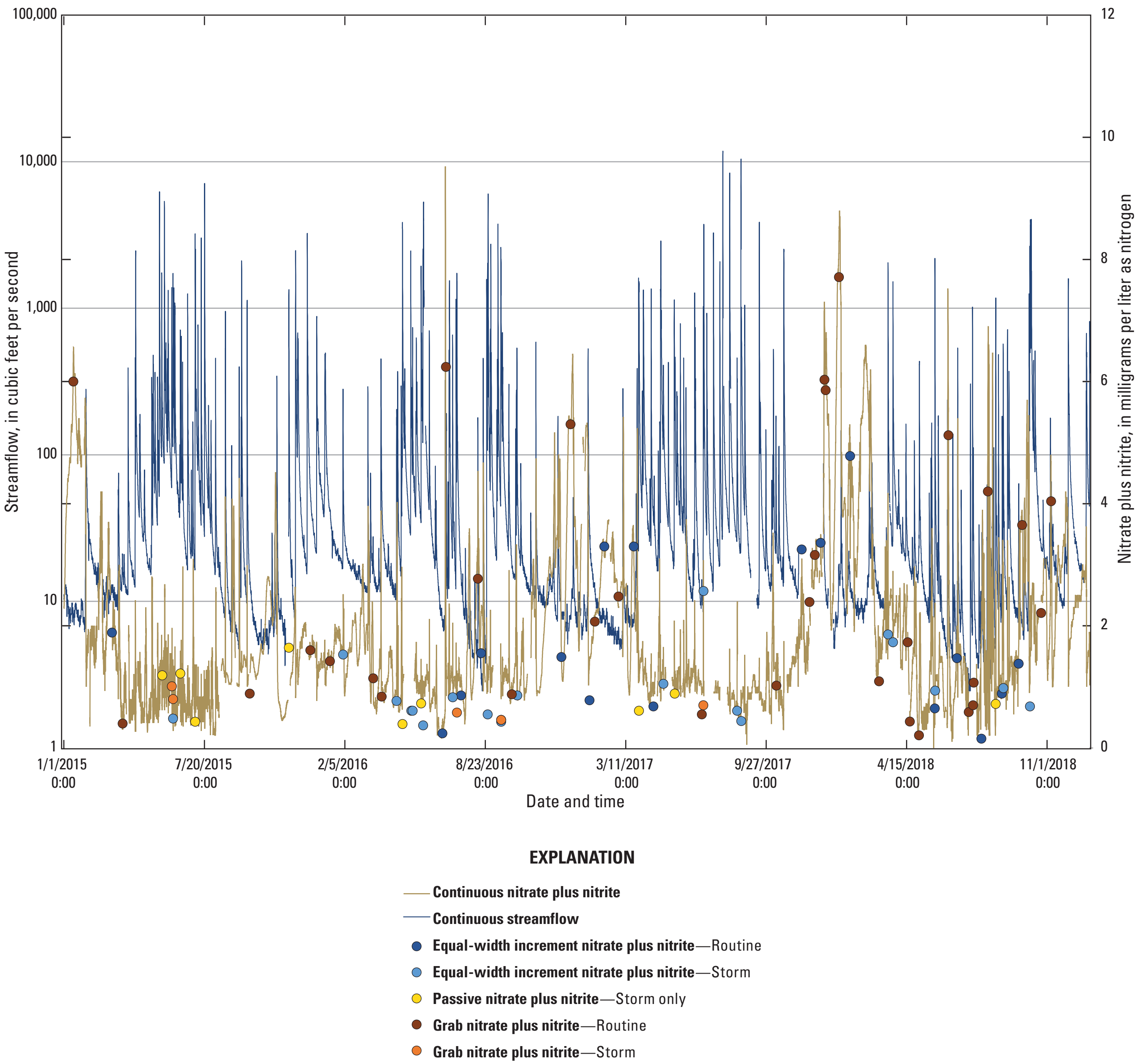

Figure 15. Continuous and discrete nitrate plus nitrite concentrations and continuous streamflow data from continuous monitoring site Mill Creek at Johnson Drive in Shawnee, Kansas. Continuous nitrate plus nitrite data were collected using a Hach Company Nitratax nitrate sensor.

power to detect changes over time, differences between sites, or the factors affecting the water quality of urban runoff. It is possible that the maximum concentration of constituents during the study period was captured at some sites and not others. A better understanding of these factors can inform future monitoring efforts, leading to datasets that are representative of storm runoff and ultimately able to detect differences between sites and over time.

Precipitation is variable across years and across watersheds. Cumulative precipitation data from StormWatch (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018) between March 1 and October 31 for five sites dispersed around Johnson County are shown in fig. 17. Overall, 2017 was the wettest year; all five sites had cumulative precipitation above the 30-year average (33.9 inches between March 1 and October 31; PRISM Climate Group, 2019). The driest year

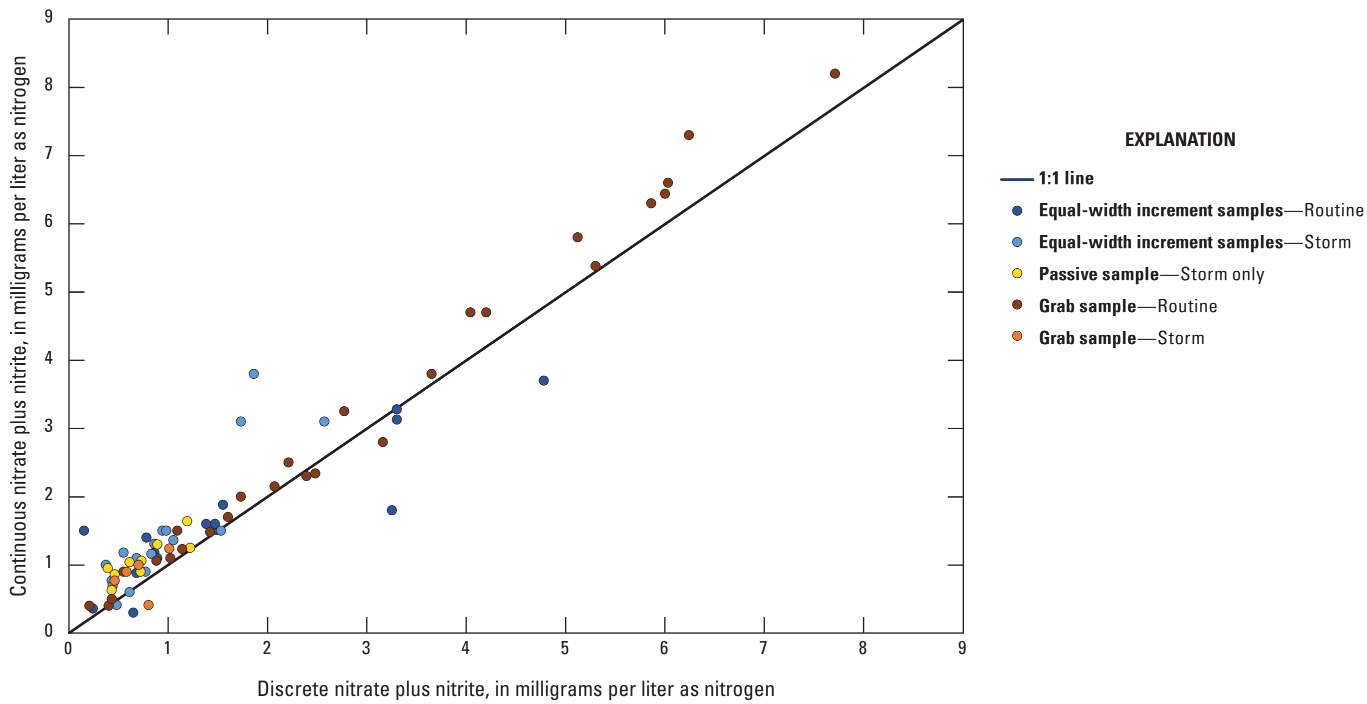

Figure 16. Comparison of concentrations between discrete nitrate plus nitrite samples and the closest-in-time continuous nitrate plus nitrite measurement at Mill Creek at Johnson Drive in Shawnee, Kansas. Positive bias of ultraviolet sensors is caused by dissolved and suspended constituents in the water column.

Table 12. Absolute numerical difference and relative percent difference, discretely sampled nitrate versus continuously measured nitrate plus nitrite, based on sampling method.

[*n*, number of discrete samples with comparable continuous data; Min, minimum; Max, maximum; RPD, relative percent difference; EWI, equal-width increment]

Discrete sample type	*n*[a]	Absolute numeric difference, in milligrams per liter as nitrogen				Median RPD
		Min	Max	Median	Mean	
Routine grab	27	0.00	1.06	0.27	0.31	9.0
Routine EWI	15	0.02	1.45	0.22	0.44	25.5
Storm grab	5	0.23	0.39	0.31	0.31	43.2
Storm passive	9	0.03	0.56	0.40	0.33	37.4
Storm EWI	17	0.01	1.94	0.42	0.50	42.0

[a]Ten discrete samples could not be compared to continuous nitrate plus nitrite data because the continuous data were unavailable.

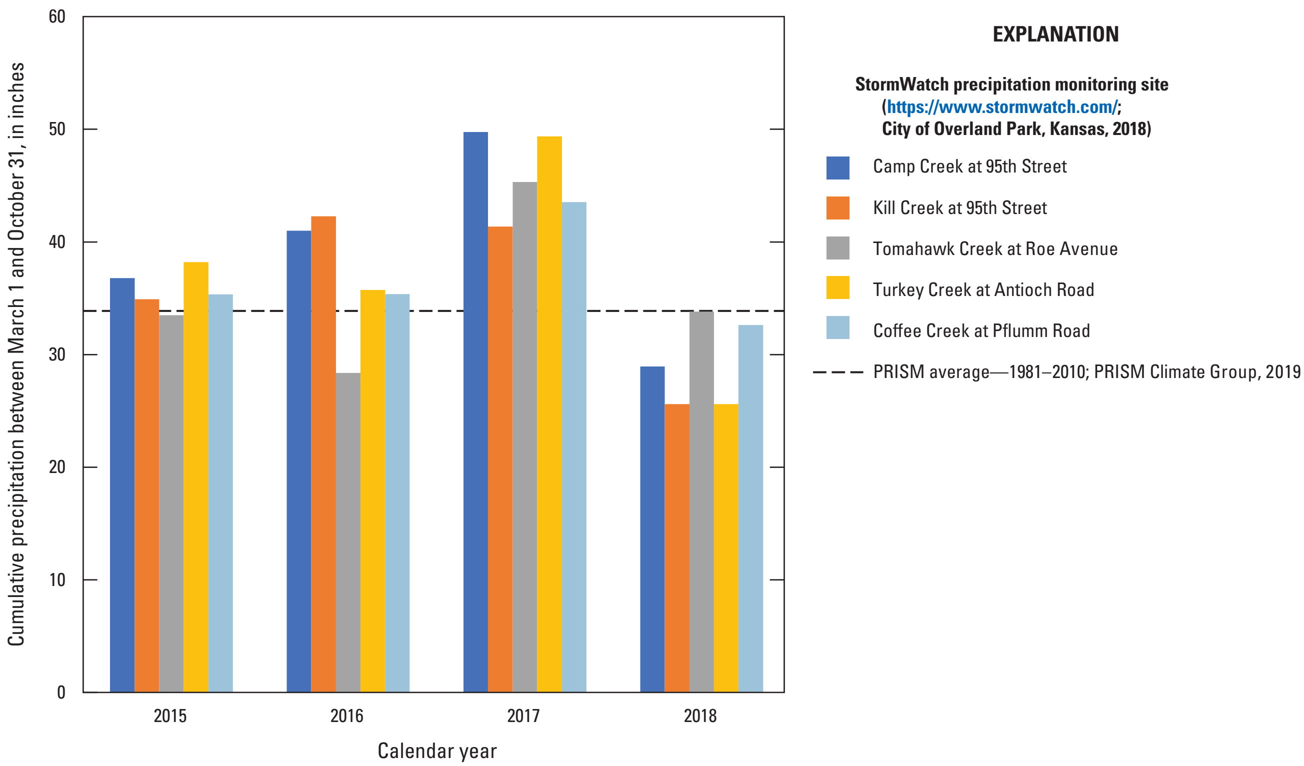

Figure 17. Cumulative precipitation between March 1 and October 31, 2015–18, at five selected sites in Johnson County, Kansas. Precipitation data courtesy of StormWatch (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018).

was 2018; all five sites had cumulative precipitation below the 30-year average. There were as much as 14 inches of difference between the driest and wettest sites each year.

During a single rainfall event, rainfall amounts can vary widely across a single watershed making it difficult to collect storm samples from the same runoff event at all sites in a watershed. For example, figure 18 shows a screenshot of cumulative 7-day precipitation from StormWatch (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018) captured on August 7, 2017. Displayed precipitation amounts vary from 1.50 to 5.36 inches. In the black box added for emphasis, three sites about 1 mile apart along Coffee Creek in southern Johnson County had precipitation amounts of 2.76, 4.32, and 2.72 inches progressing downstream. On some occasions, passive storm samples were collected at one site in a watershed, whereas the stream stage at other sites in the same watershed did not rise high enough for a passive sample to be collected.

In addition to spatiotemporal variability in precipitation, response of storm runoff to precipitation was variable as well. During the particularly dry year of 2018 (fig. 17), some sites did not have appreciable streamflow even after the 0.5 inch of precipitation threshold for the stormwater discharge permits was met. For example, the site at Kill Creek at 95th Street (site 2, fig. 1) had a precipitation event that produced 0.91 inch of rain between 15:30 and 17:45 on August 19, 2018, and resulted in a maximum streamflow of only 1.33 cubic feet per second (data not shown; data available from U.S. Geological Survey, 2019b, using station identification number in table 2).

Total Maximum Daily Load Relevance

Data collected in this study could be used to evaluate current TMDL criteria, for example total nitrogen, and to inform future TMDL criteria, for example total phosphorus or TSS. As previously discussed, it is difficult to characterize water quality based on four storm-event samples and one low-flow sample per year.

To facilitate the evaluation of general water quality, autosamplers, set sampling frequencies, or both could better capture variability between sites and across watersheds. Sampling at more evenly spaced intervals along a stream and sampling all major tributaries instead of focusing on municipal boundaries could also lead to a more comprehensive dataset across a watershed by more extensively measuring the distribution of pollutants in streams. Effectiveness of BMPs would be better measured by installing sampling sites closer to the BMPs. Contributing factors like antecedent moisture and precipitation intensity could be added to future stormwater discharge permit sampling requirements to supplement the current requirement of precipitation amount to more comprehensively understand the makeup of storm runoff in the county.

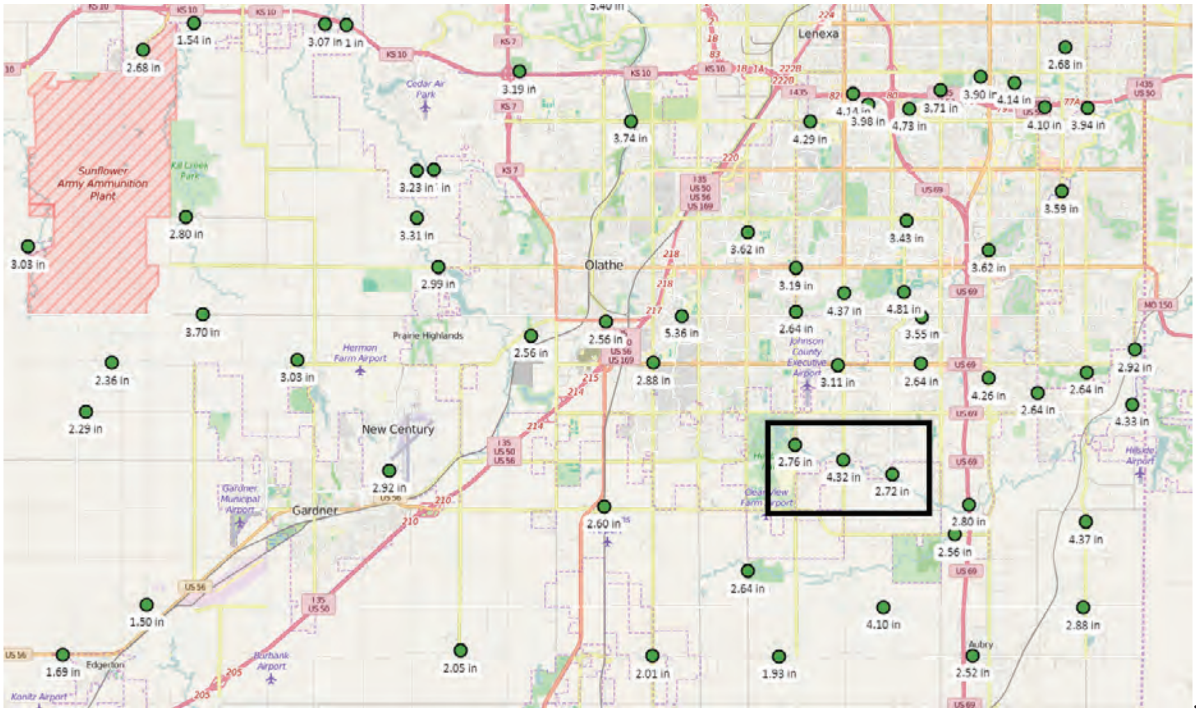

Figure 18. Cumulative 7-day precipitation values from StormWatch (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018) captured on August 7, 2017, with added black box for emphasis.

Summary

Stormwater discharges from municipalities are regulated by provisions in the Clean Water Act of 1972 to protect the Nation's water resources from harmful pollutants. In 2014, the Kansas Department of Health and Environment (KDHE) issued new stormwater discharge permits for 17 municipalities in Johnson County, Kansas, in the northeastern part of the State. The county is largely suburban with 20 municipalities within 22 watersheds. Municipalities in Johnson County are required to implement stormwater management programs that reduce discharges of pollutants, protect water quality, and satisfy applicable water-quality regulations. These requirements apply to all small municipal separate storm sewer systems in the county.

Nine of the 17 stormwater discharge permits also mandate that municipalities in Johnson County monitor water quality relative to water-quality impairments, total maximum daily loads (TMDLs) designated by KDHE, or both. Monitoring required by the permit is intended to assess change in the target waterbody resulting from best management practice implementation through stormwater management programs. In 2014, 13 streams and 2 lakes in Johnson County had designated water-quality impairments, TMDLs with monitoring requirements, or both.

In 2015, the U.S. Geological Survey, in cooperation with the Johnson County Stormwater Management Program, began a 4-year monitoring program designed to meet new stormwater monitoring requirements for some municipalities in Johnson County including sampling frequency and sampling conditions described in stormwater discharge permits. Additional data were collected to evaluate the usefulness of continuous water-quality monitoring and different sampling methods in assessing changes in water quality. Twelve of the 22 watersheds in the county were within the sampling network for this project.

Discrete water-quality samples were collected at 25 stream sites and 2 lake sites using passive, grab, and equal-width increment (EWI) sampling methods. Samples at all sites were analyzed for nutrients (dissolved phosphorus, total phosphorus, dissolved orthophosphate, dissolved nitrate plus nitrite, and total Kjeldahl nitrogen), *Escherichia coli* (*E. coli*) bacteria, total suspended solids (TSS), and suspended-sediment concentration.

Continuous water-quality data (water temperature, specific conductance, pH, dissolved oxygen, turbidity, and nitrate plus nitrite) were collected at one site—Mill Creek at Johnson Drive. Ordinary least squares regression analysis was used to relate continuous (15-minute) water-quality sensor measurements to discretely sampled constituent concentrations at this site. Surrogate regression models that define relations between *in situ* continuously measured parameters and laboratory-analyzed discrete data make possible continuous real-time estimates of particular constituents of interest. Models for total nitrogen, *E. coli*, TSS, and suspended sediment were developed to compute continuous estimates of constituent concentrations and loads.

Nine method-comparison replicate sample sets were collected. The method-comparison sample size is small because time constraints caused collection of permit samples to be prioritized over collection of method-comparison samples. Passive samples generally had higher concentrations when compared to EWI and grab samples, and grab samples and EWI samples generally had similar concentrations. Stream mixing dynamics may play a role in concentrations at the stream bank (passive samples), at the centroid of flow (grab samples), and composited across the whole stream (EWI samples).

Median storm-event nitrate plus nitrite concentrations ranged from 0.3 to 4 milligrams per liter (mg/L). The Kansas Surface Water Quality Standard for both nitrate (as nitrogen) and nitrate plus nitrite (as nitrogen) is 10 mg/L. Ninety-nine percent of storm-event samples and 98 percent of low-flow samples were less than the Kansas Surface Water Quality Standard for nitrate plus nitrite. Total Kjeldahl nitrogen was generally the more dominant nitrogen form compared to nitrate plus nitrite in both storm-event and low-flow samples. The U.S. Environmental Protection Agency ecoregion 40 reference condition for total nitrogen is 0.855 mg/L. Less than 1 percent of storm-event samples and 41 percent of low-flow samples were less than the reference condition.

Continuous measurements of nitrate plus nitrite ranged from less than 0.1 to 9.65 mg/L and had a mean value of 1.89 mg/L and a median value of 1.44 mg/L. There were 83 discrete samples collected over the study period. Discrete sample values of nitrate plus nitrite ranged from 0.15 to 7.71 mg/L and had a mean value of 1.73 mg/L and a median value of 1.01 mg/L.

Median storm-event total phosphorus concentrations ranged from 0.3 to 2.5 mg/L. A numeric Kansas Surface Water Quality Standard for phosphorus does not currently (2021) exist, but according to the KDHE, "Conditions of full support [of aquatic biology] span total phosphorus levels of 0.031 mg/L to 0.215 mg/L." Seventeen percent of storm-event samples and 88 percent of low-flow samples were less than 0.215 mg/L. The U.S. Environmental Protection Agency ecoregion 40 reference condition is 0.0925 mg/L. Three percent of storm-event samples and 63 percent of low-flow samples were less than the reference condition. For samples without a censored result for either constituent, dissolved phosphorus generally dominated (more than 50 percent) total phosphorus in low-flow samples but not in storm-event samples.

Median storm-event *E. coli* densities were between 1,000 and 40,000 colony forming units per 100 milliliters. Most streams in Johnson County are classified for primary contact recreation class B or C. The Kansas Surface Water Quality Standards for *E. coli* during the recreation season (April 1 through October 31) are 262 colony forming units per 100 milliliters for class-B stream segments and 427 colony forming units per 100 milliliters for class-C stream segments. These standards are based on the geometric mean of multiple samples throughout the recreation season, and the discrete samples collected in this study do not meet the sampling requirements set forth by the standards. However, as a basis for comparison, 1 percent of storm-event samples were less than the class-B criteria, and 3 percent of storm-event samples were less than the class-C criteria for *E. coli*. Ninety-two percent of low-flow samples were less than the class-B criteria, and 95 percent of low-flow samples were less than the class-C criteria.

Median storm-event TSS concentrations were generally between 200 and 4,000 mg/L. Since 2008, the KDHE has used a screening value of 50 mg/L TSS to designate water bodies likely to fully support aquatic life uses. Eight percent of storm-event samples and 100 percent of low-flow samples were less than the screening value of 50 mg/L. Median storm-event suspended-sediment concentrations were generally less than 2,500 mg/L.

Two sites, Kill Creek at 95th Street and Mill Creek at Johnson Drive, had robust (*n* greater than 30) historical datasets, consisting of low-flow and storm-event samples, to compare to data collected in this study. Six of the eight watershed groups in this study had historical data consisting of low-flow, storm-event, or both samples. Differences between historical and current-study data were not immediately apparent, and statistically significant determinations were not possible due to the compositions of the datasets.

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References Cited

American Public Health Association, American Water Works Association, and Water Environment Federation, 1995, Standard methods for the examination of water and wastewater (19th ed.): Washington, D.C., American Public Health Association, 905 p.

Arar, E.J., and Collins, G.B., 1997, In vitro determination of chlorophyll *a* and pheophytin *a* in marine and freshwater algae by fluorescence: U.S. Environmental Protection Agency, Method 445.0, revision 1.2, 22 p. [Also available at https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=309417.]

Bailey, J.F., and Ray, H.A., 1967, Definition of stage-discharge relations in natural channels by step-backwater analysis, chap. A *of* River hydraulics: U.S. Geological Survey Water-Supply Paper 1869, 24 p. [Also available at https://doi.org/10.3133/wsp1869A.]

Bennett, T.J., Graham, J.L., Foster, G.M., Stone, M.L., Juracek, K.E., Rasmussen, T.J., and Putnam, J.E., 2014, U.S. Geological Survey quality-assurance plan for continuous water-quality monitoring in Kansas, 2014: U.S. Geological Survey Open-File Report 2014–1151, 70 p., accessed October 2016 at https://doi.org/10.3133/ofr20141151.

City of Overland Park, Kansas, 2018, StormWatch alert flood warning system: City of Overland Park web interface, accessed October 10, 2018, at https://www.stormwatch.com/.

City of Overland Park, Kansas, 2020, About StormWatch: City of Overland Park web interface, accessed March 22, 2020, at https://www.stormwatch.com/dashboard/?dashboard=daf3e406-1dae-4cf1-8b7b-28c7c25567c9.

Davidian, J., 1984, Computation of water-surface profiles in open channels: U.S. Geological Survey Techniques and Methods book 3, chap. A15, 57 p. [Also available at https://doi.org/10.3133/twri03A15.]

Fishman, M.J., ed., 1993, v. 93–125. Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments, U.S. Geological Survey Open-File Report, 217 p. [Also available at https://doi.org/10.3133/ofr93125.]

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p. [Also available at https://doi.org/10.3133/twri05A1.]

Graham, J.L., Stone, M.L., Rasmussen, T.J., Foster, G.M., Poulton, B.C., Paxson, C.R., and Harris, T.D., 2014, Effects of wastewater effluent discharge and treatment facility upgrades on environmental and biological conditions of Indian Creek, Johnson County, Kansas, June 2004 through June 2013: U.S. Geological Survey Scientific Investigations Report 2014–5187, 78 p. [Also available at https://doi.org/10.3133/sir20145187.]

Graham, J.L., Stone, M.L., Rasmussen, T.J., and Poulton, B.C., 2010, Effects of wastewater effluent discharge and treatment facility upgrades on environmental and biological conditions of the Upper Blue River, Johnson County, Kansas and Jackson County, Missouri, January 2003 through March 2009: U.S. Geological Survey Scientific Investigations Report 2010–5248, 85 p. [Also available at https://doi.org/10.3133/sir20105248.]

Gray, J.R., Glysson, G.D., Turcios, L.M., and Schwarz, G.E., 2000, Comparability of suspended-sediment concentration and total suspended solids data: U.S. Geological Survey Water-Resources Investigations Report 2000–4191, 14 p. [Also available at https://doi.org/10.3133/wri004191.]

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p. [Also available at https://doi.org/10.3133/twri05C1.]

Hach Company, 2012, NITRATAX sc user manual 5th ed.: Germany, Hach Company, 40 p.

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States–Representing a decade of land cover change information: Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345–354.

Kansas Department of Health and Environment, 2008, Methodology for the evaluation and development of the 2008 section 303(d) list of impaired water bodies for Kansas: Kansas Department of Health and Environment, accessed May 1, 2020, at https://www.kdheks.gov/tmdl/download/2008_303_d_Methodology.pdf.

Kansas Department of Health and Environment, 2011, Water quality standards white paper bacteria criteria for streams: Kansas Department of Health and Environment, accessed July 8, 2020, at https://www.kdheks.gov/water/download/tech/Bacteria_final_Jan27.pdf.

Kansas Department of Health and Environment, 2012, Kansas 303(d) list of impaired waters, public hearing information and methodology: Kansas Department of Health and Environment web page, accessed April 2014 at https://www.kdheks.gov/tmdl/methodology.htm.

Kansas Department of Health and Environment, 2013, National pollutant discharge elimination system general permit for discharges of storm water from small municipal separate storm sewer systems (MS4s): Kansas Department of Health and Environment fact sheet, 3 p., accessed April 2014 at https://www.kdheks.gov/muni/download/stormwater/attachment_3_stormwater_ms4_reissue_fact_sheet.pdf.

Kansas Department of Health and Environment, 2016a, The basics of TMDLs: Kansas Department of Health and Environment web page, accessed December 2016 at https://www.kdheks.gov/tmdl/basic.htm.

Kansas Department of Health and Environment, 2016b, Municipal stormwater program: Kansas Department of Health and Environment web page, accessed September 14, 2016, at https://www.kdheks.gov/muni/ms4.htm.

Kansas Department of Health and Environment, 2017a, Kansas-Lower Republican Basin total maximum daily load (total phosphorus): Kansas Department of Health and Environment, accessed September 30, 2019, at https://www.kdheks.gov/tmdl/2016/Lower_KS_R_TP_TMDL.pdf.

Kansas Department of Health and Environment, 2017b, Kansas surface water quality standards, tables of numeric criteria: Kansas Department of Health and Environment, accessed September 30, 2019, at https://www.kdheks.gov/tmdl/download/SWQS_Tables_2017_12152017_final.pdf.

Lee, C.J., Mau, D.P., and Rasmussen, T.J., 2005, Effects of nonpoint and selected point contaminant sources on stream-water quality and relation to land use in Johnson County, northeastern Kansas, October 2002 through June 2004: U.S. Geological Survey Scientific Investigations Report 2005–5144, 104 p. [Also available at https://doi.org/10.3133/sir20055144.].

Lee, C.J., and Ziegler, A.C., 2010, Effects of urbanization, construction activity, management practices, and impoundments on suspended-sediment transport in Johnson County, northeast Kansas, February 2006 through November 2008: U.S. Geological Survey Scientific Investigations Report 2010–5128, 54 p. [Also available at https://doi.org/10.3133/sir20105128.]

Leiker, B.M., King, L.R., Rasmussen, T.J., and Paxson, C.R., 2021, Water-quality and preceding precipitation data for low-flow and storm-event samples collected in Johnson County, Kansas, from January 2015 through November 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P91397BC.

Myers, D.N., Stoeckel, D.M., Bushon, R.N., Francy, D.S., and Brady, A.M.G., 2014, Fecal indicator bacteria (ver. 2.1), sec. 7.1 *of* Myers, D.N., and Wilde, F.D., eds., Biological indicators: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, 73 p. [Also available at https://doi.org/10.3133/twri09A7.]

NELAC Institute, 2016, TNI standards: The NELAC Institute web page, accessed July 31, 2017, at https://www.nelac-institute.org/content/CSDP/standards.php.

Painter, C.C., and Loving, B.L., 2015, U.S. Geological Survey quality-assurance plan for surface-water activities in Kansas, 2015: U.S. Geological Survey Open-File Report 2015–1074, 33 p. [Also available at https://doi.org/10.3133/ofr20151074.]

Patton, C.J., and Kryskalla, J.R., 2011, Colorimetric determination of nitrate plus nitrite in water by enzymatic reduction, automated discrete analyzer methods: U.S. Geological Survey Techniques and Methods, book 5, chap. B8, 34 p. [Also available at https://doi.org/10.3133/tm5B8.]

Patton, C.J., and Truitt, E.P., 1992, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of total phosphorus by a Kjeldahl digestion method and an automated colorimetric finish that includes dialysis: U.S. Geological Survey Open-File Report 1992–0146, 39 p. [Also available at https://doi.org/10.3133/ofr92146.]

Patton, C.J., and Truitt, E.P., 2000, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of ammonium plus organic nitrogen by a Kjeldahl digestion method and an automated photometric finish that includes digest cleanup by gas diffusion: U.S. Geological Survey Open-File Report 2000–0170, 31 p. [Also available at https://doi.org/10.3133/ofr00170.]

Pellerin, B.A., Bergamaschi, B.A., Downing, B.D., Saraceno, J.F., Garrett, J.A., and Olsen, L.D., 2013, Optical techniques for the determination of nitrate in environmental waters—Guidelines for instrument selection, operation, deployment, maintenance, quality assurance, and data reporting: U.S. Geological Survey Techniques and Methods, book 1, chap. D5, 37 p. [Also available at https://doi.org/10.3133/tm1D5.]

PRISM Climate Group, 2019, 30-year normals: Oregon State University web page, accessed July 25, 2019, at https://www.prism.oregonstate.edu/normals/.

Rasmussen, T.J., Bennett, T.J., Stone, M.L., Foster, G.M., Graham, J.L., and Putnam, J.E., 2014, Quality-assurance and data-management plan for water-quality activities in the Kansas Water Science Center, 2014: U.S. Geological Survey Open-File Report 2014–1233, 41 p., accessed June 2016 at https://doi.org/10.3133/ofr20141233.

Rasmussen, T.J., and Gatotho, J., 2014, Water-quality variability and constituent transport and processes in streams of Johnson County, Kansas, using continuous monitoring and regression models, 2003–11: U.S. Geological Survey Scientific Investigations Report 2013–5221, 53 p., accessed June 2016 at https://doi.org/10.3133/sir20135221.

Rasmussen, T.J., Lee, C.J., and Ziegler, A.C., 2008, Estimation of constituent concentrations, loads, and yields in streams of Johnson County, northeast Kansas, using continuous water-quality monitoring and regression models, October 2002 through December 2006: U.S. Geological Survey Scientific Investigations Report 2008–5014, 103 p. [Also available at https://doi.org/10.3133/sir20085014.]

Rasmussen, T.J., and Paxson, C.R., 2017, Preliminary assessment of a water-quality monitoring program for total maximum daily loads in Johnson County, Kansas, January 2015 through June 2016: U.S. Geological Survey Scientific Investigations Report 2017–5089, 20 p. [Also available at https://doi.org/10.3133/sir20175089.]

Rasmussen, T.J., Stone, M.S., Poulton, B.C., and Graham, J.L., 2012, Quality of streams in Johnson County, Kansas, 2002–10: U.S. Geological Survey Scientific Investigations Report 2012–5279, 103 p., accessed June 2016 at https://doi.org/10.3133/sir20125279.

Sauer, V.B., and Turnipseed, D.P., 2010, Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A7, 45 p. [Also available at https://doi.org/10.3133/tm3A7.]

Seaber, P.R., Kapinos, F.P., and Knapp, G.L., 1987, Hydrologic unit maps: U.S. Geological Survey Water-Supply Paper 2294, 63 p., 1 pl. [Also available at https://doi.org/10.3133/wsp2294.]

Standard Methods for the Examination of Water and Wastewater, 2017, 9223 enzyme substrate coliform test (2017): Standard Methods for the Examination of Water and Wastewater web page, accessed July 15, 2020, at https://www.standardmethods.org/doi/10.2105/SMWW.2882.194.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p. [Also available at https://doi.org/10.3133/tm3A8.]

U.S. Census Bureau, 2018, 2010 census urban area reference maps: U.S. Census Bureau, accessed February 18, 2021, at https://www.census.gov/geographies/reference-maps/2010/geo/2010-census-urban-areas.html.

U.S. Environmental Protection Agency, 1989, Risk assessment guidance for Superfund volume I human health evaluation manual (part A): U.S. Environmental Protection Agency, accessed May 19, 2020, at https://www.epa.gov/sites/production/files/2015-09/documents/rags_a.pdf.

U.S. Environmental Protection Agency, 2000a, Ambient water quality criteria recommendations—Information supporting the development of State and Tribal nutrient criteria, rivers and streams in nutrient ecoregion IX: U.S. Environmental Protection Agency, accessed September 30, 2019, at https://www.epa.gov/sites/production/files/documents/rivers9.pdf.

U.S. Environmental Protection Agency, 2000b, Ecoregional nutrient criteria fact sheet: U.S. Environmental Protection Agency web page, accessed September 30, 2019, at https://19january2017snapshot.epa.gov/nutrient-policy-data/ecoregional-nutrient-criteria-fact-sheet_.html.

U.S. Environmental Protection Agency, 2020, Kansas surface water quality standards register (2013): U.S. Environmental Protection Agency, accessed May 1, 2020, at https://www.epa.gov/sites/production/files/2014-12/documents/kswqs-register-2009.pdf.

U.S. Geological Survey, [variously dated], National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A10, [variously paged], accessed July 1, 2018, at https://www.usgs.gov/mission-areas/water-resources/science/national-field-manual-collection-water-quality-data-nfm?qt-science_center_objects=0#qt-science_center_objects.

U.S. Geological Survey, 2006, Collection of water samples (ver. 2.0, September 2006): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, accessed July 1, 2018, at https://doi.org/10.3133/twri09A4.

U.S. Geological Survey, 2019b, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed February 1, 2019, at https://doi.org/10.5066/F7P55KJN.

U.S. Geological Survey, [undated], The branch of quality systems: U.S. Geological Survey web page, accessed July 1, 2018, at https://bqs.usgs.gov/.

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods, book 1, chap. D3, [variously paged]. [Also available at https://doi.org/10.3133/tm1D3.]

Wilkison, D.H., Armstrong, D.J., and Hampton, S.A., 2009, Character and trends of water quality in the Blue River Basin, Kansas City metropolitan area, Missouri and Kansas, 1998 through 2007: U.S. Geological Survey Scientific Investigations Report 2009–5169, 211 p. [Also available at https://doi.org/10.3133/sir20095169.]

Yellow Springs Instruments, 2017, EXO user manual—Advanced water quality monitoring platform (rev. G): Yellow Springs Instruments, 154 p., accessed December 21, 2016, at https://www.ysi.com/file%20library/documents/manuals/exo-user-manual-web.pdf.

Appendix 1. Streamflow Measurement and Estimation Methods

Stream stage (also called gage height) was collected at all sites and used to determine the time of collection for the passive samplers and calculate streamflow. Streamflow data are required by the stormwater discharge permit and are used with concentration values to calculate loads. At existing U.S. Geological Survey (USGS) streamgages, stage and streamflow were measured and reported according to standard USGS procedures (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015). At stream sites without existing USGS streamgages, streamflow was estimated based on static stage-discharge ratings developed for each site using the step-backwater methods as described in Bailey and Ray (1967), Davidian (1984), and Painter and Loving (2015).

Stream Sites with Existing U.S. Geological Survey Streamgages

Four sites were existing streamgages reporting streamflow and stage: Kill Creek at 95th Street (site 2, fig. 1 in the main body of the report), Big Bull Creek near Edgerton (site 7, fig. 1), Mill Creek at Johnson Drive (site 15, fig. 1), and Blue River near Stanley (site 27, fig. 1). Stream stage and streamflow were measured and reported according to standard U.S. Geological Survey (USGS) procedures (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015). Stream stage and streamflow data from these sites were retrieved from the National Water Information System (U.S. Geological Survey, 2019).

One site, Camp Creek at 95th Street (site 3, fig. 1), had an existing USGS streamgage reporting stage that is operated according to standard USGS procedures (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015). Streamflow measurements are occasionally obtained at the site as warranted by environmental conditions. Stream stage data from this site were retrieved from the National Water Information System (U.S. Geological Survey, 2019), and streamflow was estimated from approved stream stage using a rating curve (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015).

At the five aforementioned sites, the elevation of the passive sampler was measured and the collection time for the passive samples was set at the first 15-minute period that the reported stage exceeded the passive sampler elevation, and the streamflow value from this sample time was entered as the discrete sample's instantaneous streamflow value.

Stream Sites Without Existing U.S. Geological Survey Streamgages

For 19 stream sites without existing USGS streamgages (sites 5–6, 8–14, 17–26; fig. 1), streamflow was estimated based on static stage-discharge ratings developed for each site using the step-backwater methods as described in Bailey and Ray (1967), Davidian (1984), and Painter and Loving (2015). Streamflow estimates calculated using the step-backwater method are applicable only for this project period (2015–18). These ratings were developed using an *n*-value (roughness coefficient) selected to represent average seasonal conditions. However, the stage-discharge relation was still subject to variability as growth and decay of vegetation along the banks changed throughout the year. Any geomorphic changes that may have altered the stage-discharge relation were not accounted for due to the static nature of a single rating developed using step-backwater analysis. At Little Mill Creek near Midland Road (site 13, fig. 1), the streamflow value for the June 1, 2017, sample was deleted due to backwater effects from Mill Creek. For all other samples, it was assumed that there were no substantial backwater effects.

At the 19 ungaged sites (sites 5–6, 8–14, 17–26; fig. 1), stream stage was recorded for each discrete sample, and the elevation (stage) of the passive sampler was measured so that a streamflow value could be obtained from the stage-discharge rating. Therefore, the streamflow for every passive sample at an ungaged site was estimated to be the same.

Streamflow was estimated for storm-event samples and not for the low-flow samples collected in February and (or) March. Streamflow was not estimated for Kill Creek at 151st Street (site 1, fig. 1) because this site was added to the project in 2016 after streamflow-estimation surveying was started, but stream stage measurements were obtained for each sample.

For passive samples, an Onset HOBO U20 Water Level Logger (Onset Computer Corporation, undated) was deployed at each ungaged stream site and recorded temperature and absolute pressure every 5 minutes. The time at which absolute pressure increased, corresponding to an increase in water level, was entered as the discrete sample's sample time.

For grab samples, the time of collection was recorded. Stream stage was determined using either a wire-weight measurement or a "tape-down," where the distance between a surveyed reference point and the water level was measured with a weighted tape measure. At five sites with StormWatch (https://www.stormwatch.com/; City of Overland Park, Kansas, 2018) stage gages, Clear Creek at Woodland Road (site 14, fig. 1), Turkey Creek at Antioch (site 18, fig. 1), Tomahawk Creek at Pflumm Road (site 20, fig. 1), Coffee Creek at Pflumm Road (site 24, fig. 1), and Wolf Creek at 179th Street (site 26, fig. 1), the StormWatch wire weight was used to determine stream stage. A tape-down was used at sites without a wire weight to determine stream stage.

References Cited

Bailey, J.F., and Ray, H.A., 1967, Definition of stage-discharge relations in natural channels by step-backwater analysis, chap. A *of* River hydraulics: U.S. Geological Survey Water-Supply Paper 1869, 24 p. [Also available at https://doi.org/10.3133/wsp1869A.]

City of Overland Park, Kansas, 2018, StormWatch alert flood warning system: City of Overland Park web interface, accessed October 10, 2018, at https://www.stormwatch.com/.

Davidian, J., 1984, Computation of water-surface profiles in open channels: U.S. Geological Survey Techniques and Methods book 3, chap. A15, 57 p. [Also available at https://doi.org/10.3133/twri03A15.]

Onset Computer Corporation, [undated], HOBO U20 Water Level Logger (U20-001-0x and U20-001-0x-Ti) manual: Onset Computer Corporation, document 17153–D, accessed July 8, 2020, at https://www.onsetcomp.com/files/manual_pdfs/12315-E-MAN-U20.pdf.

Painter, C.C., and Loving, B.L., 2015, U.S. Geological Survey quality-assurance plan for surface-water activities in Kansas, 2015: U.S. Geological Survey Open-File Report 2015–1074, 33 p. [Also available at https://doi.org/10.3133/ofr20151074.]

Sauer, V.B., and Turnipseed, D.P., 2010, Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A7, 45 p. [Also available at https://doi.org/10.3133/tm3A7.]

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p. [Also available at https://doi.org/10.3133/tm3A8.]

U.S. Geological Survey, 2019, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed February 1, 2019, at https://doi.org/10.5066/F7P55KJN.

Appendix 2. Model Archive Summary for Total Nitrogen at Mill Creek at Johnson Drive, Shawnee, Kansas, 2015–18

Appendix 2 is available for download at https://doi.org/10.3133/sir20215041.

Appendix 3. Model Archive Summary for *Escherichia coli* at Mill Creek at Johnson Drive, Shawnee, Kansas, 2015–18

Appendix 3 is available for download at https://doi.org/10.3133/sir20215041.

Appendix 4. Model Archive Summary for Total Suspended Solids at Mill Creek at Johnson Drive, Shawnee, Kansas, 2015–18

Appendix 4 is available for download at https://doi.org/10.3133/sir20215041.

Appendix 5. Model Archive Summary for Suspended Sediment at Mill Creek at Johnson Drive, Shawnee, Kansas, 2015–18

Appendix 5 is available for download at https://doi.org/10.3133/sir20215041.

Appendix 6. Comparison of Historical and Project Data

Appendix 6 is available for download at https://doi.org/10.3133/sir20215041.

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