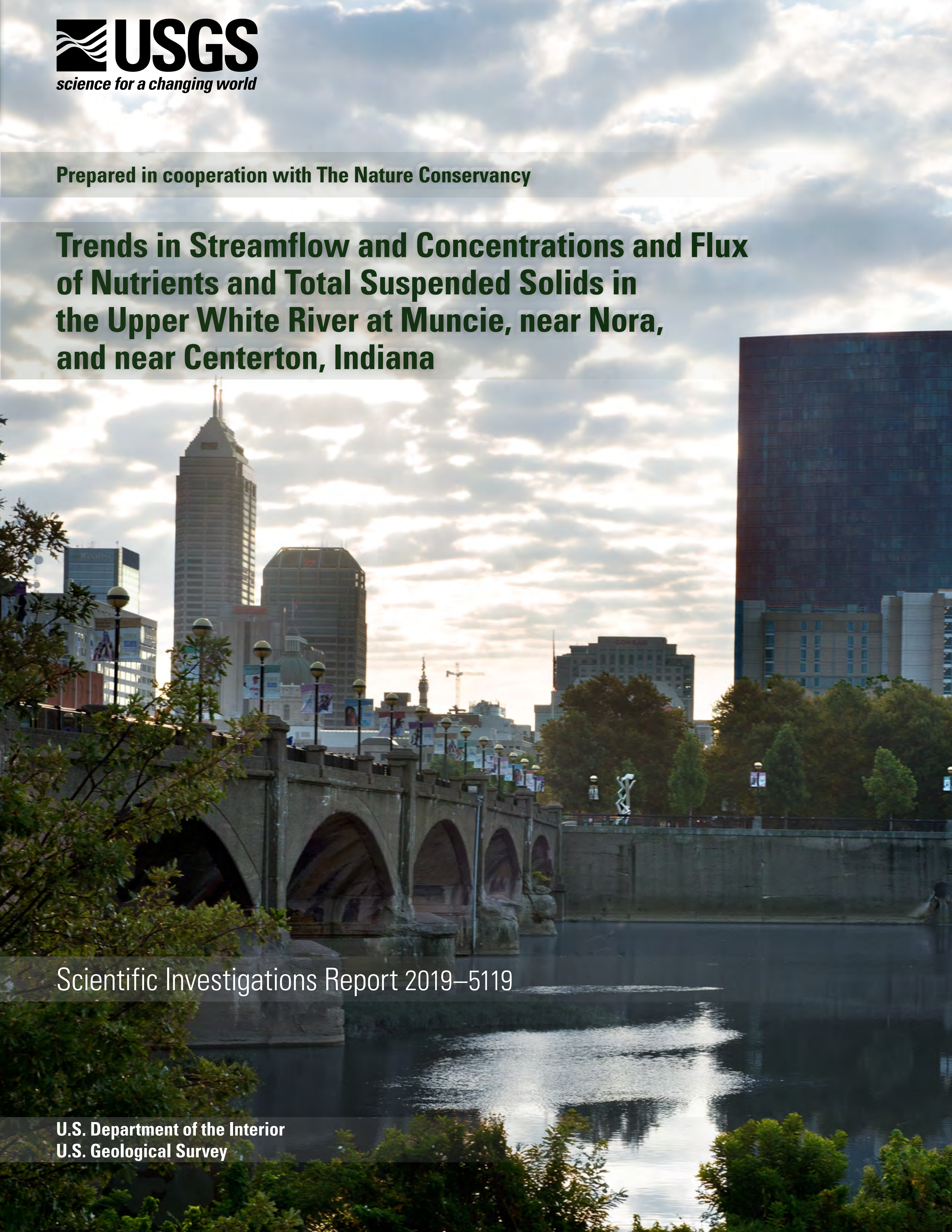

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Trends in Streamflow and Concentrations and Flux of Nutrients and Total Suspended Solids in the Upper White River at Muncie, near Nora, and near Centerton, Indiana

Scientific Investigations Report 2019–5119

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

Cover. Photograph showing the White River downstream from the White River Trail bridge, looking east toward White River State Park in downtown Indianapolis, Indiana. Photograph by Matt Williams, The Nature Conservancy.

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By G.F. Koltun

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

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

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)

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

$$°C = (°F - 32) / 1.8.$$

Supplemental Information

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

A water year is the period from October 1 to September 30 and is designated by the year in which it ends; for example, water year 2015 was from October 1, 2014, to September 30, 2015.

Abbreviations

EDI	equal discharge increment
EGRET	Exploration and Graphics for RivEr Trends
EGRETci	Exploration and Graphics for RivEr Trends Confidence Intervals
EWI	equal width increment
GCLAS	Graphical Constituent Loading Analysis System
IDEM	Indiana Department of Environmental Management
LOADEST	Load Estimator
LOWESS	LOcally WEighted Scatterplot Smoothing
NWISWeb	USGS National Water Information System: Web Interface
QC	quality control
SPARROW	SPAtially Referenced Regressions On Watershed attributes
TNC	The Nature Conservancy
USGS	U.S. Geological Survey
WBT	WRTDS bootstrap test
WRTDS	Weighted Regressions on Time, Discharge, and Season

Trends in Streamflow and Concentrations and Flux of Nutrients and Total Suspended Solids in the Upper White River at Muncie, near Nora, and near Centerton, Indiana

By G.F. Koltun

Abstract

The U.S. Geological Survey (USGS), in cooperation with The Nature Conservancy, completed a study to estimate and assess trends in streamflow and annual mean concentrations and flux of nutrients (nitrate plus nitrite, total Kjeldahl nitrogen, and total phosphorus) and total suspended solids at three USGS streamgages (hereafter referred to as "study gages") on the Upper White River at Muncie (USGS station 03347000), near Nora (USGS station 03351000), and near Centerton (USGS station 03354000), Indiana. Water-quality data used in the analyses were collected by several agencies between calendar years 1991 and 2017, and streamflow (discharge) data were collected by the USGS. For most of the water-quality constituents, there were suitable data to facilitate an analysis of the 26-year period extending from calendar years 1991 to 2017 (water years 1992 to 2017); however, shorter analytical periods were necessary for total Kjeldahl nitrogen for the study gages at Muncie and near Centerton and for total suspended solids for the study gage near Centerton.

Temporal trends in streamflows at the study gages for the period extending from water years 1978 to 2017 were assessed using Exploration and Graphics for RivEr Trends (EGRET) and Mann-Kendall and Pettitt tests. With just one exception, the annual maximum and mean daily streamflows and the annual minimum 7-day mean streamflows at the study gages demonstrated upward trends (increasing streamflows) in the EGRET analyses. The exception was the annual 7-day minimum streamflow at the study gage near Nora, which indicated no trend. Mann-Kendall tests also indicated that the average trend for the annual maximum daily, annual mean daily, and annual 7-day minimum streamflow statistics between water years 1978 and 2017 was upward at each of the study gages; however, only the trends in the annual mean daily streamflows at the study gage at Muncie and the annual maximum daily streamflows at the study gages near Nora and near Centerton were statistically significant at a 0.05 probability level. The Pettitt tests indicated that a statistically significant step trend (abrupt change) in annual mean daily streamflows occurred at each of the study gages around water year 2001.

The seasonal distributions of total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen concentrations at the study gages were evaluated to identify patterns and other distinguishing characteristics by examining boxplots of concentrations as a function of month of the year. Seasonal distributions of nitrate plus nitrite concentrations and total suspended solids concentrations differed from each other but were generally similar among the three study gages for a given constituent. Median concentrations of nitrate plus nitrite were highest during the January–June months, whereas median concentrations of total suspended solids were highest during June and July. Seasonal distributions of total phosphorus concentrations were similar at the study gages near Nora and near Centerton, but the seasonal distribution was noticeably different at the study gage at Muncie, which had monthly median concentrations that were substantially lower than at the two downstream study gages (near Nora and near Centerton). The seasonal distribution of total Kjeldahl nitrogen concentrations differed in pattern among the three study gages; however, in general, some of the higher monthly median total Kjeldahl nitrogen concentrations at each study gage were associated with the late spring and summer periods.

The Weighted Regressions on Time, Discharge, and Season (WRTDS) method implemented in EGRET was used to estimate water-year annual mean daily concentrations and flux of nutrients and total suspended solids, as well as estimates of concentrations and flux that were "normalized" to remove the effect of year-to-year variation in streamflow. The approximate coefficients of determination for the WRTDS regression models ranged from a high of 0.82 for total phosphorus for the study gage near Centerton to a low of 0.19 for nitrate plus nitrite for the study gage near Nora.

Loads and yields of total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen were estimated for analytical periods consisting of the longest periods of concurrent record at the three study gages. Loads

of each of the constituents increased sequentially from the most upstream study gage to the most downstream study gage; however, the same was not true for yields. The highest yields of total suspended solids, total phosphorus, and total Kjeldahl nitrogen occurred at the most upstream study gage (at Muncie); however, the highest yield of nitrate plus nitrite occurred at the most downstream study gage (near Centerton).

WRTDS bootstrap tests were used to assess the magnitude, direction, and likelihood of changes in annual flow-normalized mean daily concentrations and flux of total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen at the study gages between water years 1997 and 2017. Changes in flow-normalized concentrations and flux of the constituents between water years 1997 and 2017 were mostly downward (decreasing). The exceptions were likely to highly likely upward (increasing) changes in (1) flow-normalized annual mean daily concentration and annual flux for total suspended solids and total phosphorus at the study gage at Muncie, (2) flow-normalized annual mean daily total phosphorus concentration at the study gage near Centerton, (3) flow-normalized annual flux of total phosphorus at the study gage near Centerton, and (4) flow-normalized annual mean daily nitrate plus nitrite concentration at the study gage near Centerton. Although an upward change in flow-normalized nitrate plus nitrite concentrations was likely at the study gage near Centerton, flow-normalized annual flux of nitrate plus nitrite at that study gage was determined to have a highly likely downward change.

EGRET and Exploration and Graphics for RivEr Trends Confidence Intervals (EGRETci) analyses can be used to improve our understanding of how concentrations and flux change as functions of time and streamflow, as well as provide information on how the relations between streamflow and constituent concentrations have changed within the calendar year between any 2 years included in the analyses. Examples of those uses, illustrating changes between calendar years 1992 and 2017, were given for total suspended solids concentrations at the study gage near Nora and for nitrate plus nitrite concentrations at the study gage near Centerton.

Introduction

The Indiana chapter of The Nature Conservancy (TNC) plans to develop solutions to reduce the threat to water quality in the Mississippi River and Gulf of Mexico caused by high nutrient loading from agriculture and other sources in Indiana. TNC scientists used results from the U.S. Geological Survey's (USGS) SPAtially Referenced Regressions On Watershed attributes (known as SPARROW) model (Schwarz and others, 2006; Robertson and Saad, 2011) to identify Indiana's Wabash River Basin as a leading contributor of nitrogen and phosphorus (nutrients) to the Gulf of Mexico (Cassie Hauswald, The Nature Conservancy, written commun., 2018). TNC, the U.S. Environmental Protection Agency's Gulf Hypoxia Task Force, and the Indiana State Department of Agriculture have established a goal to reduce nutrients in the Wabash River by 20 percent by the year 2025 (Indiana State Department of Agriculture and Indiana Department of Environmental Management, 2018). The White River, in Indiana, is the largest tributary to the Wabash River, and the Upper White River (on the West Fork of the White River) has been identified as a major contributor of nutrients from agricultural and urban sources (Robertson and others, 2009; Robertson and Saad, 2013).

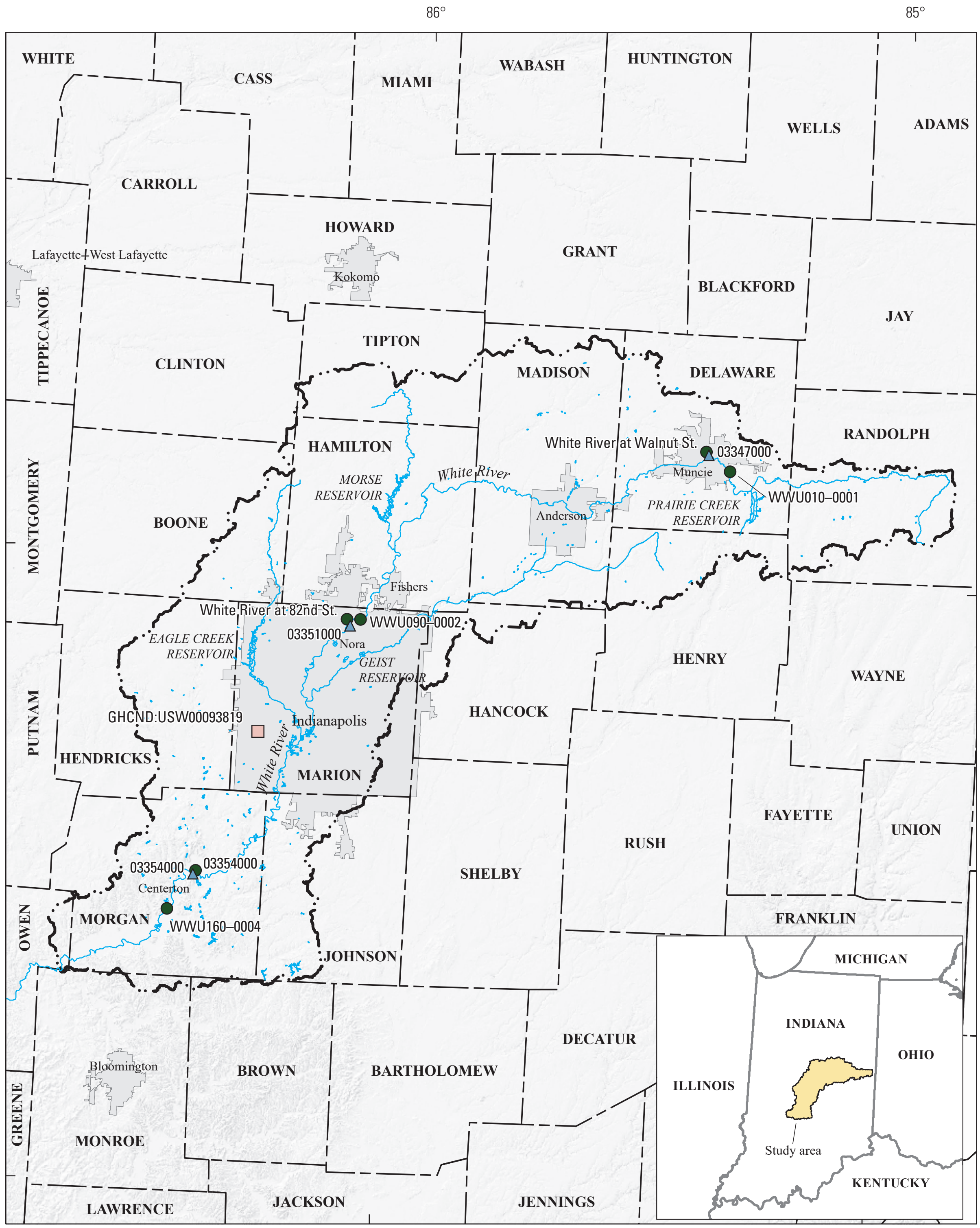
There is a relative wealth of water-quality and streamflow (discharge) data available for the Upper White River Basin. Consequently, the USGS has cooperated with TNC to leverage those data to learn more about nutrient and sediment transport characteristics by estimating time series and trends in concentrations and flux of selected nutrients and sediment at three locations in the Upper White River Basin. In the context of contaminant transport, the term "flux" refers to the rate of mass transport (reported in units of mass/time), whereas the term "load" typically refers to the amount of mass transported (reported in units of mass) and "yield" refers to the amount of mass transported per unit area (reported in units of mass/area). Flux is calculated as the product of concentration and streamflow and a units conversion factor.

Description of Study Area

The study area consists of the Upper White River Basin (hydrologic unit code 05120201), predominately in central and east-central Indiana (fig. 1). The Upper White River Basin drains an area of about 2,718 square miles and contains all or part of 16 counties that, in 2017, included 7 of the 20 most populated cities in Indiana (Indianapolis, Carmel, Fishers, Muncie, Noblesville, Greenwood, and Anderson; U.S. Census Bureau, 2018). Indianapolis is the most populated city in the State of Indiana, having a 2017 population estimated at more than 863,000 (U.S. Census Bureau, 2018).

The Upper White River Basin has more than 2,180 miles of streams (Tedesco and others, 2005) and four water-supply reservoirs (Eagle Creek Reservoir, Geist Reservoir, Morse Reservoir, and Prairie Creek Reservoir). Although Eagle Creek Reservoir has been used for water supply for the city of Indianapolis since 1976, it was developed primarily for flood control (Tedesco and others, 2005).

The drainage area upstream from locations for which streamflow and flux are discussed in this report lies predominately within the Tipton Till Plain physiographic region (not shown), with a small northerly part of the drainage area lying in the Bluffton Till Plain physiographic region. The Tipton and Bluffton Till Plains (hereafter referred to as "Till Plains") were formed by continental glaciation during the last ice age and consequently have low topographic relief. The Till Plains are characterized by a covering of glacial till and outwash material composed of 100 to 200 feet (ft) of silty clay till interspersed with thin (5 to 10 ft) layers of sand and gravel (Tedesco and



Base from U.S. Geological Survey digitial data, variously scaled
Universal Transverse Mercator projection, Zone 17 N.
North American Datum of 1983

EXPLANATION

Upper White River Basin

WWU160–0004 — Sampling location and identifier

03354000 — U.S. Geological Survey streamgage and identifier

GHCND:USW00093819 — Rain gage and identifier

Figure 1. Study area showing locations of streamgages and sampling locations.

others, 2011). Till Plain soils have attracted widespread agricultural land use but tend to have low infiltration rates so that tile drains are commonly installed to improve drainage and reduce surface runoff. A detailed description of the physiography, soils, and geology of the Upper White River Basin is included in Tedesco and others (2011).

Based on an analysis of land cover classified from Landsat satellite data circa 2011 (Homer and others, 2015), agriculture (more than 90 percent of which was in the form of cultivated crops; primarily corn and soybeans) was the dominant land cover in the Upper White River Basin, consisting of about 59.7 percent of the basin, followed by developed (24.6 percent) and forested (12.6 percent) land covers. In general, agricultural land cover in the Upper White River Basin decreases as a percentage of the drainage area from the headwaters in Randolph County to downstream locations on the White River. For example, agricultural makes up about 80 percent of the land cover for the drainage area of the White River at Muncie, Indiana, but only about 63 percent of the land cover for the drainage area of the White River near Centerton, Ind. Those decreases in agricultural land cover are predominately offset by increases in developed land covers.

Central Indiana has a humid-continental climate characterized by distinct summer and winter seasons, large annual temperature changes, and highly variable weather patterns (Tedesco and others, 2005). For the period 1981–2010, the mean annual temperature and precipitation for Indianapolis were 53.1 degrees Fahrenheit (°F) and 42.2 inches (in.), respectively (National Oceanic and Atmospheric Administration, National Centers for Environmental Information, 2018). According to Widhalm and others (2018), Indiana has warmed 1.2 °F since 1895 and temperatures are projected to rise about 5 to 6 °F above the 1971–2000 mean temperature (52.5 °F) by the mid-21st century. In addition, mean annual precipitation in Indiana has increased 5.6 in. since 1895 with more rain falling in heavy downpours (Widhalm and others, 2018). Winters and springs are projected to be much wetter than present by the mid-21st century (Widhalm and others, 2018), which would likely have an appreciable effect on nutrient and sediment flux within the Upper White River Basin (assuming practices that contribute to nutrient and sediment runoff do not change over the same period).

Purpose and Scope

This report describes the results of a study to estimate the analytical-period and annual mean concentrations and flux of selected nutrients (nitrate plus nitrite, total Kjeldahl nitrogen, and total phosphorus) and total suspended solids for the three stream locations on the Upper White River and to assess temporal trends in concentration and flux. The report also addresses temporal trends in streamflow and the seasonal distribution of concentrations of nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, and total suspended solids. The analyses described in this report are based on water-quality data collected between calendar years 1991 and 2017 (or water years 1992 and 2017) by Federal, State, and local agencies and streamflow data collected by the USGS.

Methods

The following sections describe the processes used to identify and select streamflow and water-quality data that were used for analysis, as well as data quality-control procedures and assumptions. Also described are methods used to estimate concentrations and flux and to assess temporal trends in streamflow, concentration, and flux.

Data Sources

The following agencies were contacted to determine the availability of water-quality data they may have collected within the Upper White River Basin that met the selection criteria described later:

- U.S. Geological Survey
- Indiana Department of Environmental Management (IDEM)
- Citizens Energy Group
- Indiana American Water Company
- Tipton County (Indiana) Soil and Water Conservation District
- Marion County (Indiana) Public Health Department
- Muncie (Indiana) Sanitary District, Bureau of Water Quality
- Ball State University
- Indianapolis (Indiana) Department of Public Works

Specifically, each agency was requested to identify locations and provide data for surface-water sites within the Upper White River Basin where they currently routinely collect, or collected in the past, at least six samples per year that were analyzed for one or more of the following constituents: nitrate plus nitrite (as nitrogen [N]), total Kjeldahl nitrogen (a measure of nitrogen contained in organic substances plus the nitrogen contained in the inorganic compounds ammonia and ammonium, reported as nitrogen), total phosphorus (as phosphorus [P]), total suspended solids, or suspended-sediment concentration. In addition to contacting the previously listed agencies, queries were made using the USGS National Water Information System: Web Interface (NWISWeb) and the Water Quality Portal (a web-based portal sponsored by the USGS, the U.S. Environmental Protection Agency, and the National Water Quality Monitoring Council that serves data collected by more than 400 State, Federal, Tribal, and local agencies).

Ultimately, with the exceptions of the Indiana American Water Company, Tipton County Soil and Water Conservation District, and Ball State University, all the previously listed sources had at least some data that met the selection criteria.

The locations of water-quality sampling sites with data that met the selection criteria were compared with locations of the following three USGS streamgages (hereafter referred to as "study gages") on the Upper White River in Indiana: White River at Muncie, Ind. (USGS station 03347000; hereafter referred to as the "study gage at Muncie"); White River near Nora, Ind. (USGS station 03351000; hereafter referred to as the "study gage near Nora"); and White River near Centerton, Ind. (USGS station 03354000; hereafter referred to as the "study gage near Centerton").

The study gages were chosen because of their long periods of streamflow record, their locations within the Upper White River Basin, and the known availability of at least some water-quality data collected at or near each study gage. Daily mean streamflow data for the study gages were obtained from NWISWeb (U.S. Geological Survey, 2018).

Water-quality sampling sites that met the selection criteria were identified for further consideration if they were deemed to be sufficiently close to a study gage location such that it would be reasonable to treat data collected at the sampling site as if they were collected at one of the study gages. Because instantaneous concentration data are treated as being approximately equal to daily mean concentrations in this analysis, water-quality sampling sites were considered to be sufficiently close to study gage locations if there were no known nutrient or sediment inputs between the study gage and sampling site that would likely cause the concentrations measured at the sampling sites to be unrepresentative of concentrations at the study gage (had they been measured) and if the drainage area at the sampling site was less than 10 percent different from the drainage area at the study gage. The water-quality sampling sites that were selected, the agencies that collected data at those sites, and the study gages with which the sampling sites were associated are listed in table 1.

Few suspended-sediment concentration data were available, so, because of their greater availability, total suspended solids concentration data were used to estimate sediment flux. Suspended-sediment concentration data are preferred over total suspended solids concentration data when assessing sediment concentrations or flux because the total suspended solids analysis tends to yield smaller sediment concentrations (as well as more analytical variance) than suspended-sediment concentration analyses, which results in greater uncertainty and an underestimate of the total amount of suspended sediment in transport (Gray and others, 2000).

The only constituent/site combination that may not have met the sampling-site selection criteria was total suspended solids for the study gage near Centerton, Ind. IDEM's site WWU160–0004 was the only sampling site near the study gage near Centerton where total suspended solids data were collected. There are three facilities (all nonpublicly owned treatment works) that discharge to the White River between the study gage and the IDEM sampling site that report total suspended solids concentrations as part of their permit requirements. Two of the facilities are classified as minor dischargers. The third is classified as a major discharger for noncontact cooling water but is required to sample for total suspended solids in stormwater runoff. It is not known if discharges from those facilities result in an appreciable change in concentrations measured at the sampling site relative to concentrations at the study gage. For the purposes of this analysis, it was assumed that concentrations of total suspended solids measured at the sampling site are representative of concentrations at the study gage.

Ideally, the same analytical period would be used for all sites for a given water-quality constituent to help facilitate comparisons among sites. Unfortunately, using an identical analytical period for all sites was not possible for some

Table 1. Streamgages and associated water-quality sampling sites.

[USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; mi², square mile; IDEM, Indiana Department of Environmental Quality; MBWQ, Muncie Sanitary District, Bureau of Water Quality; St, street; CEG, Citizens Energy Group]

Streamgages					Water-quality data sources				
USGS station number	Station name	Decimal latitude (NAD 83)	Decimal longitude (NAD 83)	Drainage area (mi²)	Collecting agency	Site designation	Decimal latitude (NAD 83)	Decimal longitude (NAD 83)	Drainage area (mi²)
03347000	White River at Muncie, Indiana	40.204	−85.387	241	IDEM	WWU010–0001	40.178	−85.342	225
					MBWQ	White River at Walnut St	40.204	−85.386	241
03351000	White River near Nora, Indiana	39.911	−86.106	1,219	IDEM	WWU090–0002	39.910	−86.105	1,219
					CEG	White River at 82nd St	39.910	−86.105	1,219
03354000	White River near Centerton, Indiana	39.498	−86.401	2,444	IDEM	WWU160–0004	39.434	−86.449	2,485
					USGS	03354000	39.498	−86.401	2,444

constituents without severely limiting the analytical period. For most constituents, there were suitable data to facilitate an analysis of the 26-year period extending from calendar years 1991 to 2017 (water years 1992 to 2017); however, because of the unavailability of data for a part of that period, shorter analytical periods were necessary for total Kjeldahl nitrogen at the study gages at Muncie and near Centerton and for total suspended solids at the study gage near Centerton (table 2). The median number of observations (concentration values) per year at the study gages at Muncie and near Centerton for most constituents was 12 (typically 1 observation per month), the exceptions being nitrate plus nitrite and total Kjeldahl nitrogen at the study gage at Muncie, which had medians of 19 and 11 observations per year, respectively. The study gage near Nora generally had more observations per year than the study gages at Muncie and near Centerton: the median number of observations per year at the study gage near Nora was 23 for all constituents except total suspended solids, which had a median of 22 observations per year. The water-quality data used in the analyses described in this report are available from ScienceBase (Koltun, 2019).

Most agencies collect dip or grab samples (samples collected by filling an open container held beneath the surface of the water). Although the USGS collects some grab samples, it is somewhat unique in that it frequently collects samples in a fashion intended to produce concentrations that are more representative of the sampled environment; for example, the USGS collects samples from streams using equal-width increment (EWI) and equal-discharge increment (EDI) methods (U.S. Geological Survey, 2006). The EWI and EDI methods involve collecting isokinetic samples integrated over the width and depth of a stream cross section and thus produce approximately flow-weighted mean concentrations within the cross section. EWI or EDI sampling methods are recommended by the USGS when computing the flux of constituents because they produce more accurate estimates of flux than grab or dip samples (Edwards and Glysson, 1999). However, to use all available water-quality data, analytical results from grab and EWI/EDI samples were treated equally in this analysis such that each of these results was assumed to approximate the flow-weighted mean concentrations.

Data Quality

Many agencies complete internal quality-control (QC) checks of the water-quality data they produce. Some agencies (for example, the USGS and Citizens Energy Group) document the results of their QC checks in their databases. The water-quality data obtained from the various agencies initially were assumed to be valid unless there was some notation provided with the data indicating that a result was rejected because of QC (or other) issues.

Many constituents (such as sediment and total phosphorus) that are transported in runoff tend to increase in concentration with increasing streamflow. Concentrations of constituents not strongly associated with runoff may decrease with increasing streamflow because of dilution during runoff periods. For either scenario, there tends to be a pattern of either increasing or decreasing concentration with increasing streamflow. The relation between streamflow and constituent concentrations typically is not strictly monotonic; instead, concentrations vary over time for a given streamflow because of a variety of factors. Even though there is variability, the constituent concentrations associated with a given streamflow typically tend to scatter within a limited range. Values that plot far away from most of the data in scatterplots are referred to as “outliers.”

Rudimentary quality-control screening of the data was done by creating transport plots for each constituent (not shown) and examining them for outliers. Transport plots are scatterplots where streamflow is plotted on the x-axis and concentration (or flux) is plotted on the y-axis (Glysson, 1987). The transport plots were examined to identify extreme outliers (values that plotted far away from the rest of the data), which were subsequently evaluated to determine if they likely were erroneous and should therefore be omitted from the dataset. That evaluation resulted in the removal of water-quality results for all constituents associated with the study gage near Nora

Table 2. Analysis periods and numbers of observations used for analyses of sediment and nutrient constituents associated with streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana.

[USGS, U.S. Geological Survey; TSS, total suspended solids; TP, total phosphorus as phosphorus; NOx, nitrate plus nitrite as nitrogen; TKN, total Kjeldahl nitrogen as nitrogen]

USGS station number	Station name	Beginning and ending calendar years of data used for analysis of indicated constituent				Number of observations used for analysis of indicated constituent			
		TSS	TP	NOx	TKN	TSS	TP	NOx	TKN
03347000	White River at Muncie, Indiana	1991–2017	1991–2017	1991–2017	1996–2017	388	426	467	251
03351000	White River near Nora, Indiana	1991–2017	1991–2017	1991–2017	1991–2017	518	631	627	530
03354000	White River near Centerton, Indiana	1991–2008	1991–2017	1991–2017	1996–2017	224	342	348	284

for a single day (January 27, 1994) and one total suspended solids result associated with the study gage near Centerton on May 13, 1996. All other water-quality results were retained. Constituent-specific arithmetic mean concentrations were substituted for individually measured concentrations if more than one sample was collected on the same day.

A review of the transport plots provided some insight into potential nutrient and total suspended-sediment sources in addition to helping identify outliers. The shapes of transport curves for total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen for the study gages near Nora and near Centerton were different from the curves for the study gage at Muncie. Specifically, the shapes of transport curves for total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen for the study gages near Nora and near Centerton were checkmark or “U” shaped (see fig. 2 for example), characterized by concentrations that are high at low streamflows, decrease at midstreamflows, and then increase again at higher streamflows. In contrast, the transport curves for the study gage at Muncie demonstrated a more monotonic change in concentration, with concentrations remaining level or increasing with flow throughout the range of flows. Checkmark or “U” shaped transport curves frequently are indicative of the presence of the continuous discharge of constituents from one or more upstream point sources. At low streamflows (when the point-source discharge[s] makes up a larger proportion of the total flow in the stream), the concentration of the point source(s) can substantially affect the stream concentration. As streamflows increase, the effect of the point source(s) is reduced as a result of dilution with stream water. At higher streamflows (particularly during runoff periods), constituents transported in runoff begin to dominate because runoff proportionally makes up most of the flow in the stream.

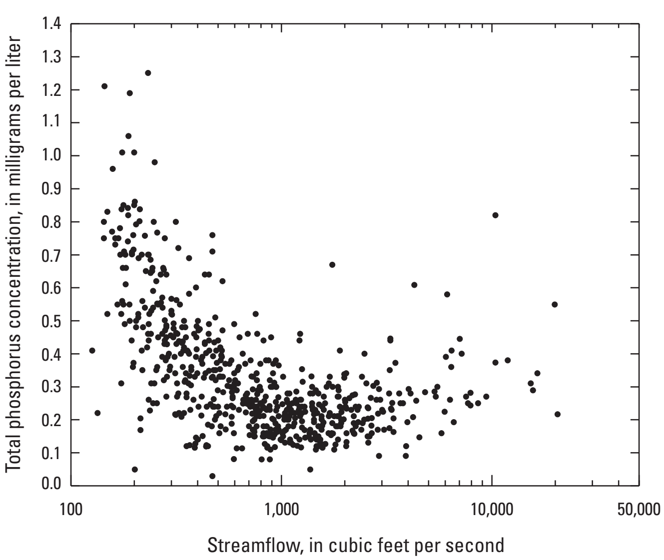


Figure 2. Transport plot for total phosphorus (as phosphorus) concentration for the White River near Nora, Indiana, streamgage (U.S. Geological Survey station 03351000).

Concentration and Flux Estimation and Trends

The USGS has produced a variety of computer programs to estimate mean concentration and annual flux; for example, the Graphical Constituent Loading Analysis System (GCLAS; Koltun and others, 2006), Load Estimator (LOADEST; Runkel and others, 2004), and the Weighted Regressions on Time, Discharge, and Season (WRTDS) method implemented in the Exploration and Graphics for RivEr Trends (EGRET) R package (Hirsch and De Cicco, 2015). Each of these programs (and the underlying analytical methods) has certain advantages and limitations. The choice of which to use depends in part on study objectives; the amount, type(s), and frequency of data available; and the presence/absence of censored results (discussed later). Given the character of the available data and the study objectives (to compute concentration and flux, as well as to evaluate trends), the decision was made to use the WRTDS method implemented in EGRET. Although GCLAS can provide more accurate estimates of flux than LOADEST or WRTDS, it requires sample concentration data collected at a high frequency, and it does not provide information about trends in concentration or flux. WRTDS was selected for use for this study because (1) the available water-quality data were not collected at the frequency required with GCLAS, (2) WRTDS has been demonstrated to produce more credible estimates of long-term trends (greater than 10 years) in concentration than LOADEST and other constant-parameter regression techniques, and (3) WRTDS provides independent estimates of trends in concentration and flux (Chanat and others, 2016). For information on design characteristics of the WRTDS method, see Hirsch and others (2010).

EGRET provides a variety of tabular and graphical outputs that can be used to evaluate if selected streamflow characteristics may be changing over time. EGRET analyses of long-term changes in streamflow characteristics are based on time-series smoothing methods pioneered by Cleveland (1979) and Cleveland and Devlin (1988). EGRET performs LOcally WEighted Scatterplot Smoothing (known as LOWESS) on annual streamflow statistics (relevant to low, high, and mean flows) to produce plots that show patterns of change over time spans of about a decade or more. A detailed discussion of the smoothing method is described in Hirsch and others (2010).

In addition to LOWESS-based assessments of trend in streamflow statistics, two tests for nonstationarity in streamflow were completed. Nonstationarity refers to a condition where the probability distribution of some process changes with time. Pettitt tests (Pettitt, 1979) were done to test for the presence of a step trend in the natural logarithms of water-year annual streamflow statistics. Step trends differ from gradual trends in that they occur abruptly and are not easily addressed when using tools like flow normalization (discussed later) in WRTDS (Hirsch and others, 2010). The null hypothesis for the Pettitt test is that there are no step trends in the time series (in other words, the observations are independent and identically distributed), whereas the alternative hypothesis is that there is at least one step trend in the time series. All hypothesis tests used in this study were based on an alpha (probability) level of 0.05. The Mann-Kendall test (Mann, 1945) was used to test for the presence of more gradual monotonic trends in the natural logarithms of water-year annual streamflow statistics. The Mann-Kendall trend test makes no assumption about the shape of the trend (for example, whether it is linear or nonlinear) but instead tests if values tend to increase or decrease overall. The null hypothesis for the Mann-Kendall test is that there is no trend in the series. Sen's slope (Sen, 1968; the median of the slopes of all lines through pairs of points) was computed to determine the median linear rate of change in the natural logarithms of water-year annual streamflow statistics. The Pettitt and Mann-Kendall tests and Sen's slope computations were all done using the trend package (Pohlert, 2018) in the R programing environment (R Core Team, 2017).

The WRTDS model describes the expected value of concentration as a function of streamflow and time. The form of each WRTDS model is shown below (Hirsch and others, 2010):

$$\ln(c)=\beta_0+\beta_1 t+\beta_2\ln(Q)+\beta_3\sin(2\pi t)+\beta_4\cos(2\pi t)+\varepsilon \qquad (1)$$

where

ln()	is the natural logarithm,
c	is the constituent concentration,
β_n	is the nth fitted coefficient,
t	is time (in years),
Q	is the daily mean streamflow,
sin()	is the sine function,
cos()	is the cosine function, and
ε	is an error term.

The sine and cosine terms in equation 1 help account for seasonality. The same form used in equation 1 is used in predefined model number 7 in LOADEST (Runkle and others, 2004); however, the estimation method used in WRTDS differs from that of LOADEST in that (1) the coefficients are not fixed but vary in a gradual manner throughout the Q, t space and (2) bias-correction factors are computed differently. Unlike LOADEST, WRTDS uses a weighted regression technique where the weights are determined as a function of the "distance" between the estimation point (defined by Q and t) and the sample points. The measure of distance is defined in three dimensions: ln(Q), t, and season (proximity to the same time of year). More details on the differences between LOADEST and WRTDS are discussed in Hirsch (2014).

WRTDS can accommodate water-quality results that are left censored or interval censored. Left-censored results are results reported as "less than" some value, and interval-censored results are reported as "less than" one value but "greater than" some other value. There were some left-censored results in the water-quality data reported by the various agencies but none that were interval censored. The way censored data were reported differed by agency; for example, the IDEM reported a laboratory result and a laboratory reporting limit. When the actual result IDEM obtained was less than the laboratory reporting limit, they reported the result as −1. By comparison, the USGS reported a left-censored value with a "less than" remark code (<) and a result value equal to the laboratory reporting limit. Each agency's convention for censored data was used to create input files in the format required for left-censored data in WRTDS.

Hirsch (2014) identified three common causes of severe bias in flux estimates for regression-based models: (1) a model that is poorly suited to the true relation between ln(c) and ln(Q), (2) substantial seasonal differences in the shape or slope of the ln(c) versus ln(Q) relation that are not accounted for by the model, and (3) substantial heteroscedasticity (unequal variance) of model residuals. The WRTDS model was determined to be more resistant to the bias problem than the LOADEST model, but it is not immune to bias (Hirsch, 2014); consequently, Hirsch and De Cicco (2015) added a flux bias statistic in WRTDS to help evaluate bias. The flux bias statistic (B) is a dimensionless number determined as a function of the difference between the sum of the estimated fluxes on all sampled days (P) and the sum of the true fluxes on all sampled days (O):

$$B=(P-O)/P \qquad (2)$$

A value of B near zero indicates that the model is nearly unbiased. A positive value indicates a positive bias, and a negative value indicates a negative bias. Values of B that are between −0.1 and +0.1 indicate that the bias in estimates of the long-term mean flux is likely to be less than 10 percent.

The concentration and flux of a constituent can be strongly affected by the particular time history of associated flow conditions. Consequently, if, for example, one observes a decrease in flux of a constituent from one year to another, it is not immediately clear whether that decrease is due primarily to changing streamflow conditions or decreases in concentrations of the constituent associated with a given range of streamflows. When seeking information about if and how the watershed system is changing, one needs to filter out the effects of year-to-year variation in streamflow without removing the effects associated with seasonal and long-term trends in streamflow. The method used to filter out the effects of year-to-year variation in streamflow in WRTDS is referred to by Hirsch and De Cicco (2015) as "flow normalization." The "flow-normalized concentration" and "flow-normalized flux" on any given day are determined as follows:

$$C_{FN}(t)=\frac{1}{n}\sum_{i=1}^{n}C(t,Q_{T_i}) \qquad (3)$$

and

$$F_{FN}(t)=\frac{1}{n}\sum_{i=1}^{n}Q_{T_i}C(t,Q_{T_i})k \qquad (4)$$

where

$C_{FN}(t)$ is the flow-normalized concentration on day t,

t is a single day at any point in the record (T),

n is the number of years in the record,

$C(t, Q_{T_i})$ is the estimated concentration on day t and streamflow Q_{T_i},

$F_{FN}(t)$ is the flow-normalized flux on day t,

Q_{T_i}, $i = 1,..., n$ is the set of daily streamflows observed on days T_i,

T_i, $i = 1,..., n$ is the set of all days in the record for a given calendar day (for example, January 1), and

k is a units conversion factor.

The flow-normalized concentration on any day t of the record is the mean of the concentrations estimated from all the daily mean streamflows that occurred on that calendar day of year over the record. The corresponding flow-normalized flux is the mean of the product of the estimated flow-normalized concentrations, the daily mean streamflows from which they were estimated, and a units conversion factor. For any given calendar day, flow-normalized values in sequential years are calculated using the same set of daily streamflows (the streamflows that occurred on that calendar day in each year of record); however, the concentrations estimated for those streamflows change from year to year because they are computed based on observations whose weights are changing as a function of their proximity in time to the time of estimation. Daily values are averaged over the year to compute annual flow-normalized mean concentration and flux.

When complex statistical methods (such as the smoothing procedure applied in WRTDS) are used, it generally is not feasible to make statements about the uncertainty of results using simple mathematical expressions, such as those that apply to ordinary least-squares regression. Instead, bootstrapping is a common approach to the problem of describing the uncertainty of these more complex analyses (Hirsch and others, 2015); consequently, trends in flow-normalized concentrations and flux were evaluated using the WRTDS bootstrap test (WBT) contained in the Exploration and Graphics for RivEr Trends Confidence Intervals (EGRETci) R package (Hirsch and others, 2015). The WBT uses a random sampling procedure with replacement to create multiple subset datasets containing measured concentrations from the original dataset. Flow-normalized annual concentrations and fluxes are then determined from each subset dataset. Results from all model iterations are used to estimate (1) the uncertainty of the flow-normalized annual values of concentration and flux and (2) the level of significance of changes in flow-normalized annual values between selected water years. Hirsch and others (2015) adopted the definitions shown in table 3 to describe the degree of statistical support that the dataset and WBT results provide regarding the likelihood associated with a direction of change over the specified period. Because trends can be upward (increasing) or downward (decreasing), table 3 also lists alternate descriptions depending on whether one wishes to describe the likelihood of an upward or downward trend; for example, if an upward trend is "highly likely," that also means that a downward trend is "highly unlikely."

In the WRTDS analysis, a one-way level of significance of 0.05 was chosen to identify a statistically significant trend; consequently, a trend described as "highly likely" is considered to be statistically significant. Analyses discussed in this report were completed using R Studio version 1.0.153, R version 3.4.1, EGRET version 3.0.0, and EGRETci version 2.0.0. The R code used to run the WRTDS analyses is available from ScienceBase (Koltun, 2019).

Trends in Streamflow and Concentrations and Flux of Nutrients and Total Suspended Solids

A variety of analyses were done to gain a better understanding of the transport of nutrients and total suspended solids in the Upper White River in Indiana. Those analyses include an assessment of temporal trends in streamflow, an examination of the seasonal distribution of observed nutrient and total suspended solids concentrations, an estimation of annual mean concentrations and flux of nutrients and total suspended solids, and an analysis of changes in the mean concentrations and flux of nutrients and total suspended solids between water years 1997 and 2017. Results from these analyses are described in the following sections.

Table 3. Definitions for descriptive statements of the likelihood of trends for the Weighted Regressions on Time, Discharge, and Season bootstrap test as a function of the posterior mean estimate of the probability of an upward trend ($\hat{\pi}$; after Hirsch and others, 2015).

[≥, greater than or equal to; ≤, less than or equal to; <, less than; >, greater than]

Range of $\hat{\pi}$ values	Upward trend descriptors	Downward trend descriptors
≥0.95 and ≤1.0	Highly likely	Highly unlikely.
≥0.90 and <0.95	Very likely	Very unlikely.
≥0.66 and <0.90	Likely	Unlikely.
>0.33 and <0.66	About as likely as not	About as likely as not.
>0.1 and ≤0.33	Unlikely	Likely.
>0.05 and ≤0.1	Very unlikely	Very likely.
≥0 and ≤0.05	Highly unlikely	Highly likely.

Trends in Streamflow

Trends in streamflows between water years 1978 and 2017 at the study gages were assessed using EGRET and using Mann-Kendall and Pettitt tests. Only streamflow records after the 1977 water year were used for trend analyses to avoid potential changes in streamflows associated with the adoption of Eagle Creek Reservoir as a water supply for the city of Indianapolis in 1976. With just one exception, the annual maximum daily streamflows, the annual mean daily streamflows, and the annual minimum 7-day mean streamflows all demonstrated upward trends in the EGRET analyses (figs. 3–5). The exception was the annual 7-day minimum streamflow at the study gage near Nora (fig. 4), which did not indicate an upward or downward trend.

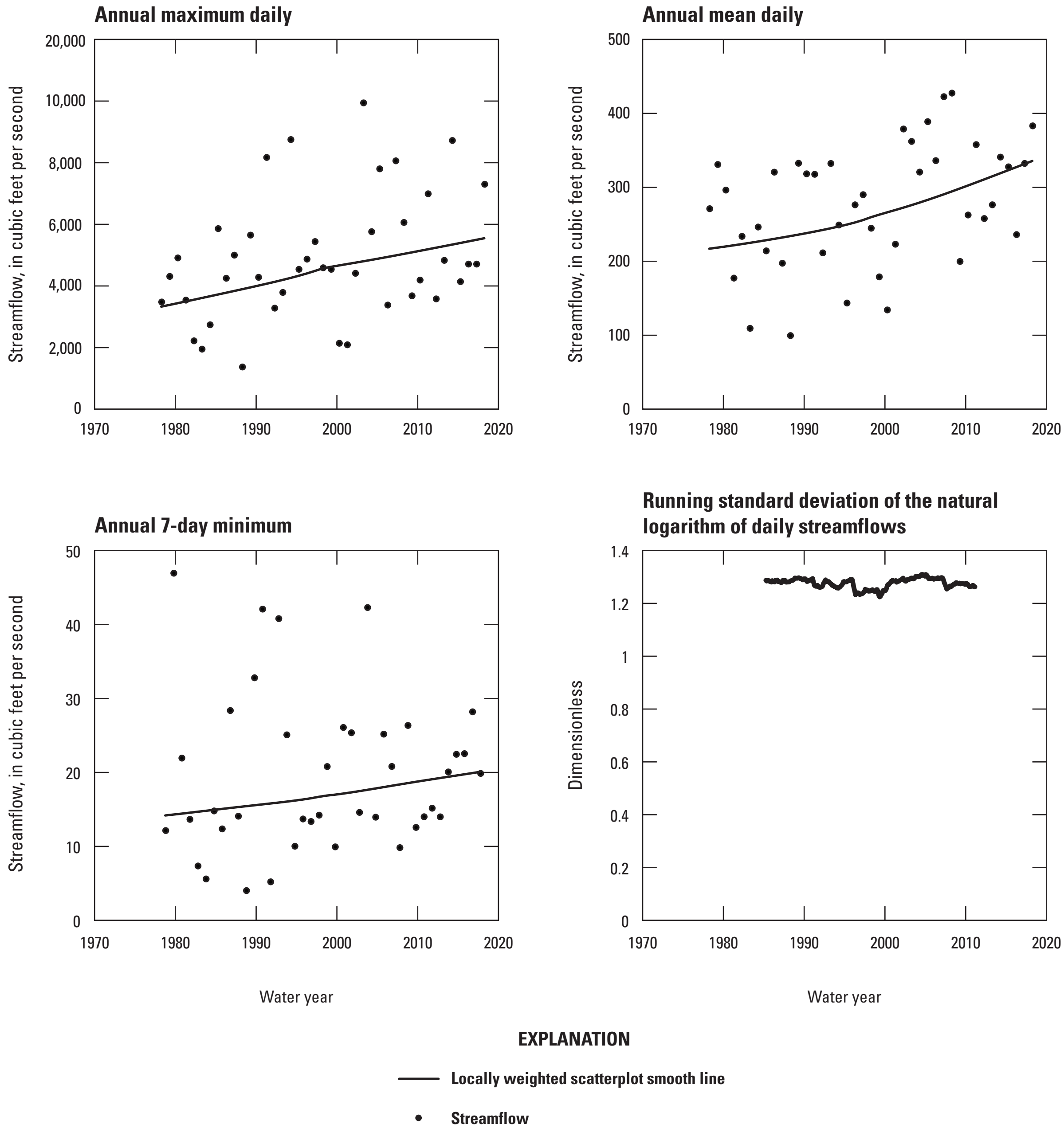


Figure 3. Annual maximum daily streamflow, mean daily streamflow, 7-day minimum streamflow, and the running standard deviation of the natural logarithm of the daily streamflow values for the White River at Muncie, Indiana, streamgage (U.S. Geological Survey station 03347000) for water years 1978 to 2018 (locally weighted scatterplot smooth lines are shown on scatterplots).

Trends in the moving averages of the standard deviations of the natural logarithm of daily mean streamflows are shown in figures 3–5. The standard deviation of the natural logarithm of the daily mean streamflows is computed for all the days ranging from 7.5 years before to 7.5 years after a center date, and the result is plotted on the graph at that center date. The computation then moves on to a new center date that is one-tenth of a year (36.5 days) later and repeats until it reaches a center date that is 7.5 years before the end of the record. The plotted points are connected with straight line segments.

Even though there are indications of an upward trend for most flow statistics shown in figures 3–5, the fact that the standard deviations of the natural logarithm of daily mean streamflow did not appreciably increase or decrease as a function of time indicates that all quantiles of the flow distribution at the study gages increased by about the same percentage.

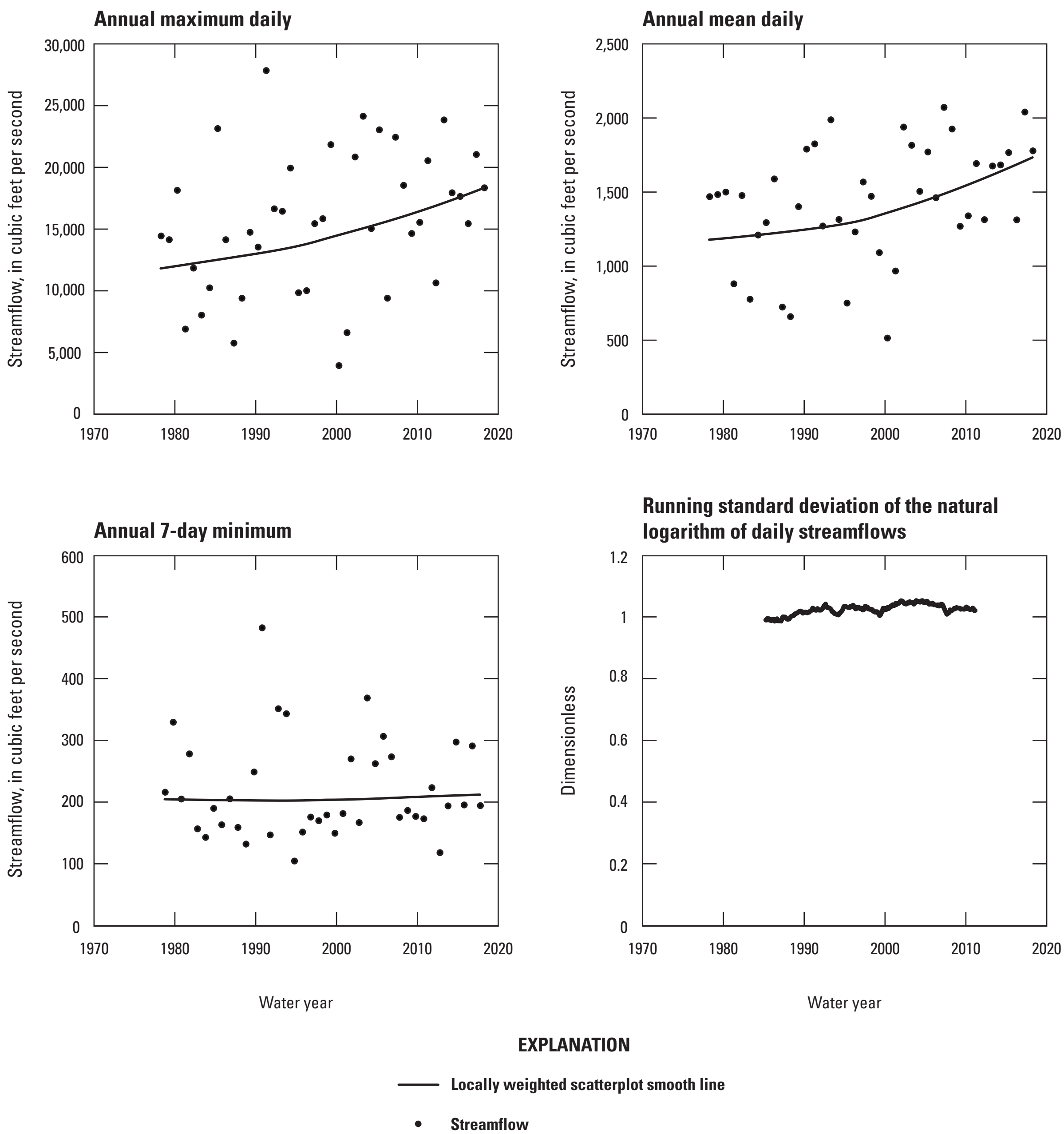


Figure 4. Annual maximum daily streamflow, mean daily streamflow, 7-day minimum streamflow, and the running standard deviation of the natural logarithm of the daily streamflow values for the White River near Nora, Indiana, streamgage (U.S. Geological Survey station 03351000) for water years 1978 to 2018 (locally weighted scatterplot smooth lines are shown on scatterplots).

If instead the change in the probability distribution of daily streamflows over time were such that there was a greater percentage change in the high end and (or) low end of the distribution, compared to the percentage change in the middle part of the distribution, then the standard deviation curves would have sloped upwards over time (Hirsch and De Cicco, 2015).

The positive tau values determined in the Mann-Kendall analyses indicated that the average trend for the annual maximum daily, mean daily, and 7-day minimum streamflow statistics between water years 1978 and 2017 was upward at each of the study gages (table 4). However, only the trends in the annual mean daily streamflows at the study gage at Muncie and the annual maximum daily streamflows at the study gages near Nora and near Centerton were statistically significant (table 4).

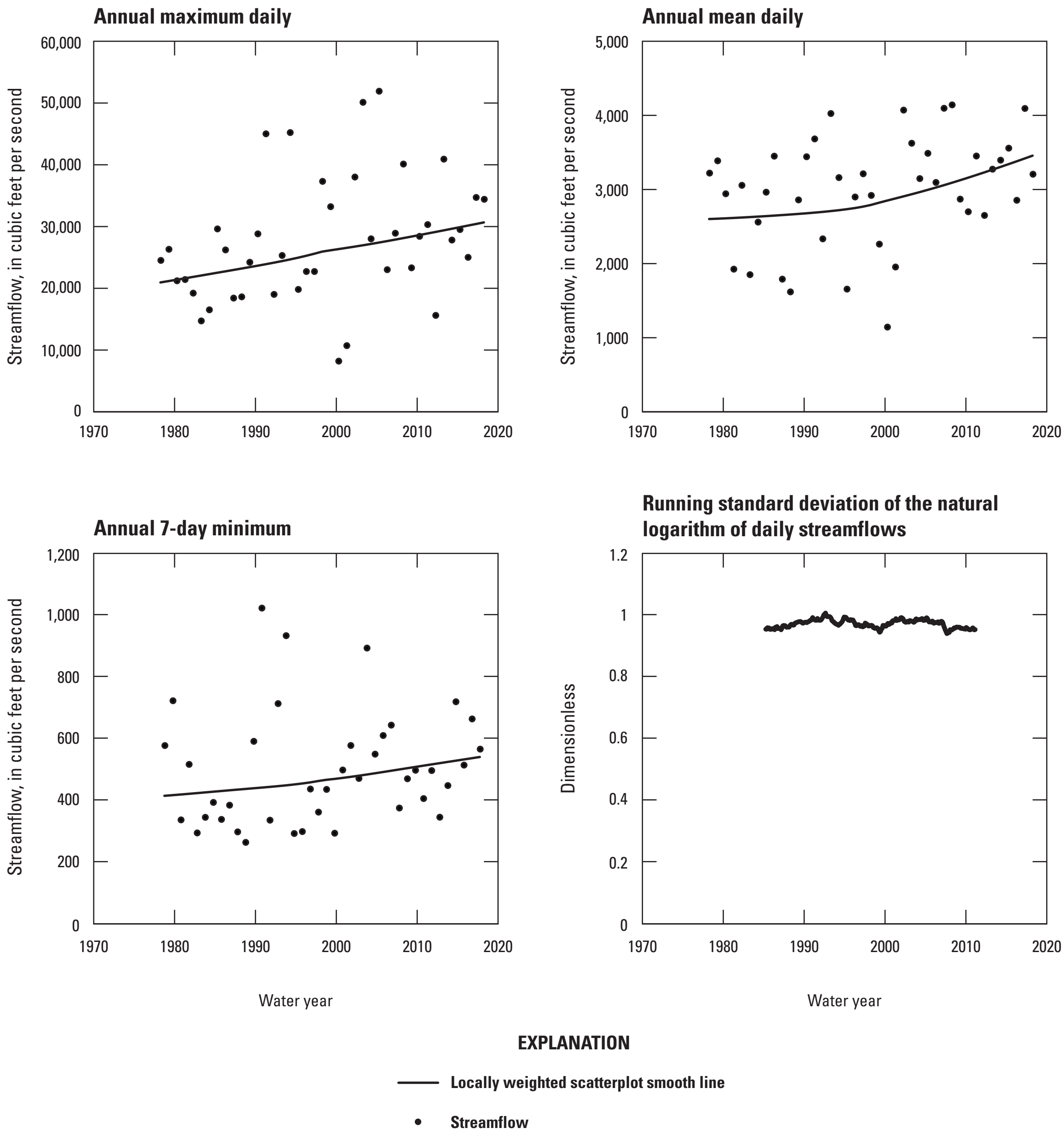


Figure 5. Annual maximum daily streamflow, mean daily streamflow, 7-day minimum streamflow, and the running standard deviation of the natural logarithm of the daily streamflow values for the White River near Centerton, Indiana, streamgage (U.S. Geological Survey station 03354000) for water years 1978 to 2018 (locally weighted scatterplot smooth lines are shown on scatterplots).

Table 4. Results of Mann-Kendall analyses for trends in selected streamflow statistics for streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1978–2017.

[Bolded values are statistically significant; USGS, U.S. Geological Survey; tau, Kendall's nonparametric correlation coefficient; *p*-value, probability value; Sen slope, reported in average logarithm of streamflow (in cubic feet per second) units]

USGS station number	Station name	Annual 7-day minimum streamflow			Annual mean daily streamflow			Annual maximum daily streamflow		
		tau	*p*-value	Sen slope	tau	*p*-value	Sen slope	tau	*p*-value	Sen slope
03347000	White River at Muncie, Indiana	0.131	0.246	0.0056	**0.236**	0.033	0.0087	0.187	0.091	0.0095
03351000	White River near Nora, Indiana	0.073	0.521	0.0036	0.213	0.055	0.0082	**0.232**	0.036	0.0098
03354000	White River near Centerton, Indiana	0.165	0.143	0.0087	0.190	0.087	0.0056	**0.245**	0.027	0.0106

The Pettitt tests indicated that a step trend (abrupt change) in annual mean daily streamflows at each of the study gages likely occurred between water years 1978 and 2017 (table 5) and that the step trends most likely occurred at each study gage around water year 2001. The EGRET plots, with noticeable increases in annual mean daily streamflows around water year 2001 (figs. 3–5), lend visual support that a step trend occurred. No statistically significant step trend was indicated for the annual 7-day minimum and annual maximum daily streamflows at the study gages (table 5); however, the Pettitt test has been determined to be less effective at detecting changes in extremes than in detecting changes in means or medians (Mallakpour and Villarini, 2016). The occurrence of a step trend in streamflows around water year 2001 adds uncertainty to the interpretation of trends in the WRTDS analysis near the year of the step trend. That uncertainty decreases as you move further away in time from the year of the step trend.

To assess if trends in streamflow might be related to changes in precipitation, a Mann-Kendall analsis was done using annual precipitation totals measured at the Indianapolis International Airport (network identifier GHCND:USW00093819) between calendar years 1932 and 2017. That analysis indicated a weak but statistically significant upward trend (tau=0.18, probability value [*p*-value]=0.012) in annual precipitation with a Sen's slope of 0.088 in. per year; consequently, although not definitive, this result indicates that the upward trends in streamflows might have resulted (at least in part) from the upward trend in precipitation.

Table 5. Results of Pettitt tests for step trends in selected streamflow statistics for streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1978–2018.

[Bolded values are statistically significant; USGS, U.S. Geological Survey; U*, Pettitt test statistic; *p*-value, probability value; na, not applicable]

USGS station number	Station name	Annual 7-day minimum streamflow			Annual mean daily streamflow			Annual maximum daily streamflow		
		U*	*p*-value	Water year change point	U*	*p*-value	Water year change point	U*	*p*-value	Water year change point
03347000	White River at Muncie, Indiana	104	0.688	na	**254**	0.005	2001	143	0.308	na
03351000	White River near Nora, Indiana	97	0.791	na	**218**	0.026	2001	188	0.079	na
03354000	White River near Centerton, Indiana	151	0.187	na	**208**	0.038	2001	198	0.055	na

Seasonal Distribution of Sediment and Nutrient Concentrations

The following discussion applies to analyses of sediment and nutrient constituents for the periods listed in table 2. Boxplots of concentration data grouped by calendar month were prepared to help visualize seasonal patterns and variability in the data and to determine the times of the year, if any, that have particularly high or low concentrations. Typically, all calendar months for a given study gage and constituent had similar numbers of the measured concentration values (table 6).

There were distinct patterns in the seasonal distribution of total suspended solids concentrations at the study gages (fig. 6). Median concentrations of total suspended solids at all study gages were highest during the meteorological summer months of June and July and tended to be lowest during the late fall and winter months (January, February, November, and December; fig. 6). Although the range of observed total suspended solids concentrations was larger at the study gage at Muncie than at the other two study gages, the medians and interquartile statistics were similar among all study gages.

There were similar patterns in the seasonal distribution of total phosphorus concentrations at the study gages near Nora and near Centerton (fig. 6). At both study gages, monthly median (medians of values by calendar month) total phosphorus concentrations gradually increased beginning in May and peaked about September or October, with the median September concentration being at least twice the median May concentration. Monthly median concentrations of total phosphorus were consistently lower at the study gage at Muncie than concentrations at the two downstream study gages. Seasonal patterns in the total phosphorus concentration at the study gage at Muncie were less evident than at the other two study gages, and the highest monthly median concentrations at the study gage at Muncie were in June and July.

Patterns in the seasonal distribution of nitrate plus nitrite concentrations were discernable but not always as apparent as those for total suspended solids and total phosphorus (fig. 7). Monthly median nitrate plus nitrite concentrations at the study gages typically were higher during January–June than during July–December. The differences in median nitrate plus nitrite concentrations between these two 6-month periods were much larger at the study gage at Muncie than at the two downstream study gages. The monthly median nitrate plus nitrite concentrations at the study gage at Muncie were lower than at the two downstream study gages, and median concentrations for July–December were considerably lower than median concentrations at the two downstream study gages.

The seasonal distribution of total Kjeldahl nitrogen concentrations differed in pattern between the three study gages (fig. 7); however, in general, some of the higher monthly median total Kjeldahl nitrogen concentrations at each study gage were associated with the late spring and summer periods. Similar to what was observed for the other constituents, the monthly median total Kjeldahl nitrogen concentrations at the study gage at Muncie were lower than at the two downstream study gages. Monthly median total Kjeldahl nitrogen concentrations at the study gage near Nora generally were higher than at the other two study gages.

Table 6. Numbers of total suspended solids and nutrient concentrations by month and constituent used in analyses with streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana.

[USGS, U.S. Geological Survey; TSS, total suspended solids; TP, total phosphorus as phosphorus; NOx, nitrate plus nitrite as nitrogen; TKN, total Kjeldahl nitrogen as nitrogen]

Month	Number of observations by month											
	White River at Muncie, Indiana (USGS station 03347000)				White River near Nora, Indiana (USGS station 03351000)				White River near Centerton, Indiana (USGS station 03354000)			
	TSS	TP	NOx	TKN	TSS	TP	NOx	TKN	TSS	TP	NOx	TKN
January	26	26	30	16	43	52	52	42	17	26	27	21
February	30	32	36	19	45	54	53	42	20	30	29	24
March	30	34	38	21	39	49	49	44	21	30	32	24
April	39	44	48	23	44	53	52	44	19	28	29	23
May	34	37	41	23	45	54	54	44	19	30	30	25
June	33	36	41	22	43	53	53	48	20	30	29	25
July	34	39	40	22	46	56	55	43	16	26	27	23
August	34	38	40	22	43	53	53	42	19	29	30	23
September	31	37	40	20	44	52	52	47	16	26	27	23
October	35	37	40	23	44	53	53	44	20	30	30	25
November	33	37	40	22	45	55	54	49	21	31	31	24
December	29	29	33	18	37	47	47	41	16	26	27	24

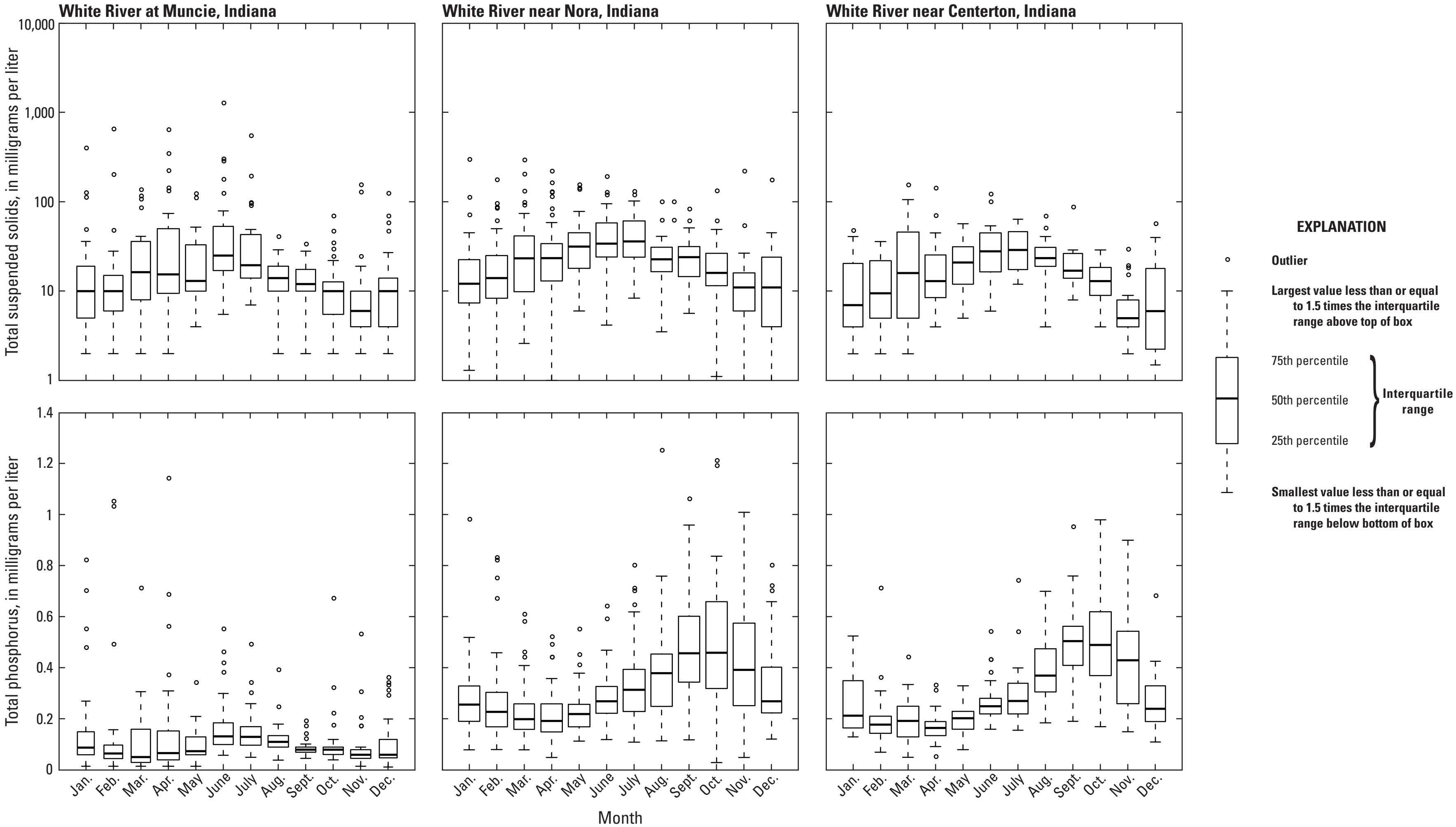


Figure 6. Boxplots showing the distribution of observed concentrations of total suspended solids, and total phosphorus by month, associated with streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana (U.S. Geological Survey stations 03347000, 03351000, and 03354000, respectively).

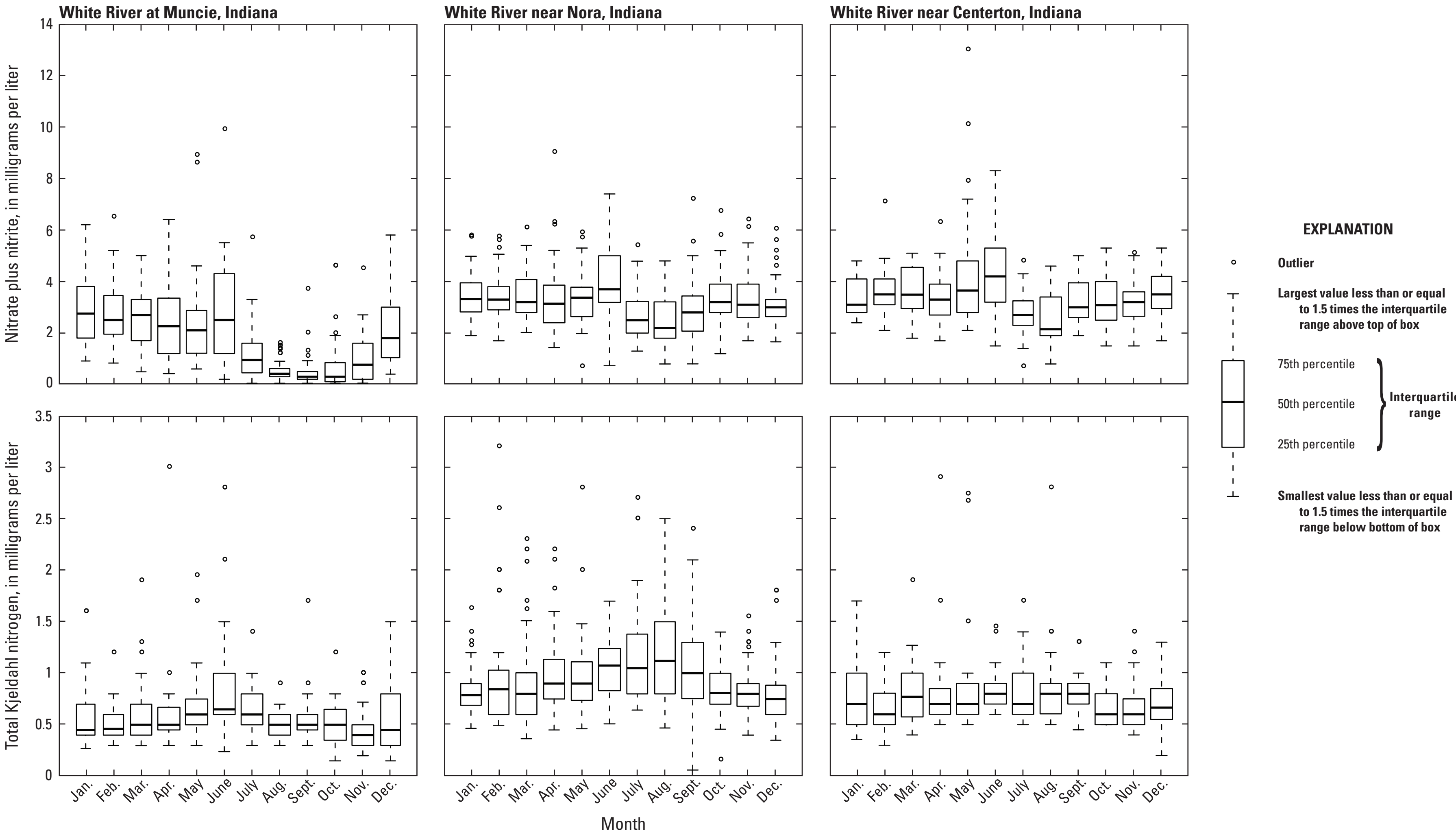


Figure 7. Boxplots showing the distribution of observed concentrations of nitrate plus nitrite and total Kjeldahl nitrogen, by month, associated with streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana (U.S. Geological Survey stations 03347000, 03351000, and 03354000, respectively).

Estimated Mean Concentrations and Flux of Sediment and Nutrients

Daily mean concentrations and flux of sediment and nutrients were estimated by water year with WRTDS. Also estimated with WRTDS were the flow-normalized daily mean concentrations and flux of sediment and nutrients by water year. As previously mentioned, the flow-normalized concentration and flux on a specific day were computed using equations 3 and 4, respectively, and the daily values were averaged over the water year to compute annual flow-normalized mean concentration and flux.

An approximate coefficient of determination (represented as R_a^2) was computed for results from each of the WRTDS analyses (table 7) based on the predicted and observed concentrations. The coefficient of determination is approximate only if an observed concentration was censored because one-half of the censoring level was used for the observation in its calculation. The approximate coefficients of determination ranged from a high of 0.82 for total phosphorus for the study gage near Centerton to a low of 0.19 for nitrate plus nitrite for the study gage near Nora. Coefficients of determination, when multiplied by 100, are commonly interpreted as the percentage of the variance in the response variable (concentration in this case) explained by the explanatory variables; consequently, for example, at the study gage near Centerton, 82 percent of the variance in total phosphorus concentrations was explained by the WRTDS regression models. Likewise, only 19 percent of the variance in nitrate plus nitrite concentrations was explained by the WRTDS regression models at the study gage near Nora.

Plots of residuals (observed minus predicted concentrations) from the WRTDS regression models were examined to assess whether the variance in the residuals was uniform as a function of (1) the predicted value, (2) streamflow, (3) time, and (4) month of the year. The plots for all sites and constituents (not shown) indicated approximately uniform variance of residuals as a function of the predicted value, streamflow, and time. Monthly boxplots of residuals also generally showed no indication that median residuals varied appreciably as a function of the calendar month; the exceptions being for nitrate plus nitrite at all three study gages and total suspended solids at the study gage near Centerton. For nitrate plus nitrite, the median residual for the month of June was noticeably more positive at all three study gages than the other months of the year (fig. 8, for example). Median observed concentrations of nitrate plus nitrite also were high during the month of June (fig. 7). The more positive residuals for the month of June may reflect a general tendency for the underprediction of nitrate plus nitrite concentrations in June, when concentrations tend to be high. Of note also is that the WRTDS regression estimates for nitrate plus nitrite at the study gages near Nora and near Centerton were noticeably less variable than the observed concentrations, indicating the WRTDS regression model did not do a good job of estimating the extremes in concentrations of nitrate plus nitrite at those study gages.

Median residuals for total suspended solids for November at the study gage near Centerton were appreciably more negative than for other months of the year (fig. 9). Median observed concentrations of total suspended solids for November at the study gage near Centerton (fig. 6) also were lower than for other months of the year. The more negative residuals for total suspended solids for November at the study gage near Centerton may be indicative of a tendency for WRTDS to overpredict total suspended solids concentrations at the study gage near Centerton in November, when total suspended solids concentrations tend to be low. It is worth noting that the range in streamflow over which samples were collected at the study gage near Centerton was considerably smaller than the overall observed range of streamflows during the analysis period (calendar years 1991–2017, water years 1992–2017), primarily because of a lack of samples collected at streamflows greater than about 16,000 cubic feet per second (ft^3/s) but also partially because of a lack of samples in the low range of streamflows. Similar flow-range sample limitations occurred for all the constituents at all three study gages; however, sample coverage at high flows at the study

Table 7. Approximate coefficients of determination for Weighted Regressions on Time, Discharge, and Season (WRTDS) regression models for estimating sediment and nutrient concentrations at streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1992–2017.

[USGS, U.S. Geological Survey; TSS, total suspended solids; TP, total phosphorus as phosphorus; NOx, nitrate plus nitrite as nitrogen; TKN, total Kjeldahl nitrogen as nitrogen]

Constituent	Period (water years)	Approximate coefficient of determination for WRTDS concentration model		
		White River at Muncie, Indiana (USGS station 03347000)	White River near Nora, Indiana (USGS station 03351000)	White River near Centerton, Indiana (USGS station 03354000)
TSS	1992–2007	0.33	0.40	0.64
TP	1992–2017	0.45	0.55	0.82
NOx	1992–2017	0.51	0.19	0.28
TKN	1997–2017	0.40	0.37	0.27

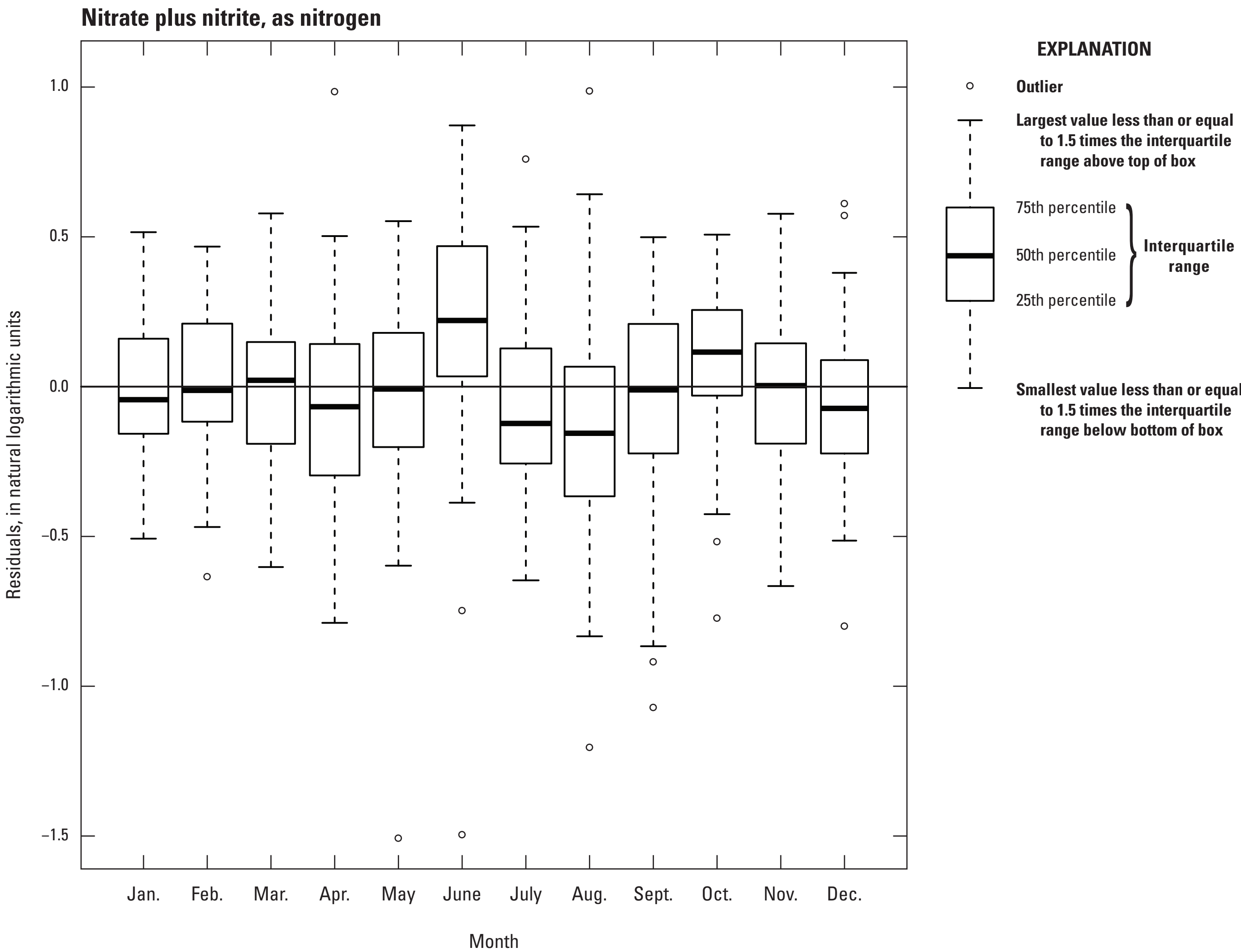


Figure 8. Boxplots, by month, of residuals from the Weighted Regressions on Time, Discharge, and Season regression model for nitrate plus nitrite (as nitrogen) at the White River near Nora, Indiana, streamgage (U.S. Geological Survey station 03351000).

gage near Nora was more complete than at the study gages at Muncie and near Centerton. It is important to collect samples over nearly the entire range of streamflows to avoid excessive extrapolation when regression models like WRTDS are applied.

Water-year annual mean daily concentrations and fluxes estimated with WRTDS (with and without flow normalization) are reported in tables 8–11 for total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen, respectively. The median flux bias statistic computed for the WRTDS models was 0.044 and ranged from a high of 0.137 to a low of −0.002 (table 12), with all but one of the bias statistics being positive. Positive flux bias statistics indicate a tendency to overpredict flux on average. The WRTDS models for total suspended solids, total phosphorus, and total Kjeldahl nitrogen for the study gage at Muncie had flux bias statistics ranging from 0.130 to 0.137, indicating a tendency for the models to overpredict flux of those constituents by about 13 to 14 percent on average. The WRTDS models for total suspended solids for the study gages near Nora and near Centerton had flux bias statistics of 0.135 and 0.110, respectively, and were the only other models with flux bias statistics that exceeded 0.10. Hirsch (2014) determined that some constituents (like total phosphorus and suspended sediment) are difficult to estimate with regression models of the form used in WRTDS because of their highly nonlinear relations with streamflow. Hirsch (2014) also determined that the relation between true flux bias and the flux bias statistic is not precise;

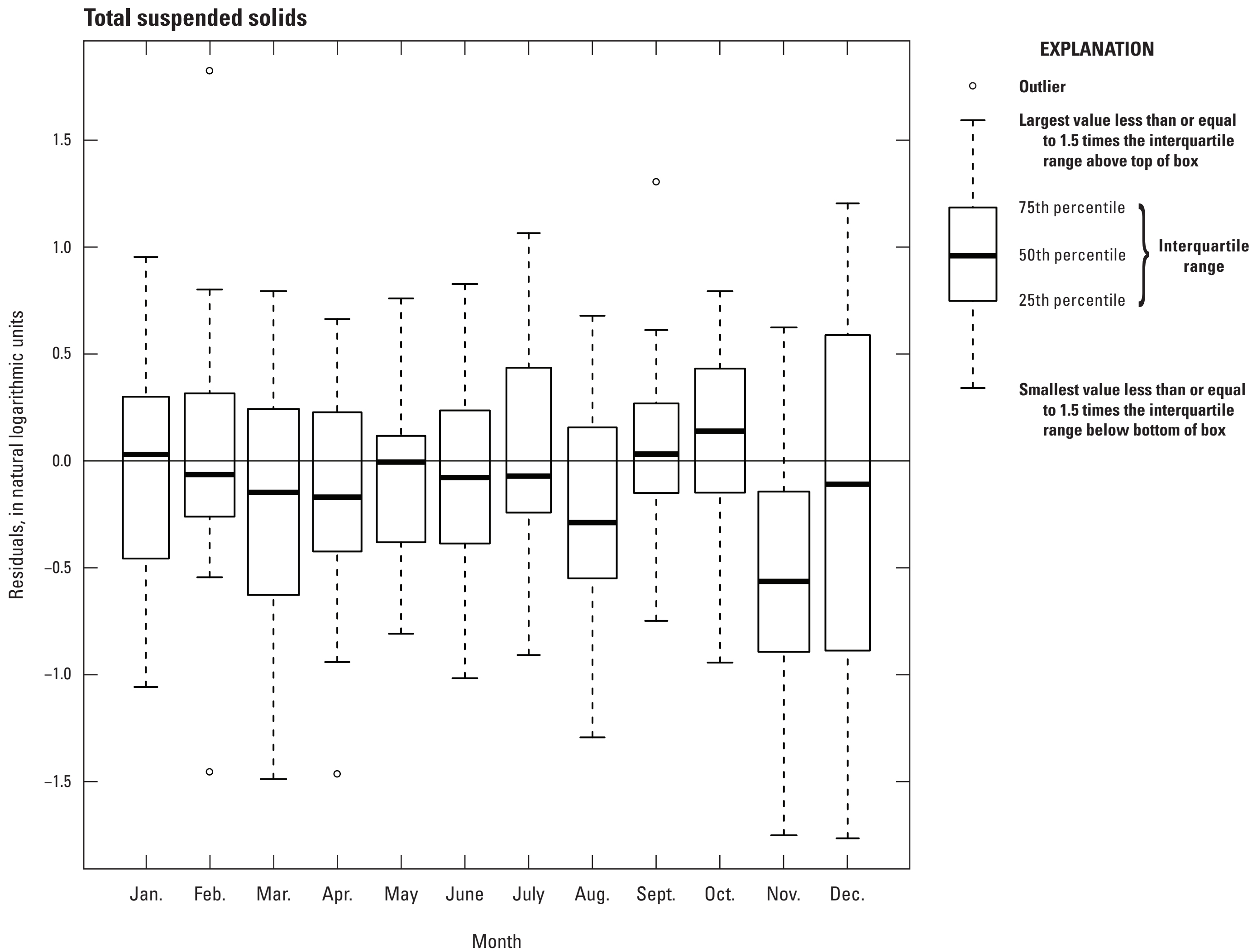


Figure 9. Boxplots, by month, of residuals from the Weighted Regressions on Time, Discharge, and Season regression model for total suspended solids at the White River near Centerton, Indiana, streamgage (U.S. Geological Survey station 03354000).

consequently, he recommended that the flux bias statistic not be used as a bias-correction factor but instead to indicate the likelihood of bias and its direction.

To facilitate comparisons between study gage locations, analytical-period loads and yields and mean annual loads and yields are summarized in tables 13 and 14 for each constituent for the longest periods of concurrent record at the three study gages. Loads of each of the constituents increased sequentially from the most upstream study gage (at Muncie) to the most downstream study gage (near Centerton). Yields did not consistently follow the same pattern as loads. It is fairly common for yields of nonpoint constituents in streams to decrease in a downstream direction. That is because stream channel (and land surface) gradients typically decrease as one moves from the headwaters to the mouth, and there is more opportunity for constituent losses (because of processes such as settling, transformation, and biological uptake) at more downgradient points in a watershed than in headwater areas. Other factors, such as spatial variation in land use, land cover, and (or) point-source discharges within a basin, can reinforce or counteract the processes that typically result in downstream yield reduction. In this case, the highest yields of total suspended solids, total phosphorus, and total Kjeldahl nitrogen occurred at the most upstream study gage (at Muncie); however, the highest yield of nitrate plus nitrite occurred at the most downstream study gage (near Centerton).

Table 8. Annual estimates of mean daily concentrations and flux (with and without flow normalization) of total suspended solids for streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1992–2017.

[USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; FN, flow normalized; t/yr, short ton per year; nd, no data]

Water year	White River at Muncie, Indiana (USGS station 03347000)					White River near Nora, Indiana (USGS station 03351000)					White River near Centerton, Indiana (USGS station 03354000)				
	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^3 t/yr)	Annual FN flux (10^3 t/yr)	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^3 t/yr)	Annual FN flux (10^3 t/yr)	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^3 t/yr)	Annual FN flux (10^3 t/yr)
1992	211	58.30	49.80	72.44	70.55	1,264	40.00	48.80	120.59	179.90	2,325	37.90	43.00	240.30	362.66
1993	331	53.10	46.40	63.48	66.47	1,980	59.00	47.40	214.40	170.53	4,016	45.50	41.60	274.14	348.33
1994	248	29.20	43.40	47.38	62.72	1,307	42.30	46.20	171.52	162.37	3,152	34.90	40.30	347.78	334.00
1995	143	27.70	40.50	36.84	58.97	743	30.40	45.00	45.53	154.43	1,647	26.50	39.00	117.95	321.87
1996	276	39.20	37.70	50.25	55.45	1,224	40.10	43.70	110.34	146.61	2,890	42.20	37.70	343.92	309.75
1997	289	34.60	35.00	60.14	52.47	1,561	44.30	42.00	134.04	136.80	3,203	33.80	36.30	197.86	298.73
1998	244	34.10	32.50	41.39	49.38	1,464	37.40	39.70	119.05	124.23	2,911	41.40	34.90	434.53	288.81
1999	178	17.60	31.10	14.30	48.83	1,084	31.00	37.10	85.32	111.55	2,253	24.30	33.20	157.63	283.29
2000	133	17.60	30.90	7.57	50.16	507	22.10	35.10	16.64	102.51	1,134	15.90	31.70	28.88	281.09
2001	222	21.80	30.90	13.72	51.26	960	28.80	33.70	39.90	97.22	1,945	18.70	30.30	50.71	278.88
2002	378	37.30	31.10	62.71	52.03	1,931	37.70	33.00	126.32	96.23	4,062	38.20	28.80	422.29	268.96
2003	361	55.20	31.80	176.28	53.79	1,809	33.20	32.20	124.67	95.24	3,615	32.60	27.20	469.03	254.63
2004	320	34.00	32.60	48.26	55.45	1,497	32.10	31.20	79.37	92.92	3,138	24.50	25.70	176.04	238.10
2005	388	39.50	33.90	87.07	58.42	1,763	33.20	30.30	137.90	92.48	3,479	28.80	24.30	452.06	222.67
2006	335	32.70	35.50	32.32	61.07	1,455	31.90	29.70	67.90	93.03	3,086	21.10	23.10	108.14	209.44
2007	422	47.30	37.00	125.64	63.27	2,064	33.80	29.40	149.25	94.14	4,087	27.30	22.00	274.03	197.31
2008	427	58.80	39.30	144.78	67.46	1,918	36.00	29.10	140.43	95.46	4,133	nd	nd	nd	nd
2009	199	27.00	40.50	23.28	68.45	1,262	25.00	28.30	79.92	95.24	2,861	nd	nd	nd	nd
2010	262	39.50	40.80	45.61	68.56	1,332	26.30	26.90	75.84	92.92	2,691	nd	nd	nd	nd
2011	357	56.80	40.90	130.63	68.45	1,685	28.50	25.30	132.72	89.40	3,443	nd	nd	nd	nd
2012	257	28.40	41.00	21.94	68.67	1,306	20.60	23.90	55.56	84.55	2,641	nd	nd	nd	nd
2013	276	33.80	40.70	36.19	68.56	1,669	24.50	22.70	104.28	79.81	3,265	nd	nd	nd	nd
2014	340	45.30	40.70	96.50	69.11	1,676	24.10	21.50	94.14	75.29	3,387	nd	nd	nd	nd
2015	327	50.50	40.70	74.86	69.78	1,759	23.40	20.60	78.48	71.98	3,549	nd	nd	nd	nd
2016	235	29.70	40.60	31.71	69.45	1,305	18.90	19.70	51.59	69.34	2,846	nd	nd	nd	nd
2017	331	60.30	40.10	127.13	68.89	2,033	23.30	18.80	103.73	66.69	4,085	nd	nd	nd	nd

Table 9. Annual estimates of mean daily concentrations and flux (with and without flow normalization) of total phosphorus (as phosphorus) for streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1992–2017.

[USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; FN, flow normalized; lb/yr, pound per year]

Water year	White River at Muncie, Indiana (USGS station 03347000)					White River near Nora, Indiana (USGS station 03351000)					White River near Centerton, Indiana (USGS station 03354000)				
	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)
1992	211	0.13	0.13	0.143	0.194	1,264	0.31	0.32	0.739	0.829	2,325	0.25	0.25	1.215	1.517
1993	331	0.14	0.13	0.185	0.192	1,980	0.26	0.33	1.032	0.842	4,016	0.22	0.26	1.876	1.563
1994	248	0.12	0.13	0.240	0.190	1,307	0.35	0.34	0.763	0.855	3,152	0.26	0.27	1.717	1.609
1995	143	0.10	0.13	0.071	0.189	743	0.41	0.35	0.459	0.869	1,647	0.32	0.28	0.869	1.662
1996	276	0.12	0.13	0.172	0.187	1,224	0.43	0.35	0.736	0.880	2,890	0.33	0.29	1.678	1.695
1997	289	0.12	0.12	0.165	0.185	1,561	0.34	0.36	0.895	0.888	3,203	0.29	0.30	1.627	1.711
1998	244	0.11	0.12	0.132	0.181	1,464	0.41	0.36	0.924	0.895	2,911	0.35	0.30	1.775	1.695
1999	178	0.09	0.12	0.081	0.178	1,084	0.41	0.36	0.679	0.897	2,253	0.34	0.31	1.228	1.660
2000	133	0.08	0.11	0.042	0.178	507	0.47	0.36	0.348	0.899	1,134	0.40	0.31	0.668	1.634
2001	222	0.10	0.11	0.080	0.179	960	0.35	0.36	0.551	0.888	1,945	0.28	0.31	0.957	1.616
2002	378	0.13	0.11	0.232	0.179	1,931	0.33	0.37	1.129	0.882	4,062	0.28	0.31	2.103	1.605
2003	361	0.13	0.11	0.320	0.179	1,809	0.37	0.37	1.168	0.880	3,615	0.29	0.31	1.973	1.592
2004	320	0.13	0.12	0.183	0.180	1,497	0.32	0.37	0.844	0.877	3,138	0.27	0.32	1.523	1.579
2005	388	0.14	0.12	0.332	0.182	1,763	0.34	0.38	1.107	0.886	3,479	0.30	0.32	1.949	1.581
2006	335	0.13	0.12	0.163	0.187	1,455	0.33	0.38	0.809	0.904	3,086	0.29	0.33	1.477	1.605
2007	422	0.15	0.12	0.388	0.191	2,064	0.37	0.39	1.294	0.919	4,087	0.33	0.34	2.138	1.649
2008	427	0.16	0.13	0.391	0.199	1,918	0.38	0.39	1.179	0.926	4,133	0.36	0.35	2.330	1.706
2009	199	0.11	0.13	0.103	0.206	1,262	0.44	0.38	0.785	0.928	2,861	0.39	0.36	1.601	1.764
2010	262	0.13	0.13	0.160	0.217	1,332	0.36	0.37	0.811	0.926	2,691	0.36	0.37	1.519	1.821
2011	357	0.16	0.14	0.411	0.231	1,685	0.39	0.35	1.087	0.915	3,443	0.43	0.37	2.105	1.856
2012	257	0.14	0.14	0.155	0.245	1,306	0.35	0.33	0.787	0.897	2,641	0.39	0.37	1.636	1.861
2013	276	0.14	0.14	0.191	0.255	1,669	0.30	0.32	0.996	0.871	3,265	0.35	0.36	1.973	1.850
2014	340	0.16	0.15	0.384	0.259	1,676	0.28	0.30	0.979	0.844	3,387	0.33	0.36	2.026	1.841
2015	327	0.16	0.15	0.265	0.269	1,759	0.25	0.28	0.911	0.822	3,549	0.31	0.35	2.006	1.830
2016	235	0.13	0.15	0.183	0.281	1,305	0.26	0.27	0.672	0.800	2,846	0.32	0.34	1.567	1.821
2017	331	0.17	0.15	0.396	0.290	2,033	0.24	0.25	1.069	0.776	4,085	0.30	0.34	2.344	1.808

Table 10. Annual estimates of mean daily concentrations and flux (with and without flow normalization) of nitrate plus nitrite (as nitrogen) for streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1992–2017.

[USGS, U.S. Geological Survey; ft³/s, cubic foot per second; mg/L, milligram per liter; FN, flow normalized; lb/yr, pound per year]

Water year	White River at Muncie, Indiana (USGS station 03347000)					White River near Nora, Indiana (USGS station 03351000)					White River near Centerton, Indiana (USGS station 03354000)				
	Mean streamflow (ft³/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)	Mean streamflow (ft³/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)	Mean streamflow (ft³/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)
1992	211	1.69	1.77	1.113	1.506	1,264	2.95	2.97	8.466	9.921	2,325	2.92	2.97	15.102	20.745
1993	331	2.11	1.84	1.786	1.556	1,980	3.13	3.04	12.721	10.097	4,016	3.16	3.07	26.367	21.495
1994	248	1.70	1.92	1.093	1.629	1,307	2.94	3.11	7.870	10.274	3,152	3.04	3.16	19.820	22.267
1995	143	1.70	2.01	0.869	1.689	743	3.09	3.18	5.225	10.428	1,647	3.15	3.26	12.456	23.082
1996	276	2.07	2.11	1.911	1.757	1,224	3.32	3.24	9.568	10.560	2,890	3.44	3.37	25.419	23.964
1997	289	2.26	2.22	1.892	1.845	1,561	3.32	3.30	11.508	10.670	3,203	3.50	3.47	25.882	25.022
1998	244	2.23	2.28	1.803	1.876	1,464	3.45	3.36	10.913	10.670	2,911	3.64	3.57	27.205	25.728
1999	178	1.93	2.26	1.144	1.865	1,084	3.36	3.38	7.848	10.472	2,253	3.51	3.63	18.276	26.081
2000	133	1.85	2.16	0.833	1.806	507	3.43	3.37	3.439	10.207	1,134	3.39	3.67	8.223	26.389
2001	222	2.09	2.03	1.270	1.726	960	3.30	3.36	6.526	9.965	1,945	3.49	3.70	14.440	26.610
2002	378	2.10	1.90	2.244	1.680	1,931	3.29	3.34	12.346	9.744	4,062	3.82	3.71	36.531	26.610
2003	361	1.84	1.82	2.028	1.656	1,809	3.27	3.33	10.097	9.568	3,615	3.72	3.72	31.570	26.279
2004	320	1.95	1.75	1.808	1.627	1,497	3.23	3.34	9.524	9.480	3,138	3.60	3.73	24.824	25.684
2005	388	1.77	1.68	1.817	1.574	1,763	3.26	3.36	10.913	9.436	3,479	3.55	3.72	25.552	24.890
2006	335	1.91	1.61	1.761	1.515	1,455	3.29	3.40	9.590	9.480	3,086	3.61	3.73	23.523	24.251
2007	422	1.58	1.58	1.995	1.462	2,064	3.34	3.47	12.743	9.590	4,087	3.52	3.73	29.277	23.832
2008	427	1.83	1.57	2.233	1.440	1,918	3.57	3.53	12.919	9.789	4,133	3.92	3.75	34.128	23.523
2009	199	1.28	1.59	0.959	1.440	1,262	3.83	3.57	8.929	9.921	2,861	3.93	3.77	22.818	23.038
2010	262	1.68	1.61	1.429	1.453	1,332	3.57	3.54	9.303	9.943	2,691	3.79	3.77	20.635	22.421
2011	357	1.56	1.62	1.914	1.470	1,685	3.66	3.48	11.552	9.766	3,443	4.03	3.74	26.389	21.760
2012	257	1.53	1.64	1.230	1.486	1,306	3.34	3.41	8.113	9.590	2,641	3.71	3.72	17.483	21.363
2013	276	1.81	1.67	1.409	1.495	1,669	3.26	3.33	10.692	9.436	3,265	3.67	3.71	23.038	21.054
2014	340	1.84	1.70	1.689	1.482	1,676	3.15	3.26	10.384	9.281	3,387	3.55	3.69	22.906	20.834
2015	327	2.10	1.74	1.900	1.486	1,759	3.10	3.19	11.045	9.127	3,549	3.54	3.68	24.339	20.613
2016	235	1.64	1.78	1.153	1.497	1,305	3.08	3.11	7.893	8.951	2,846	3.55	3.66	18.805	20.415
2017	331	1.93	1.82	1.887	1.499	2,033	2.97	3.03	12.192	8.752	4,085	3.45	3.65	27.602	20.194

Table 11. Annual estimates of mean daily concentrations and flux (with and without flow normalization) of total Kjeldahl nitrogen (as nitrogen) for streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1992–2017.

[USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; FN, flow normalized; lb/yr, pound per year; nd, no data]

Water year	White River at Muncie, Indiana (USGS station 03347000)					White River near Nora, Indiana (USGS station 03351000)					White River near Centerton, Indiana (USGS station 03354000)				
	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)	Mean streamflow (ft^3/s)	Mean daily concentration (mg/L)	Mean daily FN concentration (mg/L)	Annual flux (10^6 lb/yr)	Annual FN flux (10^6 lb/yr)
1992	211	nd	nd	nd	nd	1,264	0.84	0.93	3.075	4.167	2,325	nd	nd	nd	nd
1993	331	nd	nd	nd	nd	1,980	0.97	0.98	5.262	4.255	4,016	nd	nd	nd	nd
1994	248	nd	nd	nd	nd	1,307	1.08	1.03	4.098	4.365	3,152	nd	nd	nd	nd
1995	143	nd	nd	nd	nd	743	1.02	1.07	1.702	4.387	1,647	nd	nd	nd	nd
1996	276	nd	nd	nd	nd	1,224	1.14	1.12	3.424	4.475	2,890	nd	nd	nd	nd
1997	289	0.70	0.71	0.761	0.809	1,561	1.20	1.17	4.729	4.564	3,203	0.97	0.97	7.491	8.642
1998	244	0.66	0.69	0.644	0.796	1,464	1.17	1.21	4.497	4.542	2,911	0.97	0.94	9.182	8.466
1999	178	0.56	0.67	0.351	0.780	1,084	1.23	1.20	3.265	4.343	2,253	0.88	0.91	5.293	8.333
2000	133	0.56	0.66	0.227	0.774	507	1.22	1.17	1.162	4.123	1,134	0.83	0.89	1.903	8.201
2001	222	0.60	0.64	0.390	0.754	960	1.08	1.14	2.101	3.902	1,945	0.76	0.87	3.144	8.003
2002	378	0.67	0.62	0.924	0.734	1,931	1.10	1.10	4.954	3.770	4,062	0.90	0.85	10.721	7.915
2003	361	0.65	0.62	1.113	0.714	1,809	1.08	1.08	5.273	3.660	3,615	0.87	0.84	11.779	7.804
2004	320	0.63	0.62	0.681	0.703	1,497	1.02	1.05	3.344	3.571	3,138	0.80	0.84	6.618	7.672
2005	388	0.65	0.62	0.994	0.675	1,763	1.03	1.04	4.486	3.483	3,479	0.80	0.83	8.333	7.408
2006	335	0.66	0.62	0.631	0.666	1,455	0.99	1.02	2.945	3.483	3,086	0.81	0.82	5.657	7.209
2007	422	0.68	0.63	1.069	0.666	2,064	1.09	1.02	5.181	3.527	4,087	0.87	0.83	8.774	7.077
2008	427	0.71	0.64	1.069	0.672	1,918	1.05	1.02	4.731	3.594	4,133	0.90	0.84	10.430	7.011
2009	199	0.59	0.65	0.381	0.692	1,262	1.02	1.02	2.963	3.594	2,861	0.83	0.84	5.937	6.856
2010	262	0.65	0.66	0.560	0.708	1,332	0.97	1.00	3.023	3.571	2,691	0.81	0.83	5.445	6.680
2011	357	0.69	0.67	1.023	0.721	1,685	1.00	0.99	4.409	3.527	3,443	0.82	0.81	7.851	6.482
2012	257	0.65	0.67	0.500	0.745	1,306	1.01	0.95	2.848	3.483	2,641	0.79	0.80	4.753	6.349
2013	276	0.67	0.68	0.597	0.767	1,669	0.92	0.92	4.107	3.395	3,265	0.78	0.77	6.658	6.217
2014	340	0.69	0.68	0.966	0.791	1,676	0.87	0.87	3.913	3.307	3,387	0.77	0.76	6.510	6.129
2015	327	0.74	0.68	0.871	0.814	1,759	0.82	0.83	3.607	3.219	3,549	0.76	0.74	6.973	6.041
2016	235	0.61	0.68	0.545	0.822	1,305	0.77	0.79	2.529	3.131	2,846	0.71	0.72	4.716	5.975
2017	331	0.73	0.68	1.074	0.842	2,033	0.77	0.75	4.411	3.042	4,085	0.75	0.70	8.347	5.886

Table 12. Flux bias statistics for Weighted Regressions on Time, Discharge, and Season regression models for estimating sediment and nutrient flux at streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana, water years 1992–2017.

[USGS, U.S. Geological Survey; TSS, total suspended solids; TP, total phosphorus as phosphorus; NOx, nitrate plus nitrite as nitrogen; TKN, total Kjeldahl nitrogen as nitrogen]

Constituent	Period (water years)	Flux bias statistic		
		White River at Muncie, Indiana (USGS station 03347000)	White River near Nora, Indiana (USGS station 03351000)	White River near Centerton, Indiana (USGS station 03354000)
TSS	1992–2007	0.130	0.135	0.110
TP	1992–2017	0.137	0.045	0.043
NOx	1992–2017	−0.002	0.001	0.002
TKN	1997–2017	0.135	0.030	0.015

Table 13. Estimated analytical-period loads and yields of total suspended solids, total phosphorus, nitrate plus nitrogen, and total Kjeldahl nitrogen at streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana.

[Muncie, White River at Muncie, Indiana (U.S. Geological Survey station 03347000); Nora, White River near Nora, Indiana (U.S. Geological Survey station 03351000); Centerton, White River near Centerton, Indiana (U.S. Geological Survey station 03354000); TSS, total suspended solids; t, short ton; t/mi^2, short ton per square mile; TP, total phosphorus as phosphorus; lb, pound; lb/mi^2, pound per square mile; NOx, nitrate plus nitrite as nitrogen; TKN, total Kjeldahl nitrogen as nitrogen]

Constituent	Analytical period (water years)	Analytical-period load				Analytical-period yield			
		Units	Muncie	Nora	Centerton	Units	Muncie	Nora	Centerton
TSS	1992–2007	10^3 t	940	1,743	4,095	10^3 t/mi^2	3.90	1.43	1.68
TP	1992–2017	10^6 lb	5.57	22.8	43.9	10^6 lb/mi^2	0.023	0.019	0.018
NOx	1992–2017	10^6 lb	41.2	252	603	10^6 lb/mi^2	0.171	0.207	0.247
TKN	1997–2017	10^6 lb	15.4	78.5	147	10^6 lb/mi^2	0.064	0.064	0.060

Table 14. Estimated mean annual loads and yields of total suspended solids, total phosphorus, nitrate plus nitrogen, and total Kjeldahl nitrogen at streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana.

[Muncie, White River at Muncie, Indiana (U.S. Geological Survey station 03347000); Nora, White River near Nora, Indiana (U.S. Geological Survey station 03351000); Centerton, White River near Centerton, Indiana (U.S. Geological Survey station 03354000); TSS, total suspended solids; t, short ton; t/mi^2, short ton per square mile; TP, total phosphorus as phosphorus; lb, pound; lb/mi^2, pound per square mile; NOx, nitrate plus nitrite as nitrogen; TKN, total Kjeldahl nitrogen as nitrogen]

Constituent	Analytical period (water years)	Mean annual load				Mean annual yield			
		Units	Muncie	Nora	Centerton	Units	Muncie	Nora	Centerton
TSS	1992–2007	10^3 t	58.7	109	256	10^3 t/mi^2	0.244	0.089	0.105
TP	1992–2017	10^6 lb	0.21	0.88	1.69	10^6 lb/mi^2	0.0009	0.0007	0.0007
NOx	1992–2017	10^6 lb	1.58	9.70	23.2	10^6 lb/mi^2	0.0066	0.0080	0.0095
TKN	1997–2017	10^6 lb	0.73	3.74	6.98	10^6 lb/mi^2	0.0030	0.0031	0.0029

Changes in Flow-Normalized Concentration and Flux Between Water Years 1997 and 2017

The results of WRTDS bootstrap tests to assess the magnitude, direction, and likelihood of change in flow-normalized concentrations and flux of total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen between water years 1997 and 2017 are shown in table 15. Despite evidence of increasing streamflows, changes in flow-normalized concentrations and flux were mostly downward. The exceptions were likely upward (increasing) changes in flow-normalized annual mean daily concentration and annual flux for total suspended solids and total phosphorus at the study gage at Muncie, a highly likely (statistically significant) upward change in flow-normalized annual mean daily total phosphorus concentration and a likely upward change in flow-normalized annual flux of total phosphorus at the study gage near Centerton, and a likely upward change in flow-normalized annual mean daily nitrate plus nitrite concentration at the study gage near Centerton. Although an upward change in flow-normalized nitrate plus nitrite concentrations was likely at the study gage near Centerton, flow-normalized annual flux of nitrate plus nitrite at that study gage was determined to have a highly likely downward change.

All water-quality trends at the three study gages, except the downward trends in total Kjeldahl nitrogen at the study gage at Muncie, were determined to be either likely or highly likely (table 15). None of the indicated changes in flow-normalized concentrations or flux between water years 1997 and 2017 were statistically significant at the study gage at Muncie, whereas most of the changes in flow-normalized constituent concentrations and flux were statistically significant at the study gage near Nora. The directions of change in flow-normalized constituent concentrations and flux at the study gage near Nora were all downward. The study gages at Muncie and near Centerton had a mix of upward and downward changes; however, unlike the study gage at Muncie, several of the changes at the study gage near Centerton were statistically significant.

The largest statistically significant absolute changes in flow-normalized concentrations between water years 1997 and 2017 at the three study gages all occurred at the study gage near Nora (table 15). Flow-normalized concentrations of total suspended solids, total phosphorus, and total Kjeldahl nitrogen at the study gage near Nora all had downward changes (estimated as −23.0 milligrams per liter [mg/L], −0.104 mg/L, and −0.403 mg/L, respectively) for the period.

The only statistically significant absolute change in flow-normalized flux of total suspended solids between water years 1997 and 2017 occurred at the study gage near Nora (table 15). The annual flow-normalized flux of total suspended solids was estimated to have decreased by about 68,700 tons per year (an almost 50-percent decrease between the estimated 1997 and 2017 flow-normalized fluxes of total suspended solids).

The largest statistically significant absolute changes in the flow-normalized flux of nitrate plus nitrite and total Kjeldahl nitrogen between water years 1997 and 2017 at the three study gages occurred at the study gage near Centerton (table 15). The flow-normalized flux of nitrate plus nitrite and total Kjeldahl nitrogen at the study gage near Centerton had downward changes (estimated at about -4.74×10^6 lb/yr and -2.72×10^6 lb/yr, respectively). The changes represent decreases of about 19 and 31 percent from the estimated 1997 flow-normalized fluxes of nitrate plus nitrite and total Kjeldahl nitrogen, respectively.

The only statistically significant upward change in flow-normalized concentration or flux between water years 1997 and 2017 was for the flow-normalized total phosphorus concentration at the study gage near Centerton (table 15). The flow-normalized total phosphorus concentration was estimated to have increased by about 0.045 mg/L (15 percent) over that period. There were no statistically significant changes in the flow-normalized concentration of nitrate plus nitrite or flow-normalized flux of total phosphorus at any of the study gages.

The functions implemented in EGRET can provide information to better understand how the relations between streamflow and constituent concentrations have changed over time; for example, figure 10 illustrates the relation between streamflow and the estimated concentration of total suspended solids as a function of time at the study gage near Nora. Concentrations are represented with colored shading that varies from whites to grays at low concentrations to purples and reds at high concentrations. There is a clear progression indicating (generally) decreasing concentrations at streamflows greater than 500 ft^3/s from calendar years 1992 to 2017. The largest changes in total suspended solids concentrations from calendar years 1992 to 2017 occurred at high streamflows (3,000–5,000 ft^3/s), as evidenced by the shift from dark blue to red colors in that flow range in the early 1990s to gray to light blue colors in 2015 and later. Lines representing the 5th and 95th percentiles of daily streamflow on each calendar day of the year are included on the plot as indicators of seasonal trends in the distribution of daily streamflows. The y-axis of the plot is scaled to reflect the approximate range of streamflows that were associated with measured concentrations. Because the extremes in streamflow were not well sampled, the 5th and 95th percentile lines lie below or above the minimum and maximum streamflows plotted in parts of the plot.

The functions implemented in EGRET also can provide more detailed information about how the relations between streamflow and constituent concentrations have changed throughout the calendar year between two given years. For example, figure 11 shows the estimated change in the concentration of total suspended solids between calendar years 1992 and 2017 at the study gage near Nora as a function of streamflow and day within the calendar year. There are several pieces of information that can be gleaned from figure 11. First, there were no positive changes (that is, there were no estimated increases in concentrations at any flow or time of the

Table 15. Weighted Regressions on Time, Discharge, and Season bootstrap test results for estimated change in flow-normalized concentrations and flux of total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen between water years 1997 and 2017 for streamgages on the White River at Muncie, near Nora, and near Centerton, Indiana.

[Cells shaded red indicate upward direction change; cells shaded green indicate downward direction change. Bolded numbers are statistically significant; FN, flow normalized; mg/L, milligram per liter; USGS, U.S. Geological Survey; TSS, total suspended solids; L, likely; t/yr, ton per year; TP, total phosphorus as phosphorus; lb/yr, pound per year; NOx, nitrate plus nitrite as nitrogen; TKN, total Kjeldahl nitrogen as nitrogen; ALAN, as likely as not; HL, highly likely]

Constituent	Estimated FN concentration change (mg/L)	Change direction	Likelihood	Lower 90-percent confidence interval (mg/L)	Upper 90-percent confidence interval (mg/L)	Estimated FN flux change	Flux change units	Change direction	Likelihood	Lower 90-percent confidence interval	Upper 90-percent confidence interval
White River at Muncie, Indiana (USGS station 03347000)											
TSS	6.140	Up	L	−24.3	17.5	17.4	10^3 t/yr	Up	L	−54.2	44.5
TP	0.029	Up	L	−0.023	0.057	0.104	10^6 lb/yr	Up	L	−0.073	0.174
NOx	−0.375	Down	L	−1.114	0.127	−0.306	10^6 lb/yr	Down	L	−0.981	0.372
TKN	−0.019	Down	ALAN	−0.215	0.102	0.031	10^6 lb/yr	Up	ALAN	−0.283	0.358
White River near Nora, Indiana (USGS station 03351000)											
TSS	**−23.0**	Down	HL	−27.5	−17.0	**−68.7**	10^3 t/yr	Down	HL	−99.1	−32.0
TP	**−0.104**	Down	HL	−0.134	−0.069	−0.107	10^6 lb/yr	Down	L	−0.360	0.020
NOx	−0.244	Down	L	−0.622	0.036	**−1.806**	10^6 lb/yr	Down	HL	−3.314	−0.428
TKN	**−0.403**	Down	HL	−0.518	−0.313	**−1.473**	10^6 lb/yr	Down	HL	−2.258	−0.483
White River near Centerton, Indiana (USGS station 03354000)											
TSS	**−12.7**	Down	HL	−17.0	−3.1	−103.5	10^3 t/yr	Down	L	−182.7	30.1
TP	**0.045**	Up	HL	0.017	0.074	0.110	10^6 lb/yr	Up	L	−0.115	0.408
NOx	0.180	Up	L	−0.103	0.447	**−4.740**	10^6 lb/yr	Down	HL	−8.708	−0.642
TKN	**−0.263**	Down	HL	−0.373	−0.167	**−2.723**	10^6 lb/yr	Down	HL	−4.193	−1.089

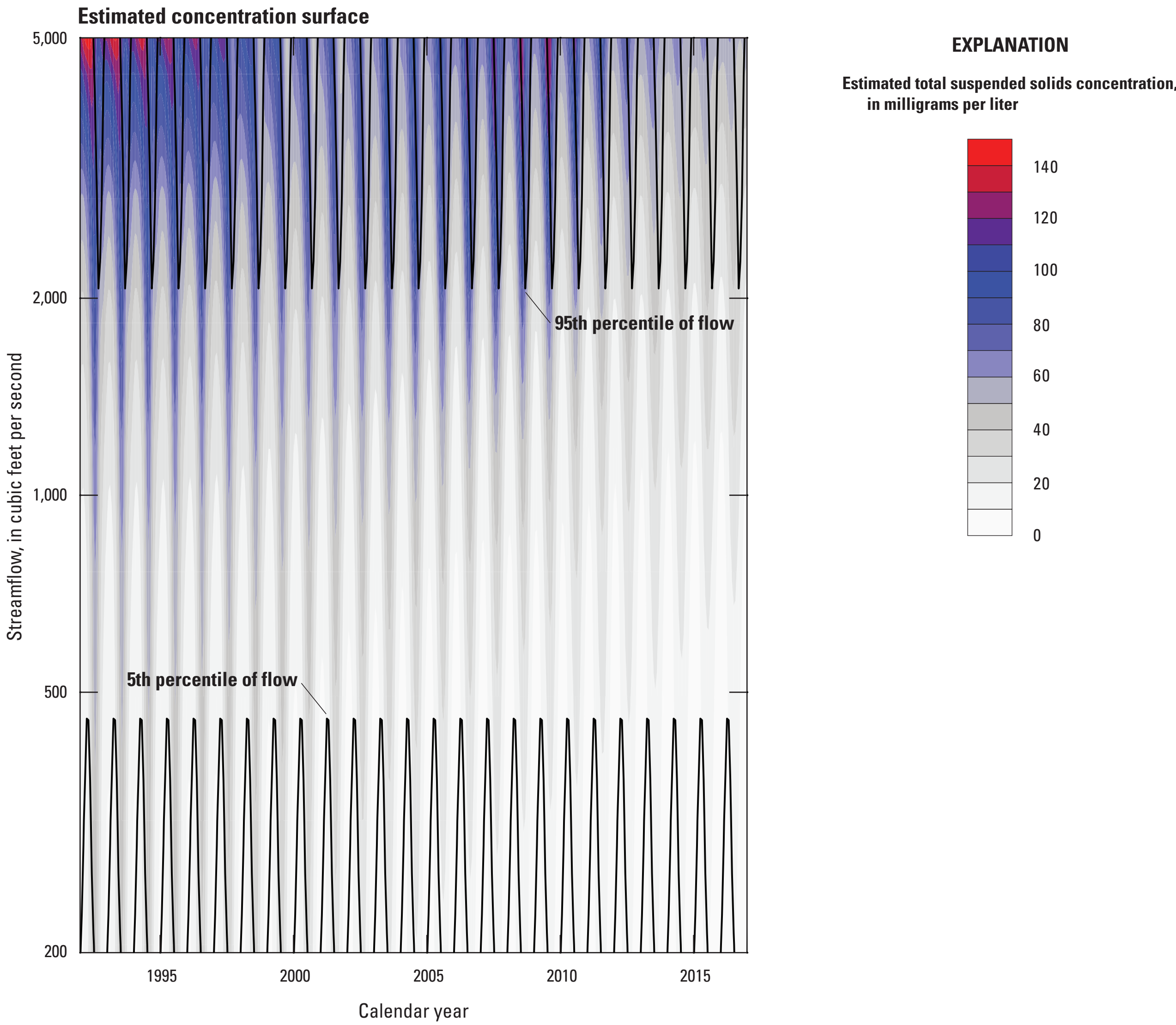


Figure 10. Relation between streamflow and the estimated concentration of total suspended solids as a function of time at the streamgage on the White River near Nora, Indiana (U.S. Geological Survey station 03351000), calendar years 1992 to 2017.

year). Second, as previously mentioned, the largest changes in total suspended solids concentrations (ranging from about −50 to −100 mg/L) are estimated to occur at higher streamflows. Finally, decreases in total suspended solids concentrations were greatest between about late June and mid-August.

Analyses of nitrate plus nitrite concentrations at the study gage near Centerton provide another example of how EGRET can be used to better understand how the relations between streamflow and constituent concentration have changed over time. The relation between streamflow and the estimated concentration of nitrate plus nitrite as a function of time at the study gage near Centerton is shown in figure 12. Estimated concentrations of nitrate plus nitrite decreased over time at higher flows and increased over time at lower flows. One possible explanation is that nonpoint runoff of nitrate plus nitrite or point sources of nitrate plus nitrite contributed by wet-weather flows, or both, decreased over the period. At the same time, dry-weather contributions of nitrate plus nitrite (likely from point sources) increased. The estimated change in the concentration of nitrate plus nitrite between calendar years 1992 and 2017 is shown in figure 13 as a function of streamflow and day within a year at the study gage near Centerton. Unlike the example of total suspended solids at the study gage near Nora (which had only decreasing concentrations; fig. 11), there are indications of positive and negative changes in concentrations of nitrate plus nitrite over the

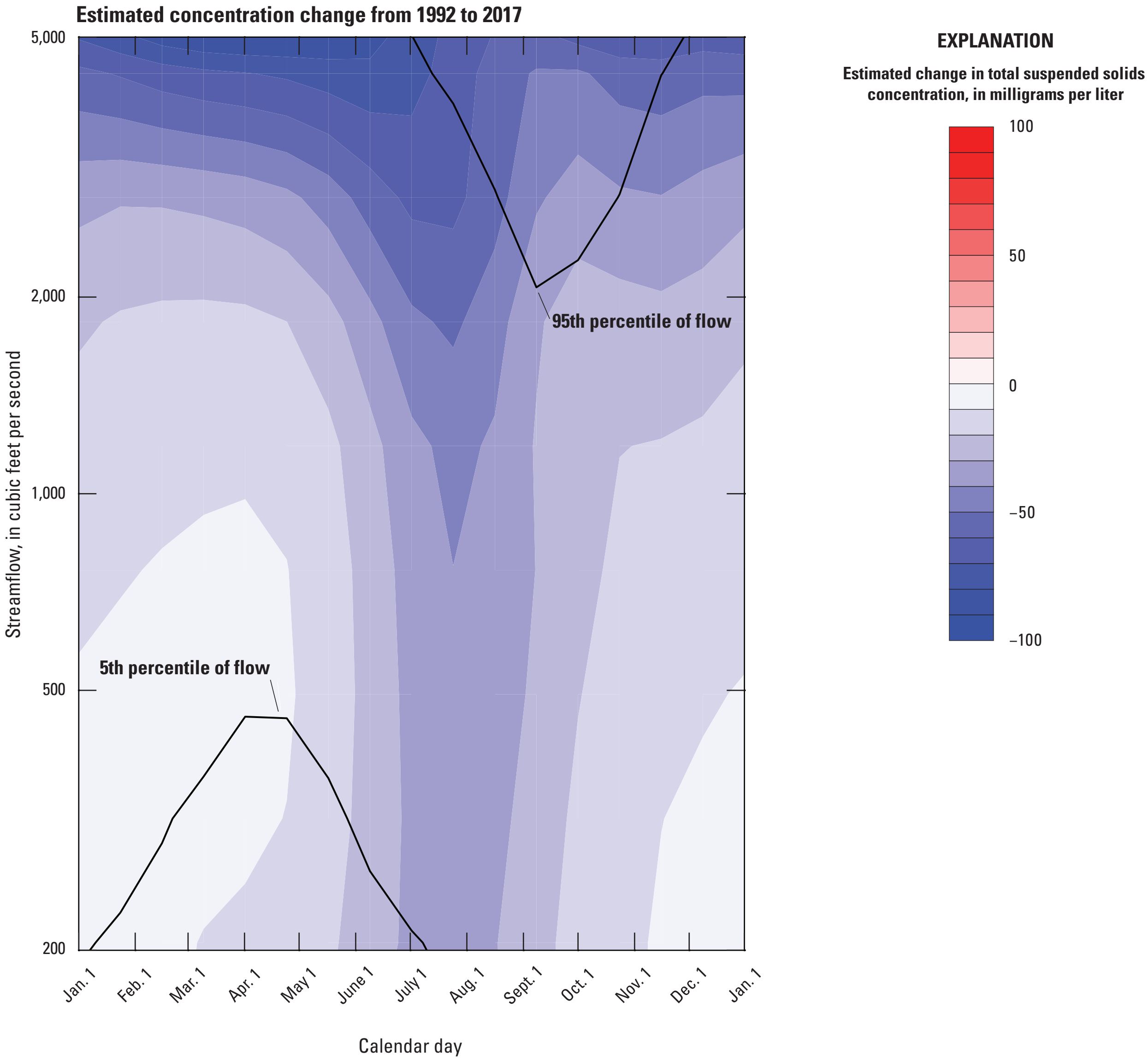


Figure 11. Estimated change in the concentration of total suspended solids as a function of streamflow and day within a year between calendar years 1992 and 2017 at the streamgage on the White River near Nora, Indiana (U.S. Geological Survey station 03351000).

calendar year between calendar years 1992 and 2017. Positive changes (increases) in nitrate plus nitrite concentrations occur throughout the year over a broad range of streamflows, with the greatest increases associated with streamflows less than 500 ft^3/s. Small negative changes (decreases) in concentration occurred at streamflows of 1,500 ft^3/s or greater during most of the year. The negative changes in concentration occurred over the widest range of flows between the months of March and June. This pattern of changes may explain why the change in nitrate plus nitrite concentrations between water years 1992 and 2017 was upward (reflecting the effect of lower flow concentrations) whereas the change in annual flux was downward (reflecting the effect of decreasing concentrations during higher flow conditions). March–June typically are relatively wet in the Upper White River Basin, so decreases in high-flow concentrations of nitrate plus nitrite during those months can appreciably reduce the annual flux (and load) of nitrate plus nitrite even if concentrations increase over a large range of lower streamflows.

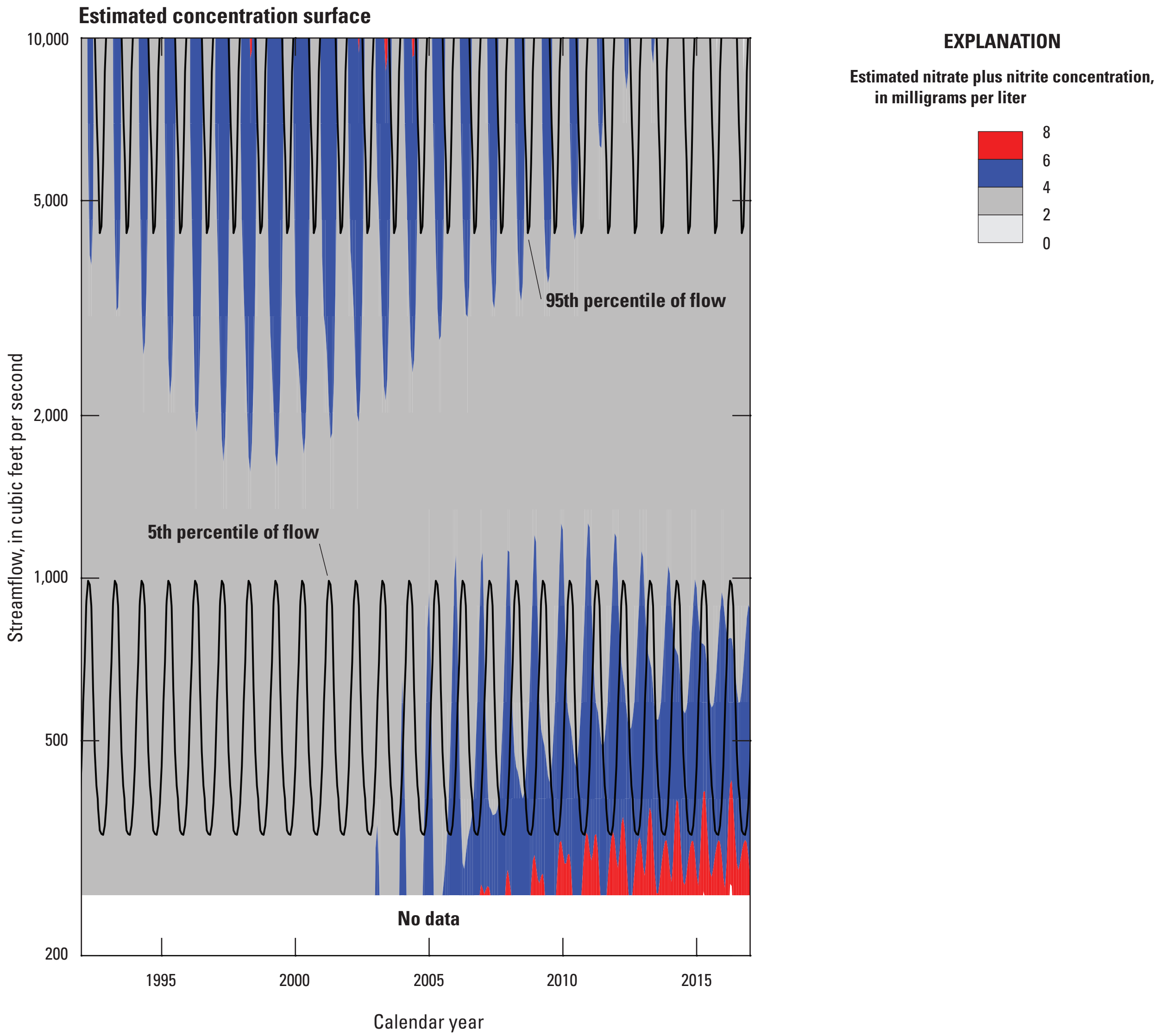


Figure 12. Relation between streamflow and the estimated concentration of nitrate plus nitrite as a function of time at the White River near Centerton, Indiana, streamgage (U.S. Geological Survey station 03354000), calendar years 1992 to 2017.

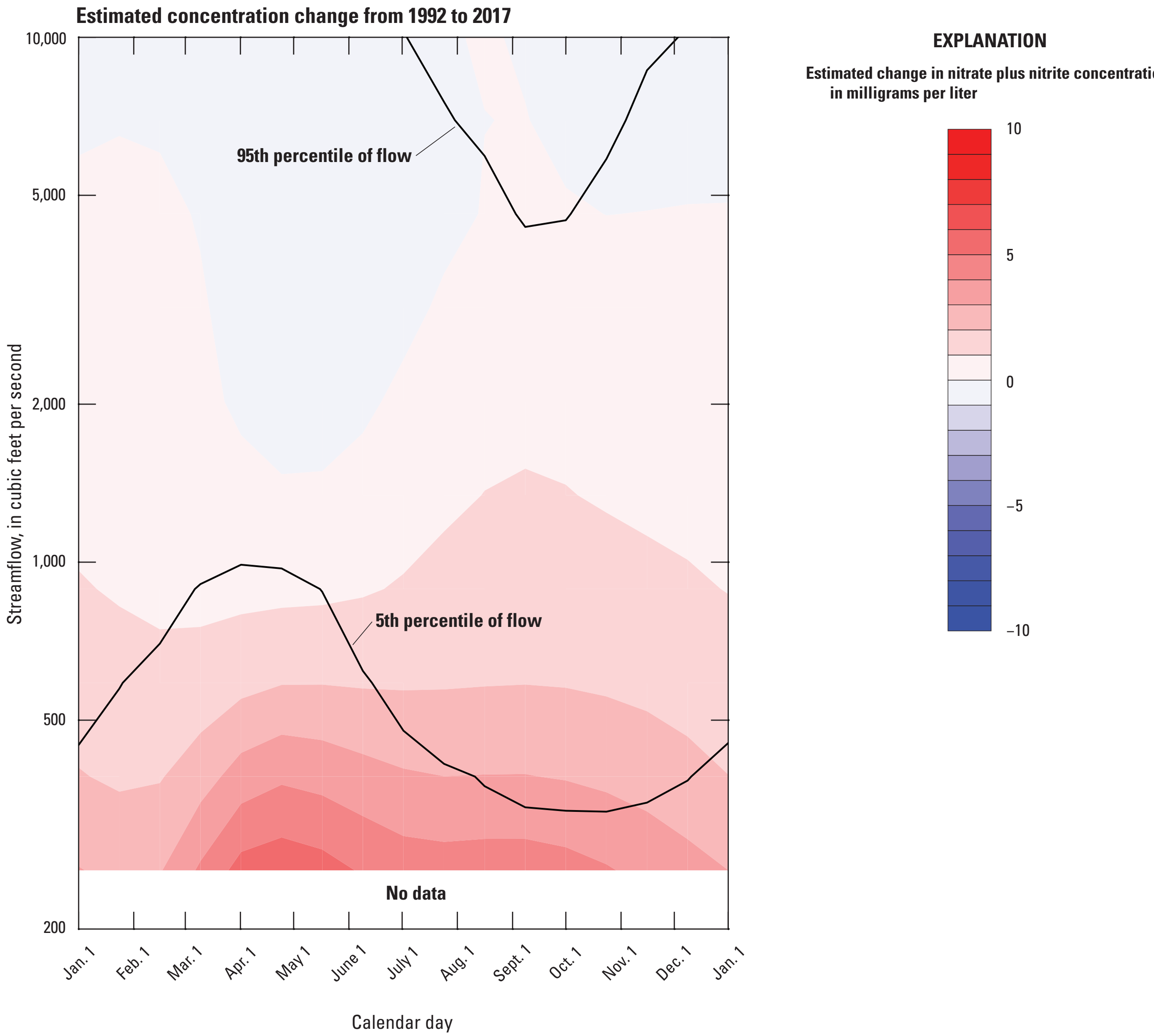


Figure 13. Estimated change in the concentration of nitrate plus nitrite as a function of streamflow and day within a year between calendar years 1992 and 2017 at the White River near Centerton, Indiana, streamgage (U.S. Geological Survey station 03354000).

Summary

The U.S. Geological Survey (USGS), in cooperation with The Nature Conservancy, completed a study to estimate and assess trends in annual mean concentrations and flux of selected nutrients and total suspended solids at three locations on the White River in the Upper White River Basin. Several agencies provided data for water-quality sampling sites within the Upper White River Basin where at least six samples per year were collected and analyzed for nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, and (or) total suspended solids or suspended-sediment concentration. Total suspended solids data had to be used to estimate sediment flux because few suspended-sediment concentration data were available. The likely consequence of using total suspended solids data instead of suspended-sediment concentration data is greater uncertainty and underestimation of the flux of sediment in suspension.

The locations of water-quality sampling sites were compared with locations of USGS streamgages (hereafter referred to as "study gages") on the Upper White River at Muncie (USGS station 03347000), near Nora (USGS station 03351000), and near Centerton (USGS station 03354000), Indiana. Sampling sites were screened to select those sites whose concentration data could reasonably be treated as being representative of concentration data that would have been collected on the same day at one of the three study gages (had they been measured). That determination was based on having no known nutrient or sediment inputs between the study gage and sampling site that would likely cause the concentrations measured at the sampling sites to be unrepresentative of concentrations at the study gage and based on the drainage area at the sampling site being less than 10 percent different from the drainage area at the study gage. It is uncertain whether total suspended solids for the study gage near Centerton met both those criteria. Three facilities discharge total suspended solids in the reach between the study gage and the sampling location; however, their effect on instream concentrations of total suspended solids is not known.

For most water-quality constituents, there were suitable data to facilitate an analysis of the 26-year period extending from calendar years 1991 to 2017 (water years 1992 to 2017); however, shorter analytical periods were necessary for total Kjeldahl nitrogen at the study gages at Muncie and near Centerton and for total suspended solids at the study gage near Centerton. Rudimentary quality-control checks of the data were done to identify probable erroneous data. As a result of the quality-control checks, results were omitted for all water-quality constituents associated with one sample for a single day at the study gage near Nora and results were omitted for total suspended solids for a single day at the study gage near Centerton. All other results were retained. Constituent-specific arithmetic mean concentrations were substituted for the individually measured concentrations if more than one sample was collected on the same day.

Trends in streamflows between water years 1978 and 2017 at the study gages were assessed using the Exploration and Graphics for RivEr Trends (EGRET) package and using Mann-Kendall and Pettitt tests. With just one exception, the annual maximum daily streamflows, the annual mean daily streamflows, and the annual minimum 7-day mean streamflows at the study gages demonstrated upward trends (increasing streamflows) in the EGRET analyses. The exception was the annual 7-day minimum streamflow at the study gage near Nora, which had no appreciable indication of upward or downward trend. Mann-Kendall tests also indicated that the average trend for the annual maximum daily, annual mean daily, and annual 7-day minimum streamflow statistics between water years 1978 and 2017 was upward at each of the study gages; however, only the trends in the annual mean daily streamflows at the study gage at Muncie and the annual maximum daily streamflows at the study gages near Nora and near Centerton were statistically significant at a 0.05 probability level. The Pettitt tests indicated that a step trend occurred for annual mean daily streamflows at each of the study gages between water years 1978 and 2017 and that the step trends most likely occurred at each study gage around water year 2001. A Mann-Kendall test of annual precipitation totals measured at the Indianapolis International Airport between calendar years 1932 and 2017 indicated a statistically significant upward trend in annual precipitation (increasing at an average rate of 0.088 inch per year), indicating that upward trends in streamflows might have resulted (at least in part) from an upward trend in precipitation.

The seasonal distributions of total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen concentrations at the study gages were evaluated by examining boxplots of concentrations as a function of month of the year. There were distinct seasonal patterns in the distribution of total suspended solids concentrations at the study gages, with median concentrations being highest during the months of June and July and generally lowest during the late fall and winter months (January, February, November, and December).

There were discernable and similar patterns in the seasonal distribution of total phosphorus concentrations at the study gages near Nora and near Centerton. At both study gages, monthly median total phosphorus concentrations gradually increased beginning in May and peaked about September or October, with the median September concentration being at least twice the median May concentration. Seasonal patterns in total phosphorus concentrations at the study gage at Muncie were less evident than at the other two study gages, and the highest monthly median concentrations at the study gage at Muncie were in June and July.

Patterns in the seasonal distribution of nitrate plus nitrite concentrations at the study gages were discernable but not always as apparent as those for total suspended solids and total phosphorus. Monthly median nitrate plus nitrite concentrations at the study gages typically were higher during the January–June months than during the July–December months.

Patterns in the seasonal distribution of total Kjeldahl nitrogen concentrations differed among the three study gages; however, in general, some of the higher monthly median total Kjeldahl nitrogen concentrations were associated with the late spring and summer periods.

The Weighted Regressions on Time, Discharge, and Season (WRTDS) function in EGRET was used to estimate water-year annual mean daily concentrations and flux of sediment and nutrients, as well as with estimates of concentrations and flux that were "normalized" to remove the effect of year-to-year variation in streamflow. The approximate coefficients of determination for the WRTDS regression models ranged from a high of 0.82 for total phosphorus for the study gage near Centerton to a low of 0.19 for nitrate plus nitrite for the study gage near Nora.

Plots of residuals from the WRTDS regression models were examined to assess whether the variance in the residuals was uniform as a function of (1) the predicted value, (2) streamflow, (3) time, and (4) month of the year. The plots for all study gages and constituents showed approximately uniform variance of residuals as a function of the predicted value, streamflow, and time. Monthly boxplots of residuals also generally showed no indication that median residuals varied appreciably as a function of month; the exceptions being for nitrate plus nitrite at all three study gages and total suspended solids at the study gage near Centerton. For nitrate plus nitrite, the median residual for the month of June was noticeably more positive (indicating underprediction) at all three study gages than the other months of the year. WRTDS regression estimates for nitrate plus nitrite at the study gages near Nora and near Centerton were noticeably less variable than the observed concentrations, indicating the WRTDS regression model did not do a good job of estimating the extremes in concentrations of nitrate plus nitrite at those study gages. Median residuals for total suspended solids for November for the study gage near Centerton were appreciably more negative than for other months of the year, possibly indicating a tendency for WRTDS to overpredict total suspended solids concentrations at the study gage near Centerton in November.

Water-year annual mean daily concentrations and flux at the study gages, along with their flow-normalized values, were estimated with WRTDS for total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen. The median flux bias statistic computed for the WRTDS models was 0.044 and ranged from a high of 0.137 to a low of −0.002 (with all but one of the statistics being positive). Positive flux bias statistics indicate a tendency to overpredict flux on average.

Loads and yields of each constituent were estimated for the longest periods of concurrent record at the three study gages. Loads of each of the constituents increased sequentially from the most upstream study gage to the most downstream study gage; however, the same was not true for yields. The highest yields of total suspended solids, total phosphorus, and total Kjeldahl nitrogen occurred at the most upstream study gage (at Muncie); however, the highest yield of nitrate plus nitrite occurred at the most downstream study gage (near Centerton).

WRTDS bootstrap tests were done with Exploration and Graphics for RivEr Trends Confidence Intervals (EGRETci) to assess the magnitude, direction, and likelihood of changes in annual flow-normalized concentrations and flux of total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen at the study gages between water years 1997 and 2017. Changes in flow-normalized concentrations and flux were mostly downward (decreasing). The exceptions were likely upward (increasing) changes in flow-normalized annual mean daily concentration and annual flux for total suspended solids and total phosphorus at the study gage at Muncie, a highly likely upward change in flow-normalized annual mean daily total phosphorus concentration and a likely upward change in flow-normalized annual flux of total phosphorus at the study gage near Centerton, and a likely upward change in flow-normalized annual mean daily nitrate plus nitrite concentration at the study gage near Centerton. Although an upward change in flow-normalized nitrate plus nitrite concentrations was likely at the study gage near Centerton, flow-normalized annual flux of nitrate plus nitrite at that study gage was determined to have a highly likely downward change.

EGRET/WRTDS analyses can provide information to better understand how the relations between streamflow and constituent concentrations have changed over time as well as providing information that can lead to insights into how those relations have changed within a calendar year between any 2 years included in the analyses. Examples of those uses, illustrating changes between calendar years 1992 and 2017, were given for total suspended solids at the study gage near Nora and for nitrate plus nitrite concentrations at the study gage near Centerton.

References

Chanat, J.G., Moyer, D.L., Blomquist, J.D., Hyer, K.E., and Langland, M.J., 2016, Application of a weighted regression model for reporting nutrient and sediment concentrations, fluxes, and trends in concentration and flux for the Chesapeake Bay Nontidal Water-Quality Monitoring Network, results through water year 2012: U.S. Geological Survey Scientific Investigations Report 2015–5133, 76 p. [Also available at https://doi.org/10.3133/sir20155133.]

Cleveland, W.S., 1979, Robust locally weighted regression and smoothing scatterplots: Journal of the American Statistical Association, v. 74, no. 368, p. 829–836.

Cleveland, W.S., and Devlin, S.J., 1988, Locally weighted regression—An approach to regression analysis by local fitting: Journal of the American Statistical Association, v. 83, no. 403, p. 596–610.

Edwards, T.K., and Glysson, D.G., 1999, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 89 p.

Glysson, G.D., 1987, Sediment-transport curves: U.S. Geological Survey Open-File Report 87–218, 47 p.

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 00–4191, 14 p.

Hirsch, R.M., 2014, Large biases in regression-based constituent flux estimates—Causes and diagnostic tools: Journal of the American Water Resources Association, v. 50, no. 6, p. 1401–1424.

Hirsch, R.M., Archfield, S.A., and De Cicco, L.A., 2015, A bootstrap method for estimating uncertainty of water quality trends: Environmental Modelling & Software, v. 73, p. 148–166. [Also available at https://doi.org/10.1016/j.envsoft.2015.07.017.]

Hirsch, R.M., and De Cicco, L.A., 2015, User guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval—R packages for hydrologic data (version 2.0, February 2015): U.S. Geological Survey Techniques and Methods, book 4, chap. A10, 93 p., accessed February 2018 at https://doi.org/10.3133/tm4A10.

Hirsch, R.M., Moyer, D.L., and Archfield, S.A., 2010, Weighted Regressions on Time, Discharge, and Season (WRTDS), with an application to Chesapeake Bay River inputs: Journal of the American Water Resources Association, v. 46, no. 5, p. 857–880. [Also available at https://onlinelibrary.wiley.com/doi/full/10.1111/j.1752-1688.2010.00482.x.]

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.

Indiana State Department of Agriculture and Indiana Department of Environmental Management, 2018, Indiana's state nutrient reduction strategy: Indiana State Department of Agriculture and Indiana Department of Environmental Management, 124 p., accessed July 23, 2019, at https://www.in.gov/isda/files/Indiana%20State%20Nutrient%20Reduction%20Strategy_Version%205%20Final.pdf.

Koltun, G.F., 2019, Total suspended solids, total phosphorus, nitrate plus nitrite, and total Kjeldahl nitrogen concentration data for the White River at Muncie, near Nora, and near Centerton, Indiana, 1991–2017; U.S. Geological Survey data release, https://doi.org/10.5066/P9VN5RKV.

Koltun, G.F., Eberle, M., Gray, J.R., and Glysson, G.D., 2006, User's manual for the Graphical Constituent Loading Analysis System (GCLAS): U.S. Geological Survey Techniques and Methods, book 4, chap. C1, 51 p. [Also available at https://pubs.usgs.gov/tm/2006/tm4C1/pdf/tm4C1.pdf.]

Mallakpour, I., and Villarini, G., 2016, A simulation study to examine the sensitivity of the Pettitt test to detect abrupt changes in mean: Hydrological Sciences Journal, v. 61, no. 2, p. 245–254. [Also available at https://doi.org/10.1080/02626667.2015.1008482.]

Mann, H.B., 1945, Nonparametric tests against trend: Econometrica, v. 13, no. 3, p. 245–249. [Also available at https://www.jstor.org/stable/1907187.]

National Oceanic and Atmospheric Administration, National Centers for Environmental Information, 2018, Climate at a glance: National Oceanic and Atmospheric Administration web page, accessed June 26, 2018, at https://www.ncdc.noaa.gov/cag/statewide/time-series/33.

Pettitt, A.N., 1979, A non-parametric approach to the change point problem: Applied Statistics, v. 28, no. 2, p. 126–135. [Also available at https://doi.org/10.2307/2346729.]

Pohlert, T., 2018, trend—Non-parametric trend tests and change-point detection: R package version 1.1.1, accessed February 1, 2019, at https://CRAN.R-project.org/package=trend.

R Core Team, 2017, R—A language and environment for statistical computing: Vienna, Austria, R Foundation for Statistical Computing. [Also available at https://www.R-project.org/.]

Robertson, D.M., and Saad, D.A., 2011, Nutrient inputs to the Laurentian Great Lakes by source and watershed estimated using SPARROW watershed models: Journal of the American Water Resources Association, v. 47, no. 5, p. 1011–1033. [Also available at https://doi.org/10.1111/j.1752-1688.2011.00574.x.]

Robertson, D.M., and Saad, D.A., 2013, SPARROW models used to understand nutrient sources in the Mississippi/Atchafalaya River Basin: Journal of Environmental Quality, v. 42, no. 5, p. 1422–1440. [Also available at https://doi.org/10.2134/jeq2013.02.0066.]

Robertson, D.M., Schwarz, G.E., Saad, D.A., and Alexander, R.B., 2009, Incorporating uncertainty into the ranking of SPARROW model nutrient yields from Mississippi/Atchafalaya River Basin watersheds: Journal of the American Water Resources Association, v. 45, no. 2, p. 534–549. [Also available at https://onlinelibrary.wiley.com/doi/full/10.1111/j.1752-1688.2009.00310.x.]

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load estimator (LOADEST)—A FORTRAN program for estimating constituent loads in streams and rivers: U.S. Geological Survey Techniques and Methods, book 4, chap. A5, 69 p., accessed February 2018 at https://doi.org/10.3133/tm4A5.

Schwarz, G.E., Hoos, A.B., Alexander, R.B., and Smith, R.A., 2006, The SPARROW surface water-quality model—Theory, application, and user documentation: U.S. Geological Survey Techniques and Methods, book 6, chap. B3, 248 p.

Sen, P.K., 1968, Estimates of the regression coefficient based on Kendall's tau: Journal of the American Statistical Association, v. 63, no. 324, p. 1379–1389. [Also available at https://www.tandfonline.com/doi/abs/10.1080/01621459.1968.10480934.]

Tedesco, L.P., Hoffman, J., Bihl, L., Hall, B.E., Barr, R.C., and Strouder, M., 2011, Upper White River Watershed Regional Watershed Assessment and Planning Report: Upper White River Watershed Alliance, variously paged, accessed December 4, 2018, at https://thewhiteriveralliance.org/wp-content/uploads/2018/08/Upper-White-River-Watershed-Regional-Plan.pdf.

Tedesco, L.P., Pascual, D.L., Shrake, L.K., Casey, L.R., Hall, B.E., Vidon, P.G.F., Hernly, F.V., and Barr, R.C., 2005, Eagle Creek Watershed Management Plan—An integrated approach to improved water quality: Indianapolis, Ind., Eagle Creek Watershed Alliance, CE Publication 2005–07, IUPUI, 182 p., accessed December 4, 2018, at https://www.in.gov/idem/nps/files/wmp_eaglecreek_98-002.pdf.

U.S. Census Bureau, 2018, Annual estimates of the resident population—April 1, 2010, to July 1, 2017: U.S. Census Bureau web page, accessed December 5, 2018, at https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.

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 December 6, 2018, at https://water.usgs.gov/owq/FieldManual/chapter4/html/Ch4_contents.html.

U.S. Geological Survey, 2018, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 14, 2018, at https://doi.org/10.5066/F7P55KJN.

Widhalm, M., Hamlet, A., Byun, K., Robeson, S., Baldwin, M., Staten, P., Chiu, C., Coleman, J., Hall, B., Hoogewind, K., Huber, M., Kieu, C., Yoo, J., and Dukes, J.S., 2018, Indiana's past & future climate—A report from the Indiana Climate Change Impacts Assessment: West Lafayette, Ind., Purdue Climate Change Research Center, Purdue University, accessed May 24, 2019, at https://doi.org/10.5703/1288284316634.

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