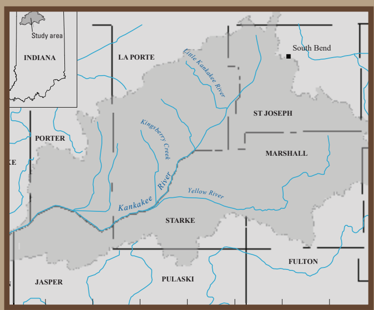
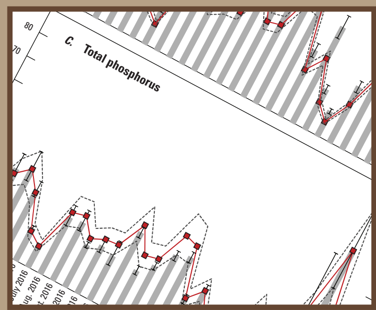
Prepared in cooperation with the Indiana Department of Environmental Management

Regression Models for Estimating Sediment and Nutrient Concentrations and Loads at the Kankakee River, Shelby, Indiana, December 2015 through May 2018





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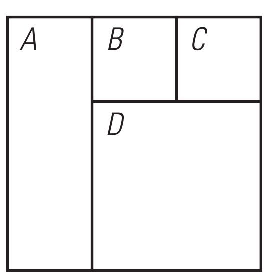

Cover. *A*, photograph showing the water-quality monitor housing during low flow conditions at the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000). Photograph taken on September 28, 2017, by Zachary Razor, U.S. Geological Survey. *B*, figure 1, the Kankakee River Basin and the location of the continuous water-quality monitoring station at Shelby, Indiana (U.S. Geological Survey station 05518000), p. 2. *C*, figure 2, estimated monthly loads at the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000), for January 2016 through May 2018 computed from combined regression and rloadest models with monthly 90 percent prediction intervals. *D*, photograph showing ice floating on the Kankakee River at the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000). Photograph taken on December 15, 2016, by Zachary Razor, U.S. Geological Survey.

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

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

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U.S. Geological Survey, Reston, Virginia: 2019

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
ounce, fluid (fl. oz)	0.02957	liter (L)
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
ton, short (2,000 lb)	0.9072	metric ton (t)
ton, long (2,240 lb)	1.016	metric ton (t)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°F – 32) / 1.8.

Datum

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

Supplemental Information

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

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

Turbidity units are given in formazin nephelometric units (FNU).

Abbreviations

Bp	load bias percent
E	Nash Sutcliffe efficiency index
GOES	Geostationary Operational Environmental Satellite
IDEM	Indiana Department of Environmental Management
PLR	partial load ratio
PRESS	predicted residual error sum of squares
PVC	polyvinyl chloride
Q	streamflow
R^2	coefficient of determination
SSL	suspended-sediment load
t/mi^2/yr	tons per square mile per year
TNL	total nitrogen load
TPL	total phosphorus load
USGS	U.S. Geological Survey

Regression Models for Estimating Sediment and Nutrient Concentrations and Loads at the Kankakee River, Shelby, Indiana, December 2015 through May 2018

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Abstract

The Kankakee River in northern Indiana flows through the area once known as the Grand Marsh. Beginning in the 1860s, anthropogenic changes to the river within Indiana resulted in downstream flooding and additional transport of sediment and nutrients. In 2015, the U.S. Geological Survey, in cooperation with the Indiana Department of Environmental Management, upgraded the gaging station Kankakee River at Shelby, Indiana, to include the collection of water-quality data. By relating continuously monitored water-quality data to discrete data collected from December 2015 through May 2018, linear regression was used to develop models for estimating concentrations of suspended sediment, total nitrogen, and total phosphorus. Developed regression models indicated a strong correlation between turbidity and specific conductance with suspended-sediment concentration (adjusted coefficient of determination equals 0.92, predicted residual error sum of squares equals 0.151), nitrate plus nitrite and specific conductance with total nitrogen (adjusted coefficient of determination equals 0.95, predicted residual error sum of squares equals 0.0248), and turbidity with total phosphorus (adjusted coefficient of determination equals 0.89, predicted residual error sum of squares equals 0.0103).

Daily loads of suspended sediment, total nitrogen, and total phosphorus were computed as the product of daily mean regression model concentrations and daily mean streamflow. Rloadest models were used to compute daily loads of each constituent during gaps in regression model loads. For 2016 and 2017, the estimated annual suspended-sediment loads were 105,000 and 91,000 tons; estimated total nitrogen loads were 8,690 and 8,890 tons; and estimated total phosphorus loads were 265 and 236 tons, respectively.

Introduction

Historically, the Kankakee River in Indiana (fig. 1) was bordered by a 400,000-acre wetland known as the Grand Marsh (not shown) (Bhowmik and others, 1980; U.S. Department of Agriculture, 1909). By the early 20th century, the entire main stem of the river in Indiana was extensively channelized to lessen flooding and drain swampland areas for agriculture (U.S. House of Representatives, 1916, 1931). Increased river slope and velocities resulted in additional flooding and transport of sediment. (Ivens and others, 1981; Bhowmik and others, 1980). Summaries of dendrogeomorphic data (Phipps and others, 1995) and analysis of discrete water-quality samples indicated that the Kankakee River is a source of suspended sediment (Terrio and Nazimek, 1997; Holmes, 1997) and nutrients (Murphy and others, 2013; Smith and others, 2003) to downstream water bodies.

The Indiana Department of Environmental Management (IDEM) is a State agency responsible for protecting public health and the environment by assessing the quality of surface water and groundwater. The IDEM fulfills Indiana responsibilities mandated by the Clean Water Act including protection of wetlands for proper drainage, flood protection, and wildlife habitat (Indiana Department of Environmental Management, 2018). In 2015, the U.S. Geological Survey (USGS), in cooperation with the IDEM, expanded the capabilities of the gaging station Kankakee River at Shelby, Indiana (USGS station 05518000) (hereafter referred to as Kankakee River at Shelby, Indiana) by deploying continuous water-quality monitors in concert with collection of representative discrete water samples. This 3-year study was completed to describe and quantify concentrations and loads of suspended sediment, total nitrogen, and total phosphorus at the Kankakee River at Shelby, Indiana.

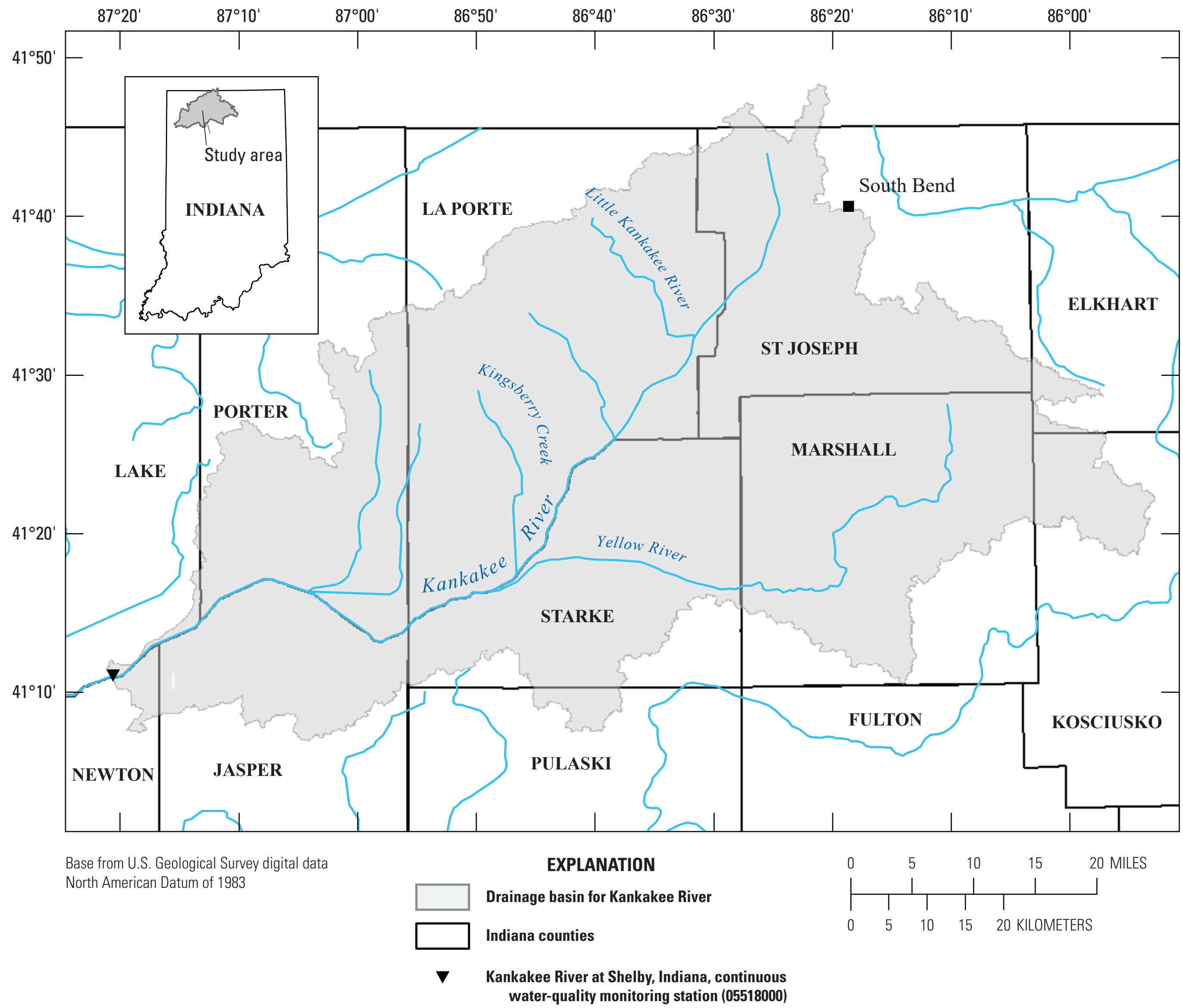

Figure 1. The Kankakee River Basin and the location of the continuous water-quality monitoring station at Shelby, Indiana (U.S. Geological Survey station 05518000).

Purpose and Scope

The purpose of this report is to document the application of models computed from regression analysis for suspended sediment, total nitrogen, and total phosphorus at the Kankakee River at Shelby, Indiana, using data collected from December 5, 2015, through May 31, 2018. Developed regression models statistically relate in-situ, continuous water-quality data with analytical results from periodically collected discrete samples throughout the range of hydrologic and seasonal conditions. The models summarized in this report can be used to estimate suspended-sediment, total nitrogen, and total phosphorus concentrations and loads at the Kankakee River at Shelby, Indiana, with ongoing model validation.

Study Area

Historically, much of the Kankakee River in Indiana meandered through a 400,000-acre wetland, called the Grand Marsh (Bhowmik and others, 1980; U.S. Department of Agriculture, 1909). Seasonally, the marsh ranged from 3 to 5 miles in width and averaged from 1 to 4 feet in depth. The slope of the river was estimated to have been 0.45 foot per mile (Ivens and others, 1981). As early as the 1860s, marsh land in Indiana began to be converted for agricultural use (U.S. House of Representatives, 1916, 1931). Construction of a deep straight channel and tributaries with additional lateral ditches drained swampland and decreased localized flooding (Ivens and others, 1981). The total length of the Kankakee River in Indiana decreased from about 250 to 82 miles resulting in increases to the river slope, water velocity, and the potential for additional transport of sediment by the Kankakee River (Ivens and others, 1981; Bhowmik and others, 1980). Downstream of Indiana, much of the Kankakee River remained in its natural form (Ivens and others, 1981). Channelization of the Kankakee River within Indiana led to increased flooding and sedimentation of the downstream non-channelized, low gradient reaches. Currently (2018), the Kankakee River Basin is a substantial contributor of sediment and nutrients within the Upper Mississippi River Basin (Murphy and others, 2013; Smith and others, 2003; Terrio and Nazimek, 1997; Holmes, 1997; Phipps and others, 1995).

The Kankakee River in Indiana has a drainage area of 1,918 square miles (fig. 1) (U.S. Geological Survey, 2016a). The Kankakee River, from its source near South Bend, Indiana, flows in a southwestwardly direction to Illinois (not shown). Major tributaries of the Kankakee River in Indiana include the Yellow River (438 square miles), the Little Kankakee River (74 square miles), and Kingsbury Creek (61 square miles) (fig. 1).

The Kankakee River lies within the Northern Moraine and Lake physiographic region of Indiana (Fenelon and others, 1992). The surficial geology consists of numerous moraines; lacustrine sediments; and a thick, latitudinal belt of sand, all of which were deposited during the Wisconsin glaciation. These glacial deposits, 20 to 250 feet deep and dominated by stratified sand and gravel, serve as the primary source of the sediments in the Kankakee River (Indiana Geological and Water Survey, 2018; Ivens and others, 1981; Gross and Berg, 1981).

Land use of the basin is predominantly row-crop agriculture (75 percent), with a few urban areas (10 percent), riverine wetlands (4.1 percent), and pockets of deciduous forest. Row-crop agriculture in the basin is dominated by corn, soybeans, wheat, and hayfields. Upstream from Shelby, Indiana, the river does not pass through any towns with more than 100 homes per square mile (Indiana Department of Natural Resources, 2018; Indiana Geological and Water Survey, 2018).

In 1992, the gaging station Kankakee River at Shelby, Indiana, was installed to measure streamflow. In 1998, the gaging station was relocated 500 feet upstream from its original location because of safety concerns. The drainage area of the Kankakee River at Shelby, Indiana, is 1,779 square miles (U.S. Geological Survey, 2016b). This gaging station, which is approximately 10.5 miles upstream from the Indiana-Illinois border, is the most downstream USGS gaging station on the Kankakee River within Indiana. All data analyzed for this report were collected at the current (2018) streamflow gaging station.

Approach and Methods

The development of regression models for suspended sediment, total nitrogen, and total phosphorus relied on the collection of representative discrete water-quality samples and the operation of in-situ continuous monitors throughout the range of water-quality conditions.

Collection and Analysis of Discrete Water-Quality Samples

Discrete water-quality samples used in the development of regression models were collected by USGS field crews from December 5, 2015, through May 31, 2018. Initially, water-quality samples were collected on a fixed schedule of every 2 weeks from April through October and monthly during cooler months. In late 2016 through the end of the project, the sampling design was altered to target high-flow events and better document the range of constituents transported by the river.

Discrete water-quality samples were collected using nationally consistent field protocols as outlined in the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, variously dated). Flow-weighted mean concentration samples were collected from the downstream side of the bridge at the monitoring site using the USGS Equal Width Increment Method to represent the entire cross section and water column of the river. During each site visit, the entire cross section of the stream was sampled twice, providing sequential samples for analysis of nutrients and sediment. Using a churn splitter, the nutrient sample was subset into two containers for evaluation of unfiltered, whole water constituents and filtered constituents smaller than 0.45 micron. Whole water nutrient samples were preserved with 1 milliliter of sulfuric acid. After preservation, nutrient samples were chilled and shipped for analysis. Each nutrient sample was analyzed by the USGS National Water Quality Laboratory for total and dissolved nitrogen and phosphorus using published methods (Patton and Kryskalla, 2011; Patton and Kryskalla, 2003; Fishman, 1993; O'Dell, 1993). The entire volume collected for the suspended-sediment sample was analyzed for concentration and sand/fines composition at the USGS Kentucky Sediment Laboratory using analytical methods described by Guy (1969). All results from these two laboratories were reviewed and quality assured by USGS personnel and stored in the USGS National Water Information System (U.S. Geological Survey, 2016b).

Continuous Water-Quality Monitoring

The gaging station Kankakee River at Shelby, Indiana, has operated continuously since 1922. In December 2015, three water-quality monitors were installed that together continuously measure water temperature, specific conductance, pH, dissolved oxygen, turbidity, nitrate plus nitrite concentration, and orthophosphate concentration. A YSI 6600 5-parameter water-quality sonde, a Satlantic Submersible Ultraviolet Nitrate Analyzer (SUNA) V2–5 nitrate monitor, and a Wetlabs Cycle P orthophosphate monitor are housed in flow-through polyvinyl chloride (PVC) pipes affixed to the downstream side of the bridge pier and located in well-mixed, flowing water. The 5-parameter water-quality sonde and nitrate monitor were deployed year-round, measuring water quality every 15 minutes. The orthophosphate monitor, a wet chemistry instrument, is deployed only in temperatures above freezing and collects measurements every 2 hours. All continuous measurements are stored on a data-collection platform at the site and are transmitted hourly by the Geostationary Operational Environmental Satellite (GOES) for archival in the publicly available USGS National Water Information System (U.S. Geological Survey, 2016b).

Continuous water-quality monitors are operated following documented USGS protocols (Pellerin and others, 2013; Wagner and others, 2006). Each monitor is cleaned and checked for calibration drift approximately biweekly from April through October and monthly from November through March when biofouling is not as prominent. During site visits, the USGS personnel evaluate and record the magnitude of any fouling and calibration drift. The field inspection information is used later to correct for drift and fouling. Data that are rated worse than poor and exceed parameter thresholds, cannot be corrected and are removed from the record (Pellerin and others, 2013; Wagner and others, 2006).

Infrequently, equipment malfunctions, excessive fouling, and high instrument drift resulted in periods of missing continuous data. Additionally, from February 14 through March 31, 2018, a large tree became lodged against the continuous monitor housing, requiring the monitors be removed. The tree was removed during lower water by the Indiana Department of Transportation. For the study period, daily mean values of continuous turbidity, specific conductance, and nitrate plus nitrite were approved 87, 92, and 93 percent of the time, respectively.

Development of Regression Models

Regression models are based on concurrent measurements of discrete and continuous water-quality data collected from December 5, 2015, through May 31, 2018, and archived in a USGS data release (Lathrop, 2019). Discrete samples were collected throughout the range of hydrologic and seasonal conditions. Continuous data were selected that closely correspond with the date and time of each discrete sample.

Potential outliers were identified by inspecting studentized residuals, which is the quotient resulting from the division of a residual by an estimate of its standard deviation. Quotients outside the range of 3 to -3 are considered potential outliers and receive further evaluation. A discrete sample of suspended sediment (December 15, 2017) exceeded the studentized residual threshold and received further review. This sample, collected during low turbidity conditions (2.3 formazin nephelometric units) but largely composed of sand-sized material (76 percent), might have been negatively affected by error during sampling and was not used in model development.

Regression models were developed following USGS protocols and methods (Rasmussen and others, 2009; Helsel and Hirsch, 2002). Each regression model relates laboratory-analyzed discrete water-quality sample data with in-situ, continuous water-quality monitor measurements. Ordinary least-squares regression was used to evaluate and determine the optimal continuous water-quality parameter(s) (explanatory variables) to be used as surrogates for each of the discrete constituents—suspended sediment, total nitrogen, and total phosphorus (response variables). Statistical models for each possible combination of explanatory and response variables were produced using stepwise regression in the R statistical package, version 3.1.2 (R Core Team, 2018). A variety of model statistics and diagnostics were used to determine the best predictors of each modeled constituent including tests of significance, standard error, adjusted coefficient of determination (R^2), and the predicted residual error sum of squares (PRESS) statistic. The PRESS statistic provides a measure of the cross-validation summary of the model fit to a sample of observations not used to estimate the model. In general, the smaller the PRESS statistic, the better the model's predictive ability (Helsel and Hirsch, 2002).

To improve potential models, explanatory and response variables were evaluated for transformations (log, square root, or square) that linearize the relation or change the distributional characteristics of data resulting in model residuals that are more symmetric, linear, and homoscedastic. Although models with two explanatory variables were investigated, simple linear models, those with only one explanatory variable, were given preference.

To further evaluate potential models, diagnostic plots were created to assess how each model's residuals varied as a function of (1) predicted values, (2) normal quantiles, (3) date, and (4) streamflow. Additional plots highlight differences among predicted and observed values, residuals by season, and residuals by year.

The optimal model often used a transformed response variable. In those instances, a smearing estimator was used to correct for bias in the back transform of the model (Helsel and Hirsch, 2002). Prediction intervals were developed for each model, following methods from Helsel and Hirsch (2002), to define the range of values within which there is 90 percent certainty that the true value occurs.

Published regression models can be used to estimate concentrations and loads of suspended sediment, total nitrogen, and total phosphorus. Daily loads of each constituent are computed as the product of daily mean model concentration, daily streamflow, and a conversion constant. Annual yields in tons per square mile per year (t/mi^2/yr) are computed by dividing annual load in tons by the drainage area.

Rloadest Development

Rloadest models were developed for suspended sediment, total nitrogen, and total phosphorus as a secondary load calculation method. LOADEST, a Fortran program originally developed by Runkel and others (2004), was updated by Runkel and De Cicco (2017) in the R programming language (R Core Team, 2018). The R version, called rloadest, is available on the USGS–R GitHub pages (https://github.com/USGS-R/rloadest). Models are typically developed in rloadest by regressing discrete concentration values (in this case, for suspended sediment, total nitrogen, or total phosphorus) against concurrent daily mean streamflow values.

For each load model, the rloadest program computes regression coefficients by means of the Adjusted Maximum Likelihood Estimation method. For each constituent, nine predefined models (Runkel and others, 2004) were tested, and the models were ranked based on Akaike information criterion (Helsel and Hirsch, 2002) scores. Retransformation bias was automatically corrected by application of a bias correction factor (Dempster and others, 1977; Wolynetz, 1979; Cohn, 1988, 2005).

After selecting the best model based on the Akaike information criterion scores, diagnostic plots were created to assess the variance and distribution of each model's residuals as a function of (1) predicted values, (2) normal quantiles, and (3) time. Additionally, the rloadest program computes bias diagnostics that compare estimated loads to observed loads. Bias diagnostics for loads include the load bias percent (*Bp*) (the percentage the model over [negative number] or under [positive number] estimates the sum of the estimated loads compared with the sum of the observed loads) and the partial load ratio (*PLR*) (a ratio of the sum of the estimated loads to the sum of the observed loads, indicates load overestimate [greater than 1] or underestimate [less than 1]). The Nash Sutcliffe efficiency index (*E*) is computed by rloadest and provides a measure of model fit that ranges from 1 (perfect fit) to negative infinity. Using the Adjusted Maximum Likelihood Estimation method, a 90-percent prediction interval was computed for each summary period to define parameter uncertainty and model error in the load estimations (Cohn, 2005).

Results of Data Collection—Discrete and Continuous Water-Quality Data

During the study period, discrete and continuous data were collected to describe in-stream conditions at Kankakee River at Shelby, Indiana. Discrete samples are manually collected at the gage site and then analyzed at a laboratory. Discrete samples describe the instantaneous abundance of in-stream constituents. In-situ water-quality monitors record continuous data every 15 minutes. The data represent river conditions during events, river extremes, and periods that field personnel are not at the site.

Discrete Data

Discrete concentration samples were collected throughout the range of hydrologic and seasonal conditions to represent each constituent's concentration at the Kankakee River at Shelby, Indiana. The regression models used 32 water samples that were collected and analyzed for suspended sediment, total nitrogen, and total phosphorus (table 1). No censored data (values below detection) were identified in this study.

Quality-control data were collected throughout the study to assess sampling variability and the potential for bias in the discrete sample results. Field blanks and replicate samples were collected each year and account for 10 percent of all samples collected. Field blanks help to identify potential contamination that may be introduced in the collection process. The contamination may be caused from contact with equipment or may be introduced during analysis. Field blanks resulted in few detections above the laboratory reporting limit, with all detections at least 80 percent below the median of the environmental population. Replicate samples

Table 1. Water-quality constituent data from discrete samples collected by the U.S. Geological Survey at the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000), December 2015 through May 2018.

[USGS, U.S. Geological Survey; *n*, sample size]

Water-quality constituent (milligram per liter)	USGS parameter code	*n*	Range	Median	Standard deviation
Discrete water-quality sample concentrations					
Suspended-sediment concentration	80154	32	18 to 195	40.5	38.49
Nitrogen, water, unfiltered, total as nitrogen	62855	32	1.41 to 4.32	2.3	0.74
Phosphorus, water, unfiltered, total as phosphorus	00665	32	0.045 to 0.308	0.109	0.05

were collected to understand the variability associated with collecting environmental data and to ensure sample results are reproducible. All replicate samples analyzed for nutrients and suspended sediment were within 10 percent of corresponding environmental samples.

Continuous Data

Water-quality monitors were deployed to continuously measure in-stream water properties. Continuous in-situ measurements are beneficial because they provide data that can be collected at night and during storms under conditions that can have major effects on concentrations and loads and during times when hydrologists may not be present to collect discrete samples. In this study, continuous water-quality data were used to provide a rich dataset for developing models. The models can be used to transform a discrete number of water-quality samples into thousands of samples, substantially expanding the range of observed water-quality concentrations (table 2). Results from the orthophosphate monitor are not given in this report because of the intermittent deployment of the monitor and insufficient quality of the data during the study period.

Minimally twice per year, an additional monitor was used to measure stream properties (water temperature, specific conductance, pH, dissolved oxygen, and turbidity) across the sampling transect to verify that the in-situ monitor location was representative of the average water-quality conditions (Wagner and others, 2006). Field results from 2016–18 at the Kankakee River at Shelby, Indiana, indicated that the continuous water-quality monitoring location was representative of the cross section and that the river was generally well mixed.

In-situ measurements of nutrients by optical and wet chemistry units in this study are not conducive for use in cross-section stream measurements. To assess instrument placement within the river, continuous, in-situ nitrate plus nitrite and orthophosphate measurements were compared to depth- and width-integrated discrete sample data collected during site visits. Additionally, following USGS protocols, continuous data were checked for bias to determine if the in-situ monitor over or under estimates instream constituents. (Pellerin and others, 2013). Continuous nutrient data collected in this study were representative of the cross section and were not systematically biased.

Regression Models

Discrete and continuous data that had been reviewed and approved were analyzed using ordinary least squares regression techniques to develop “surrogate” regression models. The models were used to estimate concentrations and loads of suspended sediment, total nitrogen, and total phosphorus as a function of selected continuously measured parameters.

Several linear and multiple linear regression models were evaluated prior to selection of the best fit models to estimate concentrations of suspended sediment, total nitrogen, and total phosphorus. Selected models used to compute each constituent are listed in table 3. In-depth model archive summaries are available for each constituent in a companion USGS data release (Lathrop, 2019).

Suspended-Sediment Concentration

The best fit suspended-sediment linear regression model used transformed variables to compute suspended-sediment concentration ($\log_{10}SSC$) from continuous turbidity ($\log_{10}TURB$) and specific conductance ($\log_{10}SC$) and demonstrated the best overall model diagnostics (table 3). The adjusted R^2 (0.92) indicated that the model predicts a large portion of the variance in the suspended-sediment concentration dataset. Root mean square error (0.0661), a measure of the accuracy of predictions made with the regression line, is low compared to other models. The PRESS statistic (0.151) is improved with the multiple linear regression model (table 3).

The explanatory variables used to compute suspended-sediment concentration are logical statistically and physically.

Table 2. Range of in-situ, continuous streamflow and water-quality values measured at the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000), December 2015 through May 2018.

[USGS, U.S. Geological Survey]

Physical property	USGS parameter code	Range, during discrete sample collection	Range, continuous data
Streamflow, in cubic feet per second	00060	676 to 6,330	433 to 6,380
Water temperature, in degrees Celsius	00010	1.2 to 26.1	-0.2 to 29.0
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	00095	472 to 663	359 to 693
pH, in standard units	00400	7.3 to 8.1	7.0 to 8.3
Dissolved oxygen, in milligrams per liter	00300	5.8 to 12.5	5.2 to 13.6
Turbidity, in formazin nephelometric units	63680	2.3 to 157	0.0 to 229
Nitrate plus nitrite, in milligrams per liter	99133	1.00 to 3.18	0.76 to 7.27

Table 3. Regression models for selected water-quality constituents at the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000), December 2015 through May 2018.

[*n*, sample size; RMSE, root mean square error; R^2, coefficient of determination; PRESS, predicted residual error sum of squares; *SSC*, suspended-sediment concentration; *TURB*, turbidity in formazin nephelometric units; *SC*, specific conductance in microsiemens per centimeter at 25 degrees Celsius; *TN*, total nitrogen; *NOx*, nitrate plus nitrite in milligrams per liter; *TP*, total phosphorus]

Constituent	Equation	Range of variable values used in model	*n*	RMSE (constituent units)	Adjusted R^2	PRESS statistic
Kankakee River at Shelby, Indiana, regression models						
Suspended-sediment concentration, in milligrams per liter	$\log_{10}SSC$=4.7904+(0.5665*$\log_{10}TURB$)+(-1.3957*$\log_{10}SC$)	*SSC*=18 to 195 *TURB*=2.3 to 157 *SC*=472 to 663	31	0.0661	0.92	0.151
Total nitrogen, water, unfiltered, total as nitrogen, in milligrams per liter	$\log_{10}TN$=(0.47*sqrt*NOx*)+(-0.000000553*SC^2)-0.0525)	*TN*=1.41 to 4.32 *NOx*=1.0 to 3.6 *SC*=472 to 663	32	0.0268	0.95	0.0248
Total phosphorus, water, unfiltered, total as phosphorus, in milligrams per liter	*TP*=0.02255*sqrt*TURB*+0.02047	*TP*=0.045 to 0.308 *TURB*=2.3 to 157	32	0.0177	0.89	0.0103

At the Kankakee River at Shelby, Indiana, suspended sediment positively correlates with in-situ turbidity. As the concentration of solids within the water column increases, the clarity of water often decreases. Specific conductance may reflect the sources of the water at different flows; for example, groundwater, shallow subsurface flow, surface runoff, and subsurface drainage. Differences in subbasin contribution also might be represented by specific conductance.

Additional transformations and explanatory variables were evaluated to compute suspended-sediment concentration. Streamflow alone did not explain enough of the variance of the dataset in a simple linear regression model and was not significant in multiple linear regression models. Exploratory statistics indicated that transformed turbidity (sqrt*TURB*) in a simple linear regression model might be used to compute suspended-sediment concentration, but diagnostic plots of model residuals as a function of time and streamflow were improved when specific conductance was added as an additional explanatory variable.

Total Nitrogen

The best fit total nitrogen linear regression model uses transformed variables to compute total nitrogen ($\log_{10}TN$) from continuous nitrate plus nitrite (sqrt*NOx*) and specific conductance (SC^2) (table 3). The model has a high adjusted R^2 (0.95), low root mean square error (0.0268) and low PRESS statistic (0.0248) (table 3). Model residuals graphed by season and year are improved from simple linear regression models. Measured compared to computed total nitrogen values indicate that the model provides good fit to the measured dataset.

The explanatory variables used to compute total nitrogen are logical statistically and physically. At the Kankakee River at Shelby, Indiana, continuous measurements of nitrate plus nitrite are appropriate as an explanatory variable because of the large composition of total nitrogen from nitrate and nitrite (71 percent) measured in discrete samples. Specific conductance is appropriate as an explanatory variable because it might reflect the source of the water from within the watershed and by a variety of pathways to the river.

Initially, exploratory statistics indicated that untransformed total nitrogen could be computed directly from continuous nitrate and nitrite. Further review of model residuals as a function of time and streamflow indicated that an additional variable(s) or transformation(s), or both, might help linearize the relation. The addition of specific conductance to the model and transformation of each of the variables improved the distributional characteristics of the data and resulted in model residuals that were more normally distributed.

Total Phosphorus

The best fit total phosphorus linear regression model computes untransformed total phosphorus from transformed continuous turbidity (sqrt*TURB*) and exhibits the best overall model diagnostics (table 3). The adjusted R^2 (0.89) suggests the model does a good job of predicting the variance in the total phosphorus dataset. The root mean square error (0.0177) is low and provides confidence regarding the accuracy of predictions made with the regression line. The PRESS statistic (0.0103), calculated in the leave-one-out cross validation process, indicates good model fit (table 3).

The explanatory variable used to compute total phosphorus is logical statistically and physically. Like suspended-sediment concentration and turbidity, particulate phosphorus often increases in rivers because of storm events, erosion, and overland flow (Ellison and Brett, 2006; Fraser and others, 1999). Particulate phosphorus often binds with other particulate matter such as suspended sediment. At the

Kankakee River at Shelby, Indiana, discrete samples analyzed for total phosphorus were largely composed of particulate phosphorus (79 percent). Diagnostic plots indicate total phosphorus is positively correlated with in-situ turbidity and increases as the clarity of water declines.

For the selected model, plots of model fit showed that transformed turbidity was a good explanatory variable of total phosphorus (Lathrop, 2019). Diagnostic plots of model residuals as a function of computed total phosphorus were normally distributed. However, residuals graphed against time and streamflow indicated that an additional parameter or transformation might improve model linearity. Additional parameters including streamflow, specific conductance, and time and seasonality coefficients were evaluated for improvement of model diagnostics with no success.

Constituent Load Models

At the Kankakee River at Shelby, Indiana, daily loads of suspended sediment, total nitrogen, and total phosphorus were computed for December 2015 through May 2018 as the product of daily mean regression model concentrations and daily mean streamflow. Rloadest models were used to compute daily loads of each constituent during gaps in regression model loads.

Rloadest Model Results

For Kankakee River at Shelby, Indiana, rloadest was used to compute daily loads of suspended sediment, total nitrogen, and total phosphorus from daily mean streamflow for the period January 1, 2016, through May 31, 2018. In rloadest, model 1 (of the nine predefined models), which uses the natural log of daily streamflow (Q) minus the natural log of a centered value of daily streamflow from the calibration dataset (ln$Q$), (Runkel and others, 2004) was the best fit model for suspended sediment ($R^2 = 0.76$, p-value <0.0001, $Bp = -2.843$, $PLR = 0.9716$, $E = 0.387$) and total phosphorus ($R^2 = 0.77$, p-value <0.0001, $Bp = -2.212$, $PLR = 0.9779$, $E = 0.5477$) (Bunch, 2019). Model 2 (Runkel and others, 2004), which uses ln(Q) and ln(Q)^2, was the best fit model for total nitrogen ($R^2 = 0.94$, p-value <0.0001, $Bp = -0.1586$, $PLR = 0.9984$, $E = 0.8596$) (Bunch, 2019). Residual plots and further supporting information on model development are available in the USGS data release by Bunch (2019).

Load Estimation Computations for Suspended Sediment, Total Nitrogen, and Total Phosphorus

Loads of suspended sediment, total nitrogen, and total phosphorus were computed for the Kankakee River at Shelby, Indiana, from January 2016 through May 2018. Daily loads

Table 4. Estimated annual loads and yields of suspended sediment, total nitrogen, and total phosphorus computed from daily loads of regression and rloadest models for the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000), from January 2016 through May 2018.

[—, no data; N, nitrogen; P, phosphorus]

Constituent	Period	Load (ton)	Load (ton), 90-percent prediction interval	Yield (ton per square mile per year)	Days estimated by rloadest models
Suspended sediment	1/1/2016–12/31/2016	105,000	74,900 to 147,000	58.8	42
	1/1/2017–12/31/2017	91,000	68,800 to 116,000	50.9	14
	1/1/2018–5/31/2018	77,800	46,800 to 129,000	—	69
	Total	274,000	190,000 to 392,000	—	125
Total nitrogen, as N	1/1/2016–12/31/2016	8,690	7,610 to 9,880	4.9	43
	1/1/2017–12/31/2017	8,890	7,950 to 9,850	5.0	9
	1/1/2018–5/31/2018	4,440	4,140 to 4,890	—	65
	Total	22,000	19,700 to 24,600	—	117
Total phosphorus, as P	1/1/2016–12/31/2016	265	233 to 311	0.15	43
	1/1/2017–12/31/2017	236	217 to 260	0.13	19
	1/1/2018–5/31/2018	167	122 to 236	—	71
	Total	669	572 to 808	—	133

were the product of regression model daily mean concentrations and daily mean streamflow. Rloadest models were used to compute daily loads of each constituent during periods that regression models were not computed (suspended sediment 14 percent, total nitrogen 13 percent, and total phosphorus 15 percent). Regression model computations had gaps when continuous explanatory variables(s) (1) exceeded USGS fouling or drift thresholds requiring deletion or (2) were not recorded because of in-situ instrument failure or removal. Following USGS guidelines, regression models also were not computed during periods when daily means of explanatory variables were 10 percent greater than the range of the regression model calibration dataset (U.S. Geological Survey, 2016c).

Monthly and annual loads of suspended sediment, total nitrogen, and total phosphorus were computed by combining regression (primary) and rloadest (secondary) model daily loads (fig. 2, table 4, respectively). Monthly 90 percent prediction intervals were computed to evaluate the uncertainty of estimated loads. Prediction intervals combine error introduced by regression and rloadest models in the proportion each model is utilized to compute the load estimate. Prediction intervals of combined load models were larger during periods with the greatest proportion of constituent loads computed by rloadest.

Suspended-Sediment Load

The total suspended-sediment load (SSL) for Kankakee River at Shelby, Indiana, from January 2016 through May 2018 was estimated at 274,000 tons. The annual SSL for 2016 and 2017 was 105,000 and 91,000 tons, respectively (table 4). The 2018 partial year SSL (January through May 2018) was 77,800 tons. Estimated monthly SSL ranged from 1,680 to 33,300 tons per month with a median SSL of 8,890 tons per month (fig. 2). Annual suspended-sediment yields for 2016 and 2017 were 58.8 and 50.9 t/mi^2/yr, respectively (table 4).

Total Nitrogen Load

The total nitrogen load (TNL) for Kankakee River at Shelby, Indiana, from January 2016 through May 2018 was estimated at 22,000 tons. The annual TNL for 2016 and 2017 was 8,690 and 8,890 tons, respectively. The 2018 partial year TNL (January through May 2018) was 4,440 tons (table 4). Estimated monthly TNL ranged from 188 to 1,310 tons per month with a median TNL of 773 tons per month (fig. 2). The annual total nitrogen yields for 2016 and 2017 were approximately 4.9 and 5.0 t/mi^2/yr, respectively (table 4).

Total Phosphorus Load

The total phosphorus load (TPL) for Kankakee River at Shelby, Indiana, from January 2016 through May 2018 was estimated at 669 tons. The annual TPL for 2016 and 2017 was 265 and 236 tons, respectively. The 2018 partial year TPL (January through May 2018) was 167 tons (table 4). Estimated monthly TPL ranged from 5.75 to 62.6 tons per month with a median TPL of 22.8 tons per month (fig. 2). The annual total phosphorus yields for 2016 and 2017 were 0.15 and 0.13 t/mi^2/yr, respectively (table 4).

Limitations

Discrete and continuous data collected at Kankakee River at Shelby, Indiana, were collected throughout a range of hydrologic and seasonal conditions and are assumed to be independent observations. Samples that are collected too closely in time may be serial correlated, which is the correlation of a signal with a delayed copy of itself as a function of delay (Helsel and Hirsch, 2002). Serial correlations among residuals can bias model diagnostics that assume independent observations (for example, PRESS and prediction interval). The sampling frequency was weekly or longer. On large rivers, the rise or fall in streamflow or a water-quality concentration caused by an event may be 1 week or more, which could be a source for serial correlation within the data for samples collected on a weekly basis.

The regression models published in this report (table 3) were computed based on concurrent continuous and discrete water-quality measurements at the Kankakee River at Shelby, Indiana. Although site visits were scheduled to cover the range of seasonal conditions and were adjusted to capture observed peaks in water-quality properties, the entire range of in-situ continuous measurements is not represented by discrete samples. Extrapolation, use of regression models outside the range of the model calibration data, should be restricted to no more than 10 percent of the maximum or minimum continuous value(s) used in development of each model (table 2).

The rloadest models were calibrated with discrete concentration data and daily mean streamflow. When explanatory variables exceeded the range of the calibration dataset, the regression equations were extrapolated, which may result in faulty estimates and invalid confidence and prediction intervals.

Summary

The Kankakee River in northern Indiana flows through the area once known as the Grand Marsh. Beginning in the 1860s, anthropogenic changes were made to the river that increased agricultural production within Indiana but also resulted in downstream flooding and transport of nutrients and sediment. In 2015, the gaging station Kankakee River at Shelby, Indiana, was upgraded in cooperation with the Indiana Department of Environmental Management to provide real-time estimates of concentrations and loads of suspended sediment, total nitrogen, and total phosphorus. Site-specific models were developed using linear regression by relating

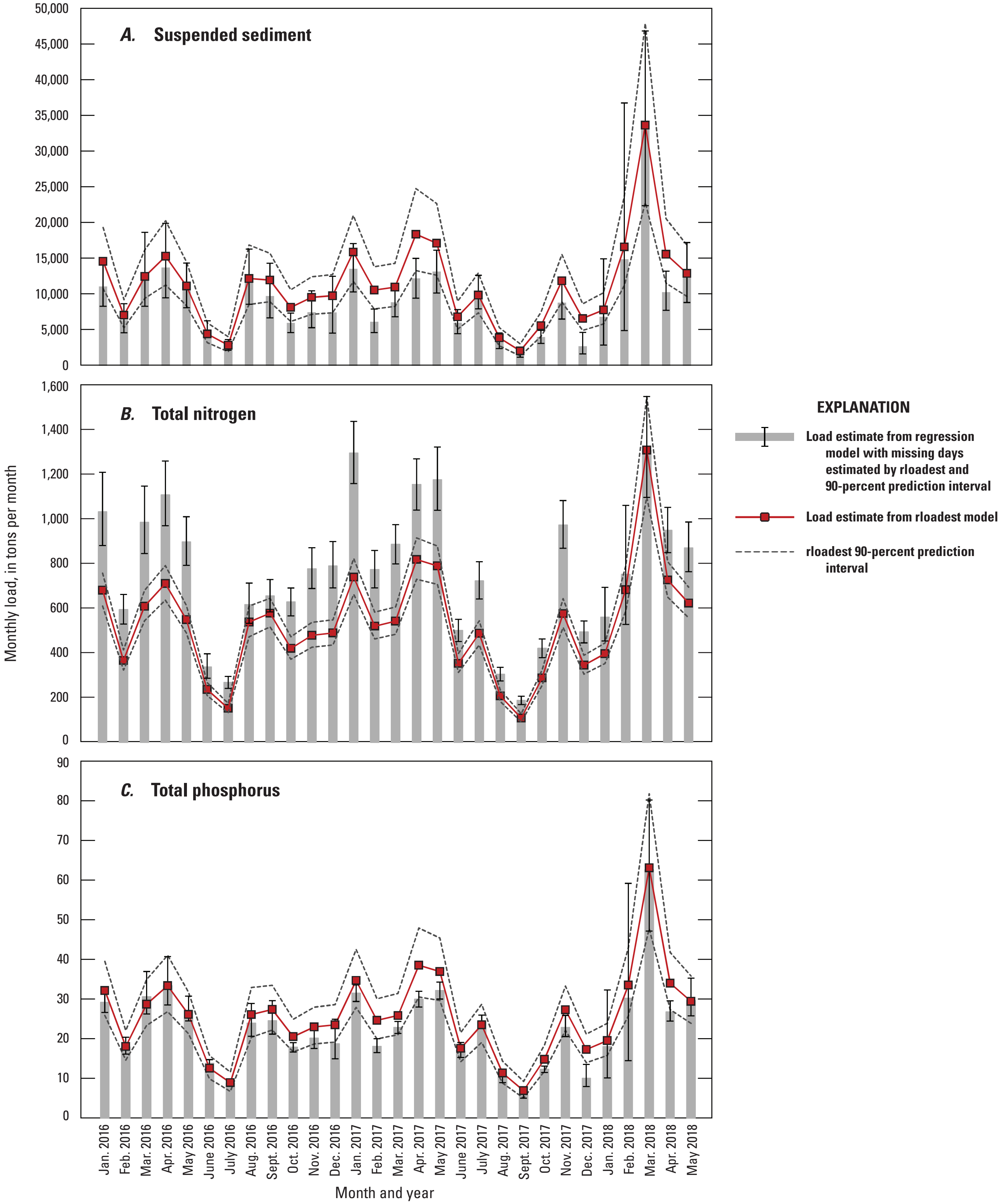

Figure 2. Estimated monthly loads at the gaging station Kankakee River at Shelby, Indiana (U.S. Geological Survey station 05518000), for January 2016 through May 2018 computed from combined regression and rloadest models with monthly 90 percent prediction intervals. *A*, suspended sediment; *B*, total nitrogen; and *C*, total phosphorus. Monthly load estimates from rloadest models are included for reference.

discrete and continuous water-quality data collected from December 2015 through May 2018. Developed regression models indicated strong correlation between turbidity and specific conductance with suspended-sediment concentration (adjusted R^2 = 0.92, PRESS = 0.151), nitrate plus nitrite and specific conductance with total nitrogen (adjusted R^2 = 0.95, PRESS = 0.0248), and turbidity with total phosphorus (adjusted R^2 = 0.89, PRESS = 0.0103).

Daily loads of suspended sediment, total nitrogen, and total phosphorus were computed as the product of daily mean regression model concentrations and daily mean streamflow. Rloadest computed loads were used to fill gaps when regression model loads were not computed. For 2016 and 2017, the estimated annual suspended-sediment loads were 105,000 and 91,000 tons; estimated annual total nitrogen loads were 8,690 and 8,890 tons; and estimated annual total phosphorus loads were 265 and 236 tons, respectively. Development of regression models for the computation of constituent concentrations and loads will inform water-resource managers and improve understanding of the transport of suspended sediment, total nitrogen, and total phosphorus in the Kankakee River Basin.

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