Prepared in cooperation with the Indiana Department of Environmental Management

Hydrologic and Ecological Investigations in the School Branch Watershed, Hendricks County, Indiana—Water Years 2016–2018

Scientific Investigations Report 2021–5061

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

Front cover. Background: U.S. Geological Survey hydrologist, Dawn McCausland, services the supergage at School Branch at County Road 750 North at Brownsburg, Indiana, photograph by Megan Shoda, April 26, 2016, U.S. Geological Survey. Top: Supergage at School Branch at County Road 750 North at Brownsburg, Indiana, photograph by Timothy Lathrop, August 18, 2015, formerly of U.S. Geological Survey. Bottom: Bluegill caught during electrofishing sampling from School Branch, photograph by Aubrey Bunch, September 1, 2016, U.S. Geological Survey.

Back cover. Left: Groundwater sampling setup at School Branch, photograph by Dawn McCausland, March 30, 2016, U.S. Geological Survey. Right: School Branch upstream of County Road 750 North, photograph by Megan Shoda, July 1, 2015, U.S. Geological Survey.

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By Aubrey R. Bunch, Dawn R. McCausland, and E. Randall Bayless

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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	
gallon (gal)	3.785	liter (L)
	Mass	
ton, short (2,000 lb)	0.9072	metric ton (t)

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

$$°F = (1.8 \times °C) + 32.$$

Datum

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

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

Supplemental Information

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 2016 was from October 1, 2015, to September 30, 2016.

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

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

Milligrams per liter and micrograms per liter are units expressing the concentration of chemical compounds in solution as weight of solute (milligrams or micrograms) per unit volume (liter) of water.

Turbidity units are given in Formazin Nephelometric Units (FNU).

Annual and monthly loads of constituents are given as tons.

Annual yields of constituents are given in pounds per acre.

Isotope Unit Explanations

Per mil ($^{0}/_{00}$): A unit expressing the ratio of stable-isotope abundances of an element in a sample to those of a standard material. Per mil units are equivalent to parts per thousand. Stable-isotope ratios are computed as follows (Kendall, 1998):

$\delta X=\{(R_{sample} - R_{standard})/R_{standard}\} \times 1{,}000$

where

δ is the “delta” notation,

X is the heavier stable isotope, and

R is ratio of the heavier, less abundant isotope to the lighter, stable isotope in a sample or standard.

The δ values for stable-isotope ratios discussed in this report are referenced to the following standard materials.

Element	R	Standard identity and reference
Hydrogen	Hydrogen-2/hydrogen-1 (δD)	Vienna Standard Mean Ocean Water and Standard Light Antarctic Precipitation (Révész and Coplen, 2008a)
Oxygen	Oxygen-18/oxygen-16 ($\delta^{18}O$)	Vienna Standard Mean Ocean Water and Standard Light Antarctic Precipitation (Révész and Coplen, 2008b)
Nitrogen-nitrate	Nitrogen-15/nitrogen-14 ($\delta^{15}N$-NO_3)	USGS34 potassium nitrate (KNO_3) and USGS32 KNO_3 (Coplen and others, 2012)

Abbreviations

BMPs	best management practices
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
EPT/C	Ephemeroptera, Plecoptera, and Trichoptera to Chironomidae ratio
EWI	equal-width increment
FBI	Family Biotic Index
GOES	Geostationary Operational Environmental Satellite
IDEM	Indiana Department of Environmental Management
IGWS	Indiana Geological and Water Survey
LRL	laboratory reporting level
MTV	mean tolerance value
N	Nitrogen
NOx	nitrate plus nitrite
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
orthoP	orthophosphate
POCIS	polar organic chemical integrative samplers
RPD	relative percent difference
TN	total nitrogen
TNL	total nitrogen load
TP	total phosphorus
USGS	U.S. Geological Survey

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By Aubrey R. Bunch, Dawn R. McCausland, and E. Randall Bayless

Abstract

School Branch in Hendricks County in central Indiana, is a small stream with a variety of agricultural and suburban land uses that drains into the Eagle Creek Reservoir, a major source of drinking water for Indianapolis, Indiana. The School Branch watershed has become the focus of a collaborative partnership of Federal, State, and local agencies; a university research center; and agricultural producers to understand the effects of land use and management practices on water quality and water quantity in the watershed. The U.S. Geological Survey, in cooperation with the Indiana Department of Environmental Management, contributed to the School Branch partnership with the operation of three streamgages (03353415 School Branch at Maloney Road near Brownsburg, Indiana; 03353420 School Branch at County Road 750 North at Brownsburg, Indiana; and 03353430 School Branch at Noble Drive at Brownsburg, Indiana) and the operation of a continuous water-quality gage (also known as a supergage) at County Road 750 North that measured dissolved oxygen, pH, temperature, specific conductance, turbidity, nitrate, and orthophosphate. Additional efforts included the use of passive samplers to identify wastewater indicators; assessment of fish and macroinvertebrate communities and stream habitat to identify ecological impairment; sampling for nutrients and sediment to estimate loads; and using major ions, stable isotopes and nested groundwater monitoring wells at County Road 750 North to determine hydrologic connectivity between the groundwater and surface water. The objectives of this study were to collect surface and groundwater data to analyze the hydrology and water quality within the watershed. Total nitrogen yields were highest at the upstream site, Maloney Road, and indicated a mixture of nitrogen sources in the watershed. Differences found in total nitrogen loading patterns throughout the watershed may be linked to differences in hydrology and land-use management from site to site. The groundwater and surface water were shown to be highly connected, and except for some low-flow periods, the water was flowing from groundwater to the stream for most of the study period. Fish and macroinvertebrate communities show improvement from upstream to downstream, with increases in diversity, richness, and species sensitive to poor water quality and habitat. These increases were most likely due to improved habitat quality at the downstream station.

Introduction

The School Branch watershed is a small watershed with a variety of agricultural and suburban land uses, typical of the row-crop agriculture found in the Midwest. Some agricultural areas of the watershed have been managed under conservation cropping practices for many years, whereas other areas have been managed under conventional cropping practices. Suburban land use in the watershed is increasing as agricultural land is converted to residential subdivisions. This makes the watershed an ideal location for implementation of scientific studies to better understand how land-use practices may be influencing water quality and quantity.

Land use can have a large influence on water quality and quantity in aquatic systems. Hydrology is often the main driver of nutrient loss from the land into streams and makes understanding the hydrology of a watershed vital to understanding its water quality (Williams and others, 2014). Some land-use practices can alter the hydrology in a watershed. Like many Midwestern States, Indiana is dominated by agricultural land use with pockets of developed areas. In Indiana, it is common for agricultural fields to be drained by subsurface drainage tiles, which are used to lower the water table where the soils would naturally be wet for parts of or all the year (Zucker and Brown, 1998). Agricultural fields drained by subsurface tiles can have reduced surface runoff due to increased water infiltration from rain events but have decreased water retention in soils as the water moves through the soil into the tiles and then to the waterway (Skaggs and others, 1994; King and others, 2014). Subsurface drainage in agricultural fields can change groundwater recharge and influence the base flow of the stream.

As hydrology changes with land use, the amount of nutrients, sediment, or other anthropogenic contaminants entering waterways is also altered. Agricultural land has been linked to increases in nutrients and sediment in adjacent streams

(Munn and others, 2018; Schmidt and others, 2019; Zeiger and Hubbart, 2019). To alleviate the effects of agricultural land use on freshwater systems, some agricultural producers have implemented conservation cropping practices such as no-till farming, use of cover crops when cash crops are not on the field, maintenance of riparian buffer zones, and precision application of nutrients. These best management practices (BMPs) have been shown to improve soil health by increasing organic matter and keeping sediment and nutrients in the field and out of waterways. Many BMPs are beneficial to agricultural producers as they have been shown to reduce erosion of soils and loss of farmland, keep nutrients such as nitrogen in the field and available to crops, and increase water infiltration into soils (Fuglie, 1999; Coughenour, 2003; Bergtold and others, 2012; Long and others, 2013; Carlisle, 2016). Specifically, cover crops improve soil health and soil productivity by sequestering carbon and nutrients and provide habitat and food for organisms living in the soil, such as bacteria, fungus, and invertebrates. Cover crops can also help reduce soil erosion. Many farmers who use cover crops have reported that the soil health benefits of cover crops have also been linked to increases in yields of corn, soybeans, and wheat the following growing season (Conservation Technology Information Center, 2017). Conservation tillage, which can range from strip tillage to strict no-till practices, reduces soil erosion and soil compaction and can improve soil health by reducing the disturbance of the soil ecosystem. Besides being beneficial to farmers, keeping nutrients and sediment out of waterways helps aquatic ecosystems, because excess nutrients can lead to eutrophication and excess sedimentation from eroding soils can cause loss of habitat and harm to some aquatic species. Sedimentation can result in the loss of heterogeneity in streams due to fine sediment filling in pools and embedding gravel and cobble substrate (Munn and others, 2018; Zeiger and Hubbart, 2019).

Increases in human population and urban development can also influence water quality and hydrology in a watershed. Higher densities of impervious surfaces such as roads, sidewalks, and roofs associated with urban development in a watershed can change hydrologic dynamics by decreasing water infiltration to soils and reducing water retention capacity in the basin, leading to increased runoff to waterways during storm events (Brabec and others, 2002, Sun and Lockaby, 2012). This can alter the timing and magnitude of runoff events (O'Driscoll and others, 2010; Caldwell and others, 2012). Urbanization can alter ecosystem processes, which causes a degradation of water quality (Sun and Caldwell, 2015). Conversion of land use from forested to developed can increase sediment and nutrient concentrations in surface water. Additionally, urban land use has been linked to increases in heavy metals, emerging contaminants, or wastewater indicators such as pharmaceuticals, and pathogenic microorganisms such as *Escherichia coli* (*E. coli*) (U.S. Geological Survey [USGS], 1999).

Changes to water quality due to agricultural and urban land uses are not just a local problem: they can have effects far downstream. Nutrients and sediment loaded into freshwater systems have been linked to hypoxic dead zones in oceans near the mouth of large rivers (Diaz and Rosenberg, 2008). Hypoxia occurs when dissolved oxygen (DO) concentration in the water falls to 2 milligrams per liter (mg/L) or lower. Most of Indiana is part of the Mississippi River Basin, which drains into the northern Gulf of Mexico. Most summers there is a large dead zone in the northern Gulf of Mexico linked to nutrient and sediment runoff from upstream systems in the Mississippi River Basin (U.S. Environmental Protection Agency [EPA], 2020). This highlights the importance of understanding water quality and hydrology at a local level to benefit downstream systems.

The School Branch watershed has become the focus of a collaborative partnership of Federal, State, and local agencies; a university research center; and agricultural producers to understand the effects of land use and management practices on water quality and water quantity in the watershed. The Natural Resources Conservation Service (NRCS) and the EPA have focused part of their National Water Quality Initiative efforts on the School Branch watershed. The USGS, in collaboration with the Indiana Department of Environmental Management (IDEM), Section 319 program, are working to accomplish National Water Quality Initiative nonpoint-source water-pollution assessment activities in the School Branch watershed. This report focuses on the IDEM and USGS portion of the School Branch partnership. The USGS contributions (in collaboration with IDEM) include the operation of three streamgages and a continuous water-quality gage (DO, pH, temperature, specific conductance, turbidity, nitrate, and orthophosphate [orthoP]), deployment of passive samplers for wastewater indicators, assessment of ecological communities, sampling for stable isotopes, and monitoring of two sets (deep and shallow) of nested groundwater monitoring wells.

Purpose and Scope

The purpose of this report is to provide a summary and analysis of the first 3 years of data collected in the School Branch watershed of Hendricks County, Indiana, by the USGS in collaboration with IDEM. These data were collected during water years 2016, 2017, and 2018 (a water year is defined as the 12-month period beginning October 1 and continuing through September 30 of the following year and is designated by the calendar year in which it ends). Data include streamflow, stream and groundwater levels, surface-water and groundwater quality, continuous water-quality, wastewater indicators from passive samplers, and ecological data. These data provide baseline information on School Branch and can be used to inform others performing research in the watershed.

These data can also be used to evaluate the effects of changing land use and land-management practices with time on water quality and quantity in the watershed.

Study Area

School Branch is a roughly 5,200-acre watershed in Hendricks County, central Indiana, west of the State capital, Indianapolis (fig. 1). School Branch merges with Eagle Creek in the Eagle Creek Reservoir, a source of drinking water for Indianapolis. The headwater stream originates in Hendricks County, Indiana, and flows through mostly agricultural land to County Road 700 North (CR700N), where developed land use dominates until the stream flows into the Eagle Creek Reservoir near Raceway Road (fig. 2).

Water-quality and ecological samples were collected at three USGS streamgages along School Branch: 03353415 School Branch at Maloney Road near Brownsburg, Indiana (henceforth referred to as Maloney Road [Rd.]); 03353420 School Branch at County Road 750 North at Brownsburg, Indiana (henceforth referred to as CR750N); and 03353430 School Branch at Noble Drive at Brownsburg, Indiana (henceforth referred to as Noble Drive [Dr.]) (fig. 1; table 1). The station at CR750N includes a continuous water-quality gage (also known as a supergage). In addition to the surface-water sites, two sets of nested groundwater wells on each side of the stream just upstream from CR750N (fig. 1, table 1) were used to monitor groundwater levels and water temperature.

The land-use percentages of the contributing basins were similar among the three surface-water sampling sites for all 3 years of the study where agricultural land use was dominant (83 to 88 percent), followed by developed land (9 to 14 percent) (table 2). These general land use categories did not change by more than 1 percent between 2016 and 2018, though the types of agriculture did vary from year to year (fig. 2, table 2, U.S. Department of Agriculture, 2016, 2017, 2018). The crop type varied by year in many fields, as some farmers practiced crop rotation, where different crops are grown in the same area in a specific order. Generally, farmers rotate between corn and soybeans, though some farmers in the School Branch watershed have added winter wheat into the rotation as well. Agricultural land-management practices varied in the watershed, from conventional farming practices to practices that have less disruption to the soil such as strip till, no till, and the use of cover crops when cash crops were not on the field. These nonconventional practices aim to conserve the soil structure and are often referred to as conservation cropping or BMPs. The NRCS performed an annual spring ground survey of land-management practices in the School Branch watershed. This survey showed no-till practices were 25, 23, and 39 percent for 2016, 2017, and 2018, respectively, for the watershed upstream from Maloney Rd. and 48, 43, and 60 percent for 2016, 2017, and 2018, respectively, for the watershed upstream from CR750N (S. Zezula, NRCS, written commun., March 2020). Implementation of BMPs was highest for land draining between Maloney Rd. and CR750N; in some of these fields, conservation cropping has been implemented for 5 to 10 years before the study.

Approach and Methods for Data Collection and Analysis

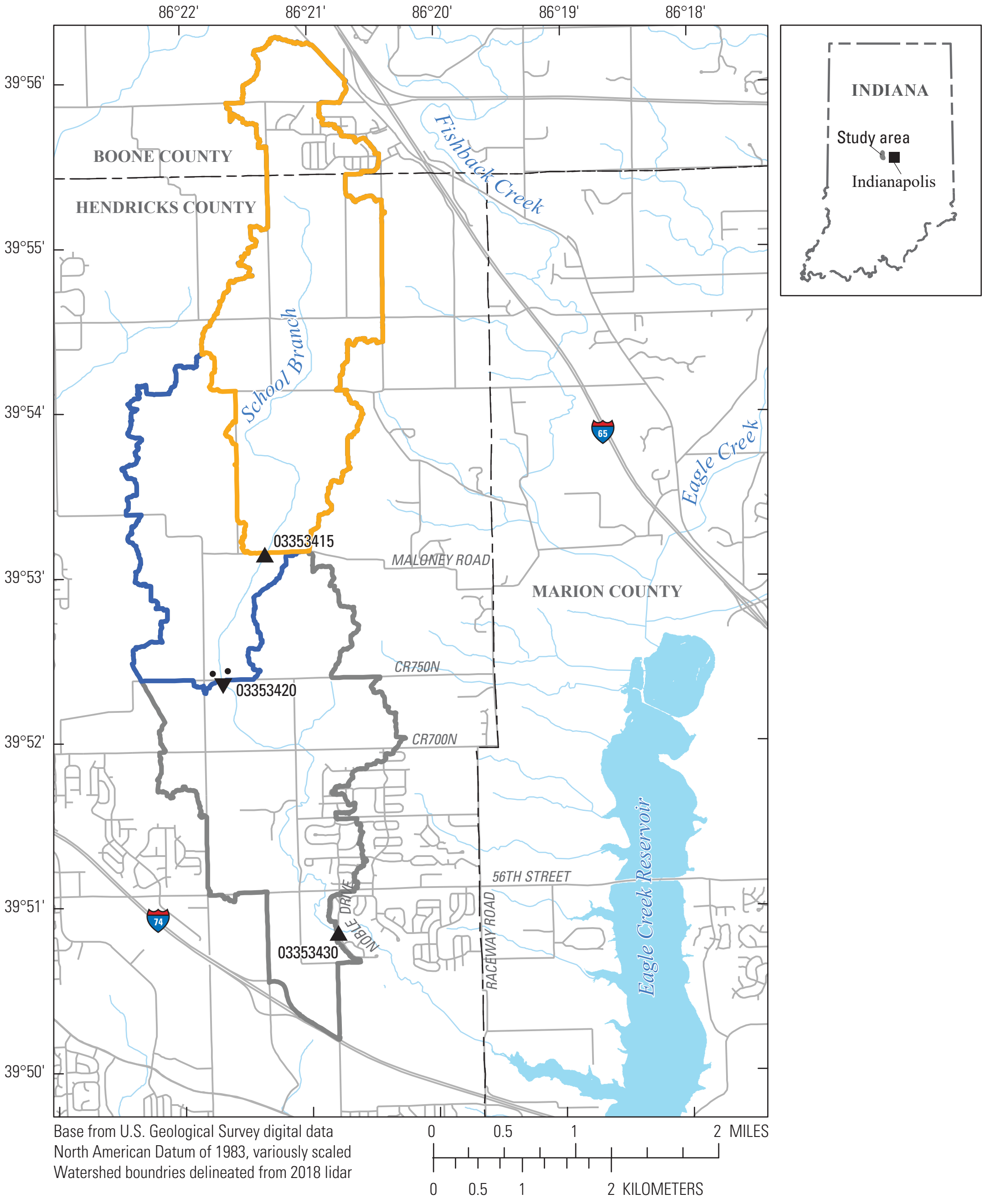
The following sections describe the methods used to collect and interpret data to evaluate the water quality and quantity of the School Branch watershed. Discussed are the methods used to collect surface-water and groundwater hydrology data, field and laboratory methods for water-quality samples and passive samplers, methods for ecological community and habitat data collection, and analytical methods used to interpret the data. Quality assurance procedures are also outlined.

Surface-Water Gage Height

Water stage (henceforth referred to as gage height) was recorded every 15 minutes at three streamgages: Maloney Rd. (03353415); CR750N (03353420); and Noble Dr (03343530) (fig. 1, table 1). Gage height data were transmitted hourly by Geostationary Operational Environmental Satellite (GOES) transmitters to the USGS National Water Information System (NWIS) database (USGS, 2019). Discharge measurements were made periodically at various gage heights to build and verify a discharge rating curve unique to each site (Turnipseed and Sauer, 2010). The rating curves were used to compute continuous discharge for the 15-minute gage height readings from each streamgage (Rantz and others, 1982a, 1982b; Kennedy, 1983, 1984; Turnipseed and Sauer, 2010).

Groundwater Monitoring Wells

One shallow (8.30- and 12.5-ft depth) and one deep well (19.7- and 25.2-ft depth) were installed on each side adjacent to School Branch, approximately 200 feet (ft) upstream (north) from streamgage CR750N (figs. 1 and 3, table 3). The wells were installed by IDEM and USGS using direct push technology to create the 3.25-inch (in.) diameter boreholes. Well casings and screens were constructed using 2-in. inner diameter polyvinyl chloride pipes. A polyvinyl chloride well screen with a 0.010-in. slot size was attached to the bottom of the casing. Screen length for the two shallower wells was 2.5 ft and for the deeper two wells was 5.0 ft. Fine gravel was used to form a gravel pack and seal the borehole wall from the well screen. Bentonite chips were used to fill the annular space between the borehole wall and well casing from 3 ft above the well screen to 3 ft below land surface. The annular space



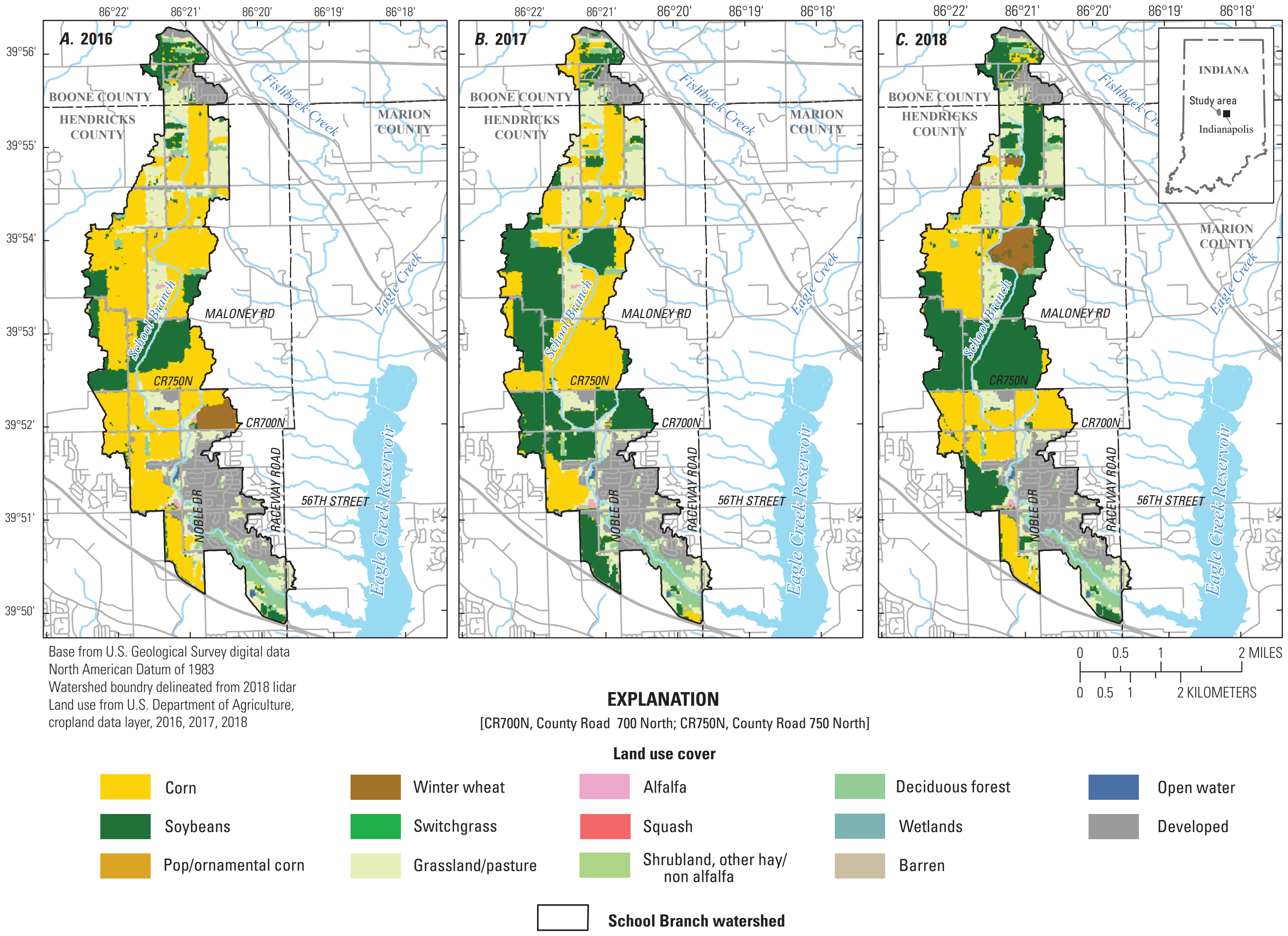
Base from U.S. Geological Survey digital data
North American Datum of 1983, variously scaled
Watershed boundries delineated from 2018 lidar

EXPLANATION

[CR700N, County Road 700 North; CR750N, County Road 750 North]

▭	**Watershed for School Branch at Maloney Road near Brownsburg, Indiana, U.S. Geological Survey streamgage 03353415**
▭	**Watershed for School Branch at County Road 750 North at Brownsburg, Indiana, U.S. Geological Survey streamgage 03353420**
▭	**Watershed for School Branch at Noble Drive at Brownsburg, Indiana, U.S. Geological Survey streamgage 03353430**
•	**U.S. Geological Survey nested groundwater well**
03353430 ▲	**U.S. Geological Survey streamgage with station identifier**
03353420 ▼	**U.S. Geological Survey streamgage and continuous water-quality monitors with station identifier**

Figure 1. Map showing sampling locations with watershed boundaries for the School Branch watershed in Hendricks County, Indiana, water years 2016 through 2018.



Base from U.S. Geological Survey digital data
North American Datum of 1983
Watershed boundry delineated from 2018 lidar
Land use from U.S. Department of Agriculture, cropland data layer, 2016, 2017, 2018

Figure 2. Maps showing School Branch watershed in Hendricks County, Indiana, with *A*, 2016; *B*, 2017; and *C*, 2018 land-use coverages (U.S. Department of Agriculture, 2016, 2017, 2018).

Table 1. Sampling locations for the School Branch project in Hendricks County, Indiana, water years 2016 through 2018.

[USGS, U.S. Geological Survey; IN, Indiana; Rd., Road; CR750N, County Road 750 North; Dr., Drive; n.a. not applicable; NAWQA, National Water-Quality Assessment; Ag, agricultural; TP26, till plain 26; DNW, deep northwest; SNW, shallow northwest; DNE, deep northeast; SNE, shallow northeast]

Site type	USGS station name	USGS station number	Drainage area, in square miles	Short name
Streamgage	School Branch at Maloney Road near Brownsburg, IN	03353415	3.39	Maloney Rd.
Streamgage and continuous water-quality monitors	School Branch at CR750N at Brownsburg, IN	03353420	4.7	CR750N
Streamgage	School Branch at Noble Drive at Brownsburg, IN	03353430	7.38	Noble Dr.
Groundwater well	NAWQA Ag Well TP26 DNW near Brownsburg, IN	395223086214202	n.a.	DNW
Groundwater well	USGS well School Branch SNW at Brownsburg, IN	395223086214201	n.a.	SNW
Groundwater well	USGS well School Branch DNE at Brownsburg, IN	395223086214204	n.a.	DNE
Groundwater well	USGS well School Branch SNE at Brownsburg, IN	395223086214203	n.a.	SNE

Table 2. Land use in the School Branch watershed for the watershed of each sampling station in Hendricks County, Indiana. Percentage of land use calculated for each water year, 2016 through 2018, using the U.S. Department of Agriculture Cropland Data Layer (U.S. Department of Agriculture, 2016, 2017, 2018). Watershed delineated from 2018 using light detection and ranging.

[USGS, U.S. Geological Survey; Rd., Road; CR750N, County Road 750 North; Dr., Drive]

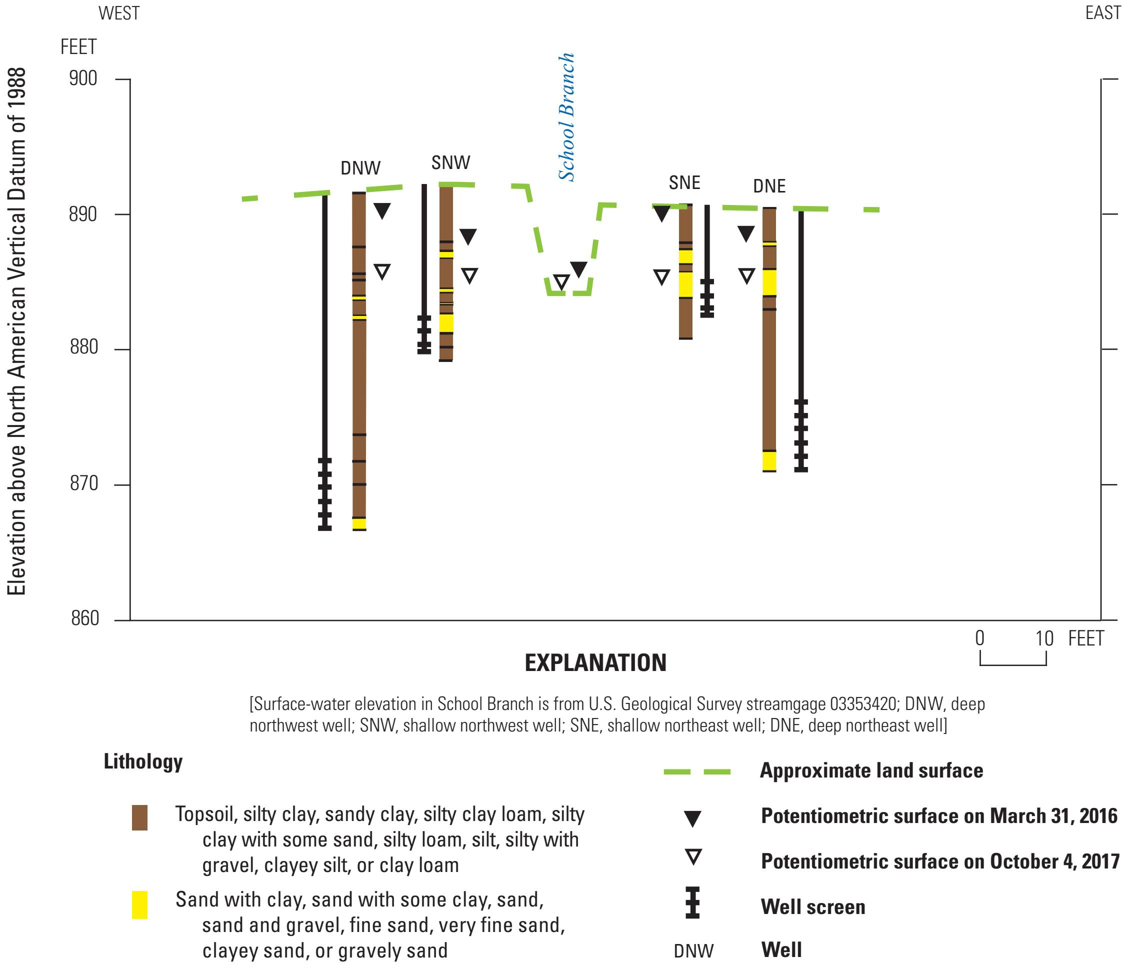
Site	Year	Percent land use type					
		Agricultural			Developed	Forest and wetland	Other
		Corn	Soybeans	Other agriculture			
Maloney Rd.	2016	43	12	29	12	3.9	0.03
	2017	39	17	29	12	3.9	0.02
	2018	11	34	39	12	3.9	0.07
CR750N	2016	49	19	20	9	2.9	0.06
	2017	38	30	19	9	2.8	0.01
	2018	22	40	26	9	2.9	0.06
Noble Dr.	2016	50	14	19	14	2.8	0.21
	2017	33	33	17	14	2.7	0.20
	2018	28	35	21	14	2.7	0.24

between the borehole wall and well casing from 3 ft below land surface to land surface was filled with concrete, and a 6-in. thick concrete pad was poured at land surface. A locking, steel protector was embedded in the concrete and used to protect the casing exposed above land surface.

The monitoring wells were each equipped with a submersible pressure transducer to record water level and a thermistor to record water temperature. Water level and temperature in each well were measured every 15 minutes and transmitted hourly by GOES to the USGS NWIS database. Water-level data were recorded in feet below a known land surface and verified against a calibrated water-level tape. Corrections to the recorded water-level data were done following USGS methods when needed (Cunningham and Schalk, 2011). Water-level data were converted to water-level elevation using the North American Vertical Datum of 1988 as reference.

***A.* Photograph of nested groundwater wells and School Branch.**

***B.* Generalized cross section of nested groundwater wells.**



[Surface-water elevation in School Branch is from U.S. Geological Survey streamgage 03353420; DNW, deep northwest well; SNW, shallow northwest well; SNE, shallow northeast well; DNE, deep northeast well]

Figure 3. Photograph showing *A*, four nested groundwater wells adjacent to School Branch, June 15, 2016, after a storm event and a generalized cross section showing *B*, the nested groundwater wells and School Branch, Hendricks County, Indiana, water years 2016 through 2018.

Table 3. Details for the nested groundwater wells adjacent to School Branch in Hendricks County, Indiana, water years 2016 through 2018.

[ft, foot; NAVD 88, North American Vertical Datum of 1988; DNW, deep northwest; SNW, shallow northwest; DNE, deep northeast; SNE, shallow northeast]

Site	Well depth below land surface, in ft	Screen length, in ft	Land-surface elevation above NAVD 88, in ft	Aquifer material, in screened interval
DNW	25.5	5	891.72	gravel, fine sand, silty clay
SNW	12.5	2.5	892.14	sand, sandy clay
DNE	19.7	5	890.56	fine sand, silty clay
SNE	8.30	2.5	890.39	gravel, sand

Discrete Water-Quality Samples

Discrete water-quality samples were collected at all three surface-water stations and the deep northwest (DNW) groundwater well. Samples were collected using techniques and methods described in the USGS “National Field Manual for the Collection of Water-Quality Data” (USGS, variously dated). Routine samples for nutrients and suspended sediment in surface water were collected more frequently than the additional samples for major ions, stable isotopes, and alkalinity. Samples for major ions, stable isotopes, and alkalinity were collected three times per year, resulting in nine total samples during the study period. Based on study objectives, different numbers of routine samples were collected at each site.

Surface Water

Water-quality samples for nutrients and suspended sediment were collected throughout the entire water year at the three surface-water stations. Samples at Maloney Rd. and Noble Dr. were collected monthly through January 2018 by IDEM personnel with chain-of-custody documentation passed to USGS for preservation and analysis. Beginning February 2018, the USGS began sampling Maloney Rd., and IDEM continued to sample Noble Dr. Samples at CR750N were collected by USGS personnel throughout the entire study period.

Samples were collected by wading in the stream or from a bridge during higher flows. When site conditions allowed, isokinetic samples were collected using the equal-width increment (EWI) method using a DH–81 hand-held depth-integrated suspended sediment and water-quality sampler during wadable conditions, or a DH–95 and a bridge crane when flow was too high to wade (USGS, variously dated). The EWI method divides the cross section of the stream into 10 equal increments. Samples were collected at the center of each increment by lowering and raising the sampler through the entire water column. This makes the sample representative of the entire cross section and water column, resulting in discharge-weighted samples (USGS, variously dated). Each vertical sample was poured into a composite container and then split into separate bottles for unfiltered, whole-water constituents and filtered constituents less than 0.45 micron. Because School Branch is a small stream, variability in site conditions often required alternate methods, primarily during low flow. Alternate methods included nonisokinetic multiple verticals or grab samples. Nonisokinetic multiple verticals were collected at 3–5 increments across the width of the stream. When the depth and width of flowing water was not enough to collect EWI or multiple vertical samples, grab samples were collected from a single point in the center of flow. All samples were collected near the surface-water gages to obtain concurrent relations between constituents and discharge.

Additional surface-water samples for major ions and stable isotopes were collected at all three sites by the USGS three times per year at different hydrologic conditions during the growing season (March through July). Alkalinity titrations in the field were not done during water year 2016 but were added for all samples in water years 2017 and 2018. Alkalinity titrations, filtration, and preservation of samples were performed in the field following USGS field methods (USGS, variously dated), and samples were sent to the appropriate laboratories for analysis as shown in table 4.

Groundwater

Water samples from the DNW groundwater well were collected by an electric submersible pump using USGS methods (USGS, variously dated). After purging a minimum of three well volumes, water samples for nutrients, major ions, and stable isotopes were collected as water was pumped from the well. These samples were collected during the growing season (March through July) with the surface-water samples (plus or minus 1 day). Samples for nutrients, major ions, and stable isotopes were collected all 3 water years. Alkalinity titrations were not done for water year 2016 but were added for all samples in water years 2017 and 2018. Alkalinity titrations and filtration and preservation of samples were performed in the field, and samples were sent to the appropriate laboratories for analysis.

Laboratory Analysis

Discrete samples were analyzed for ammonia as nitrogen (N), nitrite as N, nitrate plus nitrite (NOx) as N, total nitrogen (TN) as N, orthophosphate (orthoP) as phosphorus, and total phosphorus (TP) as phosphorus. Discrete samples were also analyzed for the following major ions: calcium, chloride, fluoride, iron, magnesium, manganese, potassium, silica, sodium, and sulfate. After collection and processing, the nutrient and major ion samples were placed on ice and shipped overnight to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado. Stable isotope samples were stored until the end of each water year and then shipped to the USGS Reston Stable Isotope Laboratory in Reston, Virginia. The stable isotope samples were analyzed for delta (δ) hydrogen-2 (deuterium)/hydrogen-1 (protium) ($^{2}H/^{1}H$), δ nitrogen-15/nitrogen-14 of nitrate ($^{15}N/^{14}N$), and δ oxygen-18/oxygen-16 ($^{18}O/^{16}O$). Suspended-sediment samples were stored and transported periodically to the USGS Kentucky Sediment Laboratory in Louisville, Kentucky. Samples were analyzed for suspended-sediment concentration and sand/fines composition. The NWQL, the USGS Reston Stable Isotope Laboratory, and the Kentucky Sediment Laboratory store analytical results in the USGS NWIS database (U.S. Geological Survey, 2019), and data can be accessed using the USGS station numbers in table 1. For a complete list of analytical processing and methods, refer to table 4.

Quality Control for Discrete Water-Quality Samples

Field blank and replicate samples were processed through all steps of sample collection, field processing, preservation, transportation, and laboratory analysis using the same procedures as the environmental samples. Field blanks and replicates were used as quality-control samples for this study to determine the amount of bias and variability during sample collection, processing, storage, and shipping (Mueller and others, 2015). Procedures used for collecting quality-control samples are explained in chapter 4, section C, of the National Field Manual for the Collection of Water-Quality Data (USGS, variously dated).

Continuous Water-Quality Monitoring

For the supergage at CR750N (fig. 4), continuous water-quality monitors were operated between June 2015 and September 2018 following USGS protocols (Pellerin and others, 2013; Wagner and others, 2006). Continuous water-quality monitoring for temperature, specific conductance, pH, DO, and turbidity was measured using a multiparameter sonde (YSI 6600 V2; YSI Inc., 2020). NOx as N concentrations were monitored using a 5-millimeter Submersible Ultraviolet Nitrate Analyzer (Sea-Bird Scientific, 2019), hereafter referred to as a nitrate monitor. The multiparameter sonde and nitrate monitor were deployed year-round, recording measurements every 15 minutes. The measurements were transmitted hourly by GOES and are available in near real time for public use and stored in the USGS NWIS database; these data can be accessed from U.S. Geological Survey (2019) by using station number 03353420. Concentrations of orthoP were measured using a Cycle-P phosphate sensor (Sea-Bird Scientific, 2019), hereafter referred to as a phosphate sensor, that was deployed in the stream at CR750N when temperatures were above freezing. Because the phosphate sensor uses premixed reagents and narrow flow-path tubing, which has the potential to freeze, the phosphate sensor was removed during times when air temperatures were predicted to fall below freezing. Measurements were recorded every 2 hours and transmitted via GOES for public use and storage in NWIS (U.S. Geological Survey, 2019).

Routine maintenance for each monitor included cleaning and calibration checks approximately every 2 weeks during April through October when biofouling was prominent. From November through March, routine maintenance was completed every 4 to 5 weeks or as needed. During routine maintenance, each monitor was cleaned and checked for calibration drift. During site visits, USGS personnel evaluated and recorded the magnitude of any fouling and calibration drift and recalibrated the monitors when measurements fell outside of acceptable drift ranges. After the site visit, the field inspection information was used to adjust for sensor-fouling and calibration drift errors. Data that exceeded parameter thresholds could not be corrected and were removed from the record (Pellerin and others, 2013; Wagner and others, 2006). Infrequent periods of missing continuous data were the result of equipment malfunctions, excessive fouling, or high instrument drift.

Passive Polar Organic Chemical Integrative Samplers

To better understand potential anthropogenic influences in the School Branch watershed, polar organic chemical integrative samplers (POCIS) were used to determine time-weighted concentrations of wastewater tracer compounds in the stream. The POCIS consist of a sorbent contained between microporous polyethersulfone membranes. This allows for water and dissolved chemicals to pass through the membranes to the sorbent where compounds are diffused into the sampler with time and are concentrated so that they can be detected at trace concentrations not detected by discrete sample collection methods. The POCIS mimic the exposure of stream organisms to these dissolved chemicals (Alvarez, and others, 2004; Jones-Lepp and others, 2004; Petty and others, 2004).

The POCIS were deployed at each of the three surface-water stations from March through June 2016. Three rounds of deployment were conducted, each lasting close to 30 days (March 29 to April 26, April 26 to May 24, and May 24 to June 21). Deployment followed guidelines described in the

Table 4. Constituents, analyses, and methods for sampling activities in School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

[USGS, U.S. Geological Survey; ID, identification; LRL, laboratory reporting level; N, nitrogen; mg/L, milligram per liter; µm, micrometer; NWQL, National Water Quality Laboratory; NO_2, nitrite; NO_3, nitrate; NH_3, ammonia; <, less than; mL, milliliter; H_2SO_4, sulfuric acid; P, phosphorus; EPA, U.S. Environmental Protection Agency; ICP, inductively coupled plasma; HNO_3, nitric acid; AES, automated emission spectrometry; µg/L, microgram per liter; APHA, American Public Health Association; SiO_2, silicon dioxide; IC, ion-exchange chromatography; IPT, inflection point titration; NFM, National Field Manual; $CaCO_3$, calcium carbonate; n.a., not applicable; RSIL, Reston Stable Isotope Laboratory; mm, millimeter]

Group	Constituent	USGS parameter code	Field preservation method	Analysis method	Method reference	Method ID	LRL	Units	Laboratory
Nutrients	Nitrogen, ammonia, water, filtered, as N, mg/L	00608	0.45-µm filter, chill	Colorimetry, Salicylate-Hypochlorite, Automated-Segmented Flow	Fishman, 1993	Method ID: I–2522–90	0.02	mg/L	NWQL
	Nitrogen, nitrite, water, filtered, as N, mg/L	00613	0.45-µm filter, chill	Colorimetry, Diazotization, Auto-Segmented Flow	Fishman, 1993	Method ID: I–2540–90, I–2542–89	0.002	mg/L	NWQL
	Nitrate + nitrite (NOx), filtered, as N, mg/L	00631	0.45-µm filter, chill	Colorimetry by enzymatic reduction	Patton and Kryskalla, 2011	Method ID: I–2547–11	0.08	mg/L	NWQL
	Total Nitrogen (NO2+NO3+NH3+Organic-N) (TN), water, unfiltered, as N, mg/L	62855	No filtration, acidify to pH <2 with 1 mL 4.5 normality H2SO4, chill	Alkaline persulfate digestion	Patton and Kryskalla, 2003	Method ID: I–4650–03	0.1	mg/L	NWQL
	Phosphorus, phosphate, ortho, water, filtered (orthoP), as P, mg/L	00671	0.45-µm filter, chill	Colorimetry, phosphomolybdate, automated-segmented flow	Fishman, 1993	Method ID: I–2601–90, I–2606–89	0.008	mg/L	NWQL
	Low-level total phosphorus (TP), mg/L	00665	No filtration, acidify to pH <2 with 1 mL 4.5 normality H2SO4, chill	Semiautomated colorimetry	EPA, 1993, Method 365.1	EPA Method 365.1	0.008	mg/L	NWQL
Major ions	Calcium, water, filtered, ICP, mg/L	00915	0.45-µm filter, acidify to pH <2 with 2 mL 7.5 normality Ultrex HNO3, chill	AES and ICP	Fishman, 1993	Method ID: I–1472–87	0.044	mg/L	NWQL
	Chloride, water, filtered, mg/L	00940	0.45-µm filter, chill	Ion-exchange chromatography	Fishman and Friedman, 1989	Method ID: I–2057–85	0.04	mg/L	NWQL
	Fluoride, water, filtered, mg/L	00950	0.45-µm filter, chill	Ion-exchange chromatography	Fishman and Friedman, 1989	Method ID: I–2057–85	0.02	mg/L	NWQL
	Iron, water, filtered, µg/L	01046	0.45-µm filter, acidify to pH <2 with 2 mL 7.5 normality Ultrex HNO3, chill	AES and ICP	Fishman, 1993	Method ID: I–1472–87	20[a]	µg/L	NWQL
	Magnesium, water, filtered, ICP–AES	00925	0.45-µm filter, acidify to pH <2 with 2 mL 7.5 normality Ultrex HNO3, chill	AES and ICP	Fishman, 1993	Method ID: I–1472–87	0.022	mg/L	NWQL
	Manganese, water, filtered, ICP–AES	01056	0.45-µm filter, acidify to pH <2 with 2 mL 7.5 normality Ultrex HNO3, chill	AES and ICP	Fishman, 1993	Method ID: I–1472–87	0.4	µg/L	NWQL
	Potassium, water, filtered, ICP–AES	00935	0.45-µm filter, acidify to pH <2 with 2 mL 7.5 normality Ultrex HNO3, chill	AES and ICP	APHA, 1998	Method ID: 3120	0.6[b]	mg/L	NWQL
	Silica, water, filtered, ICP–AES as SiO2	00955	0.45-µm filter, acidify to pH <2 with 2 mL 7.5 normality Ultrex HNO3, chill	AES and ICP	Fishman, 1993	Method ID: I–1472–87	0.1[c]	mg/L	NWQL
	Sodium, water, filtered, ICP–AES	00930	0.45-µm filter, acidify to pH <2 with 2 mL 7.5 normality Ultrex HNO3, chill	AES and ICP	Fishman, 1993	Method ID: I–1472–87	0.8[d]	mg/L	NWQL
	Sulfate, water, filtered, IC	00945	0.45-µm filter, chill	IC	Fishman and Friedman, 1989	Method ID: I–2057–85	0.04	mg/L	NWQL
	Alkalinity, water, filtered, IPT	39086	0.45-µm filter	Inflection point titration	USGS, variously dated	Method ID: TT061	0.1	mg/L as $CaCO_3$	Field
Stable isotopes	Delta hydrogen-2/hydrogen-1, water, unfiltered, per mil	82082	0.45-µm filter	Mass spectrometry	Révész and Coplen, 2008a (10–C1)	n.a	n.a.	ratio and delta[e]	RSIL
	Delta nitrogen-15/nitrogen-14 of nitrate, water, filtered, per mil	82690	0.45-µm filter	Mass spectrometry	Coplen and others, 2012	n.a.	n.a.	ratio and delta[e]	RSIL
	Delta oxygen-18/oxygen-16, water, unfiltered, per mil	82085	0.45-µm filter	Mass spectrometry	Révész and Coplen, 2008b (10-C2)	n.a.	n.a.	ratio and delta[e]	RSIL
Sediment	Suspended sediment, sieve diameter, percent smaller than 0.0625 mm	70331	n.a.	Filtration	Shreve and Downs, 2005	n.a.	n.a.	percent	Kentucky sediment lab
	Suspended-sediment concentration, mg/L	80154	n.a.	Filtration	Shreve and Downs, 2005	n.a.	1	mg/L	Kentucky sediment lab

[a] Laboratory reporting level for iron changed throughout study—20 µg/L (May 25, 2017–present), 10 µg/L (November 16, 2016–May 24, 2017), and 8 µg/L (October 1, 2004–November 15, 2016).

[b] Laboratory reporting level for potassium changed throughout study—0.6 mg/L (August 1, 2018–present), 0.2 mg/L (May 25, 2017–July 31, 2008), 0.12 mg/L (November 16, 2016–May 24, 2017), and 0.06 mg/L (September 1, 2014–November 15, 2016).

[c] Laboratory reporting level for silica changed throughout study—0.1 mg/L (August 1, 2018–present) and 0.036 mg/L (October 1, 2014–July 31, 2018).

[d] Laboratory reporting level for sodium changed throughout study—0.8 mg/L (August 1, 2018–present), 0.2 mg/L (November 16, 2016–July 31, 2018), and 0.12 mg/L (October 1, 2014–November 15, 2016).

[e] Ratio of the heavier, less abundant isotope to the lighter isotope and delta unit expressed in molecules per thousand or per mil compared against a reference material.

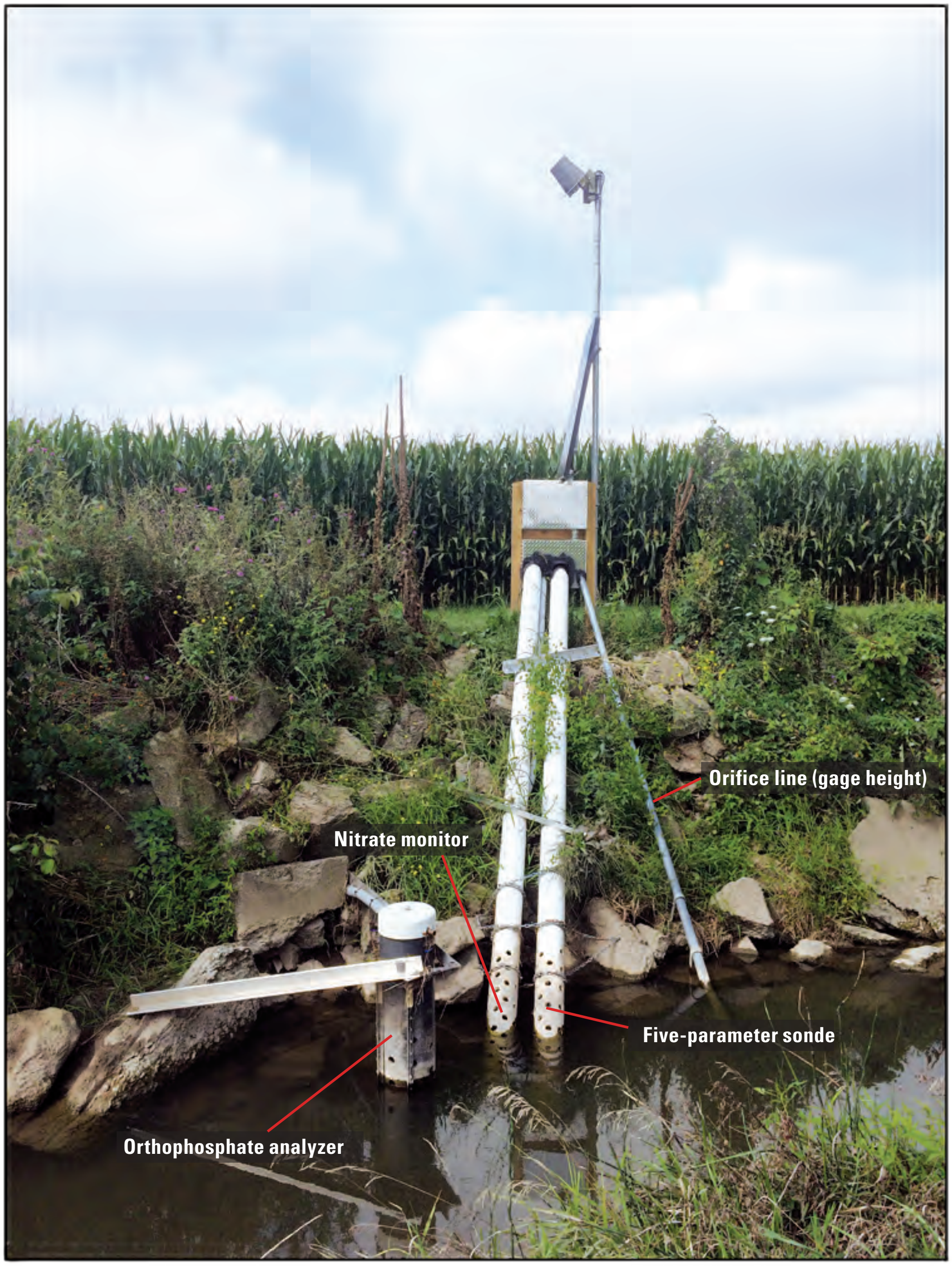


Figure 4. Photograph of the supergage at U.S. Geological Survey station 03353420, School Branch at County Road 750 North at Brownsburg, Indiana.

USGS Techniques and Methods Book 1, Section D, Chapter 4 (Alvarez, 2010). For each round of deployment, a field blank was included at one station. The blank POCIS container was opened and exposed to the air while the field POCIS was deployed and retrieved. Between deployment and retrieval, the blank POCIS was kept in an airtight container at temperatures between −20 and 0 degrees (°) Celsius (C). Environmental and blank POCIS were stored in coolers with ice packs for transport to and from the site of deployment.

After deployment, the POCIS were stored in temperatures between −20 and 0 °C at the USGS Indianapolis office until shipment to the USGS Columbia Environmental Research Center for extraction. The POCIS were extracted at Columbia Environmental Research Center following published methods (Alvarez, 2010). Extractions for the 9 environmental POCIS (3 per site), 3 blank POCIS, and 1 laboratory/fabrication blank were then sent to the USGS NWQL to be analyzed for wastewater tracer compounds using polystyrene-divinylbenzene solid-phase extraction and capillary-column gas chromatography/mass spectrometry (Zaugg and others, 2002).

Ecological Sample Collection

Ecological and habitat samples were collected in 150-meter (m) reaches at all three surface-water sites in late summer of 2016 and 2018 using USGS National Water-Quality Assessment methods (Fitzpatrick and others, 1998; Moulton and others, 2002). Habitat measurements were collected at 11 equally spaced transects along the 150-m reach, including depth, substrate size, and habitat cover at 5 sampling points at each bank and at 25, 50, and 75 percent of the wetted width (Fitzpatrick and others, 1998). A densiometer was used to measure canopy cover at the banks and in the center of the stream. A handheld Acoustic Doppler Velocimeter was used to measure streamflow in the center of the stream. Substrate size was also measured at 5 sampling points at secondary transects between each of the 11 transects.

Macroinvertebrate community samples were collected using the USGS National Water-Quality Assessment richest targeted habitat method (Moulton and others, 2002). Surber samplers with 500-micron nets were used to collect five composites from riffles within each reach. These composites were combined into a 5-gallon bucket and field elutriated to remove any rocks and large organic matter, such as leaves and sticks. Care was taken to rinse organisms off before removal of leaves and sticks. The combined sample was then placed into a 1-liter Nalgene bottle and preserved using ethanol. Macroinvertebrate samples were processed and identified to the lowest possible taxonomic resolution in the laboratory by IDEM staff. For each site, the entire sample was placed and evenly distributed into a 77-square gridded tray, and a random-numbers table was used to select 1 grid at a time. All organisms in each selected grid were removed (using forceps, spoons, and pipettes) into a petri dish, which was then observed and identified under a microscope at 10-times magnification. All organisms were then removed from the petri dish and placed into a sample vial. Grids were selected and organisms picked until a minimum of 300 organisms were collected. The grid in which the 300th organism was collected was picked until completion, so that the total number of organisms collected was greater than the minimum required (P.D. McMurray, IDEM, written commun., June 2019). Fish community samples were collected in two passes along each reach using an electrofisher (LR–24 backpack, Smith-Root). One crew member operated the backpack electrofisher, while two crew members netted the stunned fish. Fish were identified to the species level onsite and released.

Algal biomass samples were collected using modified USGS National Water-Quality Assessment methods for periphyton (Moulton and others, 2002). A delimiter was used to sample a defined area from 11 rocks within each 150-m reach. The delimited area on each rock was brushed clean to remove periphyton and rinsed into a composite bottle. After 11 rocks for a site were sampled, the total volume of the composite was recorded. The composite was then shaken, and 3 milliliters were filtered through a 45-micrometer fiber glass filter. The filter was then folded, wrapped in foil, placed into a petri dish, and frozen. Algal samples were shipped overnight on dry ice to the USGS NWQL and analyzed for chlorophyll *a* and pheophytin *a* using EPA method 445.0 (Arar and Collins, 1997).

Data Analysis Methods

Besides direct comparisons of concentrations among the sites or differences from year to year, various statistical methods were used to evaluate and interpret the data. Nutrient concentration and flow data were used to create load models. Groundwater and surface-water elevations were compared to determine hydraulic gradients, which infer potential seepage into the stream or from the stream into groundwater. Streamflow recession curves were used to estimate base flow by various hydrograph separation models. The fish and macroinvertebrate community data were used to calculate a biological condition gradient for each site to determine the ecological health of the stream. More detail on each of these methods follows.

Load Models

LOADEST, a FORTRAN program originally developed by Runkel and others (2004), was updated in the R programming language (R Core Team, 2018) (Lorenz and others, 2013; Runkel and De Cicco, 2017). The R version, called rloadest, is available on USGS–R GitHub (https://github.com/USGS-R/rloadest). The rloadest program was used to evaluate, and when appropriate data were available, create models to estimate flux and compute loads from the three stations. Constituents evaluated for rloadest analysis included TN, TP, orthoP, and suspended sediment. NOx loads were not evaluated because most of the TN was NOx, and the models would have been redundant. In rloadest, models are frequently developed by regressing discrete constituent concentration values against concurrent daily mean streamflows. Because of the stream's small size and flashy nature, the use of daily mean streamflow values as the explanatory variable in a model for School Branch may not result in the necessary accuracy to describe conditions in the stream during highly variable flows. Therefore, the developed models utilize 15-minute, instantaneous streamflow values as the explanatory variable.

For each model, the rloadest program computes regression coefficients by means of the adjusted maximum likelihood estimation method (Wolynetz, 1979). For each constituent, nine predefined models (Runkel and others, 2004) were tested, and the models were ranked based on Akaike information criterion scores (Helsel and others, 2020). Then, diagnostic plots (Bunch, 2021) were created to assess the variance (as a function of predicted values and time, season, and discharge) and the normality of each model's residuals.

Additionally, the rloadest program computes bias diagnostics that compare estimated loads to observed loads. Load bias percentage is the percentage by which the model overestimates [negative number] or underestimates [positive number] the sum of the estimated loads to the sum of the observed loads. The partial load ratio is a ratio of the sum of the estimated loads to the sum of the observed loads, which indicates load model overestimates [greater than 1] or underestimates [less than 1]). The Nash Sutcliffe efficiency index is computed by rloadest and provides a measure of model fit that ranges from 1 (perfect fit) to negative infinity. These diagnostics and the residual plots were used when selecting the model that most appropriately estimated loads for each constituent at each site. Models with an inappropriate number of variables compared to sample size were not selected due to the likelihood of overfitting. In general, 1 model variable (including the intercept) per 10 samples is considered appropriate (Peduzzi and others, 1996).

To estimate for a given period, a consistent number of discharge values must be available for each day of the period. The rloadest package was used to screen each site's discharge record for a consistent number of discharge values per day (15-minute data). When needed, missing values were filled based on the closest recorded value (no more than 12 hours difference). After the discharge record was complete, 15-minute discharge was used to estimate flux and compute loads for each site. Using the adjusted maximum likelihood estimation method, rloadest computed 90-percent prediction intervals for each model (Cohn, 2005). Retransformation bias was automatically corrected by application of a bias correction factor (Bradu and Mundlak, 1970; Cohn, 1988, 2005).

Hydrograph Separation

Hydrograph separation is a generic term for graphic and numerical techniques used to partition a streamflow hydrograph into its major components—surface runoff (or overland flow) and base flow. A streamflow hydrograph is a plot of stream discharge with time. The processes contributing water to streams in temperate climates without direct anthropogenic inputs may include surface runoff, interflow, direct precipitation, and base flow. Surface runoff occurs when the precipitation rate exceeds the infiltration capacity of the soil and water is forced to flow over the land surface. Interflow occurs when infiltrating precipitation or meltwater encounters shallow deposits with low permeability, and flow changes from primarily vertical to mostly horizontal. Direct precipitation is the term for precipitation that falls directly onto the stream surface. Base flow is groundwater that discharges to the stream through the streambed in response to hydraulic heads that are higher in the adjacent geologic deposits than in the stream. Assumptions commonly applied to hydrograph separation techniques were invoked for the School Branch analyses. Those assumptions are that the magnitudes of direct precipitation and interflow are small in comparison to runoff and base flow, and the contributions of those processes to streamflow (and the hydrograph) are negligible.

The quantities of runoff and base flow contributing to streamflow in School Branch were estimated using hydrograph separation techniques included in the USGS Groundwater Toolbox (Barlow and others, 2015). The six methods included the Standard and Modified Base-Flow Index methods (Wahl and Wahl, 1995); the Fixed Interval, Sliding Interval, and Local Minimum HySEP (Sloto and Crouse, 1996); and PART (Rutledge, 1998). All the methods separate surface runoff from groundwater base flow by computing the duration and extent of base-flow recession. Each of the methods uses different mathematical approaches to identify and connect low streamflow values on the hydrograph that represent base-flow conditions. Details on the mathematics and assumptions behind each technique can be found in the cited references or in Barlow and others (2015). In addition to streamflow data, all methods use the drainage-basin area as a computational variable, and some use additional empirically derived variables (table 5). Default parameters were used for this evaluation.

The School Branch base-flow-separation evaluation was used to examine data from water years 2016–18 for the three streamgage sites. Multiyear analyses are more reliable than daily or monthly estimates of base flow (Barlow and others, 2015). The Groundwater Toolbox acquired the watershed areas and daily mean streamflow values for the three gages examined in this evaluation from NWIS (USGS, 2019).

Assumptions for applying the hydrograph separation techniques include (1) the streamflow is a combination of base flow and runoff; (2) the recharge is from diffuse input that is widely and uniformly distributed within the watershed; (3) all groundwater in the watershed, except that lost to the atmosphere through evapotranspiration, discharges by continuous flow to the stream; (4) there are no anthropogenic mechanisms directly affecting streamflow; (5) the watershed area is more than 1 and less than 500 square miles; and (6) the watershed slope should not be negligible. Although these assumptions were generally met for School Branch, hydrograph separation may be complicated by (1) discharges to School Branch from agricultural tile drains and (2) deeper groundwater that did not discharge to School Branch.

Fish Biological Condition Gradient

Fish communities were assessed using the biological condition gradient for fish assemblages in Indiana streams (Stamp and others, 2016). The BCG is a conceptual model that describes changes in biological communities in response to increasing levels of human-caused disturbance or stress. The BCG ranges from level 1, which represents streams in their natural condition, to level 6, which represents streams that have undergone severe changes in ecological structure and

Table 5. Empirically derived parameters and drainage-basin areas used by the U.S. Geological Survey Groundwater Toolbox (Barlow and others, 2015) for the six hydrograph separation methods used to evaluate the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

[BFI, Base-Flow Index; f, turning point test factor; N, streamflow record segment; K', daily recession index; n.a., not applicable; N(sr), days of continuous recession; A, watershed area; mi^2, square mile]

Method	Parameter	Default value	Value used	Citation
Standard BFI	f	0.9 (dimensionless)	0.9 (dimensionless)	Wahl and Wahl, 1995
Standard and modified BFI	N	5 days	5 days	Wahl and Wahl, 1995
Modified BFI	K'	n.a.	n.a.	Wahl and Wahl, 1995
PART	N(sr)	n.a.	machine generated	Rutledge, 1998
All hydrograph separation methods	A	n.a.	3.39, 4.70, 7.38 mi^2	Sloto and Crouse, 1996

function. Changes that result in level 6 streams could be due to water chemistry, habitat, and flow regimes that have been severely altered from natural conditions.

A stream is categorized as a specific BCG level based on a set of narrative and numeric decision criteria specific to the stream's size. The structure of the fish community is used for many of these decision criteria. The BCG categorizes fish taxa into nine attributes (indicated by Roman numeral) based on their abundance, sensitivity to pollution, and native status, among other characteristics (Stamp and others, 2016). The stream is then assigned a level based on the composition of the attributes from level 1 (pristine) to level 6 (extreme alterations); however, because there are no watersheds in Indiana without humans, the lowest level a stream can be categorized is a level 2. The methods for developing the BCG for Indiana and a full list of rules used to assign a BCG level for the School Branch can be found in Stamp and others (2016).

Benthic Macroinvertebrate Biological Indices and Biological Condition Gradient

For the benthic macroinvertebrate community, multiple biological indices were calculated based on the taxonomic results. Taxa richness was calculated by counting the number of distinct taxa (identified to the lowest taxonomic level possible, usually genus or species) identified at each site. The Distribute Parents Among Children method for ambiguous taxon resolution was found to give high suitability scores when compared to other methods and was used to resolve ambiguous parent-child pairs (for example, *Baetis intercalaris* and *Baetis* sp.) (Cuffney, 2003; Cuffney and Brightbill, 2011; Cuffney and others, 2007). For the Distribute Parents Among Children method, the abundance of the ambiguous parent was distributed among the associated children in proportion to the relative abundance of each child in the sample. Taxa richness can be used to determine the diversity of taxa in a stream. Higher diversity can indicate a healthier macroinvertebrate community, though some studies have shown that diversity may go up as more tolerant species move into impaired streams (Plafkin and others, 1989). Percentage dominant family equals the total number of organisms in the most numerically dominant family divided by the total of individuals in the sample. Being dominated by one family can indicate the community is not balanced and may indicate environmental stress (Plafkin and others, 1989). Richness and percentage of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa are used to evaluate macroinvertebrate communities because EPT taxa tend to be intolerant of pollution and nutrient enrichment and are found to be less abundant in impaired streams. Percentage Chironomidae taxa abundance was calculated because the family Chironomidae tend to be tolerant of pollution and therefore more abundant in impaired streams. The EPT (to Chironomidae ratio (EPT/C) is used to determine whether there is a disproportionally higher number of Chironomidae individuals in the community than intolerant individuals. An EPT/C ratio less than 1 can indicate environmental stress, whereas a ratio greater than 1 may indicate that a stream has conditions more favorable to sensitive taxa such as lower levels of nutrients, heavy metals, or higher DO (Plafkin and others, 1989).

The Family Biotic Index (FBI) (Hilsenhoff, 1988; Bode and others, 1996) ranks each macroinvertebrate family with a tolerance value from 0 to 10. Taxa with a tolerance score of 0 are the most intolerant of environmental stressors, and taxa with a score of 10 are the most tolerant. The FBI was calculated by multiplying the sum of each taxa's abundance by its tolerance score and dividing by the total abundance for the sample. Along with calculating FBI, the tolerance values can be used to evaluate the community. The mean tolerance value (MTV) is the mean tolerance value for all distinct taxa in the sample; when used in conjunction with FBI, MTV can give more weight to less abundant taxa (Lillie and Schlesser, 1994). Examining the percentage of intolerant (tolerance scores less than 4) and tolerant (tolerance scores greater than 8) values can help to assess the overall tolerance of the community.

Like the fish BCG described above, methods to determine a stream's BCG level based on the macroinvertebrate assemblages in Indiana have also been developed (Jessup and others, 2017). The macroinvertebrate BCG assigns a BCG attribute to each taxa. The BCG attributes assigned to macroinvertebrates are as follows: (I) sensitive, long-lived, or regionally endemic taxa; (II) highly sensitive taxa; (III) intermediate sensitive taxa; (IV) taxa of intermediate tolerance; (V) tolerant native taxa; (VI) non-native taxa; and x or NA for no attribute assigned. Based on the macroinvertebrate community's taxa richness, EPT taxa abundance, and BCG attributes, streams were placed into BCG levels with the same definitions for each level as the fish BCG.

Concentrations of Nutrients, Major Ions, and Suspended Sediment in Discrete Water-Quality Samples

Discrete water-quality samples for nutrients and suspended sediment were collected at three surface-water sites throughout the sampling period at a variety of flows to characterize seasonal and flow-related differences (fig. 5). Three times each year during spring and summer, samples were collected at surface-water sites and one of the four groundwater wells over the period of 2 days and analyzed for nutrients, suspended sediment, major ions, and stable isotopes.

Discrete Sample Data

Minimum, maximum, and median values were computed for nutrients, major ions, and suspended-sediment concentrations for all surface-water sites and the DNW groundwater well as shown in table 6. The results were calculated by first excluding the censored values less than the laboratory reporting level (LRL). The results were then calculated again to include all censored values by using the R package NADA (nondetects and data analysis for environmental data) using methods described in Helsel and Cohn (1988). There was no substantial qualitative difference in the results between these two methods; therefore, the reported summary values in table 6 are calculated without censored values. The results exclude all censored values, which are values less than the LRL.

In general, concentrations of the nitrogen and phosphorus species were consistent across the three surface-water stations, but varied from the groundwater site (fig. 6, table 6). Although Maloney Rd. and CR750N had higher maximum concentrations of ammonia (0.57 mg/L and 0.33 mg/L, respectively) than DNW (0.31 mg/L), the median concentration of ammonia at DNW (0.30 mg/L) was an order of magnitude higher than that of the three surface-water sites. Ammonia was the only nutrient in which higher concentrations were found in DNW than the surface-water sites and indicates reducing conditions in the groundwater. In DNW, NOx and nitrite concentrations were less than (<) the LRL for all samples. NOx comprised 86.7–93.3 percent of the median and maximum TN at the three surface-water sites. Maloney Rd. had the highest maximum concentration for all nitrogen species except nitrite, where Noble Dr. was slightly greater (table 6). For ammonia, NOx, and TN, maximum concentrations generally decreased moving downstream from Maloney Rd. to Noble Dr. Conversely, for the two phosphorus species, CR750N had the highest maximum concentration among the sites sampled.

Stable ion concentrations for calcium, fluoride, iron, magnesium, and potassium had little variation among surface-water sites (fig. 7, table 6). Chloride, sodium, and sulfate concentrations were generally higher at Noble Dr. than at the other two surface-water sites; manganese concentrations were highest at Maloney Rd.; and silica concentrations decreased going downstream from Maloney Rd. to Noble Dr. Of the surface-water sites, Maloney Rd. had the highest manganese concentration, with a maximum 0.17 mg/L and a median 0.059 mg/L; these measurements were more than double those at CR750N and Noble Dr.

Apart from potassium, the major ion constituent concentrations from DNW were inconsistent with those of the surface-water sites (fig. 7, table 6). The range of constituent concentrations from the groundwater site was smaller than the ranges from the surface-water sites. Additionally, chloride and sulfate concentrations were lower at DNW than the three surface-water sites. Conversely, for calcium, fluoride, iron, magnesium, silica and sodium, the concentrations from DNW were higher than that of the surface-water sites. Maximum fluoride and iron concentrations (1.3 mg/L and 1.4 mg/L, respectively) were an order of magnitude higher in DNW than in the three surface-water sites. The median concentration of iron in the DNW well was nearly five times higher than the National Secondary Drinking Water Standard Regulations of 0.3 mg/L (EPA, 2019). Secondary standards are nonenforceable guidelines that may cause cosmetic (for example, tooth discoloration), aesthetic (for example, taste and odor), or technical (for example scaling and corrosion of water pipes) effects. The EPA recommends these standards but does not require compliance (EPA, 2019).

The median values for suspended sediment were relatively similar across the three surface-water sites; however, the maximum concentrations decreased in a downstream pattern from Maloney Rd. to Noble Dr. (fig. 8, table 6). Suspended-sediment concentrations were highest during runoff events because suspended-sediment concentrations tended to increase when streamflow increased. It is important to note that samples from the three surface-water sites were collected consecutively from downstream to upstream, not concurrently. Because School Branch is a small agricultural stream, temporal and spatial site conditions are variable and may quickly change. The values are from discrete samples collected at a specific point and time.

Quality-Control Data

Field blank samples were collected during the study period: six for nutrient analysis and four for major ion analysis. All surface-water sites and the DNW well had at least one

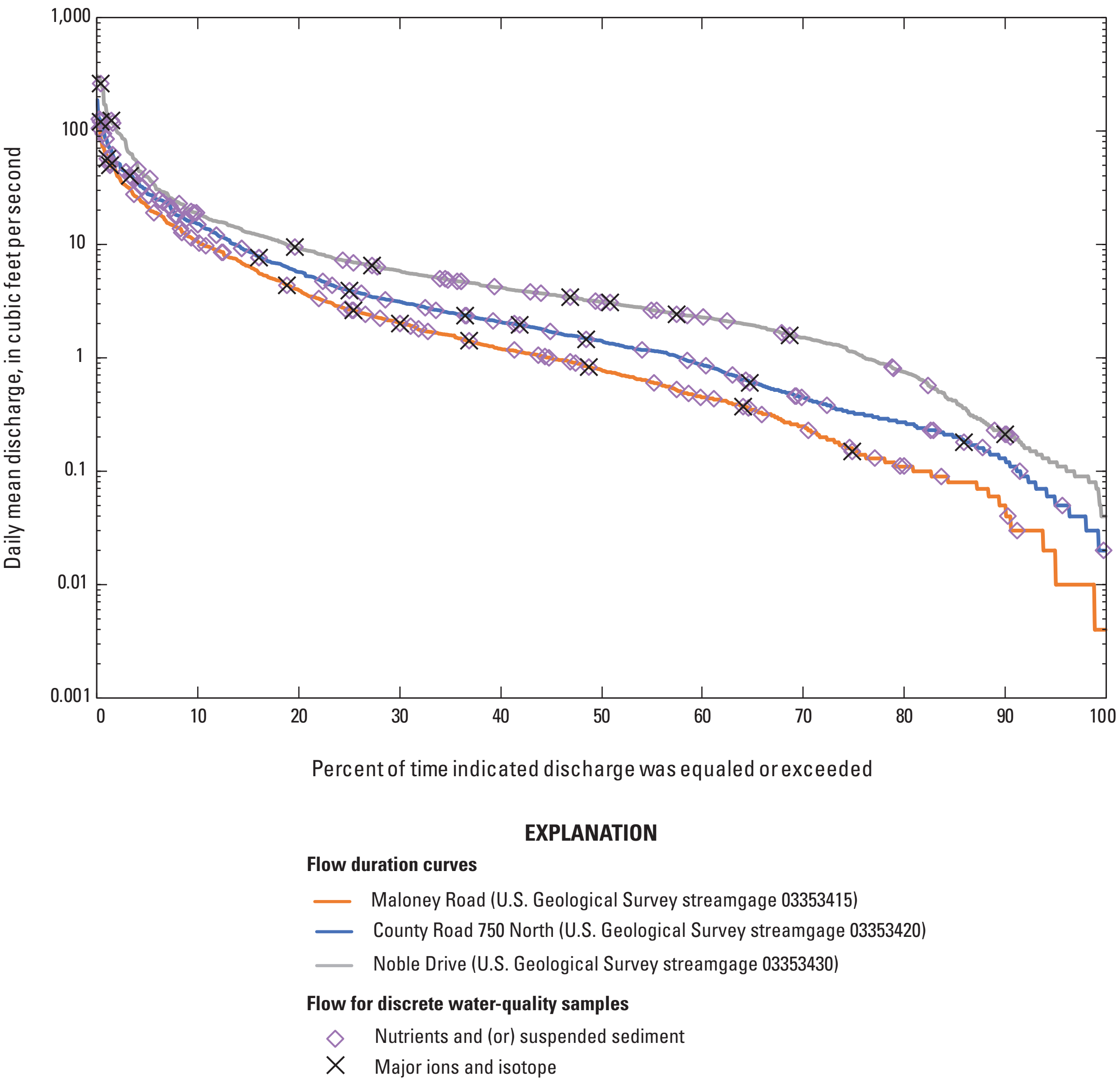


Figure 5. Graph showing flow-duration curves for Maloney Road (U.S. Geological Survey [USGS] station 03353415), County Road 750 North (USGS station 03353420), and Noble Drive (USGS station 03353430) and flow for discrete water-quality samples plotted along each curve for the three streamgage stations from June 2015 through water year 2018 in the School Branch watershed, Hendricks County, Indiana.

field blank sample collected and analyzed during the study period (table 7). Field blanks were collected and processed using inorganic blank water tested by the USGS NWQL and certified to have constituent concentrations less than the LRL for targeted constituents (table 4). The LRL is the minimum laboratory reporting level used by the NWQL to ensure accuracy of results. Results for field blanks are listed in table 7 and were analyzed and reported using the analytical detection level. Note the detection levels in table 7 are lower than the LRLs in table 4. Detections below or at the LRL, but above detection level, were found in samples for five analytes and are treated as nondetections for this study. The analytes were ammonia (detection = 0.011 mg/L, LRL<0.02), total phosphorus (detection = 0.006 mg/L, LRL <0.008), chloride (detection = 0.04 mg/L, LRL <0.04), manganese (detection =0.30 mg/L, LRL <0.40), potassium (detection = 0.15 mg/L, LRL <0.6), and silica (detections = 0.020 and 0.019 mg/L, LRL <0.036). The field blank sample for chloride was analyzed twice, and both times had a result equal to the LRL of 0.04 mg/L. The field blank concentrations for chloride were several orders of magnitude lower than that of the environmental sample of 22.9 mg/L. There was one quantifiable result (detection) in the

Table 6. Summary of nutrients, major ions, and suspended-sediment concentrations for surface-water and groundwater discrete water-quality samples in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

[USGS, U.S. Geological Survey; N, nitrogen; mg/L, milligram per liter; n, sample size; Rd., Road; CR750N, County Road 750 North; Dr., Drive; DNW, deep northwest groundwater well; <, less than; LRL, laboratory reporting level; P, phosphorus; µg/L, microgram per liter; SiO_2, silicon dioxide; $CaCO_3$, calcium carbonate; mm, millimeter]

Site	Minimum	Median[a]	Maximum	n	Number censored	Percent censored
Ammonia, as N, in mg/L (USGS parameter code 00608)						
Maloney Rd.	0.01	0.04	0.57	47	2	4.3
CR750N	0.01	0.03	0.33	43	6	14.0
Noble Dr.	0.01	0.03	0.20	41	4	9.8
DNW	0.27	0.30	0.31	9	0	0
Nitrite, as N, in mg/L (USGS parameter code 00613)						
Maloney Rd.	0.004	0.028	0.164	47	0	0
CR750N	0.001	0.020	0.130	43	1	2.3
Noble Dr.	0.001	0.014	0.184	41	1	2.4
DNW	<LRL	<LRL	<LRL	9	9	100
Nitrate + nitrite (NOx), as N, in mg/L (USGS parameter code 00631)						
Maloney Rd.	0.24	2.72	8.27	47	0	0
CR750N	0.05	3.24	8.24	43	1	2.3
Noble Dr.	0.09	2.33	7.59	41	1	2.4
DNW	<LRL	<LRL	<LRL	9	9	100
Total nitrogen (TN), as N, in mg/L (USGS parameter code 62855)						
Maloney Rd.	0.88	3.01	9.42	47	0	0
CR750N	0.55	3.61	8.83	43	0	0
Noble Dr.	0.30	2.69	8.21	41	0	0
DNW	0.35	0.37	0.39	9	0	0
Orthophosphate (orthoP), as P, in mg/L (USGS parameter code 00671)						
Maloney Rd.	0.007	0.066	0.239	51	1	2.0
CR750N	0.005	0.069	0.714	48	0	0
Noble Dr.	0.005	0.043	0.187	41	7	17.1
DNW	0.008	0.011	0.015	9	1	11.1
Total phosphorus (TP), as P, in mg/L (USGS parameter code 00665)						
Maloney Rd.	0.016	0.107	0.878	48	0	0
CR750N	0.018	0.123	0.968	44	0	0
Noble Dr.	0.016	0.065	0.541	41	0	0
DNW	0.010	0.011	0.019	9	0	0
Calcium, in mg/L (USGS parameter code 00915)						
Maloney Rd.	23.0	71.9	81.2	9	0	0
CR750N	13.1	72.7	83.1	9	0	0
Noble Dr.	14.9	69.2	79.0	9	0	0
DNW	71.0	80.5	82.4	9	0	0
Chloride, in mg/L (USGS parameter code 00940)						
Maloney Rd.	4.0	26.1	36.9	9	0	0
CR750N	1.8	22.9	30.1	9	0	0
Noble Dr.	3.9	30.4	45.9	9	0	0
DNW	4.5	4.9	5.2	9	0	0

Table 6. Summary of nutrients, major ions, and suspended-sediment concentrations for surface-water and groundwater discrete water-quality samples in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.—Continued

[USGS, U.S. Geological Survey; N, nitrogen; mg/L, milligram per liter; n, sample size; Rd., Road; CR750N, County Road 750 North; Dr., Drive; DNW, deep northwest groundwater well; <, less than; LRL, laboratory reporting level; P, phosphorus; µg/L, microgram per liter; SiO_2, silicon dioxide; $CaCO_3$, calcium carbonate; mm, millimeter]

Site	Minimum	Median[a]	Maximum	n	Number censored	Percent censored
Fluoride, in mg/L (USGS parameter code 00950)						
Maloney Rd.	0.12	0.15	0.24	9	0	0
CR750N	0.10	0.15	0.21	9	0	0
Noble Dr.	0.08	0.16	0.23	9	0	0
DNW	1.19	1.27	1.30	9	0	0
Iron, in µg/L (USGS parameter code 01046)						
Maloney Rd.	8.9	15.2	211	9	1	11.1
CR750N	8.3	13.3	212	9	0	0
Noble Dr.	7.0	15.8	222	9	0	0
DNW	1070	1370	1440	9	0	0
Magnesium, in mg/L (USGS parameter code 00925)						
Maloney Rd.	5.5	21.5	23.7	9	0	0
CR750N	2.9	22.2	24.2	9	0	0
Noble Dr.	3.6	22.2	26.1	9	0	0
DNW	27.1	28.1	29.0	9	0	0
Manganese, in µg/L (USGS parameter code 01056)						
Maloney Rd.	19.3	59.2	170	9	0	0
CR750N	16.2	21.4	74.9	9	0	0
Noble Dr.	12.7	15.1	44.2	9	0	0
DNW	58.6	64.5	67.4	9	0	0
Potassium, in mg/L (USGS parameter code 00935)						
Maloney Rd.	1.0	1.3	3.1	9	0	0
CR750N	1.0	1.3	3.3	9	0	0
Noble Dr.	1.1	1.5	3.3	9	0	0
DNW	1.3	1.4	1.5	9	0	0
Silica, as SiO_2, in mg/L (USGS parameter code 00955)						
Maloney Rd.	3.2	8.4	16.4	9	0	0
CR750N	2.1	8.4	12.1	9	0	0
Noble Dr	2.0	6.5	10.8	9	0	0
DNW	18.6	20.1	21.4	9	9	100
Sodium, in mg/L (USGS parameter code 00930)						
Maloney Rd.	2.4	10.0	18.2	9	0	0
CR750N	0.9	9.0	13.6	9	0	0
Noble Dr.	2.0	13.1	21.9	9	0	0
DNW	19.2	20.5	21.6	9	0	0
Sulfate, in mg/L (USGS parameter code 00945)						
Maloney Rd.	3.8	18.4	27.3	9	0	0
CR750N	2.3	20.0	28.1	9	0	0
Noble Dr.	4.2	29.5	39.1	9	0	0
DNW	11.2	11.6	12.2	9	0	0

Table 6. Summary of nutrients, major ions, and suspended-sediment concentrations for surface-water and groundwater discrete water-quality samples in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.—Continued

[USGS, U.S. Geological Survey; N, nitrogen; mg/L, milligram per liter; n, sample size; Rd., Road; CR750N, County Road 750 North; Dr., Drive; DNW, deep northwest groundwater well; <, less than; LRL, laboratory reporting level; P, phosphorus; µg/L, microgram per liter; SiO_2, silicon dioxide; $CaCO_3$, calcium carbonate; mm, millimeter]

Site	Minimum	Median[a]	Maximum	n	Number censored	Percent censored
Alkalinity, in mg/L $CaCO_3$ (USGS parameter code 39086)						
Maloney Rd.	63	202	251	6	0	0
CR750N	45	191	256	6	0	0
Noble Dr.	39	190	248	6	0	0
DNW	275	318	346	6	0	0
Suspended sediment, in mg/L, sieve diameter, percent smaller than 0.0625 mm (USGS parameter code 70331)						
Maloney Rd.	53	92	100	30	0	0
CR750N	61	96	100	30	0	0
Noble Dr.	45	91	100	33	0	0
Suspended-sediment concentration, in mg/L (USGS parameter code 80154)						
Maloney Rd.	4	26	556	30	0	0
CR750N	2	31	435	30	0	0
Noble Dr.	4	29	308	33	0	0

[a]The reported values were computed by excluding the censored values (values less than laboratory reporting level).

groundwater field blank for calcium (detection = 0.048 mg/L, LRL <0.044). Both concentrations were several magnitudes below the environmental sample. None of the detections in blanks were found in high enough concentrations to cause concern of contamination in the environmental sample results.

Field replicates were collected seven times throughout the study period from Maloney Rd., CR750N, and DNW. A total of 89 replicate pairs were analyzed from randomly selected samples of nutrients, major ions, and suspended sediment (table 8). Relative percent differences (RPDs) were calculated for each replicate pair of constituents having values at or above the detection level. RPDs were calculated using the following equation:

$$\mathrm{RPD}=[(C_1-C_2)/(C_1+C_2)/2]\times 100 \tag{1}$$

where:

C_1 is the constituent concentration, in milligrams per liter, from one replicate sample;

and

C_2 is the constituent concentration, in milligrams per liter, from the second replicate sample.

All the nutrient and major ion replicate pairs were either negligible in terms of differences in actual concentrations or less than 10-percent RPD. When concentrations are low, near detection limit, the RPD can seem high but the difference in concentrations is low. The Maloney Rd. and CR750N iron samples on May 23, 2018, which have RPDs greater than 15 percent, have actual concentration differences of less than 0.005 mg/L, which are negligible.

Although two suspended sediment replicate pairs sampled on May 23, 2018, at Maloney Rd. and CR750N had RPDs of 28.6 percent and 40.0 percent, respectively, the difference in the absolute concentrations for both replicate pairs were 1 mg/L. Likewise, the DNW well orthoP samples collected on July 16, 2018, had an RPD of 40.0 percent but the absolute difference was 0.005 mg/L. A high RPD does not necessarily indicate a problem with variability, and the magnitude of concentrations being compared also need to be considered (Opsahl and others, 2018). However, there was one suspended sediment replicate pair at Maloney Rd. on April 3, 2018, with an RPD of 17.4 percent. Suspended-sediment values were 556 mg/L and 467 mg/L, respectively. The samples were collected during a high flow rain event, with 10 verticals across the stream for both replicates. The field notes indicate there were thunderstorms that day, and the samples were collected with sampler type DH–76 from the bridge. A DH–76 is a medium-weight hand-line suspended-sediment sampler. School Branch is a flashy stream, and it is not uncommon for conditions to change rapidly; however, for this one sample pair, it is uncertain if the variation was in the timing of the sample collection or biased by other factors. Overall, the results for most replicate pairs during the study period indicate that variability would not affect interpretation of results and that these results are easily reproducible.

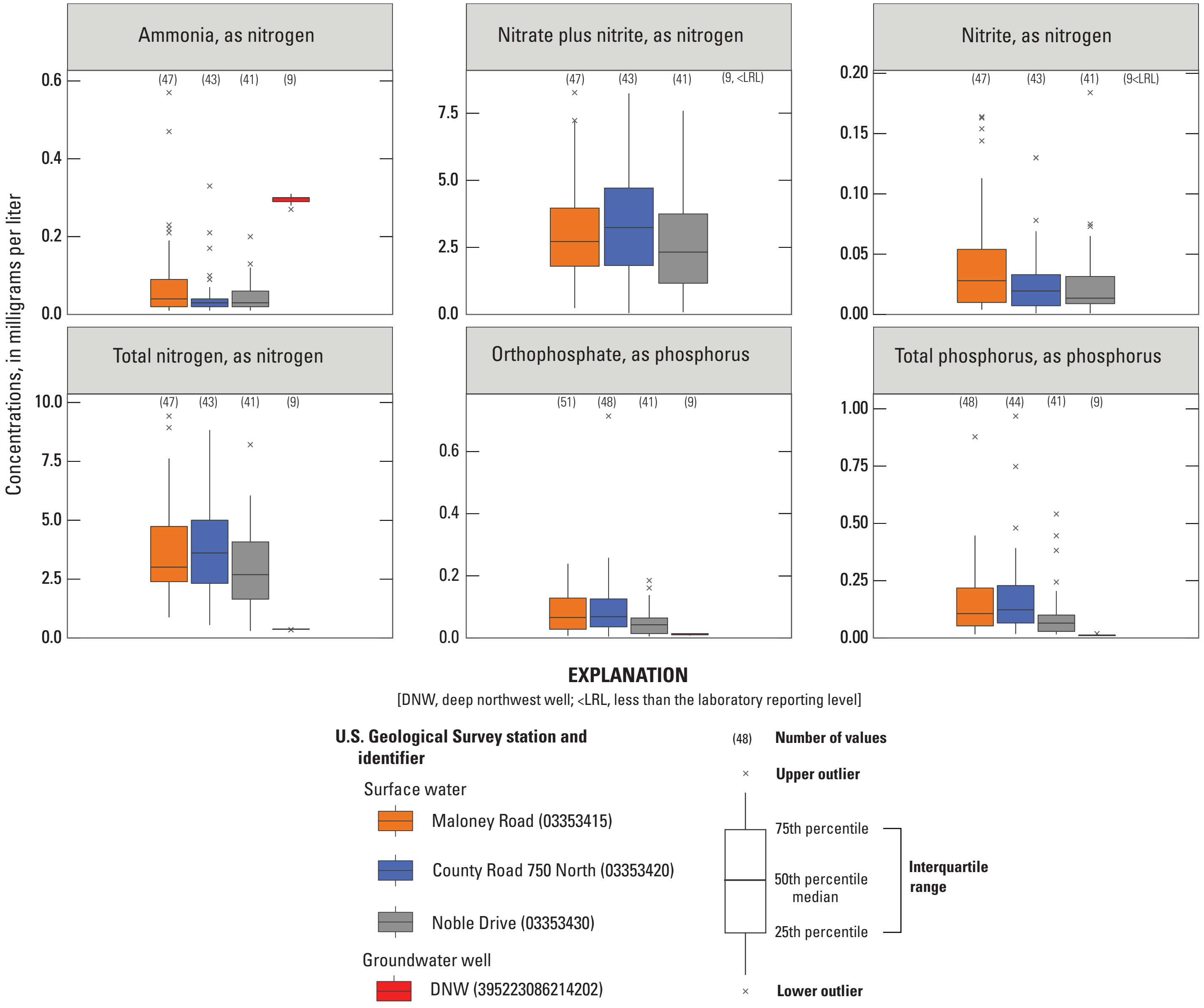


Figure 6. Boxplots showing nutrient constituent concentrations from discrete samples at 3 surface-water stations and 1 groundwater station in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018. The results exclude all censored values, which are values less than the laboratory reporting level.

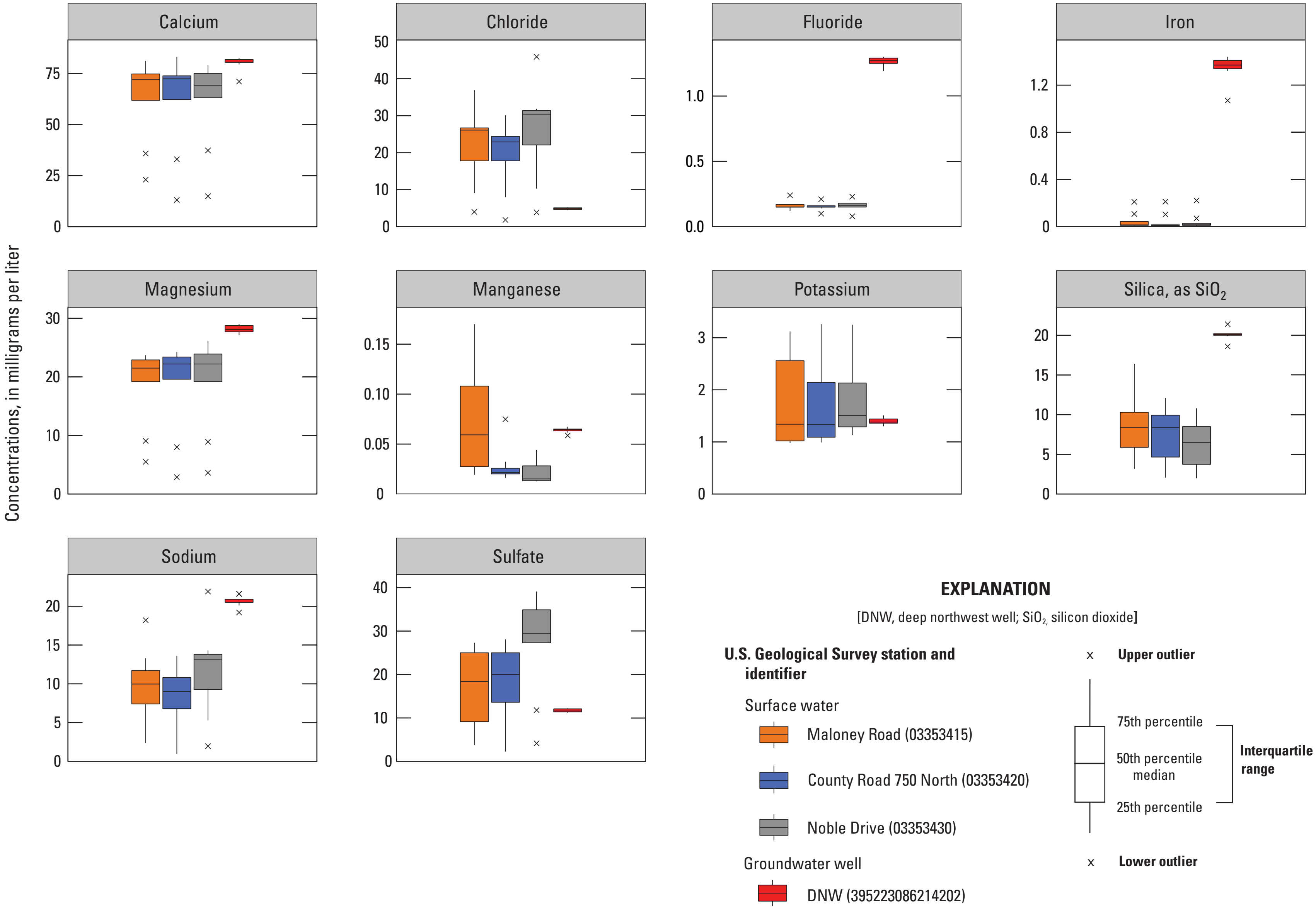


Figure 7. Boxplots showing major ion constituent concentrations from 9 discrete samples at 3 surface-water stations and 1 groundwater station in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

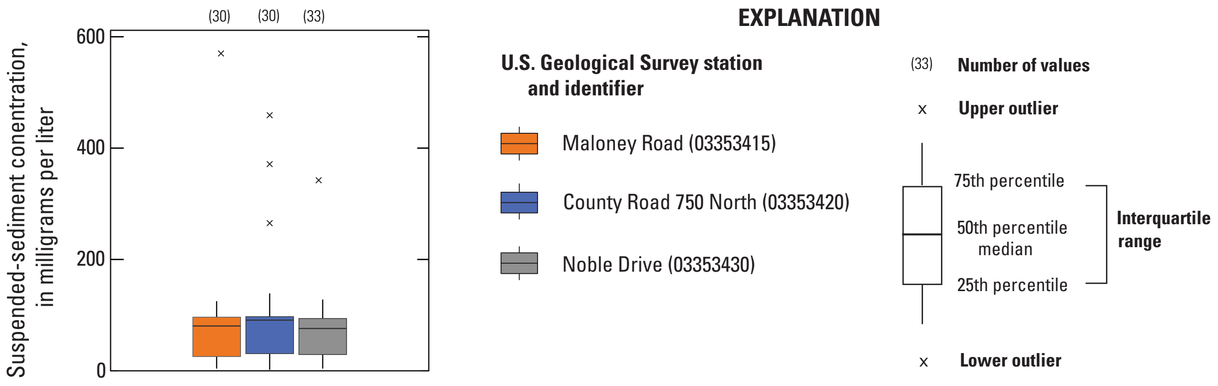


Figure 8. Boxplot showing suspended-sediment concentrations from discrete samples at three surface-water stations in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

Continuous Water-Quality Monitor Data

Summary statistics from the continuous water-quality monitor at CR750N show the variability of measurements in this small stream for temperature, pH, specific conductance, DO, turbidity, NOx, and orthoP (table 9). The maximum values for turbidity (1,550 Formazin Nephelometric Units) and NOx (29.4 mg/L) were recorded during rain events and demonstrated the value of having continuous monitors in the stream, as these extremes would have been missed otherwise. It is difficult for field personnel to collect samples at the peak of a storm, especially on a flashy stream like School Branch, where stream conditions can change quickly. If only discrete samples were collected, the full range of concentrations would not be known. All continuous data, including daily statistics, can be found in NWIS using the station numbers in table 1 (USGS, 2019).

In addition to capturing the range of values for the study period, the continuous data are used to evaluate temporal changes in the stream that could be influencing stream biota. By comparing the daily maximum and minimum values, the diurnal fluctuation of the continuously monitored constituents can be inferred. Daily temperature swings were as large as 9.8 °C. Dissolved oxygen concentrations varied as much as 15.1 mg/L in a 24-hour period, with lower DO concentrations at night and early morning and higher midday concentrations likely linked to the diurnal instream respiration and photosynthesis of periphyton and other microorganisms (Anderson, 2005). Large swings in DO have been associated with nutrient enrichment in streams (Suplee and others, 2019). These large daily variations in temperature and DO can cause stress to aquatic organisms such as fish and macroinvertebrates.

The continuous data can also be used to evaluate seasonal trends in water quality by evaluating changes in the water-quality properties and constituents through the seasons (figs. 9 and 10). Water temperature was higher in the warm summer months (fig. 9A). Specific conductance did not show a large seasonal trend, though the highest measured specific conductance values occurred in January, possibly linked to road salts used to remove snow or ice (fig. 9B). The pH values did not show a distinguishable seasonal trend, though the months of April and May did show a wider range of values than the other months (fig. 9C). Dissolved oxygen values were lowest in the summer (fig. 9D), coinciding with higher water temperatures; this reflects that naturally warmer water cannot hold as much DO as cooler water. Turbidity did not show large variability from month to month (fig. 9E). For the continuous nutrients, NOx and orthoP had their highest measured concentrations in June (fig.10). NOx had the highest monthly median concentrations in June after the spring application of fertilizer (fig.10A), and orthoP had the highest monthly median in August (fig. 10B).

Loads and Yields

For the three surface-water sites in the School Branch watershed, rloadest was used to evaluate load models for nutrients and suspended sediment. Fifteen-minute discharge values and the associated discrete sample concentration for each constituent at each of the three sites were used as inputs to the models. Of the constituents evaluated, only TN provided usable models that estimated loads reasonably at the three sites based on load model diagnostics and residual plots. Model 5 (of the nine predefined rloadest models in Runkel and others [2004]) was selected as the most appropriate model for TN loads at the three sites. The model used the natural logarithm of daily mean streamflow minus the natural logarithm of the centered value of daily mean streamflow from the calibration dataset ($\ln Q$), $\ln Q^2$, and the decimal time of the sample minus the center of decimal time for the calibration dataset as

Table 7. Results of quality-control field blanks for nutrients and major ions in School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

[Limits in this table are detection levels. To compare to laboratory reporting level, see table 4. USGS, U.S. Geological Survey; CR750N, County Road 750 North; Dates shown as month/day/year; Dr., Drive; DNW, deep northwest well; Rd., Road; N, nitrogen; mg/L, milligram per liter; <, less than; P, phosphorus; --, not collected; µg/L, microgram per liter; SiO_2, silicon dioxide]

Constituent, units (USGS parameter code)	Site and date of field blank sample					
	CR750N 05/31/2016	Noble Dr. 06/16/2017	DNW 05/22/2018	Noble Dr. 05/23/2018	Maloney Rd. 09/10/2018	CR750N 09/10/2018
Nutrients						
Ammonia, as N, mg/L (00608)	<0.01	0.011[a]	<0.01	<0.01	<0.01	<0.01
Nitrite, as N, mg/L (00613)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nitrate + nitrite (NOx), as N, mg/L (00631)	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Total nitrogen (TN), as N, mg/L (62855)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Orthophosphate (orthoP), as P, mg/L (00671)	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Total phosphorus (TP), as P, mg/L (00665)	0.006[a]	<0.004	<0.004	<0.004	<0.004	<0.004
Major ions						
Calcium, mg/L (00915)	<0.022	<0.022	0.048	<0.022	--	--
Chloride, mg/L (00940)	0.04[ab]	<0.02	<0.02	<0.02	--	--
Fluoride, mg/L (00950)	<0.01	<0.01	<0.01	<0.01	--	--
Iron, µg/L (01046)	<4	<10	<10	<10	--	--
Magnesium, mg/L (00925)	<0.011	<0.011	<0.011	<0.011	--	--
Manganese, µg/L (01056)	<0.2	<0.2	0.30[a]	<0.2	--	--
Potassium, mg/L (00935)	<0.03	<0.10	<0.10	0.15[a]	--	--
Silica, as SiO2, mg/L (00955)	0.020[a]	<0.018	0.019[a]	<0.018	--	--
Sodium, mg/L (00930)	<0.06	<0.10	<0.10	<0.10	--	--
Sulfate, mg/L (00945)	<0.02	<0.02	<0.02	<0.02	--	--

[a] Below the laboratory reporting level but above the method detection level.

[b] Chloride blank analyzed twice and both times chloride was above the laboratory reporting level at approximately 0.04 mg/L.

the predictive variables. A summary of the load models and load model statistics for TN at the three sites is provided in table 10. Full model equations, diagnostic plots, and further supporting information on TN load model development are available in the USGS data release by Bunch (2021).

Models for total phosphorus and suspended-sediment loads for School Branch were evaluated; however, accurate estimates were not obtained. Estimating loads using rloadest methods has been shown to be less accurate for total phosphorus and suspended sediment, especially in smaller streams with variable streamflow, such as School Branch (Lee and others, 2019). During storm events, smaller streams experience a large change in discharge and concentration in a short period of time, resulting in a large variability of nutrient or sediment fluxes (Baker and others, 2004; Zarnetske and others, 2018). Small streams have also been shown to have higher variability in the relations between constituent concentration and discharge (Zhang and others, 2009). These changes may be hard to account for when load models are based on discrete sampling and discharge, because the rapid changes are likely missed and can potentially lead to biased estimations of loads (Cohn and others, 1989; Lee and others, 2019). Kelly and others (2018) compared uncertainty in load models that used discharge and concentration for nutrients and sediment in streams dominated by agricultural land use and found that nitrate had the least uncertainty in annual load estimates, whereas suspended sediment had the highest, similar to School Branch. Higher resolution data are needed in small flashy streams such as School Branch to capture the variability and reduce uncertainty. Fifteen-minute discharge values for each of the three School Branch sites were used as input in the developed rloadest models to estimate total nitrogen loads (TNL). Total nitrogen yields were calculated by dividing the load by the contributing drainage-basin area.

The monthly TNLs did not show the same trends each year and did not always show the same patterns for the three sites (fig. 11). Because the TNL is closely linked to discharge, differences in the loading patterns among the sites could be due to differences in the hydrology caused by land use. Soil retention affected by subsurface tile drains or impervious surfaces in the contributing watershed could lead to differences in the timing and magnitude of discharge changes during higher flows. Land-use practices that alter the amount of base flow could also influence the loading of TN during drier conditions. Though the total annual precipitation was similar for all 3 years, the monthly precipitation patterns were not. In 2017, there were 3 months during the growing season that had more than 6 in. of rain (April, May, and July). In contrast, during water years 2016 and 2018, rainfall amounts were more evenly distributed throughout the year with only 1 month in water year 2016 (December) and 1 month in water year 2018 (September) that had 6 in. or more. The higher amounts of rain in April and May of water year 2017 resulted in longer periods of higher flows and higher monthly TNLs, especially for the most downstream station, Noble Dr. (fig. 11).

Annual TNLs at the three stations were estimated for each water year (table 10, fig.12A). The increase in TNL from the upstream site to the downstream site is to be expected because streamflow increases going downstream, and the amount of discharge can drive load values. Additionally, the downstream contributing land area is higher than the upstream contributing land area, which also could increase the possible sources of TN to the stream. The annual precipitation in the watershed was similar at 40.4, 38.9, and 40.7 in. of rain for water years 2016, 2017, and 2018, respectively; therefore, when considering each year as a whole, precipitation does not seem to influence the loads (Indiana Geological and Water Survey [IGWS], 2020a, b). However, the timing of rain events for each year may have influenced the loads. Water year 2018 had the lowest TNL for all three sites (table 10). In 2018, the percentages of agricultural land use consisting of corn in the contributing watersheds were the lowest for all sites, and the percentage of soybeans was the highest (table 2). Soybean plants can fixate nitrogen from the atmosphere and require less fertilizer than corn. The larger percentage of soybeans in the watersheds in 2018 may have led to lower fertilizer application in the watershed, hence lower loads of TN. The trend of more corn in 2016 and more soybeans in 2018 may be why decimal time minus center of decimal time for model calibration period (DECTIME) was a significant variable ($p < 0.05$) in the models. Although concentration of nitrogen in the water can influence the load, the amount of water plays a larger role in determining the load of a constituent.

Among the three stations, total nitrogen yield estimates were the highest for Maloney Rd. for all 3 water years (fig. 12B). The watershed size increases by 38.6 percent between Maloney Rd. and CR750N. When comparing the TNL at these two upstream sites, the annual load from the contributing land to School Branch increased by 26.9, 5.61, and 21.1 percent for water years 2016, 2017, and 2018, respectively. This annual difference in load contribution indicates that the increase in watershed size did not result in a proportionate increase in the load from the land draining between Maloney Rd. and CR750N, especially in 2017; and instead, might indicate that the land between Maloney Rd. and CR750N is contributing less TN per acre than the land above Maloney Rd. The agricultural land in the watershed upstream from Maloney Rd. is managed using mainly conventional methods, where most of the agricultural land between the two sites is managed under the BMPs of no-till, cover crops, and precision application of fertilizers.

Potential Sources of Water and Contaminants

Multiple methods were used to better understand the sources of water and contaminants in the School Branch watershed. Nested groundwater wells that monitored water elevation and temperature, hydrograph separation modeling of the stream, and major ions and water isotope samples from groundwater and surface water, were used to investigate the connectivity of surface water and groundwater. Storm event dynamics of continuous water-quality properties and constituents were investigated to try to determine pathways that nutrients and sediment were taking to enter the stream during runoff events. Isotope signatures were used for nitrogen source tracking. Lastly, passive samplers were used to determine the presence of wastewater indicator compounds in the stream that could be linked to possible septic influence.

Groundwater and Surface-Water Interaction

Groundwater levels measured in nested monitoring wells and surface-water levels measured in School Branch were used to characterize hydraulic gradients near the stream (fig. 3). Water levels in School Branch were not measured directly at the site of the monitoring-well transect, but were instead measured at the gage, 200 ft downstream. This prohibited direct computation of a hydraulic gradient between groundwater and surface water. However, the water surface slope of the stream at CR750N is minimal (stream gradient from CR750N to 150 m upstream was 0.0005 at low flow in 2016), so analysis of the data is still useful in assessing hydraulic gradient in the stream. Hydraulic gradients are an indication that conditions are favorable for groundwater to flow to or from School Branch. Vertical hydraulic gradients existed in both well pairs throughout the period of study. Groundwater levels in well DNW exceeded the levels in the shallow northwest well (SNW) except during drier conditions (fig. 13); for purposes of this evaluation, drier conditions were identified by the median groundwater level in SNW below approximately 886.6 ft. Water levels from the wells and the stream indicate that most of the time hydraulic gradients showed the potential for flow from the deeper geologic deposits toward the shallower geologic deposits and School Branch. Vertical gradients were occasionally reversed, such as during November 2015 and October 2017 to January 2018, when groundwater levels were higher in SNW than DNW.

Table 8. Results of quality-control replicates for nutrients, major ions, and suspended-sediment samples in School Branch study area, water years 2016 through 2018.

[CR750N, County Road 750 North; Dates shown as month/day/year; Rd., Road; DNW, deep northwest well; RPD, relative percent difference; %, percent; mg/L, milligram per liter; N, nitrogen; <, less than; n.a., not applicable; P, phosphorus; --, not collected; µg/L, microgram per liter; mm, millimeter; sd, sieve diameter]

Constituent	CR750N 05/31/2016			Maloney Rd. 08/04/2017			Maloney Rd. 04/03/2018			CR750N 04/03/2018			Maloney Rd. 05/23/2018			CR750N 05/23/2018			DNW 07/16/2018		
	Replicate 1	Replicate 2	RPD, in %	Replicate 1	Replicate 2	RPD, in %	Replicate 1	Replicate 2	RPD, in %	Replicate 1	Replicate 2	RPD, in %	Replicate 1	Replicate 2	RPD, in %	Replicate 1	Replicate 2	RPD, in %	Replicate 1	Replicate 2	RPD, in %
Nutrients																					
Ammonia, in mg/L as N	0.09	0.09	0	0.14	0.14	0	0.08	0.08	0	0.04	0.04	0	0.09	0.09	0	0.07	0.07	0	0.29	0.29	0
Nitrate + nitrite (NOx), in mg/L as N	3.54	3.54	0	1.66	1.65	1	0.992	0.973	2	0.664	0.686	3	2.73	2.68	2	3.16	3.15	0	<0.040	<0.040	n.a.
Nitrite, in mg/L as N	0.078	0.078	0	0.060	0.060	0	0.008	0.008	0	0.007	0.006	15	0.050	0.051	2	0.069	0.070	1	<0.001	0.002	n.a.
Orthophosphate (orthoP), in mg/L as P	0.052	0.051	1.9	0.100	0.110	9.5	0.216	0.221	2.3	0.168	0.167	0.6	0.049	0.050	2.0	0.039	0.040	2.5	0.015	0.010	40.0
Total phosphorus (TP), in mg/L as P	0.073	0.071	2.8	0.140	0.130	7.4	0.878	0.888	1.1	0.748	0.710	5.2	0.080	0.079	1.3	0.064	0.064	0	0.010	0.011	9.5
Total nitrogen (TN), in mg/L as N	3.94	3.83	2.8	2.31	2.27	1.7	2.89	2.75	5.0	1.97	2.31	15.9	3.06	3.17	3.5	3.54	3.46	2.3	0.38	0.37	2.7
Major ions																					
Calcium, in mg/L	82.9	84.2	1.6	--	--	--	--	--	--	--	--	--	73.1	75.5	3.2	70.3	73.5	4.5	79.4	80.6	1.5
Chloride, in mg/L	22.9	22.9	0	--	--	--	--	--	--	--	--	--	26.1	26.1	0	22.7	22.7	0	5.16	5.19	0.6
Fluoride, in mg/L	0.15	0.15	0	--	--	--	--	--	--	--	--	--	0.17	0.17	0	0.16	0.16	0	1.29	1.30	0.8
Iron, in µg/L	8.3	8.3	0	--	--	--	--	--	--	--	--	--	22.4	26.4	16	13.3	15.8	17	1430	1410	1.4
Magnesium, in mg/L	24.2	25.0	3.3	--	--	--	--	--	--	--	--	--	22.9	23.7	3.4	22.4	23.0	2.6	28.8	28.7	0.3
Manganese, in µg/L	25.8	27.2	5.3	--	--	--	--	--	--	--	--	--	156.4	165.8	5.8	21.4	22.8	6.3	63.2	62.9	0.5
Potassium, in mg/L	1.11	1.14	2.7	--	--	--	--	--	--	--	--	--	1.34	1.35	0.7	1.33	1.38	3.7	1.38	1.37	0.7
Silica, in mg/L	11.3	11.7	3.5	--	--	--	--	--	--	--	--	--	8.55	9.12	6.5	8.55	8.81	3.0	20	20	0
Sodium, in mg/L	8.17	8.62	5.4	--	--	--	--	--	--	--	--	--	11.67	11.96	2.5	8.99	9.05	0.7	20.9	20.7	1
Sulfate, in mg/L	28.1	28.2	0.4	--	--	--	--	--	--	--	--	--	16.4	16.4	0	19.7	19.7	0	12.1	12.1	0
Suspended sediment																					
Suspended sediment <0.0625, in mm, sd	--	--	--	--	--	--	90	91	1.1	82	83	1.2	97	100	3.0	92	100	8.3	--	--	--
Suspended-sediment concentration, in mg/L	--	--	--	--	--	--	556	467	17.4	435	429	1.4	4	3	28.6	3	2	40.0	--	--	--

Table 9. Continuous water-quality data summary for County Road 750 North (03353420) supergage for School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

[°C, degree Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; FNU, Formazin Nephelometric Unit; N, nitrogen; P, phosphorus; <, less than; DL, detection level]

Water-quality property or constituent	Units	Summary statistic			
		Minimum	Maximum	Median	Mean
Water temperature	°C	−0.2	28.2	12.8	12.8
Specific conductance	µS/cm	65	1,120	582	572
pH	standard units	6.4	9.2	7.8	7.8
Dissolved oxygen	mg/L	0.1	23.7	9.1	9.4
Turbidity	FNU	0.1	1,550	5.4	12
Nitrate plus nitrite, as N	mg/L	0.03	29.4	2.84	2.8
Orthophosphate, as P[a]	mg/L	<DL	0.57	0.03	0.06

[a] Orthophosphate data through November 27, 2017.

Throughout the study period, even during peak streamflows, the water levels in DNW and SNW were higher than the water level of School Branch at the CR750N gage.

Groundwater levels in well DNE exceeded levels in well SNE throughout the study period, except during some hydrograph peaks when groundwater levels in SNE would briefly exceed those in DNE (fig. 14). During most of the year, hydraulic gradients indicated the potential for flow from the deeper geologic deposits toward the shallower geologic deposits and School Branch. When these gradients are reversed and stream elevation is above groundwater elevation there is potential for flow from surface to groundwater.

Groundwater temperatures in shallower wells showed greater annual variability than deeper wells and indicated thermal stratification related to seasonal warming and cooling at land surface (fig. 15, table 11). Further, the temperature variability in wells on the east side of School Branch was greater than observed in the corresponding wells on the west side, likely because the east-side wells were shallower than the wells on the west side of the stream (fig. 15, tables 3 and 11). Plotted lines of groundwater temperatures for shallower wells were less smooth and more closely followed the pattern of surface-water temperatures than the deeper wells did indicating greater connectivity to processes occurring at land surface (fig. 15).

Major Ions in Surface Water and Groundwater

Major ion samples from the DNW groundwater well and the three surface-water sites were used to assess the groundwater and surface-water connection. Surface-water samples were collected over a range of streamflows, and groundwater samples were collected within plus or minus 1 day of the surface-water sample. Samples were dominated by the calcium cation and the bicarbonate anion (measured by alkalinity titration) (table 6). When the major ion results were plotted on a piper diagram (Piper, 1944), all sample data regardless of site or sample date were grouped together in each section of the plot (fig. 16). This grouping indicates a common water composition and source.

Hydrograph Separation

Hydrograph separation was done on streamflow data collected at the three streamgages on School Branch to determine the amount of streamflow that comes from groundwater or the percent of daily base flow. The hydrograph separation analyses did not specifically account for subsurface tile drains when assessing base flow. It is known that tiles are in the basin, though the influence of tile flow is not completely understood at this time. It is assumed that tile flow was included as base flow in the hydrograph separation analysis.

The uses of quantified base flow include an improved understanding of processes affecting water quality and ecosystem health in the School Branch watershed. Hydrograph separation analyses identified variability in base flow related to estimation method, site characteristics, and water year. Results of the six methods for hydrograph separation showed that some methods consistently estimated relatively higher or lower base flows than other methods. The median estimated daily base flow as a percentage of total flow varied notably among methods (fig. 17). The median base flow estimated using PART was highest in all cases and ranged from 93.5 to 97.4 percent of the total streamflow. The median base flow computed using the HYSEP methods ranged from 81.8 to 92.0 percent. The median base-flow estimates computed using the Base-Flow Index methods were consistently the lowest and ranged from 51.3 to 63.1 percent.

The magnitudes and general trends in estimated percentage of daily base flow were similar at the three School Branch sites and ranged from less than 2 to 100 percent of the total streamflow for all six methods at the three sites (fig. 17). The range of median estimated percentage of daily base flow at the

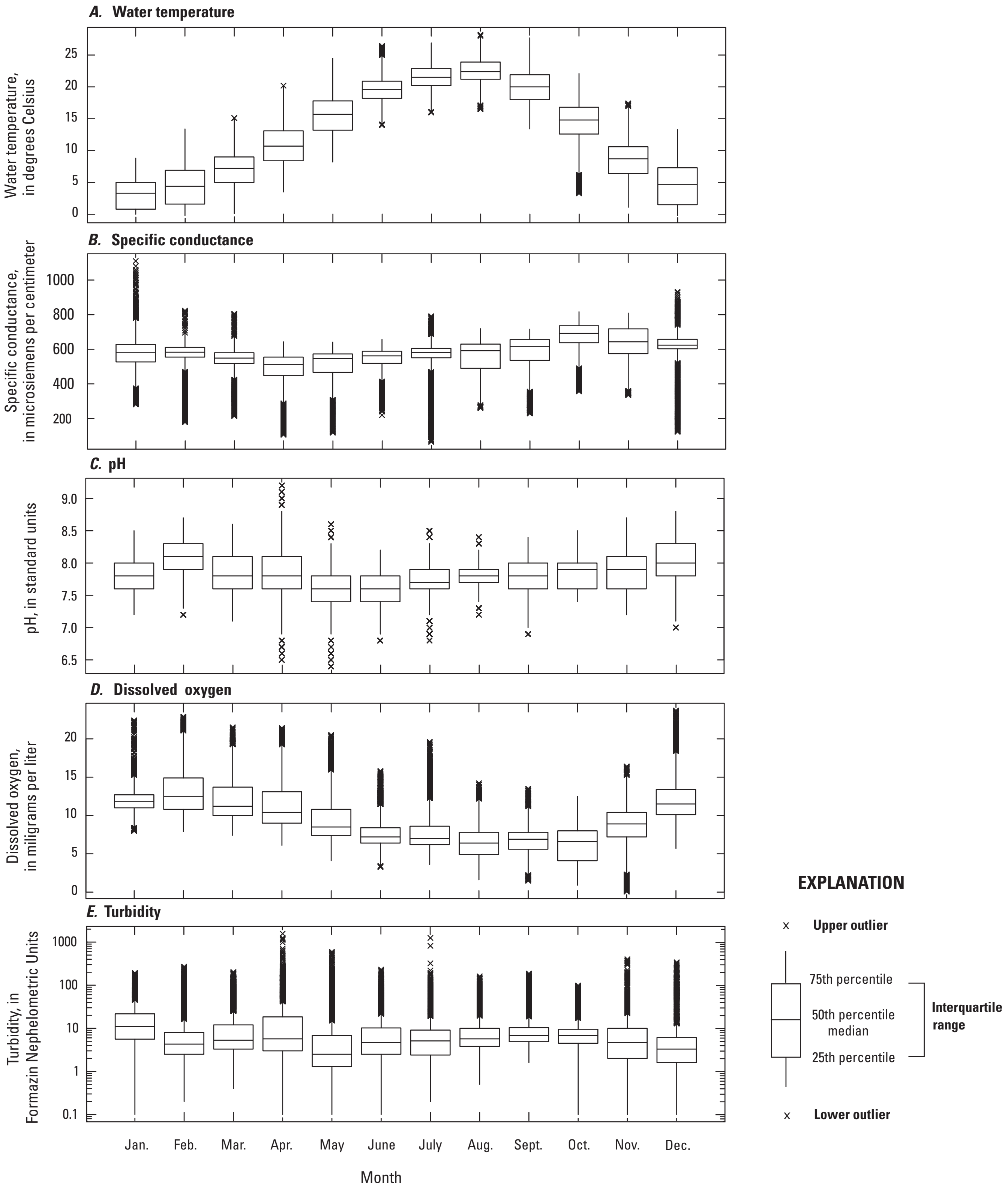


Figure 9. Graphs showing a summary by month of continuous water-quality properties (15-minute data) collected by a five-parameter sonde at School Branch at County Road 750 North at Brownsburg, Indiana, for water years 2016 through 2018: *A*, water temperature; *B*, specific conductance; *C*, pH; *D*, dissolved oxygen; and *E*, turbidity.

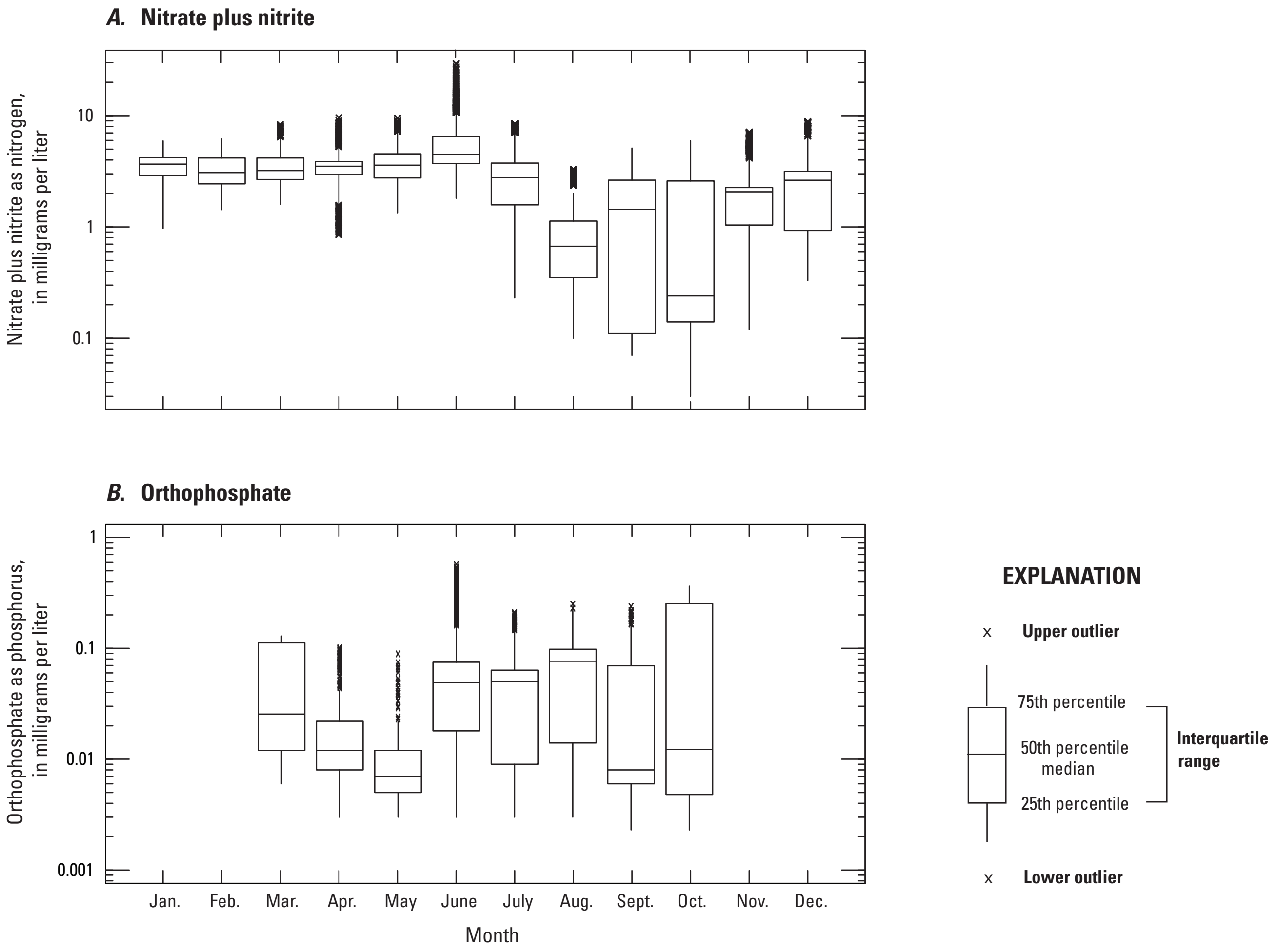


Figure 10. Graphs showing a summary by month of continuous nutrient values collected by a *A*, nitrate monitor and *B*, orthophosphate sensor for School Branch at County Road 750 North at Brownsburg, Indiana, for water years 2016 through 2018.

Table 10. Load model summary and estimated annual loads for total nitrogen at three stations in School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

[n, number of samples used in model calibration; *Bp*, load bias percentage; *PLR*, partial load ratio; *E*, Nash Sutcliffe efficiency index; TN, total nitrogen; Rd., Road; ln, natural log; *Q*, discharge minus the center of discharge for model calibration period; DECTIME, decimal time minus center of decimal time for model calibration period; CR750N, County Road 750 North; Dr., Drive]

Site	n	rloadest model number	Model coefficients	*Bp*	*PLR*	*E*	Annual TN load per water year (tons)		
							2016	2017	2018
Maloney Rd.	48	5	ln$Q$, lnQ^2, DECTIME	7.06	1.07	0.910	25.4	24.9	14.8
CR750N	47	5	ln$Q$, lnQ^2, DECTIME	4.14	1.04	0.930	32.2	26.3	18.0
Noble Dr.	42	5	ln$Q$, lnQ^2, DECTIME	2.44	1.02	0.910	45.0	51.1	26.6

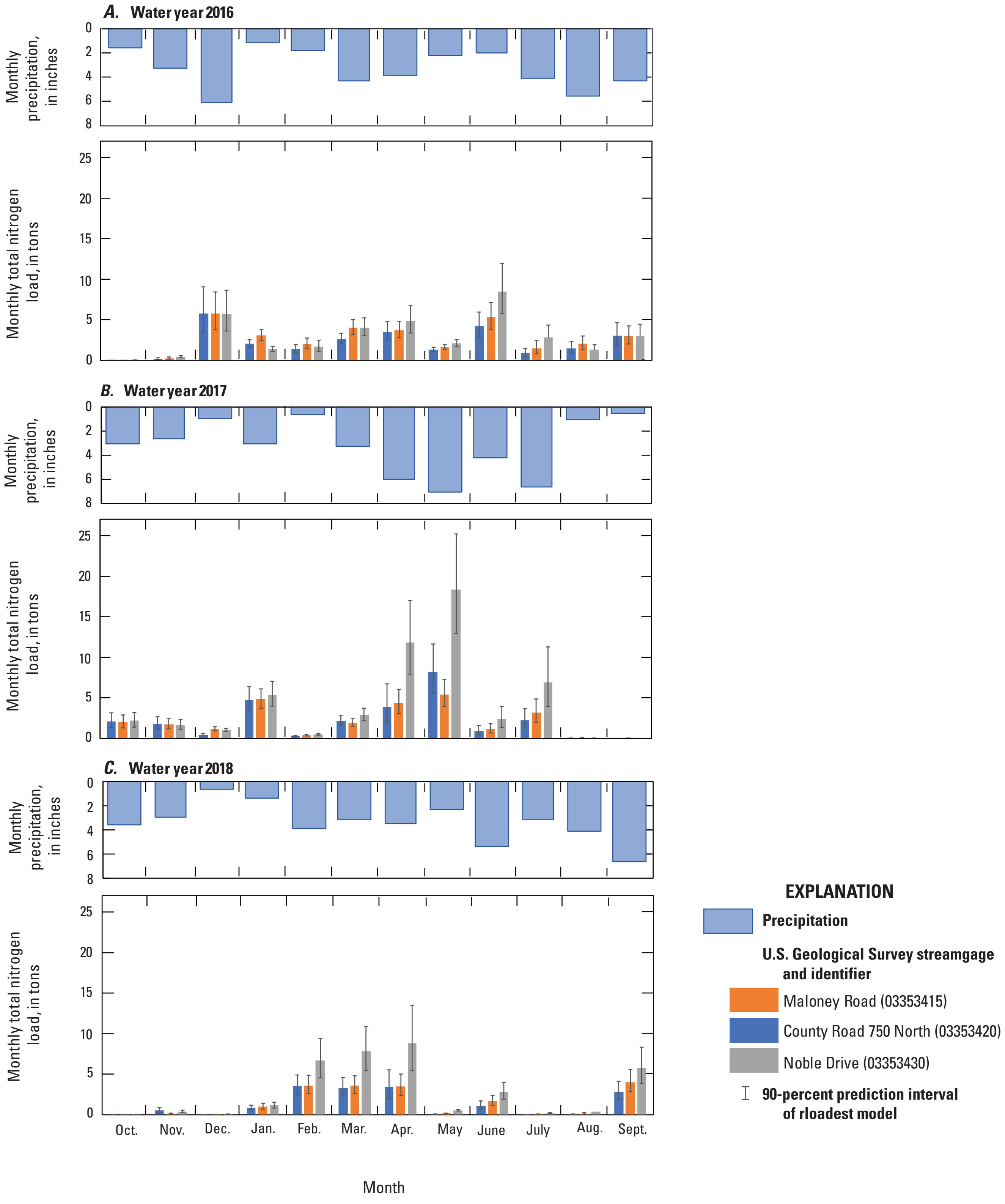


Figure 11. Graphs showing monthly estimated total nitrogen loads using rloadest models and precipitation from the Indiana Geological and Water Survey water balance network (Indiana Geological and Water Survey, 2020a) for water years *A*, 2016; *B*, 2017; and *C*, 2018 for the three stations in the School Branch study area, Hendricks County, Indiana.

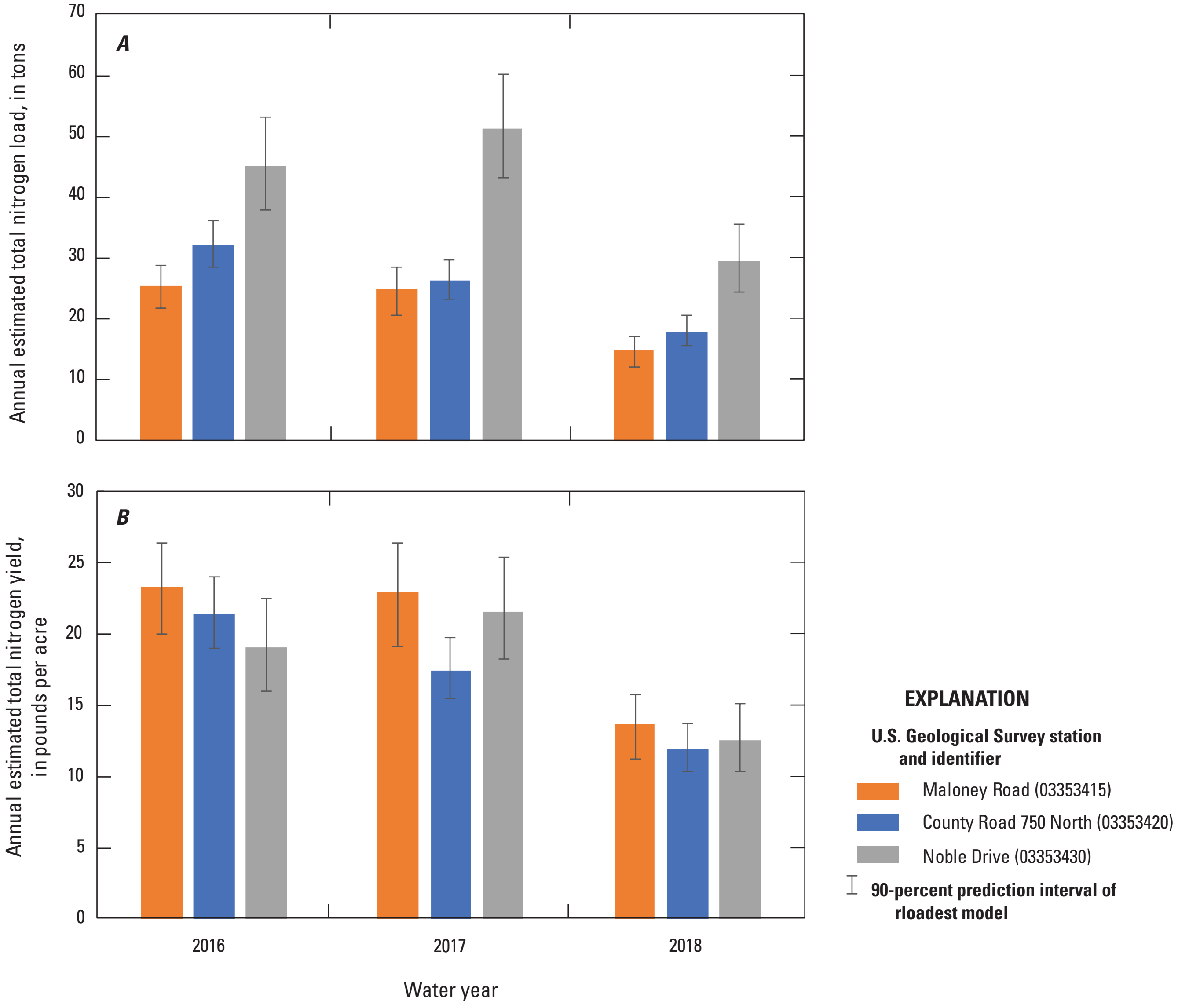


Figure 12. Graphs showing annual total nitrogen of *A*, estimated loads and *B*, estimated yields using rloadest for the three stations in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

CR750N streamgage (62.9 to 97.4 percent of total streamflow) was slightly higher than the ranges at Maloney Rd. (51.3 to 93.5 percent) and Noble Dr. (53.3 to 93.7 percent). The higher estimated percentage of daily base flow at CR750N may result from watershed characteristics that include a greater density of tile-drain outfalls and enhanced infiltration rates that result from conservation tillage practices. A minimum of 26 tile drains have been visually identified in the School Branch reach between Maloney Rd. and CR750N. The number of agricultural-tile drains upstream from the Maloney Rd. surface-water gage is uncertain. The land surrounding the reach between CR750N and Noble Dr. is more urbanized than upstream reaches and may have a less dense network of agricultural drains.

The temporal distribution of estimated base flow was inconsistent during water years 2016 through 2018 (fig. 18). Factors affecting the temporal distribution of base flow are precipitation, runoff, and subsequent streamflow. The periods with the highest percentage of base flow relative to total streamflow coincide with the periods of lowest streamflow and precipitation. Other factors that may affect seasonal base flow include the quantity, timing, and intensity of precipitation; the quantity and timing of snowmelt; the antecedent soil moisture at the time of precipitation; the timing of crop growth and resultant plant transpiration; and the meteorological factors affecting evaporation. Data from a precipitation gage near the Maloney Rd. streamgage that is operated by the IGWS (IGWS, 2020a, b) measured 40.4, 38.9, and 40.7 in.

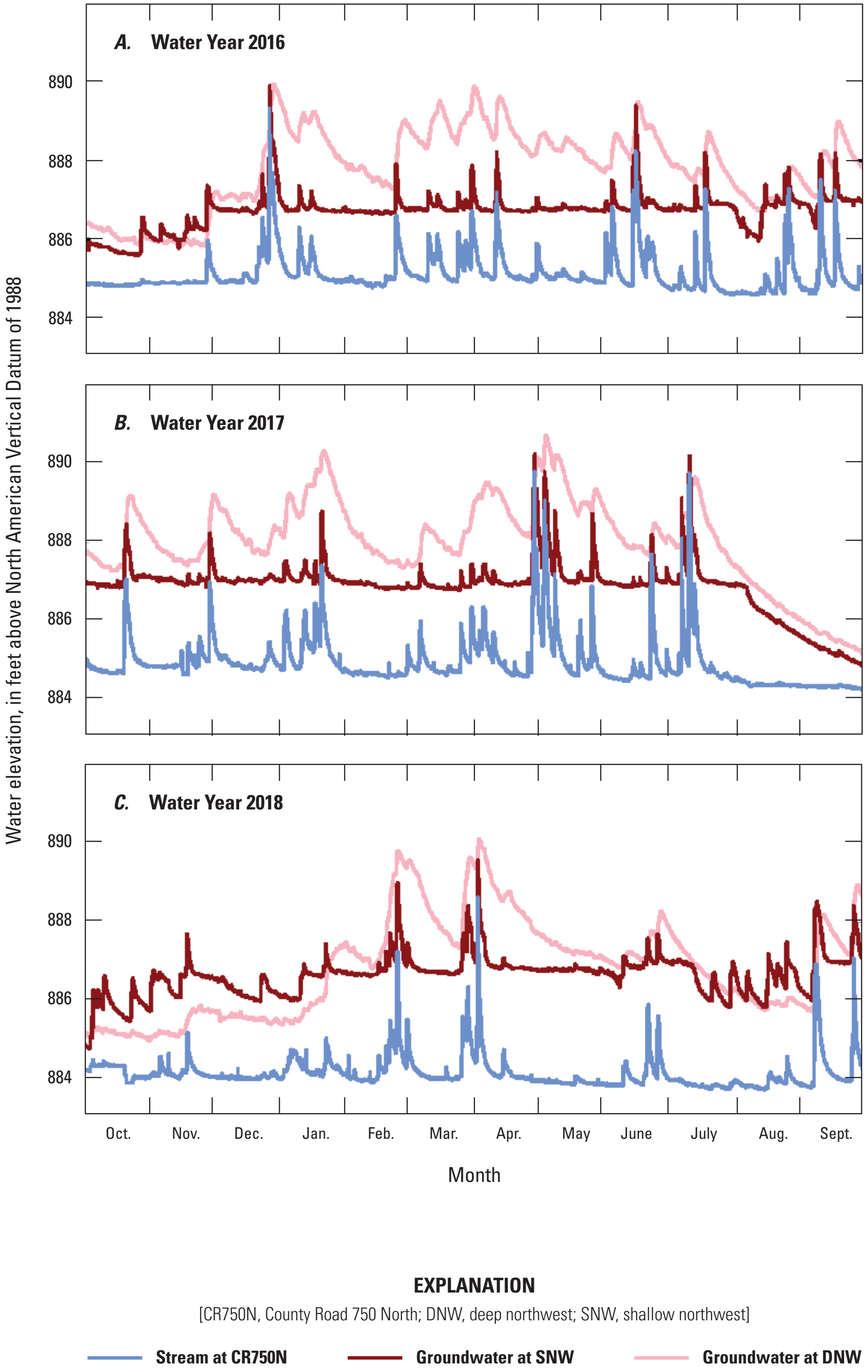


Figure 13. Graphs showing continuous water levels in the nested northwest groundwater wells and for School Branch at County Road 750 North (03353420) in the School Branch study area, Hendricks County, Indiana, from water year *A*, 2016; *B*, 2017; and *C*, 2018. The streamgage is approximately 200 feet downstream from the nested groundwater wells.

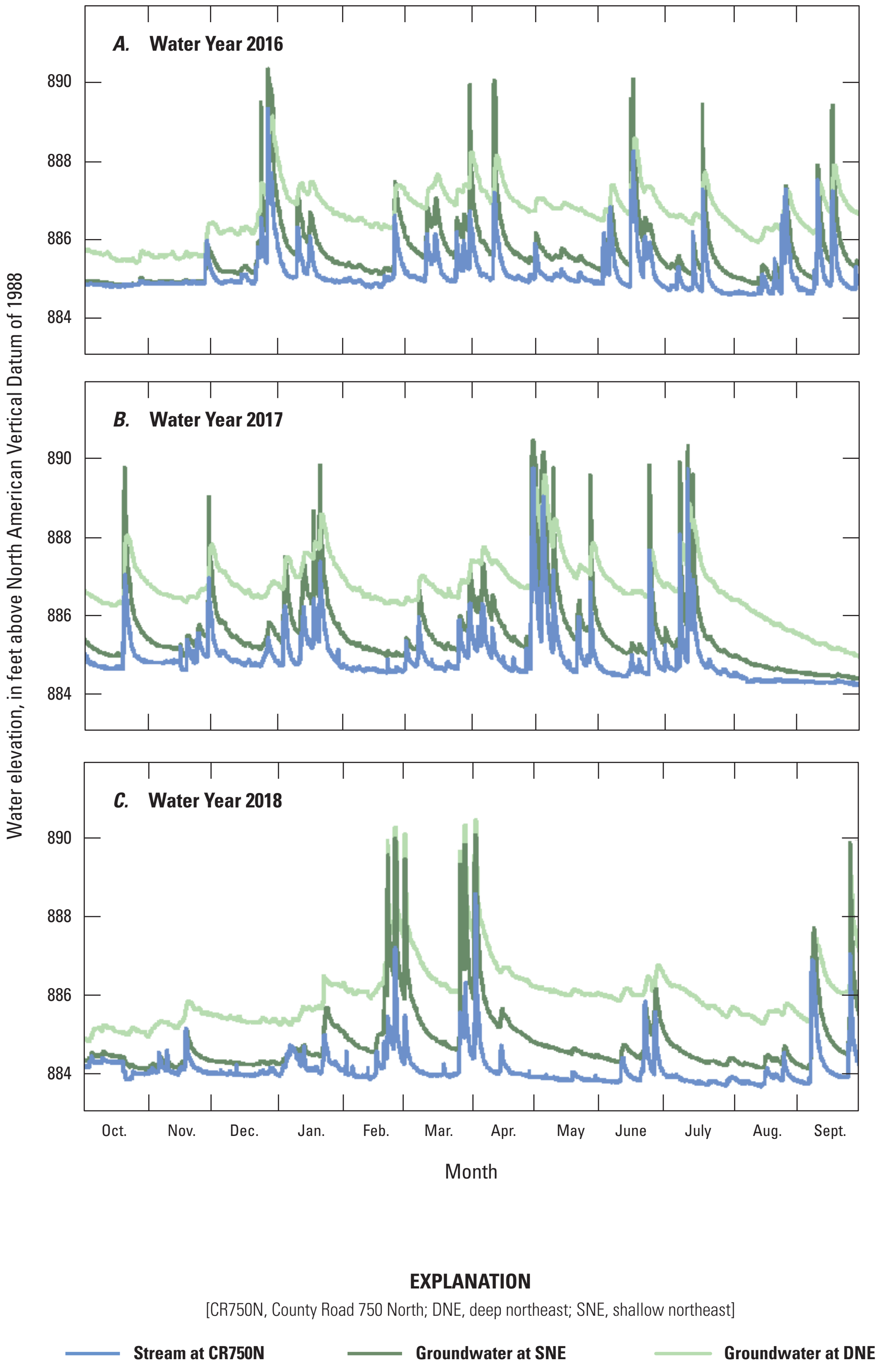


Figure 14. Graphs showing continuous water levels in the nested northeast groundwater wells and for School Branch at County Road 750 North (03353420) in the School Branch study area, Hendricks County, Indiana, from water year *A*, 2016; *B*, 2017; and *C*, 2018. The streamgage is approximately 200 feet downstream from the nested groundwater wells.

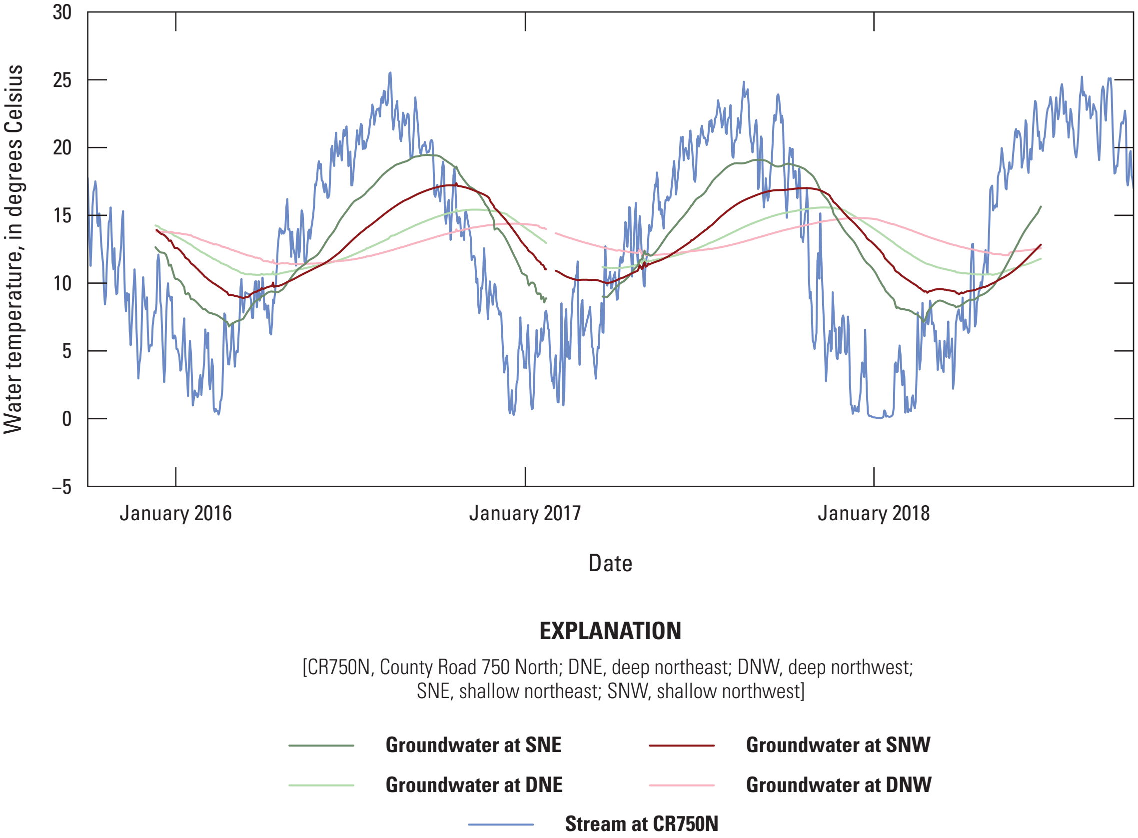


Figure 15. Graph showing continuous water temperatures for the four nested groundwater wells and stream water at County Road 750 North (03353420) for the School Branch study area, Hendricks County, Indiana, for water years 2016 through 2018. The streamgage is approximately 200 feet downstream from the nested groundwater wells.

Table 11. Summary statistics for continuous groundwater temperatures in the nested groundwater well pairs at School Branch in Hendricks County, Indiana, water years 2016 through 2018.

[USGS, U.S. Geological Survey; DNW, deep northwest well; SNW, shallow northwest well; DNE, deep northeast well; SNE, shallow northeast well]

Site	USGS station number	Well depth	Temperature, in degrees Celsius				Range
			Minimum	Maximum	Mean	Median	
DNW	395223086214202	25.2	11.4	14.8	13.0	12.9	3.4
SNW	395223086214201	12.5	8.90	17.4	12.8	12.2	8.5
DNE	395223086214204	19.7	10.6	15.6	12.9	12.7	5.0
SNE	395223086214203	8.30	6.79	19.5	13.3	12.7	12.7

of precipitation during water years 2016, 2017, and 2018, respectively. Although the temporal distribution of estimated base flow varied notably from year to year, similar increases and decreases in base flow between sites indicated that the factors affecting temporal distribution of base flow were generally consistent across all three watersheds. The daily base-flow percentage (base flow divided by total flow multiplied by 100) was averaged for the entire study period for all methods at each site (table 12). For all methods, CR750N consistently had slightly higher base-flow percentage. All methods estimated mean base-flow percent above 50 percent for all sites further indicating that the two reaches between the three streamgages gained flow from groundwater base flow or tile discharges through most of the study period.

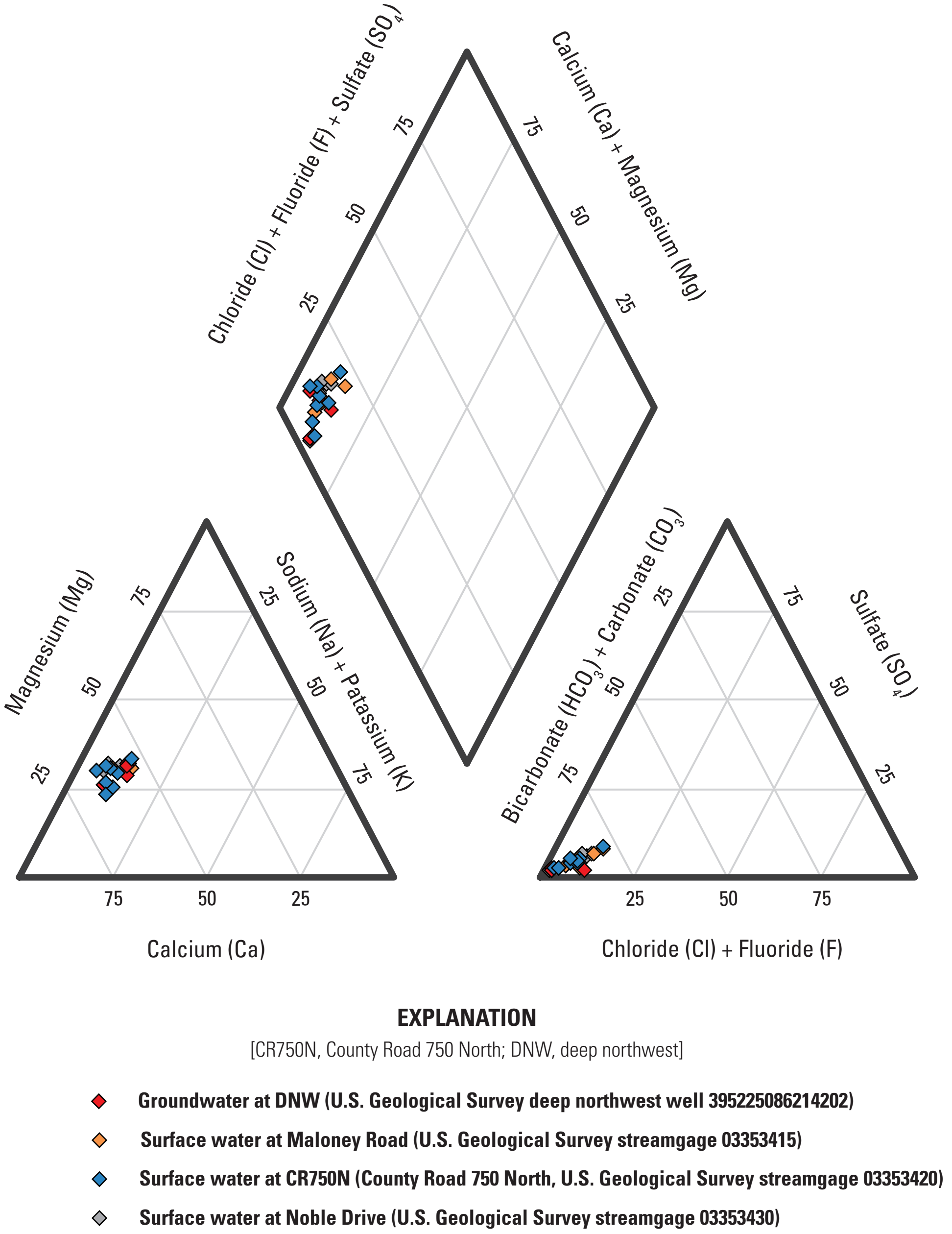


Figure 16. Diagram showing a comparison of relative percentages of major ions in groundwater and surface water from stations in the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018.

Changes in selected properties recorded by the continuous water-quality monitor from July 5 to July 15, 2017, illustrate the way School Branch reacts during a typical storm at CR750N during the growing season. Precipitation during this period is shown in figure 19A and is from a rain gage near School Branch operated by the IGWS (IGWS, 2020a, b). Typically, specific conductance decreased as discharge increased at the beginning of storm events and slowly recovered as discharge decreased after a storm event (fig. 19B). This is due to dilution because of the low specific conductance of rainwater and resulting runoff. Turbidity increased as discharge increased at the start of each event (fig. 19C). Higher turbidity is often the result of higher concentrations of suspended sediment in the stream. The sharp increase in turbidity at the beginning of a storm event displays the link between sediment in streams and runoff from overland

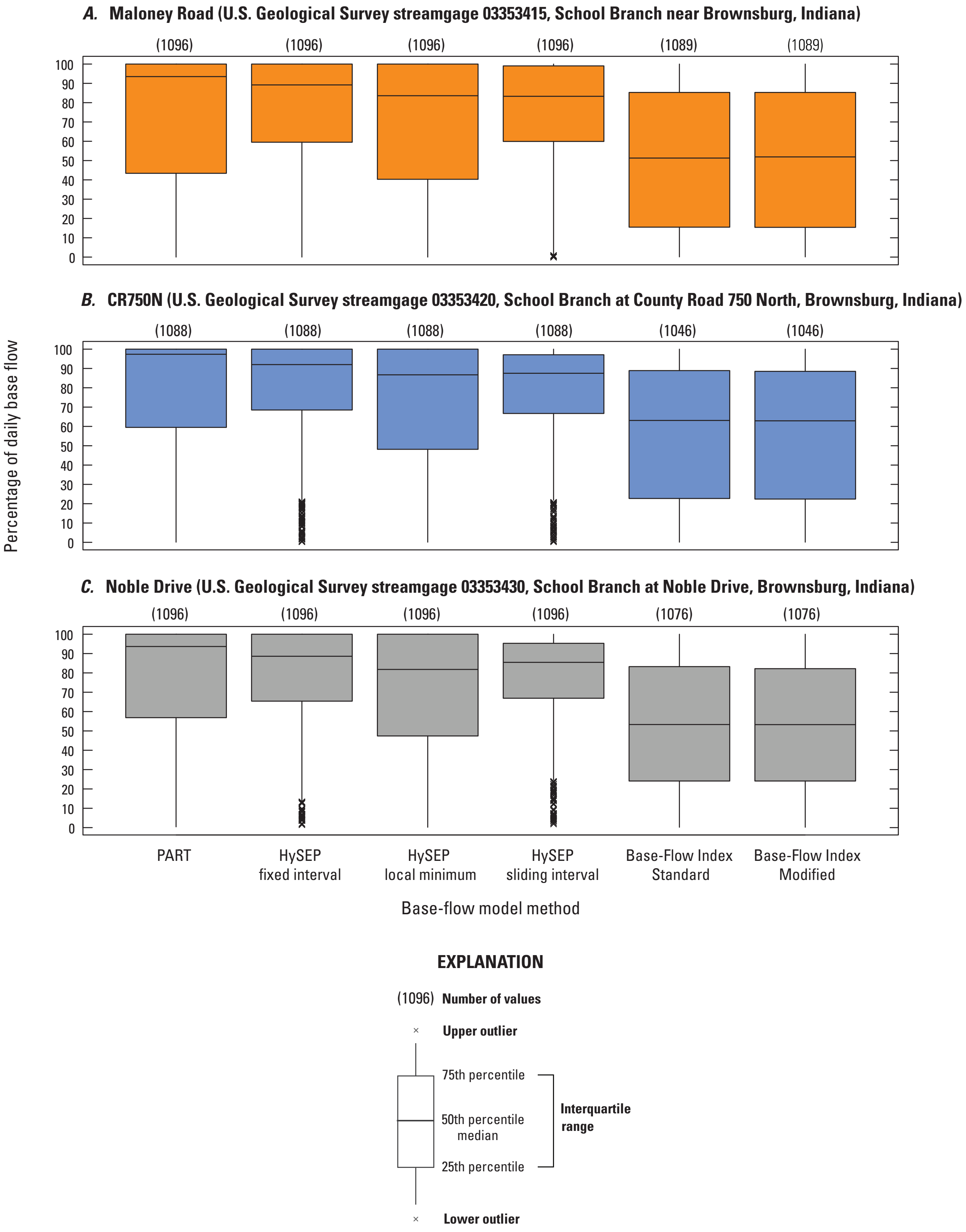


Figure 17. Boxplots showing daily base-flow percentage computed using six methods in the U.S. Geological Survey Groundwater Toolbox (Barlow and others, 2015) for water years 2016 through 2018 for *A*, School Branch at Maloney Road near Brownsburg, Indiana (03353415); *B*, School Branch at County Road 750 North at Brownsburg, Indiana (03353420); and *C*, School Branch at Noble Drive at Brownsburg, Indiana (03353430).

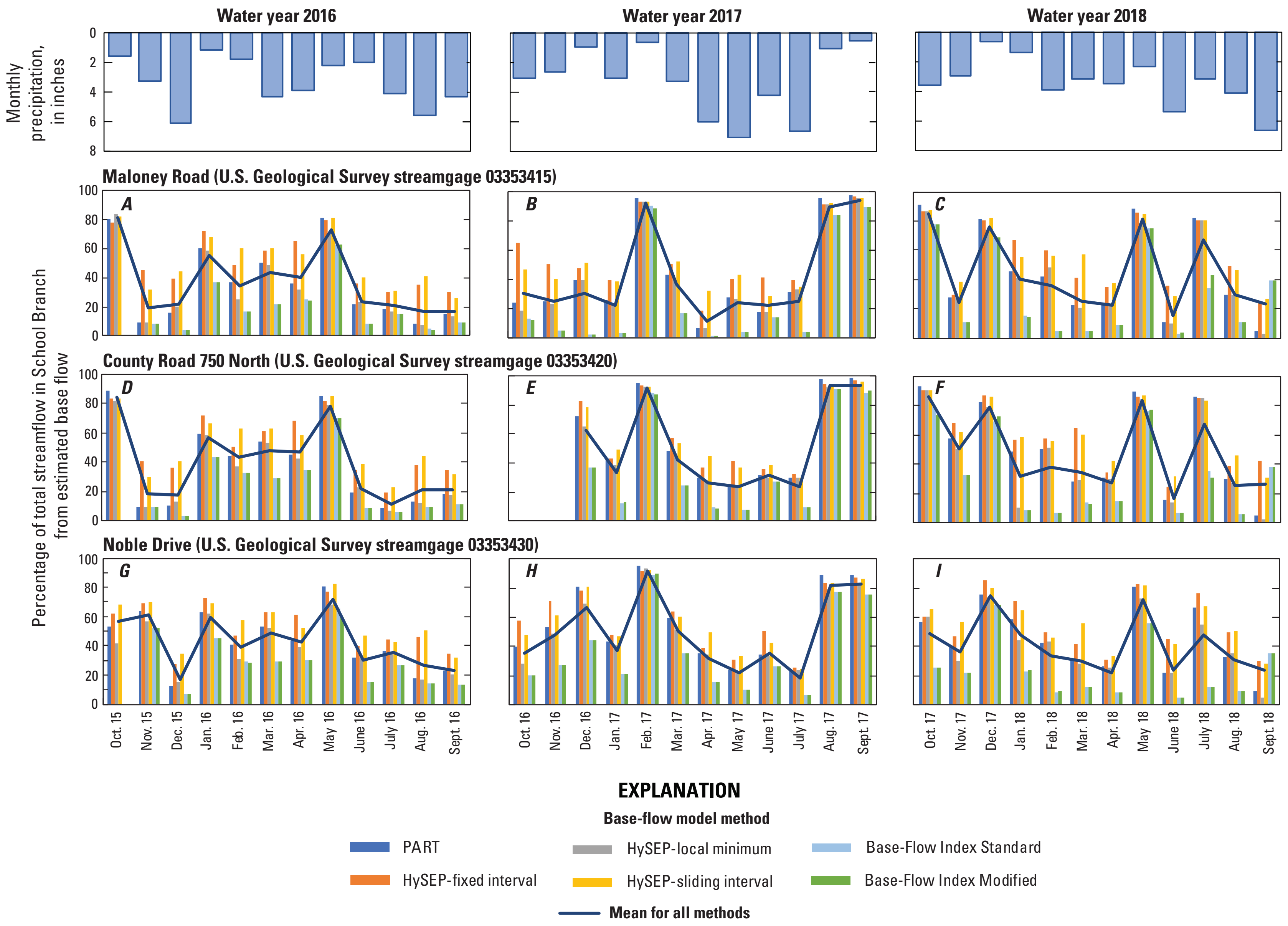


Figure 18. Plots showing monthly precipitation and estimated base flow at the three School Branch stations as a percentage of total streamflow computed using six methods in the U.S. Geological Survey Groundwater Toolbox (Barlow and others, 2015) during water years 2016 through 2018.

flow and resuspension of sediment from the stream bed due to increases in flow. NOx concentrations tended to have an initial decrease in concentration at the beginning of each runoff event (fig. 19D) that indicates NOx is diluted by initial runoff from overland flow and precipitation. After the initial runoff and the peak of streamflow, NOx concentrations increased above the prestorm levels; however, after each additional rain event, the spike of NOx concentrations was lower than previous events. OrthoP also increased with discharge, although it was not as closely linked to the beginning of the storm event (fig. 19E). There was a slight delay in the increased concentrations of orthoP. This delay in peak concentrations for orthoP and NOx may be linked to subsurface drainage from tile inputs of these nutrients. After a rain event, tile flow will typically be delayed and occur later than surface flow. The water must infiltrate through the soil before entering tile drains and reaching the stream. The response of orthoP and NOx concentrations from the continuous monitors during storm events indicates that subsurface drainage may be a larger source of these nutrients to streams than overland flow. In a study of another agriculturally dominated watershed in Indiana, investigators found similar results where tiles were the most important contributor of agricultural chemicals, including nutrients, to streams (Baker and others, 2006).

In contrast to a typical storm event in July 2017, the orthoP and NOx concentrations during the storm events in June 2016 (fig. 20) did not show an initial dilution or delay as discharge increased (fig. 20D and E). During the storm event on June 5, 2016, the continuous monitors recorded their peak nutrient concentrations of the 3-year study period: NOx (29.4 mg/L) and orthoP (0.57 mg/L) (table 9). Personal correspondence with farmers in the area indicated that fertilizer was applied to fields upstream from the supergage in late May 2016, just before the storms in early June. The large increase in NOx and orthoP concentrations at the start of each of the three following storm events indicates that fertilizer applied to the fields shortly before these events was flushed from the fields and may have contributed to the elevated nutrient levels in the stream.

Nitrogen Source Tracking

Understanding the sources of nutrients and other contaminants in a stream can help focus efforts to improve water quality. Identifying the sources of nitrogen in water can be difficult because there are multiple potential point and nonpoint sources and biological processes that can alter chemical concentrations (Kendall and others, 2007). Isotopes in nitrate (delta nitrogen-15 [$\delta^{15}N\text{-}NO_3$] and delta oxygen-18 of nitrate [$\delta^{18}O\text{-}NO_3$]) have been used to identify potential sources of nitrogen in water because different sources can have specific isotopic compositions; this isotopic analysis allows for a direct way to help identify sources of nitrogen in water (Kendall and others, 2007, Kendall and others, 2013).

The dual-nitrogen isotope signature can be used to separate the potential inorganic sources of nitrogen (atmospheric deposition and synthetic fertilizers) from organic sources (cover crops and plant composts or liquid and solid animal or septic waste) based on previously published ranges (Böhlke and others, 2003; Kendall and others, 2007; Xue and others, 2009; Kendall and others, 2013). This technique does have some limitations due to mixing of sources and instream nutrient processing (nitrification and denitrification) that can cause variability in the isotopic signature from the original source(s) (Panno and others, 2006; Kendall and others, 2007). Eight of the nine surface-water samples collected for each site had high enough concentrations of nitrate to allow for dual-nitrogen isotopic analysis of $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$. All groundwater samples had nitrate concentrations below the LRL (0.08 mg/L), so nitrate-isotope analysis was not possible. The results of the measured dual-nitrate isotopes for the three surface-water sites are shown in figure 21.

None of the sample concentrations showed a signature that would indicate atmospheric deposition from rainfall as a main source of nitrogen to the stream (fig. 21A). Nitrate concentrations in rainfall typically have a higher $\delta^{18}O\text{-}NO_3$ signature (greater than +60 per mil [‰]) (Kendall and others, 2007; Kendall and others, 2013). Additionally, the samples did not show a signature for either nitrate or ammonium from

Table 12. Base-flow percentage for the three streamgages on School Branch for the study period, water years 2016 through 2018.

[HySEP, hydrograph separation; BFI, Base-Flow Index; Rd., Road; CR750N, County Road 750 North; Dr., Drive]

Site	Base-flow percentage (ratio of base flow to streamflow multiplied by 100)					
	Hydrograph separation method (Barlow and others, 2015)					
	PART	HySEP fixed interval	HySEP local minimum	HySEP sliding interval	BFI-standard	BFI-modified
Maloney Rd.	72.74	76.79	69.14	74.89	51.04	51.17
CR750N	77.23	80.16	71.75	78.42	56.81	56.51
Noble Dr.	76.52	79.04	70.74	77.90	53.17	52.91

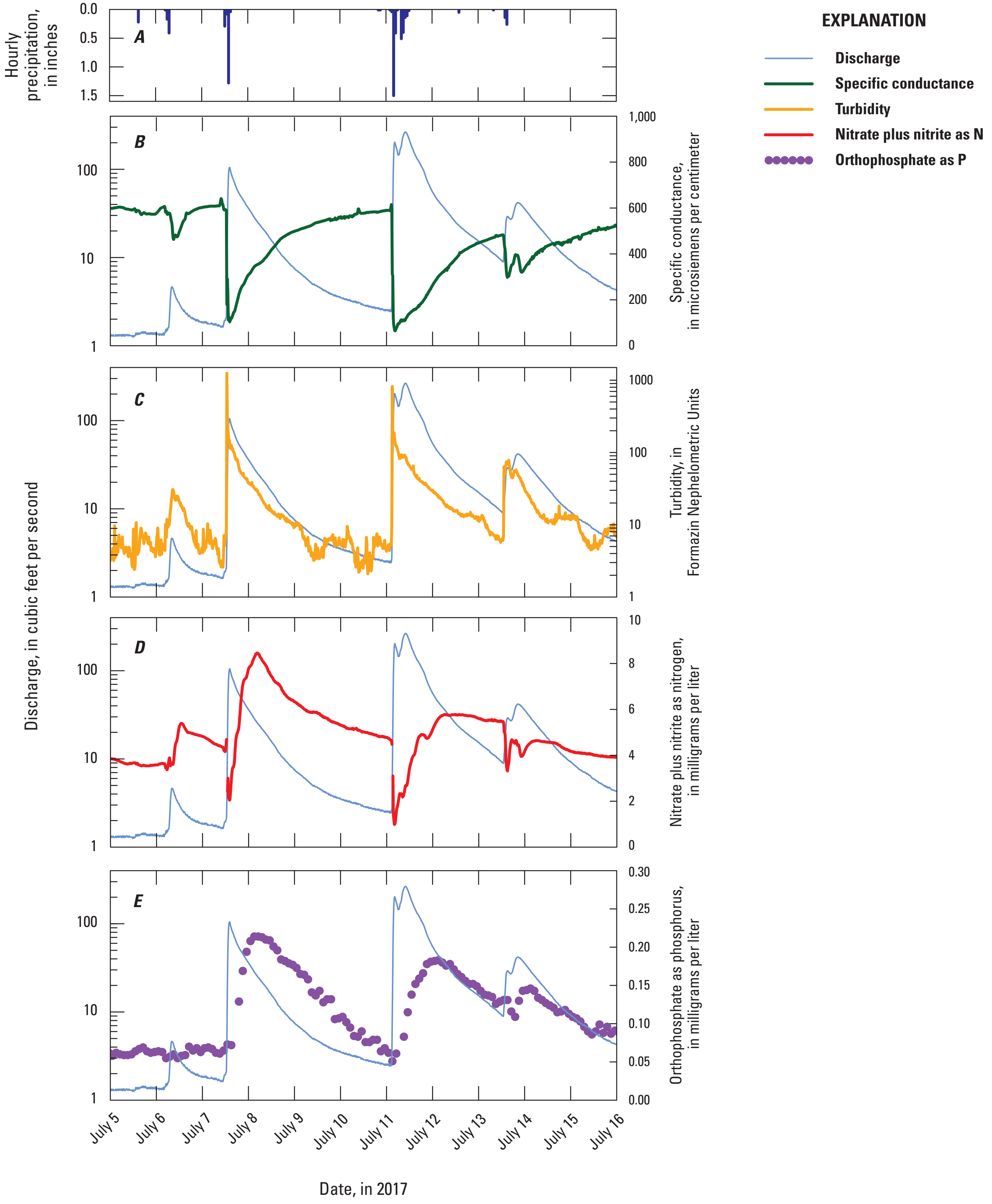


Figure 19. Graphs showing *A*, hourly precipitation and change in discharge and continuous water quality for *B*, specific conductance; *C*, turbidity; *D*, nitrate plus nitrite; and *E*, orthophosphate during storm events for School Branch at County Road 750 North at Brownsburg, Indiana (03353420), July 5 through July 15, 2017.

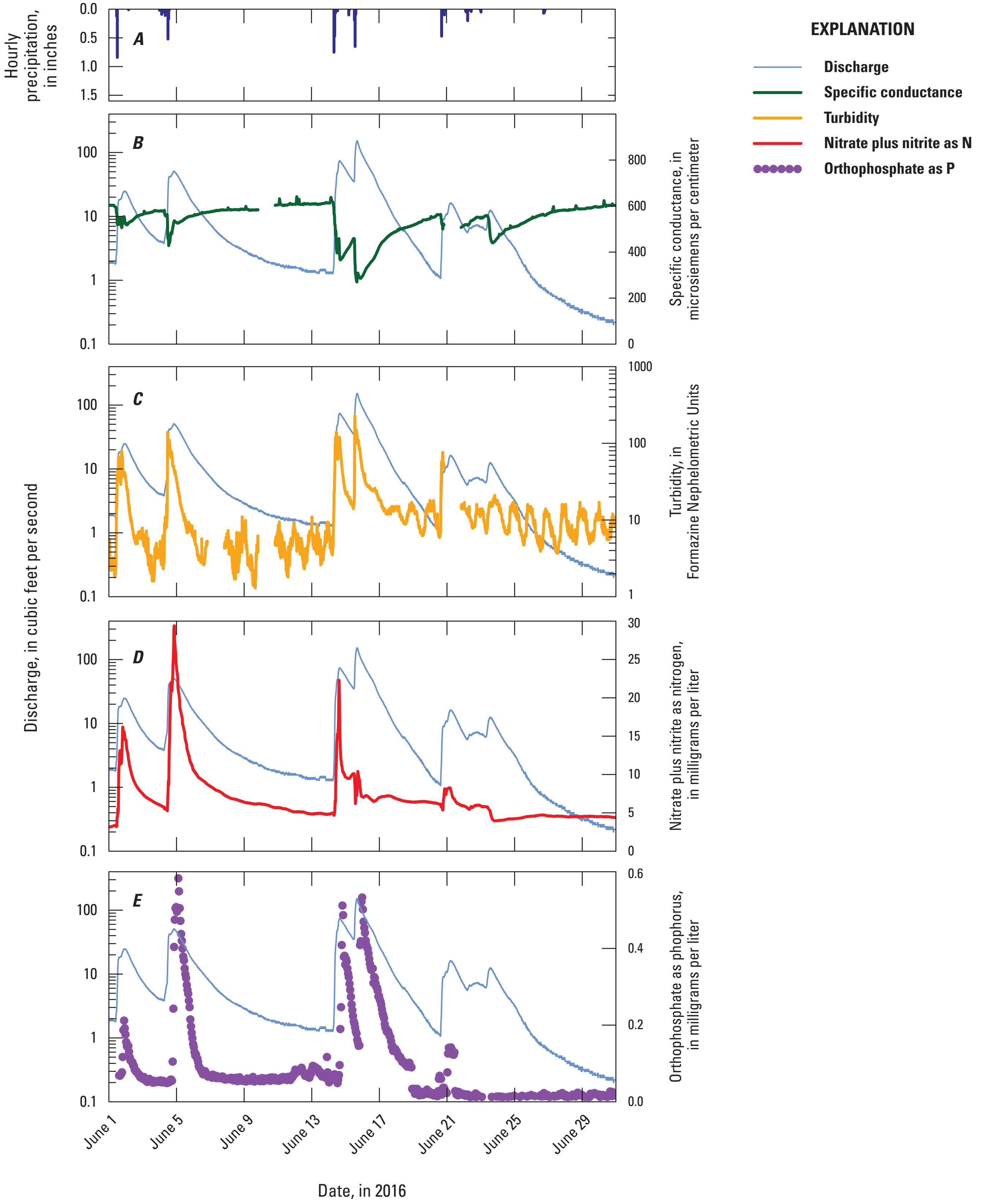
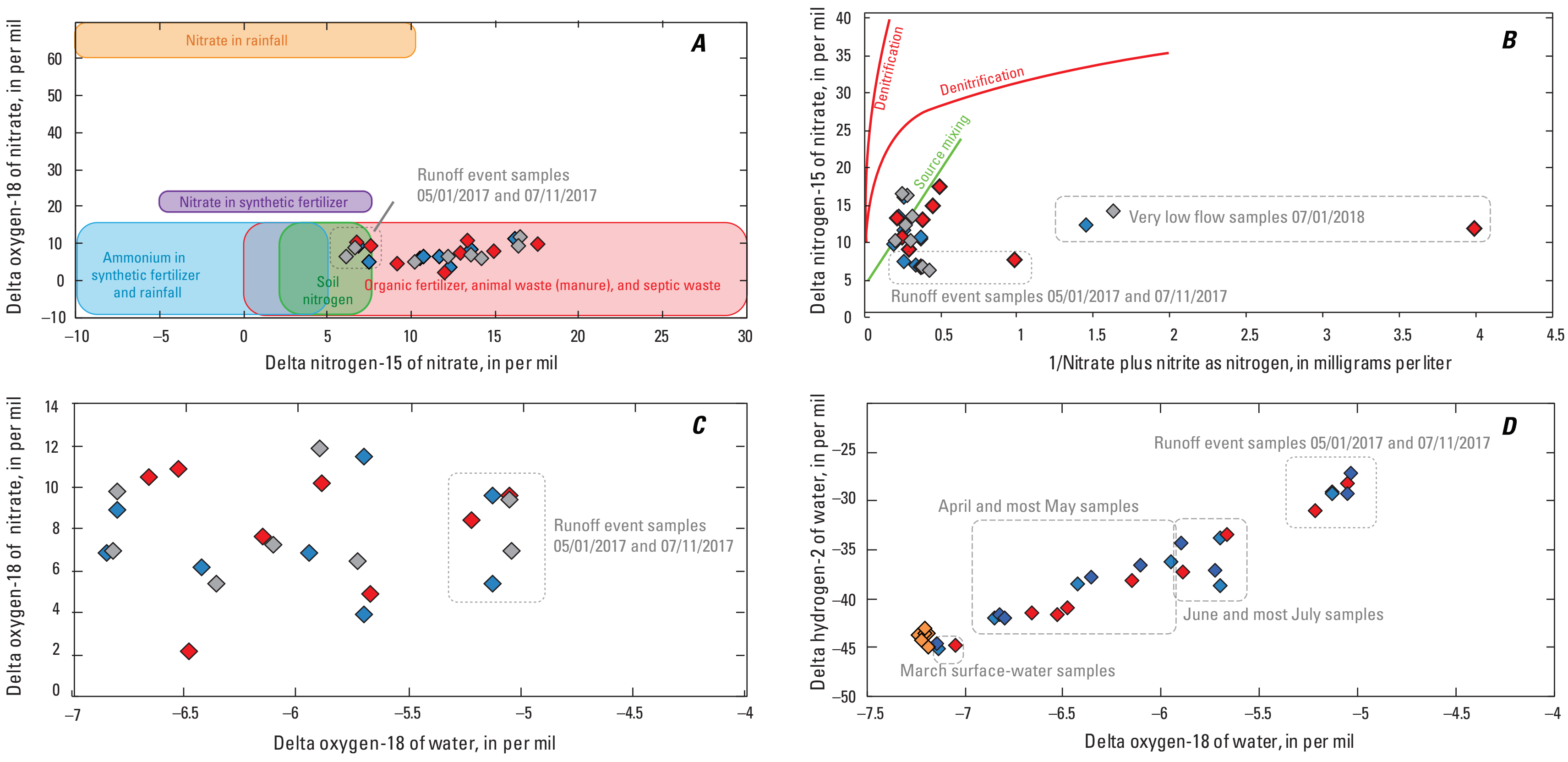


Figure 20. Graphs showing *A*, hourly precipitation and change in discharge and continuous water quality for *B*, specific conductance; *C*, turbidity; *D*, nitrate plus nitrite; and *E*, orthophosphate during storm events for School Branch at County Road 750 North at Brownsburg, Indiana (03353420), June 2016.



EXPLANATION

[MM, MONTH; DD, DAY; YYYY, YEAR; CR750N, County Road 750 North; DNW, deep northwest]

◆ **Groundwater at DNW (U.S. Geological Survey deep northwest well 395223086214202)**

◆ **Surface water at Maloney Road (U.S. Geological Survey streamgage 03353415)**

◆ **Surface water at CR750N (U.S. Geological Survey streamgage 03353420)**

◆ **Surface water at Noble Drive (U.S. Geological Survey streamgage 03353430)**

Figure 21. Graphs showing the results from stable isotope analysis measured in water samples collected from the School Branch study area, Hendricks County, Indiana, water years 2016 through 2018. *A*, stable nitrogen isotopes of nitrate (delta nitrogen-15 [$\delta^{15}N\text{-}NO_3$]) versus delta oxygen-18 of nitrate [$\delta^{18}O\text{-}NO_3$]); *B*, the inverse of nitrate water concentrations versus $\delta^{15}N\text{-}NO_3$ (modified from Mariotti and others, 1988); *C*, delta oxygen-18 of water ($\delta^{18}O\text{-}H_2O$) versus $\delta^{18}O\text{-}NO_3$; and *D*, delta oxygen-18 of water ($\delta^{18}O\text{-}H_2O$) versus delta hydrogen-2 of water ($\delta^2H\text{-}H_2O$).

synthetic fertilizers as a dominant source of nitrogen to the stream. Synthetic fertilizers tend to have higher $\delta^{18}O\text{-}NO_3$ signatures ranging from +17 to +25‰ or +46 to +48‰ depending on the fertilizer source (Böhlke and others, 2003; Vitoria and others, 2004). The samples for all three sites had $\delta^{18}O\text{-}NO_3$ values ranging from +2.19 to +11.87‰. All samples from the three sites had a $\delta^{15}N\text{-}NO_3$ signature indicative of either organic fertilizers (cover crops, plant composts or liquid, and solid animal waste) or septic waste. These sources typically have higher $\delta^{15}N\text{-}NO_3$ values ranging from +2 to +30‰ (Kendall and others, 2007). The samples for all three sites had $\delta^{15}N\text{-}NO_3$ values ranging from +6.18 to +17.57‰. There are no known applications of manure within the School Branch Basin (S. Zezula, NRCS, written commun., March 2020).

The samples for each of the three surface-water sites collected on May 1, 2017, and July 11, 2017, fall in the overlapping range of organic fertilizers or septic waste and nitrogen from soil (fig. 21A). Nitrate from soil sources typically have $\delta^{15}N\text{-}NO_3$ values ranging from +1 to +8‰ (Kendall, 1998; Kendall and others, 2013). The six samples that fall in the overlapping ranges for soil and organic fertilizer or animal (including human) waste had values of $\delta^{15}N\text{-}NO_3$ between +6.18 and +7.59‰. These samples were collected at higher discharges during a runoff event. The sample collected on May 1, 2017, occurred on the falling end of a runoff event, while discharge was still high but decreasing. The sample collected on July 11, 2017, occurred near the peak of a runoff event. It has been shown that shifts of several per mil in isotope signatures can happen with storm events because of washout of nitrogen bearing materials (Heaton, 1986), and might explain why the isotopic signatures of the samples collected during runoff events look different. The samples from the three surface-water sites collected on July 1, 2018, were outliers compared to the other samples and were collected at base-flow conditions.

Although results did not fall into generally accepted ranges for synthetic fertilizers, this does not mean that synthetic fertilizers are not a source of nitrogen to the watershed. Nitrogen cycling can alter the isotopic fractionation and mixing of multiple sources can obscure the original source signal of isotopes from nitrate. Nitrate concentrations, in conjunction with nitrate isotopes, have been used to further understand whether there is mixing of sources or if nutrient cycling is influencing isotopic signatures in surface and groundwater (Mariotti and others, 1988; Kendall and others, 2007). Past studies have determined that when plotting the inverse of nitrate concentrations against $\delta^{15}N\text{-}NO_3$, mixing of sources will yield a straight-line relation; and if denitrification is altering the original source signal, it will yield a curved relation. Fourteen of the 24 isotope samples in the School Branch watershed fall along the straight line that indicates source mixing. It can be inferred that the isotopic signatures are from a mixture of sources and not from the nitrogen cycling of one main source altering the signature (fig. 21B). The samples that do not fall along the line were those collected during runoff events on May 1, 2017, and July 11, 2017, and samples collected during base-flow conditions on July 1, 2018.

Stable isotopes of water (delta hydrogen-2 of water [$\delta^{2}H\text{-}H_2O$] and delta oxygen-18 of water [$\delta^{18}O\text{-} H_2O$]) were also collected from 3 surface-water stations and 1 groundwater station. Stable isotopes of water can be used to further understand sources of nitrogen and water in the watershed. Previous studies have shown that plotting $\delta^{18}O\text{-}H_2O$ against $\delta^{18}O\text{-}NO_3$ can help determine nitrogen processing. A strong correlation between $\delta^{18}O\text{-}H_2O$ and $\delta^{18}O\text{-}NO_3$ indicates that nitrification is the dominant process affecting $\delta^{18}O\text{-}NO_3$ (Casciotti and others, 2002; Wankel and others, 2006; McMahon and Böhlke, 2006). Nitrification is the conversion of ammonia to nitrite and eventually nitrate. Results from the three surface-water sites did not show a trend between $\delta^{18}O\text{-} H_2O$ and $\delta^{18}O\text{-}NO_3$, indicating that nitrification is not playing a large role in altering the isotopic signature of nitrate in the stream (fig. 21C). The low concentrations found within the streams also support this finding.

The isotopic signature of water ($\delta^{2}H\text{-}H_2O$ and $\delta^{18}O\text{-}H_2O$) will vary based on the amount of precipitation (from overland flow, direct precipitation into the stream, or shallow subsurface drainage) and groundwater contributing to the stream (Kendall and Coplen, 2001). Delta (δ) values have a seasonal trend and are generally higher (more positive) in the summer and lower (more negative) in the winter. Surface-water samples from the School Branch watershed show somewhat of a seasonal trend for the 3 years of sampling (fig. 21D). The samples collected in late winter (March) have more negative δ values, and δ values become more positive in spring (April and May) samples and in summer (June and July) samples. The exception to this pattern was the samples from the two highest flow events (May 1, 2017, and July 11, 2017), which had the most positive $\delta^{2}H\text{-}H_2O$ and $\delta^{18}O\text{-}H_2O$ values from all the samples collected during the study. The groundwater samples, regardless of time of year of sampling, had the most negative $\delta^{2}H\text{-}H_2O$ and $\delta^{18}O\text{-}H_2O$ values, indicating that groundwater recharge occurs mainly in the winter months.

Passive Sampling for Wastewater Influence

Wastewater indicators are compounds that are linked to human use. They generally fall under three categories: household use, such as fragrances, flavoring in food or beverages, stimulants, or other additives in foods or household products; agricultural use, such as pesticides and herbicides, and industrial use such as solvents and plasticizers. The POCIS (passive samplers) were used to detect wastewater indicators at low levels at the three surface-water sites. The compounds, their common uses, and their detections in School Branch, are listed in table 13.

During the three POCIS deployments during March through June 2016, the percentage of compounds detected at the three surface-water sites ranged from 16.9 to 33.9 percent,

Table 13. Wastewater indicator compounds detected by polar organic chemical integrative samplers in the School Branch study area, Hendricks County, Indiana, water year 2016.

[Rd., Road; CR750N, County Road 750 North; Dr., Drive; X, compound residue detected above the method detection limit; UV, ultraviolet; o, compound residue not detected above the method detection limit; n.a., not applicable]

Indicator compound	Use or sources	Deployment 1 (March 29 to April 26, 2016)			Deployment 2 (April 26 to May 24, 2016)			Deployment 3 (May 24 to June 21, 2016)			Percent detection
		Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	
Acetophenone	Fragrance in detergent and tobacco, flavor in beverages	X	X	X	X	X	X	X	X	X	100
Atrazine	Herbicide	X	X	X	X	X	X	X	X	X	100
Caffeine	Stimulant	X	X	X	X	X	X	X	X	X	100
Diethyl phthalate	Plasticizer	X	X	X	X	X	X	X	X	X	100
Methyl salicylate	Liniment, food, beverage, UV-absorbing lotion	X	X	X	X	X	X	X	X	X	100
Metolachlor	General use pesticide, indicator of agricultural drainage	X	X	X	X	X	X	X	X	X	100
N,N-diethyltoluamide	Insect repellent	X	X	X	X	X	X	X	X	X	100
Para-cresol	Wood preservative	X	X	X	X	X	X	X	X	X	100
Camphor	Flavor, odorant, ointments	X	o	X	X	X	X	X	X	X	89
Diethylhexyl phthalate	Plasticizer	X	X	X	X	X	X	X	o	X	89
Isophorone	Solvent for lacquer, plastic, oil, silicon, resin	X	o	X	X	X	X	X	X	X	89
Cholesterol	Ubiquitous, produced by animals and plants (animal sterol)	X	o	X	X	o	X	X	X	X	78
Galaxolide	Synthetic fragrance in cosmetics, cleaning agents, detergents, air fresheners, perfumes	o	o	X	X	X	X	X	X	X	78
Benzophenone	Fixative for perfumes and soaps	o	X	o	o	X	o	o	X	X	44
Ethyl citrate	Cosmetics, pharmaceuticals	o	o	X	X	X	X	o	o	o	44

Table 13. Wastewater indicator compounds detected by polar organic chemical integrative samplers in the School Branch study area, Hendricks County, Indiana, water year 2016.—Continued

[Rd., Road; CR750N, County Road 750 North; Dr., Drive; X, compound residue detected above the method detection limit; UV, ultraviolet; o, compound residue not detected above the method detection limit; n.a., not applicable]

Indicator compound	Use or sources	Deployment 1 (March 29 to April 26, 2016)			Deployment 2 (April 26 to May 24, 2016)			Deployment 3 (May 24 to June 21, 2016)			Percent detection
		Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	
Anthraquinone	Manufacturing of dye/textiles, seed treatment, bird repellant	o	o	X	o	o	X	o	o	X	33
Bromacil	Herbicide, greater than 80-percent noncrop usage on grass	o	o	o	o	o	o	X	X	X	33
Metalaxyl	General use pesticide, herbicide, fungicide, mildew, blight, pathogens, golf/turf	o	o	o	o	o	o	X	X	X	33
Bisphenol A	Plasticizer	o	o	o	o	o	o	o	o	X	11
Prometon	Herbicide, noncrop only, applied prior to blacktop	o	o	o	o	o	o	o	o	X	11
Skatol	Fragrance, stench in feces and coal tar	o	o	o	o	o	o	o	o	X	11
1,4-dichlorobenzene	Moth repellant, fumigant, deodorant	o	o	o	o	o	o	o	o	o	0
3,4-dichlorophenyl isocyanate	Used as a chemical intermediate	o	o	o	o	o	o	o	o	o	0
3-beta-coprostanol	Carnivore fecal indicator, useful sewage tracer	o	o	o	o	o	o	o	o	o	0
4-cumylphenol	Nonionic detergent metabolite	o	o	o	o	o	o	o	o	o	0
4-n-octylphenol	Nonionic detergent metabolite	o	o	o	o	o	o	o	o	o	0
4-tert-octylphenol	Nonionic detergent metabolite	o	o	o	o	o	o	o	o	o	0
5-methyl-1H-benzotriazole	Antioxidant in antifreeze and deicers	o	o	o	o	o	o	o	o	o	0
Beta Hydroxy Acids	Used in cosmetics	o	o	o	o	o	o	o	o	o	0

Table 13. Wastewater indicator compounds detected by polar organic chemical integrative samplers in the School Branch study area, Hendricks County, Indiana, water year 2016.—Continued

[Rd., Road; CR750N, County Road 750 North; Dr., Drive; X, compound residue detected above the method detection limit; UV, ultraviolet; o, compound residue not detected above the method detection limit; n.a., not applicable]

Indicator compound	Use or sources	Deployment 1 (March 29 to April 26, 2016)			Deployment 2 (April 26 to May 24, 2016)			Deployment 3 (May 24 to June 21, 2016)			Percent detection
		Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	
Beta-sitosterol	Plant sterol	o	o	o	o	o	o	o	o	o	0
Bromoform	Wastewater ozination byproduct, military/explosives	o	o	o	o	o	o	o	o	o	0
Carbaryl	Insecticide, crop and garden uses, low persistence	o	o	o	o	o	o	o	o	o	0
Carbazole	Insecticide, manufacturing of dyes, explosives, and lubricants	o	o	o	o	o	o	o	o	o	0
Chlorpyrifos	Insecticide, domestic pest and termite control (domestic use restricted as of 2001)	o	o	o	o	o	o	o	o	o	0
Cotinine	Nicotine metabolite	o	o	o	o	o	o	o	o	o	0
Cumene	Manufacturing phenol/acetone, fuels and paint thinner	o	o	o	o	o	o	o	o	o	0
Diazinon	Insecticide, greater than 40-percent nonagricultural usage	o	o	o	o	o	o	o	o	o	0
Dichlorvos	Insecticide to control household pests	o	o	o	o	o	o	o	o	o	0
d-limonene	Fungicide, antimicrobial, antiviral, fragrance in aerosols	o	o	o	o	o	o	o	o	o	0
Ethanol, 2-butoxy-, phosphate	Solvent found in paint thinners and household cleaners	o	o	o	o	o	o	o	o	o	0
Indole	Inert pesticide ingredient, fragrance in coffee	o	o	o	o	o	o	o	o	o	0

Table 13. Wastewater indicator compounds detected by polar organic chemical integrative samplers in the School Branch study area, Hendricks County, Indiana, water year 2016.—Continued

[Rd., Road; CR750N, County Road 750 North; Dr., Drive; X, compound residue detected above the method detection limit; UV, ultraviolet; o, compound residue not detected above the method detection limit; n.a., not applicable]

Indicator compound	Use or sources	Deployment 1 (March 29 to April 26, 2016)			Deployment 2 (April 26 to May 24, 2016)			Deployment 3 (May 24 to June 21, 2016)			Percent detection
		Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	
Isoborneol	Fragrance in perfumery, in disinfectants	o	o	o	o	o	o	o	o	o	0
Isoquinoline	Flavors and fragrances	o	o	o	o	o	o	o	o	o	0
Menthol	Cigarettes, cough drops, liniment, mouthwash	o	o	o	o	o	o	o	o	o	0
NPEO1-total	Nonionic detergent metabolite	o	o	o	o	o	o	o	o	o	0
NPEO2-total	Nonionic detergent metabolite	o	o	o	o	o	o	o	o	o	0
OPEO1	Nonionic detergent metabolite	o	o	o	o	o	o	o	o	o	0
OPEO2	Nonionic detergent metabolite	o	o	o	o	o	o	o	o	o	0
Para-nonylphenol-total	Lubricating oil additives, laundry and dish detergents, emulsifiers, and solubilizers	o	o	o	o	o	o	o	o	o	0
Pentachlorophenol	Restricted use pesticide industrial wood preservative	o	o	o	o	o	o	o	o	o	0
Phenol	Disinfectant, leachate	o	o	o	o	o	o	o	o	o	0
Stigmastanol	Plant sterol	o	o	o	o	o	o	o	o	o	0
Tetrachloroethylene	Solvent, degreaser, veterinary anthelmintic	o	o	o	o	o	o	o	o	o	0
Tonalide	Fragrance in cosmetics, detergents, cigarettes	o	o	o	o	o	o	o	o	o	0
Tri(2-chloroethyl) phosphate	Flame retardant	o	o	o	o	o	o	o	o	o	0
Tri(dichlorisopropyl) phosphate	Flame retardant	o	o	o	o	o	o	o	o	o	0

Table 13. Wastewater indicator compounds detected by polar organic chemical integrative samplers in the School Branch study area, Hendricks County, Indiana, water year 2016.—Continued

[Rd., Road; CR750N, County Road 750 North; Dr., Drive; X, compound residue detected above the method detection limit; UV, ultraviolet; o, compound residue not detected above the method detection limit; n.a., not applicable]

Indicator compound	Use or sources	Deployment 1 (March 29 to April 26, 2016)			Deployment 2 (April 26 to May 24, 2016)			Deployment 3 (May 24 to June 21, 2016)			Percent detection
		Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.	
Tributylphosphate	Disinfectant, antimicrobial (concern for acquired microbial resistance)	o	o	o	o	o	o	o	o	o	0
Triclosan	Disinfectant, antimicrobial (concern for acquired microbial resistance)	o	o	o	o	o	o	o	o	o	0
Triphenyl phosphate	Plasticizer, resin, wax, finish, roofing paper	o	o	o	o	o	o	o	o	o	0
Total number of compounds detected	n.a	12	10	15	14	14	15	15	15	20	n.a.
Percentage of compounds detected	n.a.	20.3	16.9	25.4	23.7	23.7	25.4	25.4	25.4	33.9	n.a.

[a] Use or source from Reif and others, 2012.

with the highest percentages observed at Noble Dr.—the site farthest downstream (table 13). Of the 59 compounds analyzed with the POCIS, 21 were detected in samples from 1 or more of the 3 sites during at least 1 deployment. The wastewater indicators, commonly linked to household wastewater, acetophenone, caffeine, diethyl phthalate, methyl salicylate, and para-cresol were detected in POCIS at all three sites for all deployments. There were more detections at the most downstream site. Anthraquinone (manufacturing of dye/textiles, all three deployments), bisphenol A (plasticizer, only deployment 3), skatol (fragrance, only deployment 3), and prometon (non-crop herbicide, only deployment 3) were detected at Noble Dr., the most downstream site, but not the two sites upstream. Given that there are no wastewater treatment facilities on this stream, these results indicate potential septic wastewater influences throughout the watershed. The highest numbers of detections for each site were during the third deployment from May 24 to June 21, 2016. The herbicide bromacil and the general use pesticide metalaxyl were both detected at all three sites in round three but not for any other round. The herbicide atrazine and the general use pesticide, metolachlor; are linked to agricultural use and were also detected in all POCIS samples.

Ecological Conditions in the Watershed

Multiple indices were used to compare changes in the ecological conditions from upstream to downstream. The fish and macroinvertebrate communities were assessed for the three reaches and each site was given a biological condition gradient score based on community attributes. Also, algal biomass was measured to assess eutrophic conditions of the stream. Steam habitat can influence aquatic community structure and function, and a habitat survey was completed and used to highlight differences in the quality of habitat along the stream that may be driving differences seen in biological communities at the three sites.

Fish Community

There were differences in the fish community structure in School Branch from upstream to downstream and between sampling years 2016 and 2018 (table 14, fig. 22). In 2016, the fish communities at the two upstream stations (Maloney Rd. and CR750N) only had intermediate tolerant taxa (attribute IV) and highly tolerant taxa (attribute V). Because of the composition of the taxa found at the two upstream sites in 2016, the sites were categorized as level 5. In level 5, sensitive taxa are markedly diminished, there is a conspicuously unbalanced distribution of major groups, the organism condition shows signs of physiological stress, and system function shows reduced complexity and redundancy (Stamp and others, 2016). At CR750N, in 2016, there were anomalies or external deformities, erosions, lesions, or tumors found on 13 percent of the fish caught, mainly in the form of fin erosions and lesions on the *Lepomis cyanellus* (green sunfish) population. Because of this, the BCG level was demoted to a 5− (minus). In 2016, the fish community at the downstream site, Noble Dr., was also made up of many of the same BCG attribute IV and V species that were found upstream. The most dominant taxa, however, was the *Cottus bairdi* (mottled sculpin), which is considered an intermediate sensitive and common taxon (attribute III). Noble Dr. met the criteria for level 4 on the BCG scale. Level 4 is defined as a community that exhibits moderate changes in structure due to replacement of intermediate sensitive taxa by more tolerant taxa; however, reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups is maintained; and ecosystem functions are largely maintained through redundant attributes (Stamp and others, 2016).

In 2018, the fish communities at the CR750N and Noble Dr. sites had higher taxa richness compared to 2016 (table 14). There were no anomalies or external deformities, erosions, lesions, or tumors found on fish at the CR750N site in 2018. The community composition in 2018 resulted in Maloney Rd. still falling in BCG level 5, whereas the improvements in the community at CR750N resulted in an increase to BCG level 4. At Noble Dr., there was also a slight improvement due to the increase in taxa richness. In 2018, the fish community met all criteria to be considered BCG level 3 except for one that could not be calculated. To be considered BCG level 3, the percentage biomass of attribute V and VI taxa must be less than 50 percent. Biomass data were not collected for fish, so it could not be determined if Noble Dr. qualified for BCG level 3. For this reason, Noble Dr. was categorized as 4+ (plus) for 2018.

Aquatic Macroinvertebrate Community

Biological indices were used to evaluate the macroinvertebrate community and health of School Branch. Richness, or the number of distinct taxa, typically decreases when water quality or habitat quality decreases (Plafkin and others, 1989). However, in some cases, richness can increase in nutrient enriched streams as the number of pollutant tolerant species increases. This makes it important to evaluate the community by not only numbers of distinct taxa present but also which taxa are present, at what numbers, and how sensitive those taxa are to environmental stressors.

The macroinvertebrate indices calculated for the three School Branch stations are shown in table 15; these indices indicate a general improvement in the macroinvertebrate community from upstream at Maloney Rd. to downstream at Noble Dr. Richness was similar at all 3 sites with 34 distinct taxa at Maloney Rd., 37 at CR750N, and 30 at Noble Dr. The macroinvertebrate orders were more evenly distributed at the two upstream sites; in contrast, at Noble Dr., more

Table 14. Summary of fish community assemblages for three sites in School Branch study area, Hendricks County, Indiana, water years 2016 and 2018.

[BCG, Biological Condition Gradient (Stamp and others, 2016); Rd., Road; CR750N, County Road 750 North; Dr., Drive; DELTs, anomalies or external deformities, erosions, lesions, or tumors]

Fish index used to determine BCG	2016			2018		
	Maloney Rd.	CR750N	Noble Dr.	Maloney Rd.	CR750N	Noble Dr.
Total number of taxa	7	7	11	7	9	19
Number of individuals	149	158	143	409	331	181
Percentage BCG attribute I+II+III+X taxa, + IV taxa	0, 87.2	0, 68.4	49.0, 80.4	0, 50.4	0, 58.9	20.4, 70.7
Percentage most dominant taxa, BCG attribute V or VI	9.40	27.2	7.69	43.0	26.0	17.7
Percentage attribute BCG V+VI taxa	12.8	31.6	19.6	49.6	41.1	28.7
Number of DELTs	1	21	0	0	0	2
BCG level	5	5-	4	5	4	4+

than 50 percent of organisms identified were from the order Trichoptera (fig. 23). The percentage dominant macroinvertebrate family (which can also help to evaluate evenness of the community) was approximately 30 percent for all three sites. The dominant family changed from Elmidae (riffle beetle) at the two upstream sites to Hydropsychidae (net-spinning caddisflies) at Noble Dr.; both families have a tolerance value of 4 on a scale from 0 (no tolerance to organic pollution) to 10 (tolerant of severe organic pollution). Dominant macroinvertebrate families ranked with a tolerance level of 4, as seen in School Branch, might indicate tolerance to some organic pollution (Hauer and Lamberti, 1996).

Although Noble Dr. had the lowest total richness, it had the highest EPT taxa richness at 10 (the other two sites had an EPT taxa richness of 8). The percentage of the community abundance made up of EPT individuals also increased from upstream to downstream (table 15). These EPT taxa tend to be more sensitive to environmental stress, so having higher EPT taxa richness with higher numbers of individuals in those taxa can indicate a reduction in the physical and chemical stressors in the reach. Chironomidae are generally a more tolerant taxa and their presence in larger numbers can indicate impairments in water quality and habitat of a stream. The percentage of the community abundance made up of Chironomidae was decreased downstream as well (table 15). A community with good biotic condition will have a more even distribution of abundance between EPT and Chironomidae and therefore an EPT/C closer to 1. A community with a higher proportion of Chironomidae than EPT typically indicates stress caused by higher nutrients or poor habitat and would have an EPT/C less than 1 (Plafkin and others, 1989). The EPT/C was larger than 1 for all three stations (table 15).

The FBI takes the tolerance level and abundance of each macroinvertebrate family into consideration to assign a score ranging from 0 (excellent water quality) to 10 (very poor water quality) (table 15; Hilsenhoff, 1988). The FBI decreased at the three sites from upstream to downstream. The macroinvertebrate FBI scores rate the water quality at each site as fair (fairly substantial pollution likely) at Maloney Rd. (5.02), good (some organic pollution likely) at CR750N (4.67), and very good (possible slight organic pollution) at Noble Dr. (4.17), indicating that there is an improvement in the macroinvertebrate community as the water flows downstream. The MTV (Lillie and Schlesser, 1994) of taxa was 5.92 at Maloney Rd., 5.90 at CR750N, and 5.44 at Noble Dr. Though not a large difference, the difference in MTV shows that there are more sensitive taxa downstream. Tolerant organisms (FBI scores of 8 or greater) decrease from upstream to downstream, whereas the percentage of intolerant organisms (FBI score 4 or less) increases. The percentage abundance of noninsect taxa (which tend to be more tolerant taxa) decreases from upstream to downstream.

Many of the macroinvertebrate indices described above indicate a slight improvement from upstream at Maloney Rd. to downstream at Noble Dr. The BCG levels assigned to the three stations corroborate this finding (table 15). The three stations were assigned to BCG level 4, which by definition indicate moderate changes in structure due to more tolerant taxa replacing intermediate sensitive taxa with populations of some sensitive taxa remaining, a balanced distribution of all expected major groups, and ecosystem functions largely maintained through redundant attributes (Jessup and other, 2017). There was some variability, however, in the macroinvertebrate community BCG levels among the three stations. The upstream stations at Maloney Rd. and CR750N were assigned a BCG level of 4, and the most downstream station at Noble Dr. was assigned a BCG level of 4+. Noble Drive exceeded the level 4 metrics with a higher number and percentage abundance of more sensitive taxa (BCG attribute I+II+III) and with more EPT taxa than the other two sites. Though close, Noble Dr. did not meet all metrics for a BCG level 3.

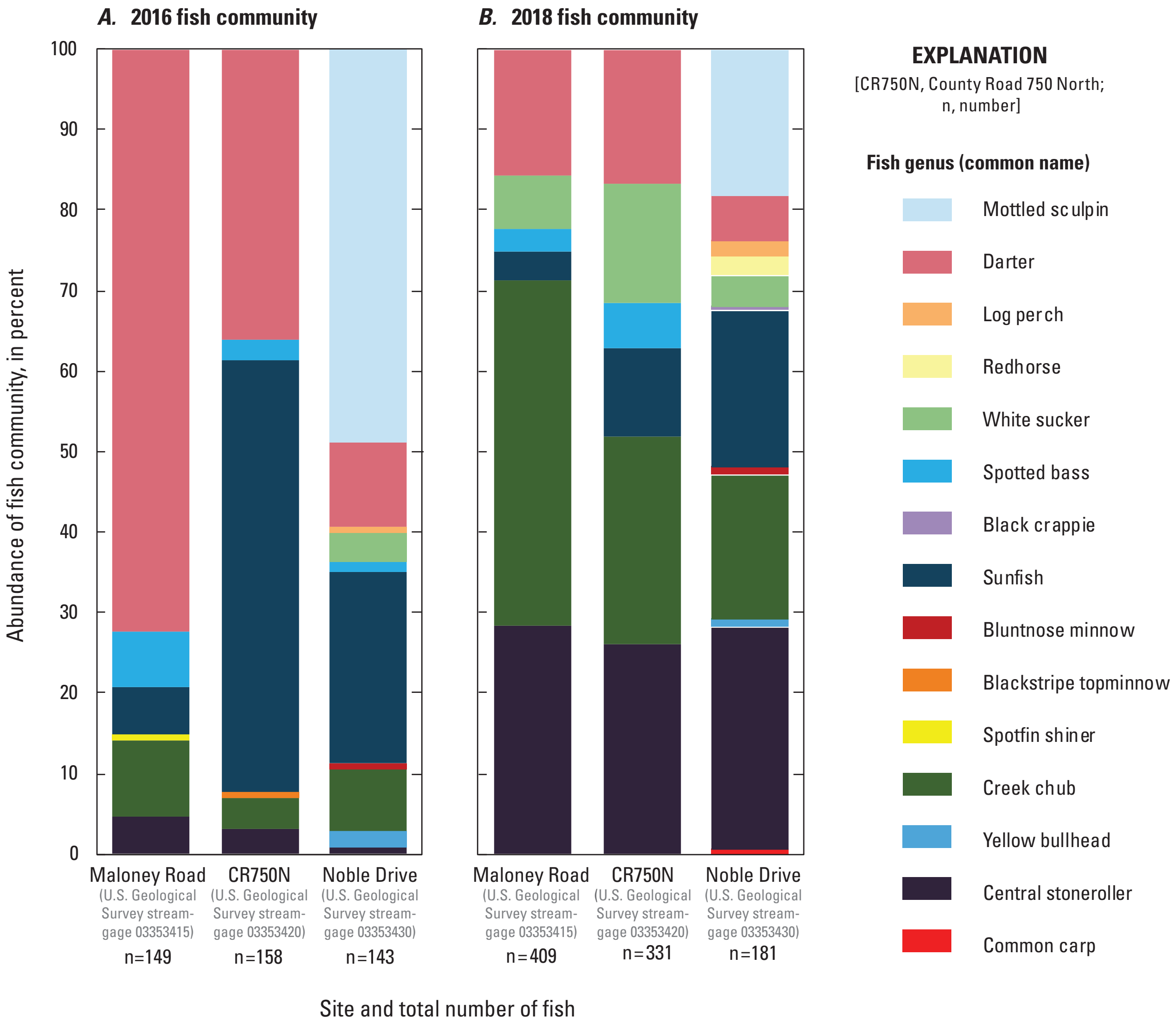


Figure 22. Graphs showing fish community composition (percentage) for the three sites along School Branch in Hendricks County, Indiana, water years *A*, 2016 and *B*, 2018.

Algal Biomass

Algal biomass was similar for all three sites. Ash free dry mass of periphyton from the most upstream to downstream site was 36, 30, and 32 grams per square meter at Maloney Rd., CR750N, and Noble Dr., respectively. Chlorophyll *a* concentrations were 66.7, 63.2, and 62.3 milligrams per square meter (mg/m^2), and pheophytin *a* was 31.4, 24.3, and 31.5 mg/m^2, respectively. Chlorophyll concentrations of 70 mg/m^2 have been used to define streams as eutrophic (Dodds and others, 1998). All three sites on School Branch were close to this eutrophic concentration category, indicating that nutrients were elevated throughout the stream.

Habitat

The fish and macroinvertebrate communities in School Branch showed slight improvements moving from upstream to downstream. This could indicate an improvement in water quality; however, habitat also plays a large role in aquatic biological community structures. Habitat data were collected at each of the three surface-water sites in 2016 and 2018. The stream habitat at each of the sites did not show large changes between sampling years. However, the stream habitat did show differences from site to site as the stream flowed through the watershed (table 16). As expected, the stream had larger wetted width, depth, and velocities at Noble Dr., the site farthest downstream. Noble Dr. also had more course substrate including boulders, cobble, and gravel. Larger substrate was sparse

Table 15. Summary of macroinvertebrate biological indices for three sites in School Branch study area, Hendricks County, Indiana, water year 2016.

[Shaded attributes used in assigning BCG level. Rd., Road; CR750N, County Road 750 North; Dr., Drive; EPT, Ephemeroptera, Plecoptera, Trichoptera; EPT/C, Ephemeroptera, Plecoptera, and Trichoptera to Chironomidae ratio (Plafkin and others, 1989); FBI, Family Biotic Index (Hilsenhoff, 1988); MTV, mean tolerance value (Lillie and Schlesser, 1994); ≥, greater than or equal to; ≤, less than or equal to; BCG, Biological Condition Gradient (Jessup and others, 2017)]

Macroinvertebrate index	Site		
	Maloney Rd.	CR750N	Noble Dr.
Taxa richness	34	37	30
EPT taxa richness	8	8	10
Percentage EPT abundance	27.4	35.4	74.8
Percentage Chironomid abundance	11.7	17.7	3.86
EPT/C	2.34	2.00	19.4
Percentage noninsect abundance	25.8	15.9	5.64
Percentage dominant family abundance	33.8	29.4	31.2
FBI	5.02	4.67	4.17
MTV	5.92	5.90	5.44
Percentage abundance tolerant FBI score ≥8	21.8	15.0	2.97
Percentage abundance intolerant FBI score ≤4	66.8	66.1	85.5
Number of BCG attribute I+II+III taxa	2	2	5
Percentage abundance BCG attribute I+II+III taxa	0.615	5.11	19.0
Percentage abundance of the dominant 5 taxa	55.4	67.6	65.90
Percentage abundance attribute V taxa	8.30	2.40	0.29
BCG level	4	4	4+

at the two upstream sites where finer substrate (mostly silt and sand) was found. The upstream sites were straight with mostly run habitat and manmade/riprap riffles under the bridges in the reaches. This is typical of many streams influenced by agricultural land use. In 2018, a second gravel substrate riffle was identified at Maloney Rd., possibly resulting from lower flow during sampling in 2018. Noble Dr. had more sinuosity and multiple riffle, run, and pool habitats. Riparian cover was lowest in the reach at CR750N, with tall grasses and a few trees along the streambanks. Maloney Rd. had a tree line on both sides of the stream, and Noble Dr. runs through a wooded green space within the subdivision. The change in habitat moving downstream may influence the biological communities more than water quality, as many of the water-quality data did not indicate large differences among the three sites.

Limitations and Considerations

There were some limitations to the data analysis and interpretation. Specifically, load models could not be developed at all three surface-water sites for all constituents of interest. Load modeling has been shown to be more accurate in larger streams with less variability in streamflow (Lee and others, 2019) and are more accurate when assessing longer periods for load (annual versus daily load). There were a small number of samples available at the time of this report. Models that included variables that may have improved load models, such as seasonality and time for the study period, were not considered due to the likelihood of overfitting the models. The load models for TN that were developed had large confidence intervals that make it difficult to determine if the load or yield changed substantially along the stream with changes in land-use practices. This was especially evident at Maloney Rd., where the stream enters mainly conservation farmland, and CR750N, where the stream leaves the mainly conservation farmland. There was some indication that the land managed under mainly conservation cropping practices between the two sites helped to reduce the yield of TN, but the results are somewhat ambiguous due to the large confidence intervals and variability in the load models.

The continuous water-quality data from the supergage at CR750N provided data that made it easier to assess changes in stream-water quality in near real-time. This was especially valuable at School Branch because high variability of streamflow and constituent concentrations. The supergage will allow for the development of surrogates for constituents that could not be measured in real-time and could not be modeled using traditional load models. However, there was still a gap in understanding if conservation practices between Maloney Rd. and CR750N were altering the water quality or quantity because the continuous data were only available at CR750N.

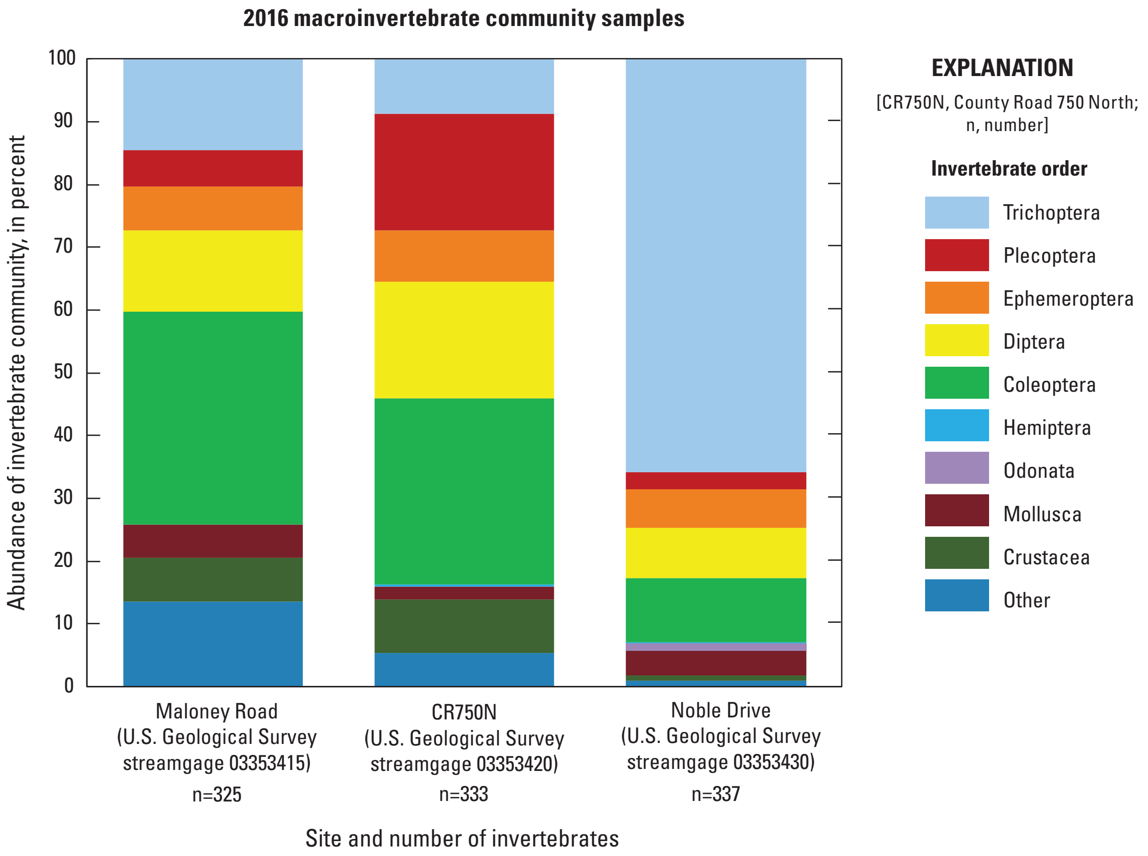


Figure 23. Graph showing macroinvertebrate community composition (percentage) for the three sites along School Branch in Hendricks County, Indiana, 2016.

Table 16. Stream habitat summary for three stream reaches in School Branch study area, Hendricks County, Indiana, August of 2016 and 2018.

[m, meter; ft/s, foot per second; mm, millimeter; Rd., road; <, less than; CR750N, County Road 750 North; Dr., drive]

Site	Year	Mean wetted width, in m	Mean depth, in m	Mean velocity, in ft/s	Mean particle size, in mm	Median particle size, in mm	Dominant substrate type	Percent canopy cover
Maloney Rd.	2016	3.16	0.10	0.17	12.7	<0.06	silt	87.0
CR750N		4.09	0.17	0.11	18.8	1.00	sand	64.7
Noble Dr.		6.15	0.23	0.29	64.9	20.00	gravel	89.4
Maloney Rd.	2018	2.67	0.07	0.01	16.0	<0.06	silt	83.3
CR750N		3.33	0.11	0.02	6.36	1.00	sand	67.4
Noble Dr.		5.18	0.20	0.28	23.3	1.00	gravel	88.2

The nested groundwater wells indicated a hydrologic connection between groundwater and surface water. However, it is uncertain what influence agricultural tiles in the study area have on the hydrology and water quality. Tile drains were not explicitly accounted for in the hydrograph separation evaluations but certainly play a role in BFI. Tile flow likely appears as base flow in the BFI calculations. Also, the major ion signatures in the stream and in the deep northwest groundwater well were similar during the growing season when sampling occurred. Because groundwater sampling was only conducted during the growing season and in one of the four wells, differences between seasons or between deep and shallow groundwater could not be assessed. Additionally, stable isotope sampling was only conducted a few times a year at the same time as groundwater sampling. The stable isotope data showed some shift in the nitrogen isotope signature with storm events. Perhaps more frequent sampling of groundwater, major ions, and isotopes would provide more conclusive information on the source of water and nutrients in the stream.

Planned Future Work

Sampling for the School Branch study is planned to continue into at least 2022. The second phase is building upon the work done in this study. More intensive and targeted sampling of groundwater and surface water is planned to help further identify potential sources of contaminants in the watershed. Continued sampling of nutrients and sediment may allow for more appropriate modeling of loads and may help to explain water-quality differences throughout the watershed. Additionally, a targeted tile drain synoptic study between Maloney Rd. and CR750N is being conducted. Through work as part of this study, 24 tile drains have been identified in the mile of stream between the 2 streamgages that were sampled for flow and water quality.

Although rloadest could not produce unbiased load estimates for total phosphorus and suspended sediment at the three sites, continuous water-quality data from the supergage at CR750N could be used to develop surrogate models by relating discrete concentrations to continuously measured parameters to model real-time concentrations and loads of these constituents. This has been done at other supergage sites in Indiana (Lathrop and others 2019a; Lathrop and others 2019b), by relating NOx from nitrate monitor to discrete TN concentrations and continuous turbidity values to suspended sediment and total phosphorus concentrations. By incorporating the continuous water-quality data, the surrogate models may more accurately estimate concentrations and loads at School Branch.

A second supergage was installed at the Maloney Rd. site in the fall of 2018 in cooperation with NRCS. There are plans to compare continuous loads and yields at the Maloney Rd. and CR750N sites once surrogates can be developed. This would further the understanding of the dynamics of the stream and the concentrations of constituents throughout the watershed. The surrogates from the supergage provide a more accurate and appropriate method to estimate concentrations and loads in this small, dynamic watershed, especially when evaluating differences for smaller time steps. For example, daily load may provide more useful and representative information than annual load. By bracketing the study area with two supergages, the loads entering and leaving the study area may provide more insight into how the land-use practices implemented in different parts of the watershed are influencing water quality in the stream.

Additionally, many changes may be seen in the watershed during the next few years. Hendricks County is planning an expansion of the expressway that will cut through the watershed and alter the land use. Although the initial focus of the study was to understand the effects of agricultural land-management practices, the results in this report may provide a baseline for water quality of the School Branch watershed as it transitions from mostly agricultural land use to a more urbanized environment.

Summary

The objective of this study was to provide information on the water quality and quantity in the School Branch watershed of Hendricks County, Indiana. The School Branch watershed has a variety of agricultural and suburban land uses nested in the Eagle Creek watershed west of Indianapolis, Indiana. The U.S. Geological Survey, in collaboration with the Indiana Department of Environmental Management, operated three streamgages (03353415 School Branch at Maloney Road near Brownsburg, Indiana [hereafter Maloney Rd.], 03353420 School Branch at County Road 750 North at Brownsburg, Indiana [hereafter CR750N], and 03353430 School Branch at Noble Drive at Brownsburg, Indiana [hereafter Noble Dr.]); a continuous water-quality gage at CR750N that measured dissolved oxygen, pH, temperature, specific conductance, turbidity, nitrate (nitrate plus nitrite or NOx), and orthophosphate (orthoP); and two sets of nested groundwater wells at CR750N that monitored groundwater level and temperature. Discrete water-quality samples were collected from surface water and groundwater for nutrients, sediment (surface water only), major ions, and stable isotopes. Passive samplers were used to identify wastewater indicators. The stream ecology was analyzed by assessing fish and macroinvertebrate communities and a stream habitat survey at three reaches in School Branch.

Because of limited data, only total nitrogen (TN) load models were produced for the three sites along School Branch. This allowed for the estimation of TN load (TNL) and yields through the watershed. The TNL increased moving downstream as the contributing land area and potential sources for nitrogen increased. The monthly loading patterns were not always similar for the three sites. Because the TNL is closely linked to discharge, differences in the loading patterns between the sites could be due to differences in the hydrology caused by land use. Soil retention, subsurface tile drains, or impervious surfaces in the contributing watershed could lead to differences in the timing and magnitude of discharge changes during higher flows, which in turn could cause differences in the TNL patterns. Land-use practices that alter the amount of base flow could also influence the loading of TN during drier conditions. Differences in the land use in the watershed for each of the sites along the stream may be why the load patterns varied. Land-use practices that reduce the intensity of runoff events and keep water on the land longer could result in reduced loading.

Among the three sites, total nitrogen yield estimates were the highest for Maloney Rd., the site farthest upstream for all 3 water years. The watershed size increases by 38.6-percent between Maloney Rd. and CR750N. When comparing TNL for the two upstream sites, the annual load from the contributing land to School Branch increased by 26.9, 5.61, and 21.1 percent between Maloney Rd. and CR750N for the 3 water years. The increase in watershed size did not result in a proportionate increase in TNL from the land draining between Maloney Rd. and CR750N, especially in 2017. This lack of a proportionate increase in TNL indicates that the land between the two sites, managed mostly under best management practices, is contributing less TN per acre to the stream than the land above Maloney Rd. that is mostly managed using conventional methods.

Continuous water-quality properties and constituents were used to investigate changes in water quality. The continuous data showed seasonal trends in temperature, dissolved oxygen, and nutrients. The characteristics of orthoP and NOx from the continuous monitors during a typical runoff event indicated that subsurface drainage may be a larger source of these nutrients to streams than overland flow. Increases in orthoP and NOx concentrations during typical storm conditions were delayed when compared to discharge increases. NOx tends to have an initial dilution of concentration that was not observed for orthoP. Turbidity sharply increased at the start of storm events indicating it was closely tied to overland flow or suspension of instream sediment. When a storm event occurred shortly after fertilizer was applied to fields in the watershed, NOx and orthoP patterns of concentration changes were similar to turbidity. Thus, the loss of applied fertilizer from the field to the stream via overland flow emphasizes the need for land managers to closely monitor weather forecasts before applying fertilizer.

Groundwater and surface-water elevations, temperature, and water-quality samples were used to evaluate the connections between groundwater and the stream. These data indicated that there is a connection between groundwater and surface water in the School Branch watershed. Comparison of the computed percentage of base flow to total streamflow for the three School Branch streamgages indicated that the two reaches between the three streamgages gained flow from groundwater base flow or tile discharges through most of the year. The hydraulic gradient between wells and School Branch also indicated the potential for groundwater base flow to the stream throughout most of the year. During some low-flow conditions, estimated discharge at a downstream gage was less than the estimated flow at an upstream gage, indicating that School Branch may be discharging surface water to groundwater. Major ions in the groundwater and surface water indicated a common water composition and source at all three surface-water sites and in the groundwater from the deeper northwest well.

Nitrogen sources in the watershed were examined by looking at the isotopic signature of stable isotopes of nitrate and water. There was no indication of different isotopic signatures among the three sites. None of the surface-water samples showed a nitrogen isotopic signature that would indicate atmospheric deposition from rainfall, nitrate, or ammonium from synthetic fertilizers as a dominant source of nitrogen to the stream. All samples from the three sites had nitrate isotopic signatures that are indicative of either organic fertilizers (cover crops, plant composts or liquid, and solid animal waste) or septic waste. The results from samples collected during two runoff events fell in the overlapping range of nitrogen from soil as well. Although results did not fall into generally accepted ranges for synthetic fertilizers, this does not mean that synthetic fertilizers are not a source of nitrogen to the watershed. The comparison of NOx concentrations in conjunction with nitrate isotopes indicated that the isotopic signatures are from a mixture of sources and not from nitrogen cycling of one main source altering the signature. The comparison of stable oxygen isotopes of water and nitrate further indicated that the source of nitrogen in the watershed is from a mixture of sources. The isotopic signature of water in the surface-water samples from the School Branch watershed showed somewhat of a seasonal trend for the 3 years of sampling. Late winter samples have more negative δ values, and δ values become more positive in spring and summer samples. The exception to this pattern was the samples from the two highest flow events sampled, which had the most positive values from all the samples collected during the study. The groundwater samples, regardless of time of year of sampling, had the most negative values and were most similar to the late winter samples, indicating groundwater recharge occurs mainly in the winter.

Results from polar organic chemical integrative samplers indicated potential wastewater influences throughout the watershed with more detections at the most downstream site for all three deployments. Of the 59 compounds analyzed with the polar organic chemical integrative samplers, 21 were detected at least once at 1 of the sites. The wastewater indicators acetophenone, para-cresol, methyl salicylate, diethyl phthalate, and caffeine; the herbicides atrazine and metolachlor; and the insecticide N, N-diethyltoluamide were detected in every sample. The wastewater indicators anthraquinone (all three deployments), bisphenol A (only deployment 3), and methyl salicylate (only deployment 3) and the herbicide prometon (only deployment 3) were detected at Noble Dr., the most downstream site, but not the two sites upstream.

Ecological sampling, including macroinvertebrate and fish community samples and stream habitat surveys, were conducted at the three surface-water sites. The macroinvertebrate and fish community samples were used to calculate biological indices to assess the health of the aquatic organisms in the stream. In general, the macroinvertebrate community showed improvements moving downstream. This was due to an increase of more sensitive or intolerant taxa and a decrease in noninvertebrate species, which tend to be more tolerant from upstream to downstream. Fish communities were assessed in 2016 and 2018, and like macroinvertebrate community indices, the fish community showed improvements in the biological community moving downstream. The improvements in the fish community were indicated by improving biological condition gradient scores. There was also an improvement in the fish communities at the two downstream sites from 2016 to 2018. This was mainly due to increases in taxa richness and a decrease in physical abnormalities, such as the lesions and fin erosions on *Lepomis cyanellus* (green sunfish), that were recorded at CR750N in 2016 but not in 2018. The stream habitat may have played a large role in the differences seen in the biological community from upstream to downstream because the stream turns from a small channelized stream, dominated by silt and sand substrate, to a larger stream with more sinuosity, variability in habitat (riffle, run, pool), and larger cobble substrate.

Analysis of the first 3 years of data have highlighted some limitations that are mainly due to the short duration of the study and the timing and number of samples. As sampling efforts in the School Branch watershed expand and continue, some of these limitations may be addressed to allow for a more in-depth understanding of water-quantity and quality in the watershed. Specifically, more targeted sampling and surrogates from the continuous water quality gage at CR750N, and those that are planned to be developed for the new supergage at Maloney Rd., may allow for a more thorough understanding of differences in nutrient and sediment loads and sources in the watershed. This report provides a baseline for hydrologic and water-quality conditions in School Branch and provides a resource for understanding future changes driven by land-use changes in the watershed.

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