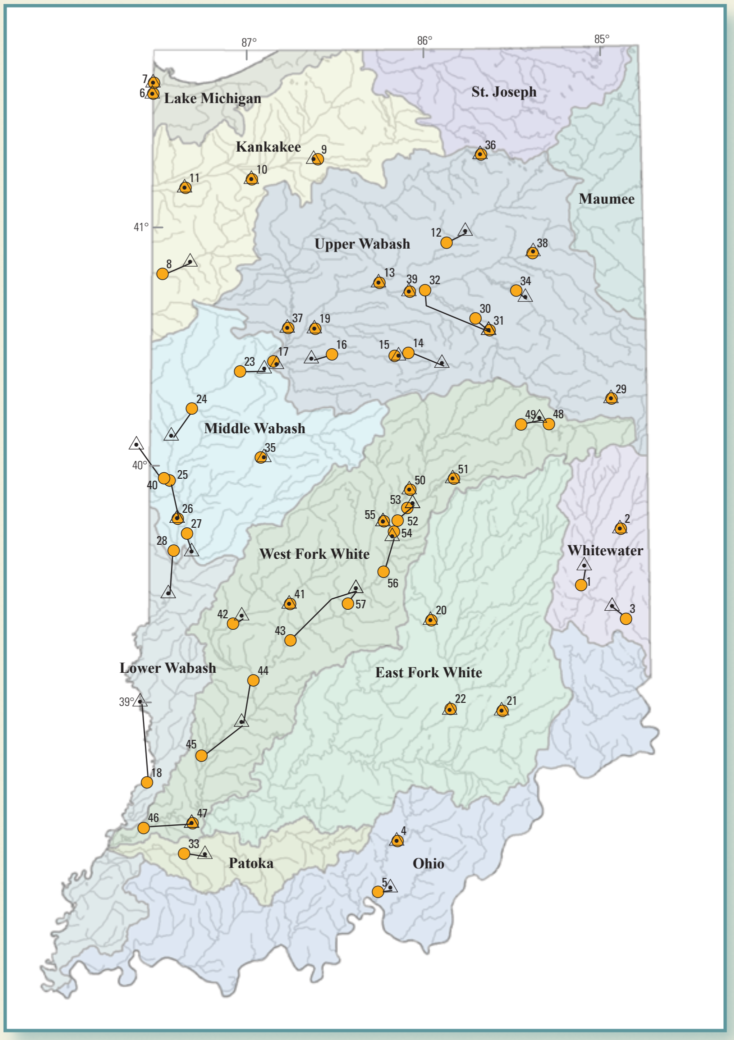
Prepared in cooperation with the Indiana Department of Environmental Management

Water Quality in Indiana: Trends in Concentrations of Selected Nutrients, Metals, and Ions in Streams, 2000–10



Scientific Investigations Report 2014–5205

U.S. Department of the Interior
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Cover figure. Selected Indiana Fixed Station Monitoring Program stream sites and associated streamgages used in this study.

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Contents

Figures

Figures (continued)

Tables

Conversion Factors and Datum

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)

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

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C= (°F-32)/1.8

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

Abbreviations

AIMS	Assessment Information Management System
CBNGP	Cornbelt and Northern Great Plains
FSMP	Fixed Station Monitoring Program
GIS	Geographic Information System
IDEM	Indiana Department of Environmental Management
MGDR	Mostly Glaciated Dairy Region
NHD	National Hydrography Dataset
NWIS	National Water Information System
PARMA	Periodic Autoregressive Moving Average
STFPH	Southeast Temperate Forested Plains and Hills
USGS	U.S. Geological Survey

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By Martin R. Risch, Aubrey R. Bunch, Aldo V. Vecchia, Jeffrey D. Martin, and Nancy T. Baker

Abstract

Water quality in Indiana streams generally improved during the 2000–10 study period, based on trends in selected nutrients, metals, and ions. This study combined water-quality data from the Indiana Fixed Station Monitoring Program (FSMP) with streamflow data from nearby U.S. Geological Survey streamgages. A parametric time-series model, QWTREND, was used to develop streamflow-adjusted constituent concentrations, to adjust for seasonal variance and serial correlation, and to identify trends independent of streamflow-related variability. This study examined 7,345 water samples from 57 FSMP sites for 11 years. Concentration trends were analyzed for 12 constituents—the nutrients nitrate, organic nitrogen, and phosphorus; suspended solids; the metals copper, iron, lead, and zinc; the ions chloride, and sulfate together with hardness as a measure of the calcium carbonate ion; and dissolved solids.

Nutrient concentrations in this study generally were too high relative to standards and criteria. The national recommended criteria for the three ecoregions in Indiana were exceeded by more than one-half of the nitrate and most of the phosphorus concentrations. Copper, lead, zinc, chloride, sulfate, and dissolved solids concentrations were in acceptable ranges relative to standards and criteria in more than 97 percent of samples. The two Lake Michigan Basin sites had the highest concentrations and were in a unique statistical group for 10 of the 12 constituents, with concentrations many times higher than the statewide median and higher than the medians of most other basins. The two Ohio River Basin sites had the lowest concentrations and were in a unique statistical group for 6 of the 12 constituents.

Statistically significant trends were identified that included 167 downward trends and 83 upward trends. The Kankakee River Basin had the most significant upward trends while the most significant downward trends were in the Whitewater River Basin, the Lake Michigan Basin, and the Patoka River Basin. For most constituents, a majority of sites had significant downward trends. Two streams in the Lake Michigan Basin have shown substantial decreases in most constituents. The West Fork White River near Indianapolis, Indiana, showed increases in nitrate and phosphorus and the Kankakee River Basin showed increases in copper, zinc, chloride, sulfate, and hardness. Upward trends in nutrients were identified at a few sites, but most nutrient trends were downward. Upward trends in metals corresponded with relatively small concentration increases while downward trends involved considerably larger concentration changes. Downward trends in chloride, sulfate, and suspended solids were observed statewide, but upward trends in hardness were observed in the northern half of Indiana.

Introduction

This study combined water-quality and streamflow data from two monitoring programs in Indiana to determine temporal trends in concentrations of selected constituents. A long-term, State-operated network of sites with laboratory analysis of monthly water samples provided an archive of information about stream chemistry. A long-term, federally managed network of streamgages provided daily mean streamflow values. For sites at or close to streamgages, data were combined to understand changes in stream-water quality that were independent of changes in streamflow.

In 2012, the Indiana Department of Environmental Management (IDEM) evaluated their Fixed Station Monitoring Program (FSMP) and determined that an assessment of trends in constituent concentrations was needed. In 2013, the U.S. Geological Survey (USGS), in cooperation with the IDEM, completed an initial study of the FSMP data, which is described in this report. An important element of this study was that water-quality concentration data were combined with streamflow data from associated USGS streamgages and analyzed with sophisticated statistical techniques to identify and quantify trends as described in the Methods section of this report.

Knowledge about long-term temporal changes in water quality is important for water-resource and land-use managers, public officials, planners, scientists, and citizens. This knowledge includes the number and location of stream sites with long-term increases or decreases in concentrations of selected constituents, along with the significance and magnitude of these changes. Trends in constituent concentrations from a stream or streams in a major drainage basin can be indicative of the effectiveness of regulatory and voluntary actions intended to protect and improve water quality. Trends may reveal regional rather than local conditions and may involve point-source and nonpoint-source causes.

This study for Indiana is comparable with other modern studies that have reviewed trends in water-quality constituents in networks spanning major watersheds or geographic regions. In the following examples, which are discussed later in this report, streamflow and water-chemistry information were used for the trends analysis and the analysis was for decade-long or multi-decade time frames. Murphy and others (2013) provide an update on nitrate trends in the Mississippi River and its tributaries for 1980–2010. Lorenz and others (2008) examined trends in nutrients and suspended sediment in watersheds of the north-central U.S. for 1975–2004. Sprague and others (2009) investigated trends in nutrients in major rivers of the U.S. for 1993–2003. Galloway and others (2012) studied trends in nutrients, metals, and ions for North Dakota streams.

Fixed Station Monitoring Program in Indiana

Since 1957, the IDEM has routinely monitored water quality in streams in Indiana as part of the FSMP. The main use of the FSMP has been to provide data for preparing and reviewing permits for wastewater discharges and evaluating associated stream-water quality. As of 2012, there were 163 sites in the FSMP at which monthly grab samples of water were collected for laboratory analysis of water chemistry (primarily nutrients, metals, and ions) and indicator bacteria, and field determinations of water-quality properties (water temperature, dissolved oxygen, and pH). Detailed documentation of laboratory analytical and quality-assurance methods for the FSMP are not provided in this report, but the quality and consistency of the data were assumed to be suitable for trends analysis. The water-quality data are archived in the Indiana Assessment Information Management System (AIMS) database (Indiana Department of Environmental Management, 2013). The FSMP data provide an extensive archive of time-series water-quality information for the major streams and drainage basins in Indiana, including multiple locations from upstream to downstream in these drainage basins. Other sources of information about the FSMP are the Indiana Department of Environmental Management (2006) and the Indiana Water Monitoring Council (2013).

Streamflow Monitoring Program in Indiana

Streamflow is the amount of water in a stream, moving past a monitoring location (called a streamgage), per unit time. Streamflow, the term used in this report, involves the measurement and calculation of discharge, which is the product of stream velocity and stream cross-section area. The USGS has maintained a statewide network of streamgages in Indiana since the 1930s (Jian and others, 2012). In 2012, there were 202 USGS streamgages in Indiana. At these streamgages, a continuous record of stream stage (water height above a datum) is measured and combined with periodic measurements and calculations of discharge during a range of conditions. The mathematical relation of stream stage and discharge at each streamgage is determined, and a continuous record of discharge is calculated. The streamflow data from the USGS streamgages are archived in the National Water Information System (NWIS; U.S. Geological Survey, 2013a) database. The USGS National Streamflow Information Program is described at U.S. Geological Survey (2013b).

Streamflow is important for understanding trends in water quality because as the amount of water moving in a stream increases and decreases, constituent concentrations measured in time-series water samples can change. Statistical analysis to distinguish the changes in constituent concentrations that are independent of changes in streamflow can provide useful indicators to evaluate the effectiveness of pollution control and management programs.

Purpose and Scope

This report presents summary statistics and trends for concentrations of selected constituents in monthly water samples at 57 Indiana FSMP stream sites at or nearby a USGS streamgage. Although Indiana streamflow data were used, trends in streamflow alone were beyond the scope of this study. The 12 selected constituents are the nutrients nitrate, organic nitrogen, and phosphorus; suspended solids; the metals copper, iron, lead, and zinc; the ions chloride, and sulfate together with hardness as a measure of the calcium carbonate ion; and dissolved solids. The time period for the summary statistics and trends is 11 years (January 1, 2000–December 31, 2010). This report does not attempt to explain why trends in concentrations of specific constituents have occurred, or why specific monitoring sites exhibit trends.

Study Area

Indiana is 35,887 square miles (mi^2) in size, which is 38th in geographic area in the Nation. The State population census in 2010 was 6.48 million, 15th in the Nation; population density was approximately 181 individuals per square mile. Indiana has approximately 63,130 miles (mi) of rivers and streams (Indiana Department of Environmental Management, 2014); 277 mi^2 of reservoirs, lakes, and ponds (U.S. Geological Survey, 2014a);[1] 1,270 mi^2 of wetlands (Indiana

[1] The National Hydrography Dataset (NHD) of the National Map (U.S. Geological Survey, 2014a), described by Simley and Carswell (2009) was cited by the Indiana Department of Environmental Management (2014) as the source of information for the number of stream miles in Indiana. For this report, the NHD was accessed for Indiana, and the features identified as reservoirs, lakes, and ponds greater than 1 acre at 1:24,000 scale were identified and summed by use of a geographic information system (GIS) and spreadsheet software to determine the area.

Figure 1. Major rivers in Indiana.

Department of Environmental Management, 2014); and 59 mi of Lake Michigan shoreline (Indiana Department of Environmental Management, 2014).

The climate of Indiana is continental, influenced mainly by eastward-moving cold polar air masses and warm gulf air masses. The low-pressure centers formed by the interaction of these air masses are the major sources of precipitation in Indiana. Spring and early summer are normally the wettest periods of the year, as storm systems tap moisture from the Gulf of Mexico and travel across Indiana. Early fall is generally the driest period. Seasonal precipitation patterns vary statewide, particularly in the summer (when isolated thunderstorms are common) and winter (when lake-effect snows fall in northern Indiana). Normal January minimums range from 15 to 21 degrees Fahrenheit (°F) north to south. July is the warmest month with daily maximums averaging 80 to 83 °F and minimums of 63 to 65 °F north to south (Indiana State Climate Office, 2013).

The statewide average annual precipitation ranges from 37 inches (in.) for northern Indiana to nearly 47 in. for southern Indiana. Snowfall (as liquid) accounts for 2 to 7 in. of the average annual precipitation, with the greatest amounts of snowfall in northern Indiana (Indiana State Climate Office, 2013). According to Clark and Larrison (1980), approximately 68 percent of the mean annual precipitation in Indiana returns to the atmosphere through evapotranspiration, 24 percent enters streams and lakes through surface runoff, and 8 percent recharges groundwater. Generally, runoff is greatest in areas with steep slopes and relatively impermeable soils, which are characteristic of much of the southern third of Indiana.

In this report, drainage basins are used to organize data for summarizing concentration statistics and reporting trend-analysis results. A drainage basin, from a water-resources standpoint, is the area that gathers water from precipitation and delivers it to a series of streams that join to form a major river. Major rivers in Indiana (fig. 1) flow either to the Great

Lakes or to the Mississippi River (Clark and Larrison, 1980). Approximately 10 percent of the land area in Indiana is drained by the St. Joseph River that flows to Lake Michigan and the Maumee River that flows to Lake Erie. Approximately 82 percent of the State land area is drained by rivers that flow to the Ohio River and then to the Mississippi River—the Wabash River, the West Fork White River, the East Fork White River, the Whitewater River, the Patoka River, and tributaries of the Ohio River. Approximately 8 percent of the State land area is drained by rivers that flow to the Illinois River and then to the Mississippi River—the Kankakee River and the Iroquois River.

Methods

The methods for data compilation, site selection, and constituent selection are described in the following section. Summary information about the study sites is provided. Techniques are explained for the calculation of summary statistics for constituent concentrations statewide and in individual drainage basins, and for determination of significant differences in constituent concentrations among the drainage basins in Indiana. In the design of this study, statistical techniques were used that could identify trends in constituent concentrations that were independent of trends in streamflow, as described in this section.

Data Compilation

Data were compiled for the study with the purpose of selecting sites for trends analysis. Water-quality data for Indiana were obtained from the AIMS for 2000–10. A consistent name and 5-digit NWIS code was assigned to each constituent, along with a consistent unit for concentrations and reporting limits. (A reporting limit is the concentration below which a constituent is considered to not be detected, although a reporting limit may not be equivalent to an analytical detection limit. A value less than the reporting limit is called a censored value.) It was determined that 57 FSMP sites had “complete” annual records, meaning that they had at least 9 of 12 monthly water-quality samples analyzed for a minimum of 16 constituents every year for the period 2000–10. Constituent selection is described in the next section.

Streamflow data for Indiana were obtained from the NWIS database for 2000–10. A GIS (ESRI, 2007) was used to identify 50 USGS streamgages that were collocated or on the same stream reach as the 57 FSMP sites. (Note that more than one FSMP site could be associated with a single streamgage.) A criterion for considering the streamgage and FSMP site to be on the same reach was that a tributary of the next lower stream order did not confluence with the stream of the streamgage between the FSMP site and the streamgage. Similar criteria are in use for retrospective data compilation in the National Water-Quality Assessment Program (U.S. Geological Survey, 2014b). The program waterData (Ryberg and Vecchia, 2012) was used to screen and standardize zero and missing streamflow values and to mathematically assign probable streamflow values for missing values. The final dataset for this study consisted of 4,015 daily mean streamflow values from the NWIS database for 50 USGS streamgages in Indiana, 2000–10.

Study Sites

In 2012, 57 of the 163 FSMP sites in Indiana met the site selection criteria for the concentrations trends analysis in this report (fig. 2). Characteristics and locations of the 57 FSMP sites and the 50 associated streamgages in this report are shown in table 1 and figure 3. Among the 57 FSMP sites, the streamgage was collocated at 25 sites, upstream at 25 sites, and downstream at 7 sites (fig. 3). The 57 FSMP sites are located in 10 of the 12 major drainage basins in Indiana (known as hydrologic subregion accounting units in Seaber and others, 1987); the exceptions are the Maumee and St. Joseph River Basins (fig. 3). The number of study sites in the 10 drainage basins is not uniform and ranges from 1 to 4 sites in 7 basins and up to 16 or 17 sites in 2 basins (table 2). The size of the watersheds upstream from the sites were computed with the GIS (fig. 4*A*) and ranged from 10 mi^2 (site 7, table 2) to 13,765 mi^2 (site 18, table 2); three-fourths of the sites had watershed sizes of 2,031 mi^2 or less (fig. 4*B*).

Streamflow conditions on days of sampling were determined to be representative of overall streamflow conditions during the study period. Distributions of daily mean streamflow, 2000–10, were not significantly different from distributions of daily streamflow at the time of the monthly water-quality samples (Wilcoxon rank-sum test, $\alpha = 0.05$).

Constituent Selection

The water-quality data for the 16 constituents at the 57 FSMP sites (2000–10) were examined, and 4 constituents were excluded from this report. The water-quality properties (water temperature and dissolved oxygen) have daily fluctuations, and pH has a non-linear scale of measurement (characteristics incompatible with the statistical trends-analysis technique used in this study). Ammonia-nitrogen had 87.9 percent censored values, and trend analysis was not meaningful.

For presentation and discussion of results in this report, the 12 constituents selected for the study were divided into 3 groups of 4 constituents each and given simple names. Reported concentrations were total or total recoverable forms of the constituents (with the exception of dissolved solids, by definition). Additional information about the constituents is presented in the Water Quality in Indiana Streams section of this report.

The four constituents in the nutrients and suspended solids group are nitrate plus nitrite as nitrogen (named *nitrate* in this report); total Kjeldahl nitrogen, known as TKN, the sum of organic nitrogen, ammonia, and ammonium (named *organic*

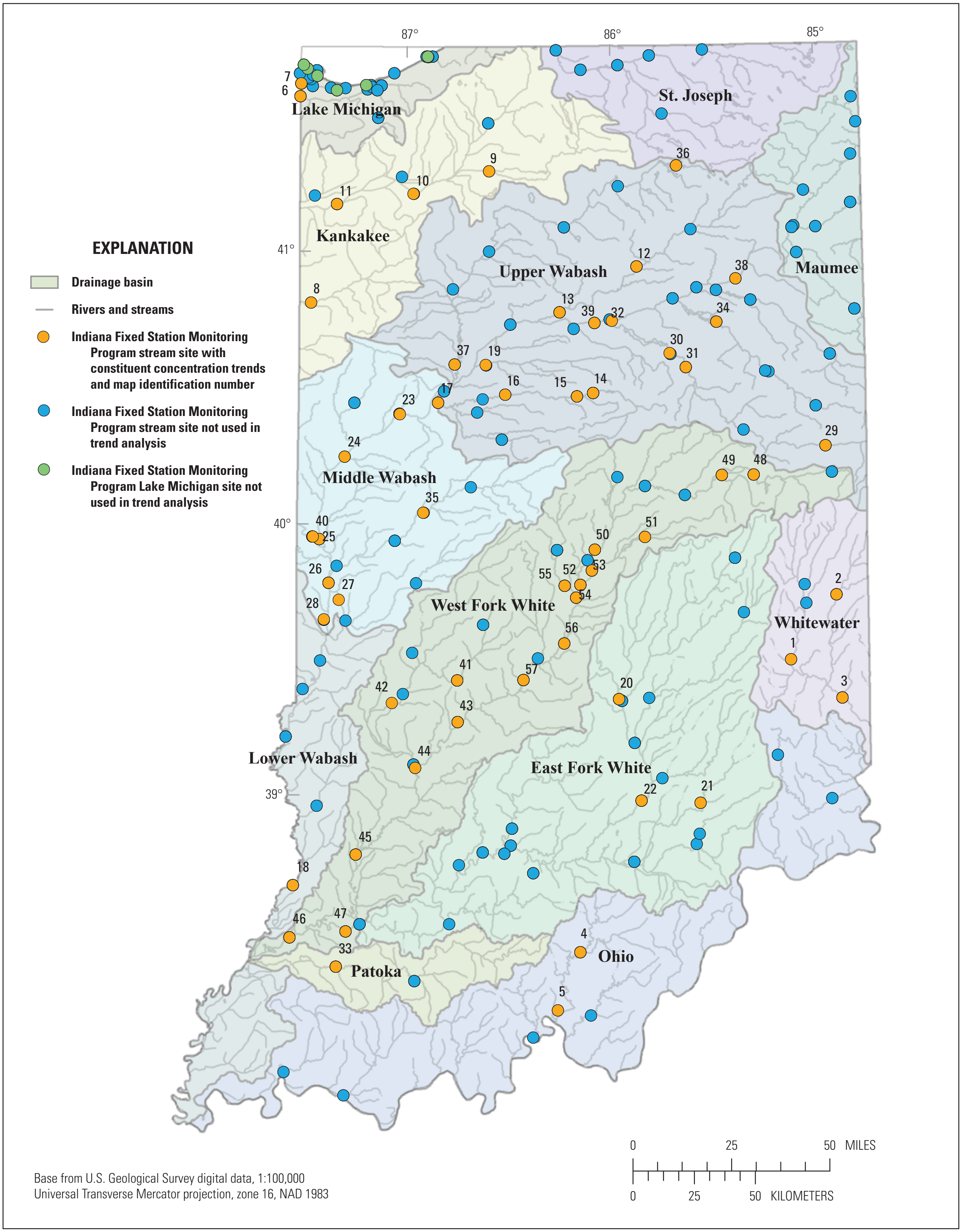

Figure 2. All Indiana Fixed Station Monitoring Program sites and stream sites selected for use in this study.

Table 1. Indiana Fixed Station Monitoring Program stream sites and U.S. Geological Survey streamgages used in this study.

[ID, identification; FSMP, Fixed Station Monitoring Program; USGS, U.S. Geological Survey]

Map ID number	FSMP site number	FSMP site stream name	USGS streamgage number	USGS streamgage name	Position of streamgage to FSMP site	Difference in streamgage and FSMP site watersheds (percent)[1]
1	GMW040-0005	Whitewater River	03275000	Whitewater River near Alpine	upstream	10
2	GMW070-0006	East Fork Whitewater River	03275600	East Fork Whitewater River at Abington	collocated	0
3	GMW080-0001	Whitewater River	03276500	Whitewater River at Brookville	upstream	7
4	OBS140-0004	Blue River	03302800	Blue River at Fredericksburg	collocated	0
5	OBS150-0008	Blue River	03303000	Blue River near White Cloud	upstream	5
6	UMC030-0004	Little Calumet River	05536195	Little Calumet River at Munster	collocated	0
7	UMC050-0002	Grand Calumet River	05536357	Grand Calumet River at Hohman Ave at Hammond	collocated	0
8	UMI050-0006	Iroquois River	05524500	Iroquois River near Foresman	upstream	18
9	UMK060-0001	Yellow River	05517000	Yellow River at Knox	downstream	2
10	UMK080-0001	Kankakee River	05517500	Kankakee River at Dunns Bridge	collocated	0
11	UMK110-0002	Kankakee River	05518000	Kankakee River at Shelby	collocated	0
12	WAE050-0001	Eel River	03328000	Eel River at North Manchester	upstream	15
13	WAE070-0011	Eel River	03328500	Eel River near Logansport	collocated	0
14	WAW010-0063	Wildcat Creek	03333450	Wildcat Creek near Jerome	upstream	17
15	WAW020-0004	Wildcat Creek	03333700	Wilcat Creek at Kokomo	upstream	3
16	WAW020-0039	Wildcat Creek	03334000	Wildcat Creek at Owasco	downstream	6
17	WAW050-0005	Wildcat Creek	03335000	Wildcat Creek near Lafayette	upstream	0
18	WBU200-0003	Wabash River	03342000	Wabash River at Riverton	upstream	4
19	WDE050-0002	Deer Creek	003329700	Deer Creek near Delphi	collocated	0
20	WED090-0004	Sugar Creek	03362500	Sugar Creek near Edinburgh	collocated	0
21	WEM070-0001	Vernon Fork Muscatatuck River	03369500	Vernon Fork Muscatatuck River at Vernon	collocated	0
22	WEU040-0001	East Fork White River	03365500	East Fork White River at Seymour	collocated	0
23	WLV030-0003	Wabash River	03335500	Wabash River at Lafayette	upstream	3
24	WLV080-0003	Wabash River	03336000	Wabash River at Covington	downstream	1
25	WLV140-0001	Wabash River	03340500	Wabash River at Montezuma	downstream	14
26	WLV150-0001	Wabash River	03340500	Wabash River at Montezuma	collocated	0
27	WLV190-0012	Big Raccoon Creek	03341300	Big Raccoon Creek at Coxville	upstream	6
28	WLV200-0001	Wabash River	03341500	Wabash River at Terre Haute	downstream	5
29	WMI020-0002	Mississinewa River	03325500	Mississinewa River near Ridgeville	collocated	0
30	WMI060-0004	Mississinewa River	03326500	Mississinewa River at Marion	upstream	5
31	WMI060-0005	Mississinewa River	03326500	Mississinewa River at Marion	collocated	0
32	WMI060-0006	Mississinewa River	03326500	Mississinewa River at Marion	upstream	17
33	WPA060-0002	Patoka River	03376300	Patoka River at Winslow	upstream	7
34	WSA040-0005	Salamonie River	03324300	Salamonie River near Warren	upstream	2
35	WSU050-0002	Sugar Creek	03339500	Sugar Creek at Crawfordsville	collocated	0
36	WTI010-0001	Tippecanoe River	03330241	Tippecanoe River at North Webster	collocated	0
37	WTI150-0011	Tippecanoe River	03333050	Tippecanoe River near Delphi	collocated	0
38	WUW120-0002	Little River	03324000	Little River near Huntington	collocated	0

[1] Difference in the watershed area of FSMP site and streamgage as a percentage of the watershed area of the FSMP site.

Table 1. Indiana Fixed Station Monitoring Program stream sites and U.S. Geological Survey streamgages used in this study.—Continued

[ID, identification; FSMP, Fixed Station Monitoring Program; USGS, U.S. Geological Survey]

Map ID number	FSMP site number	FSMP site stream name	USGS streamgage number	USGS streamgage name	Position of streamgage to FSMP site	Difference in streamgage and FSMP site watersheds (percent)[1]
39	WUW160-0006	Wabash River	03327500	Wabash River at Peru	collocated	0
40	WVE100-0001	Vermillion River	03339000	Vermilion River near Danville IL	upstream	10
41	WWE060-0002	Mill Creek	03358000	Mill Creek near Cataract	collocated	0
42	WWE080-0001	Eel River	03360000	Eel River at Bowling Green	upstream	4
43	WWL020-0003	West Fork White River	03354000	White River near Centerton	upstream	18
44	WWL030-0003	West Fork White River	03360500	White River at Newberry	downstream	7
45	WWL070-0003	West Fork White River	03360500	White River at Newberry	upstream	6
46	WWL100-0001	White River	03374000	White River at Petersburg	upstream	2
47	WWL100-0005	White River	03374000	White River at Petersburg	collocated	0
48	WWU010-0001	West Fork White River	03347000	White River at Muncie	downstream	10
49	WWU020-0005	West Fork White River	03347000	White River at Muncie	collocated	0
50	WWU090-0002	West Fork White River	03351000	White River near Nora	collocated	0
51	WWU100-0001	Fall Creek	03351500	Fall Creek near Fortville	collocated	0
52	WWU110-0001	Fall Creek	03352500	Fall Creek at Millersville	upstream	6
53	WWU110-0002	Fall Creek	03352500	Fall Creek at Millersville	upstream	5
54	WWU120-0001	Eagle Creek	03353500	Eagle Creek at Indianapolis	upstream	15
55	WWU120-0002	Eagle Creek	03353500	Eagle Creek at Indianapolis	collocated	0
56	WWU140-0003	West Fork White River	03353611	White River at Stout Generating Station	upstream	7
57	WWU160-0004	West Fork White River	03354000	White River near Centerton	upstream	2

[1] Difference in the watershed area of FSMP site and streamgage as a percentage of the watershed area of the FSMP site.

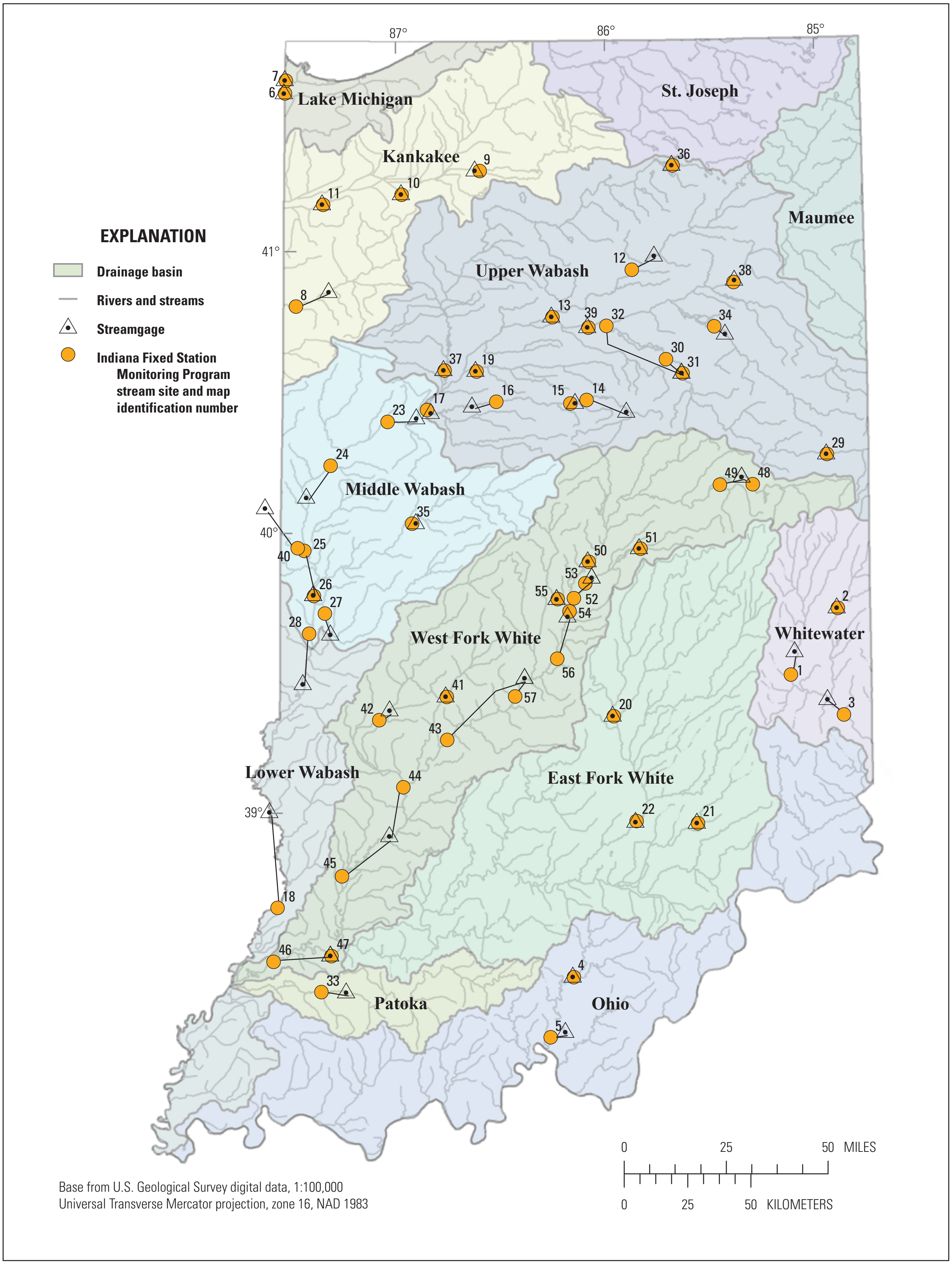

Figure 3. Selected Indiana Fixed Station Monitoring Program stream sites and associated streamgages used in this study.

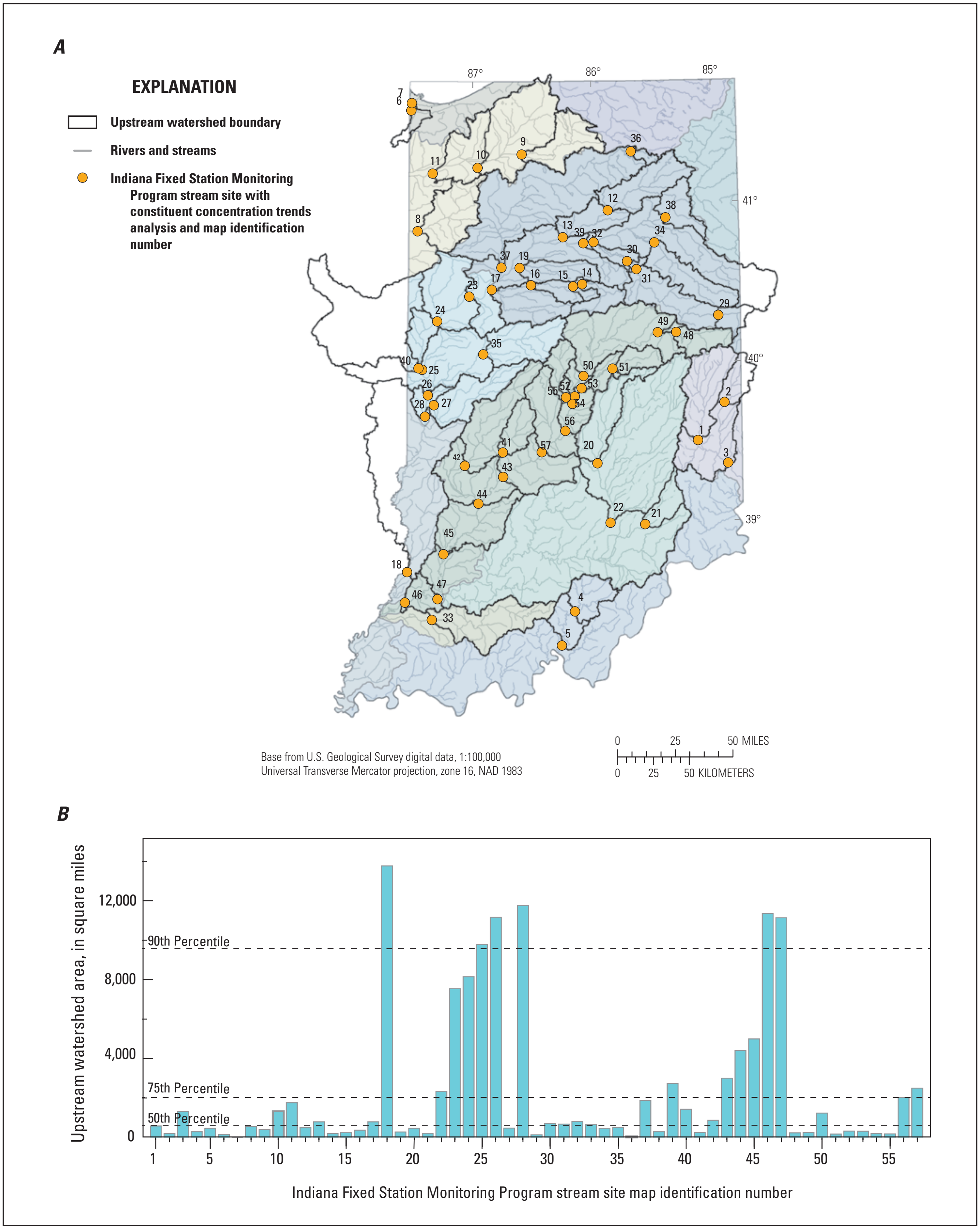

Figure 4. Indiana Fixed Station Monitoring Program stream sites used in this study with diagram of upstream watershed size. *A*, Map. *B*, Diagram.

Table 2. Characteristics of Indiana Fixed Station Monitoring Program stream sites used in this study.

[ID, identification; FSMP, Fixed Station Monitoring Program; mi², square mile; Rd, road; R., River; SR, State Road; US, United States (Highway); Ave, Avenue; CR County Road; W, west; E, east; N, north; St, Street; S, south; Dr, Drive]

Map ID number	FSMP historic site ID and site description	Indiana county	Major drainage basin	Latitude	Longitude	Hydrologic unit code	Upstream watershed (mi²)
1	WHW-47, Whitewater River, Laurel Rd, Laurel	Franklin	Whitewater R.	39.49806	85.18250	50800030408	579
2	WHE-27, East Fork Whitewater River, Potter Shop Rd, Abbington	Wayne	Whitewater R.	39.73250	84.95972	50800030710	200
3	WHW-22, Whitewater River, old SR 1	Franklin	Whitewater R.	39.35333	84.94278	50800030805	1,319
4	BLW-57, Blue River, US 150, Fredericksburg	Washington	Ohio R.	38.43389	86.19167	51401040805	294
5	BLW-10, Blue River, off of SR 62, Near Wyandotte Cave	Crawford	Ohio R.	38.22056	86.29833	51401040905	468
6	LCR-13, Little Calumet River, Hohman Ave, Hammond	Lake	Lake Michigan	41.57778	87.52222	71200030305	153
7	GCR-34, Grand Calumet River, Hohman Ave, Hammond	Lake	Lake Michigan	41.62444	87.51778	71200030407	10
8	I-63, Iroquois River, CR 400 W, north of Kentland	Newton	Kankakee R.	40.82014	87.46403	71200020503	548
9	YR-12, Yellow River, CR 500 E, east of Knox	Starke	Kankakee R.	41.30229	86.60154	71200010506	413
10	KR-91, Kankakee River, CR 500 E, Dunns Bridge	Porter	Kankakee R.	41.22001	86.96908	71200010807	1,327
11	KR-68, Kankakee River, SR 55, Shelby	Newton	Kankakee R.	41.18270	87.34058	71200011103	1,761
12	ELL-41, Eel River, SR 15, northeast of Roann	Wabash	Upper Wabash R.	40.94792	85.89076	51201040509	496
13	ELL-7, Eel River, CR 150 N, northeast of Logansport	Cass	Upper Wabash R.	40.78233	86.26450	51201040705	789
14	WC-66, Wildcat Creek, US 31, Kokomo	Howard	Upper Wabash R.	40.48611	86.10750	51201070109	195
15	WC-60, Wildcat Creek, CR 300 W, near Kokomo	Howard	Upper Wabash R.	40.47361	86.18417	51201070403	244
16	WC-32, Wildcat Creek, SR 75, near Cutler	Carroll	Upper Wabash R.	40.48179	86.53010	51201070408	366
17	WC-3, Wildcat Creek, SR 25, near Lafayette	Tippecanoe	Upper Wabash R.	40.45378	86.85139	51201070409	789
18	WB-130, Wabash River, Vigo St, Vincennes	Knox	Lower Wabash R.	38.68125	87.53472	51201111903	13,765
19	DC-5, Deer Creek, CR 300 N, Northeast of Delphi	Carroll	Upper Wabash R.	40.59050	86.62140	51201050508	276
20	SGR-1, Sugar Creek, CR 800 S, Edinburgh	Johnson	East Fork White R.	39.36083	85.99806	51202040705	468
21	VF-38, Vernon Fork Muscatatuck River, CR 60 S, Vernon	Jennings	East Fork White R.	38.97639	85.62000	51202070701	209
22	EW-168. East Fork White River, CR 725 N, Seymour	Jackson	East Fork White R.	38.98722	85.89889	51202060502	2,336
23	WB-303, Wabash River, CR 300 W, near Lafayette	Tippecanoe	Middle Wabash R.	40.41182	87.03624	51201080503	7,537
24	WB-284, Wabash River, CR 2000 W, Williamsport	Warren	Middle Wabash R.	40.25509	87.29967	51201080604	8,142
25	WB-256, Wabash River, SR 234, Cayuga	Vermillion	Middle Wabash R.	39.95179	87.41964	51201081602	9,773
26	WB-240, Wabash River, US 36, Montezuma	Vermillion	Middle Wabash R.	39.79243	87.37415	51201081605	11,158
27	RC-5, Big Racoon Creek, Mecca	Parke	Middle Wabash R.	39.72938	87.32497	51201081504	475
28	WB-230, Wabash River, near SR 163, Clinton	Vermillion	Middle Wabash R.	39.65767	87.39582	51201081607	11,747
29	MS-99, Mississinewa River, CR 100 W, near Ridgeville	Randolph	Upper Wabash R.	40.28000	84.99528	51201030203	133
30	MS-28, Mississinewa River, off of CR 380 W, Jalapa	Grant	Upper Wabash R.	40.62806	85.73583	51201030601	710

Table 2. Characteristics of Indiana Fixed Station Monitoring Program stream sites used in this study.—Continued

[ID, identification; FSMP, Fixed Station Monitoring Program; mi², square mile; Rd, road; R., River; SR, State Road; US, United States (Highway); Ave, Avenue; CR County Road; W, west; E, east; N, north; St, Street; S, south; Dr, Drive]

Map ID number	FSMP historic site ID and site description	Indiana county	Major drainage basin	Latitude	Longitude	Hydrologic unit code	Upstream watershed (mi²)
31	MS-36, Mississinewa River, near Highland Ave, Marion	Grant	Upper Wabash R.	40.57611	85.65972	51201030601	677
32	MS-1, Mississinewa River, SR 124, near Peru	Miami	Upper Wabash R.	40.74937	86.01206	51201030606	812
33	P-35, Patoka River, CR 300 W, near Oakland City	Pike	Patoka R.	38.38250	87.33333	51202090605	652
34	S-25, Salamonie River, SR 124, near Lancaster	Huntington	Upper Wabash R.	40.74167	85.50889	51201020405	448
35	SC-39, Sugar Creek, US 136, Crawfordsville	Montgomery	Upper Wabash R.	40.05006	86.92269	51201100604	512
36	TR-164, Tippecanoe River, SR 13, North Webster	Kosciusko	Upper Wabash R.	41.31639	85.69222	51201060105	51
37	TR-9, Tippecanoe River, SR 18, near Delphi	Carroll	Upper Wabash R.	40.59382	86.77071	51201061309	1,878
38	LR-7, Little River, CR 200 E, near Huntington	Huntington	Upper Wabash R.	40.89861	85.41333	51201011103	290
39	WB-370, Wabash River, Business US 31	Miami	Upper Wabash R.	40.74276	86.09622	51201011602	2,730
40	V-0.8, Vermillion River, SR 63, Cayuga	Vermillion	Middle Wabash R.	39.96178	87.45085	51201090907	1,429
41	MC-18, Mill Creek, US 231	Owen	West Fork White R.	39.43333	86.76333	51202030512	251
42	EEL-38, Eel River, CR 200 E, near Bowling Green	Clay	West Fork White R.	39.35068	87.07278	51202030706	873
43	WR-162, West Fork White River, South Main St, Spencer	Owen	West Fork White R.	39.28028	86.76194	51202020205	3,002
44	WR-134, West Fork White River, SR 157, Worthington	Greene	West Fork White R.	39.11194	86.96250	51202020404	4,407
45	WR-81, West Fork White River, SR 358, near Edwardsport	Daviess	West Fork White R.	38.79500	87.24167	51202020803	4,993
46	WR-19, White River, Old US 41, Hazleton	Gibson	West Fork White R.	38.49000	87.55000	51202021007	11,344
47	WR-46, White River, SR 61, Petersburg	Pike	West Fork White R.	38.51167	87.28861	51202021001	11,129
48	WR-319, West Fork White River, Memorial Dr, Muncie	Delaware	West Fork White R.	40.17833	85.34222	51202010110	231
49	WR-309, West Fork White River, Tiger Drive, Yorktown	Delaware	West Fork White R.	40.17889	85.49500	51202010305	253
50	WR-248, West Fork White River, 86th St, Nora	Marion	West Fork White R.	39.91037	86.10503	51202011006	1,233
51	FC-26, Fall Creek, SR 238, Fortville	Hamilton	West Fork White R.	39.95444	85.86694	51202010808	174
52	FC-0.6, Fall Creek, Stadium Dr, Indianapolis	Marion	West Fork White R.	39.78173	86.17679	51202010904	322
53	FC-7, Fall Creek, Keystone Ave, Indianapolis	Marion	West Fork White R.	39.83434	86.12189	51202010904	319
54	EC-1, Eagle Creek, Raymond St, Indianapolis	Marion	West Fork White R.	39.73528	86.19658	51202011110	209
55	EC-7, Eagle Creek, Lynhurst Dr, Indianapolis	Marion	West Fork White R.	39.77825	86.25067	51202011110	177
56	WR-210, West Fork White River, SR 144, near Waverly	Morgan	West Fork White R.	39.56694	86.25583	51202011402	2,031
57	WR-192, West Fork White River, SR 39, Martinsville	Morgan	West Fork White R.	39.43389	86.44944	51202011503	2,499

nitrogen in this report); total phosphorus (named *phosphorus* in this report); and total suspended solids[2] (named *suspended solids* in this report). The four constituents in the metals group are copper, iron, lead, and zinc. The four constituents in the ions and dissolved solids group are chloride, sulfate, hardness as calcium carbonate (named *hardness* in this report), and total dissolved solids (named *dissolved solids* in this report).[3]

An evaluation of the concentration values for the 12 selected constituents was made to identify extreme outliers and to reconcile multiple reporting limits for censored values. Rank-ordered data indicated a total of 3 high values for 3 constituents were more than 20 to 700 times the interquartile range for each constituent, and these 3 extreme outlier values were removed from the data for this study. Multiple reporting limits were observed for censored values of the constituents organic nitrogen, phosphorus, suspended solids, copper, lead, and zinc, so the highest reporting limit was applied to a small number of censored values, to be compatible with the statistical trends-analysis technique used in this study. The final dataset for this study consisted of 86,110 concentration values from the AIMS database for the 12 constituents in 7,345 water samples from 57 FSMP sites for 2000–10.

Statistical Analysis

The parametric statistical time-series model for detecting trends (called QWTREND), developed by USGS and described in Vecchia (2000, 2003, 2005) and supplemental documentation (Vecchia, 2004a, 2004b), was used to determine whether there were statistically significant trends in concentrations of the 12 water-quality constituents in this study. The QWTREND model is used for analyzing streamflow-related variability in constituent concentrations so that time-series constituent concentration trends independent of streamflow-related variability can be determined. Most of the variability in constituent concentrations is caused by variability in streamflow. This streamflow-related variability is often complex and cannot be determined by a simple regression model of constituent concentration and streamflow at the time of sample collection. Streamflow conditions for days, months, or even years prior to the water-quality sample can affect concentration. Concentration data with streamflow-related variability removed, called flow-adjusted concentrations, usually have seasonal variance and serial correlation structure remaining, that can cause problems in statistical trends analysis. The QWTREND model for daily streamflow and constituent concentration adjusts for seasonal variance and serial correlation.

To detect the water-quality trends for this study, concentration data were partitioned into several components according to the following equation:

$$\log (C) = MC + ANNC + SEASC + HFVC + TRENDC$$

where

log denotes the base-10 logarithm;
C is the concentration, in milligrams or micrograms per liter;
MC is the long-term mean of the log-transformed concentration, as the base-10 logarithm of milligrams or micrograms per liter;
ANNC is the annual concentration variability (dimensionless);
SEASC is the seasonal concentration variability (dimensionless);
HFVC is the high-frequency variability of the concentration (dimensionless); and
TRENDC is the concentration trend (dimensionless).

The annual concentration variability ANNC, seasonal concentration variability SEASC, and high-frequency variability HVFC terms represent natural variability in concentration for different time scales. Annual, seasonal, and high-frequency variability in streamflow contribute to concentration variability, but are uncorrelated at any specific time and depend only on streamflow up to that specific time (Ryberg and Vecchia, 2012).

ANNC is an estimate of the interannual variability in concentration that can be attributed to long-term variability in streamflow. For example, extended dry and wet periods affect the proportions of surface runoff and base flow in streams, which can change the water quality. SEASC is an estimate of the seasonal variability in concentration that can be attributed to seasonal variability in streamflow or to seasonality in other factors other than streamflow. For example, seasonal snowmelt and water temperatures affect water quality, as can seasonal applications of fertilizer or road deicers. HFVC is an estimate of the variability in concentration for time scales of several days or weeks that are shorter than a season. For example, daily changes in weather may cause variability in streamflow and water quality. Unlike annual and seasonal concentration variability, which depend on antecedent streamflow, high-frequency variability includes serial correlation among concentrations, the tendency for high or low values to persist for several days or weeks before returning to normal.

TRENDC is an estimate of the long-term systematic changes in concentration that are unrelated to long-term variability in streamflow. A statistically significant trend might indicate changes in human activities that affect water quality. Trends from different causes can occur at different times

[2] It is known that nutrients, particularly phosphorus, are attached to suspended sediment in water (U.S. Geological Survey, 2013c) and that is why suspended solids are grouped with the nutrients. Note that the suspended solids in a sample can be inorganic and organic in origin and may or may not include attached nutrients. Also, other constituents will attach to and can be part of the suspended sediment, including the metals in this study.

[3] Total dissolved solids includes the anions chloride, sulfate, and calcium carbonate, but also nitrate (Hem, 1985) and cations such as aluminum, magnesium, potassium, sodium, and silica.

and in different directions, so the trends in this study are not monotonic (entirely upward or entirely downward). Trends can persist for a short time before ending or reversing direction. For this study, a trend was defined as a statistically significant increase or decrease in median concentration for a period of at least 11 years, 2000–10.

QWTREND includes the bivariate, periodic autoregressive moving average (PARMA) model fitted to the high-frequency variability of streamflow and concentration to account for serial correlation and nonstationarity (Vecchia, 2000). The PARMA model is fitted using Gaussian maximum likelihood estimation. For this study, QWTREND was used to determine trends of increasing concentrations (uptrends) and decreasing concentrations (downtrends) during the 11-year study period. Statistically significant trends were identified when the probability of a Type I error[4] was less than 5 percent ($\alpha = 0.05$). The magnitude of uptrends and downtrends were measured as a percent change and as a concentration change between the median annual concentration in 2000 and the median annual concentration in 2010.

Significant differences in constituent concentrations among basins were determined with a statistical technique that took into account the censored values for 6 of the 12 constituents. The technique was the generalized Wilcoxon test (Helsel, 2004), which compares two groups at a time using a null hypothesis that the locations (central tendency) of the distributions of the groups differ by zero. For discussion in this report, the median is used to describe the central tendency of a group.

Summary statistics for constituents with censored data were determined by use of the Maximum-Likelihood Estimation technique (Helsel and Hirsch, 2002). Although the concentration data were assumed to have a lognormal distribution, this technique provides unbiased estimates of percentiles, median, and interquartile range for a variety of data distributions for environmental studies, even those which are not lognormal.

Water Quality in Indiana Streams

This section provides a description of each constituent with a statistical summary of concentrations in Indiana during the study period. The standards and criteria for each constituent are explained and compared with the concentrations in Indiana. Trends in constituent concentrations during the study period are identified and discussed.

[4] A Type I error in statistics is identification of a significant trend when no trend was actually present.

Constituents, Criteria, and Concentrations

The following discussion provides background information on the 12 constituents and relies on information from Hem (1985), the Indiana water-quality standards rules for surface water (Indiana Administrative Code, 2013), and the national recommended fresh-water-quality criteria (U.S. Environmental Protection Agency, 2009 and references therein). Concentrations of the constituents at the sites in this study have been summarized statewide (table 3). Six constituents—nitrate, iron, chloride, sulfate, hardness, and dissolved solids—did not have censored values. Censored values were less than 9 percent of samples for each of the other constituents, with the exception of lead (57.9 percent) and zinc (34.6 percent).

Nutrients and Suspended Solids

Nutrients for plants include nitrogen, phosphorus, and potassium. As described earlier, the constituents nitrate, organic nitrogen, and phosphorus are included in this study, along with suspended solids that may be a substrate for nutrient transport.

Nitrate is the main anion form of nitrogen in water, generally found with lesser amounts of nitrite, ammonia, and organic nitrogen. The nitrogen cycle includes components in the air, water, land, and biota. Nitrogen levels in water can be increased by wastewater discharges and fertilizer runoff. Excessive nitrogen in water can lead to harmful algal blooms, eutrophication, and depleted oxygen. The Indiana rules list a criterion for nitrate plus nitrite nitrogen of 10 milligrams per liter (mg/L), applied at the point of public-water system intake to protect human health. A chronic aquatic criterion for nitrate plus nitrite nitrogen is not listed in the Indiana rules. Nitrate concentrations in this study exceeded the 10 mg/L Indiana water-quality standard in 87 samples (1.2 percent); the maximum concentration was 17 mg/L.

Organic nitrogen includes natural materials such as proteins, peptides, nucleic acids, urea, and synthetic organic materials. Organic nitrogen levels can be high in sewage and animal wastes, as can ammonia. A criterion for organic nitrogen is not listed in the Indiana rules.

Phosphorus is an element with small concentrations in water because of the low solubility of its inorganic ions and uptake by biota as a nutrient. Analysis of total phosphorus in water includes dissolved, mostly orthophosphate ions, and particulate forms. Phosphorus is a component of sewage and fertilizer, and levels in water can be increased by wastewater discharges and fertilizer runoff. Excessive phosphorus in water can contribute to harmful algal blooms, eutrophication, and depleted oxygen. A criterion for phosphorus is not listed in the Indiana rules.

The national recommended water-quality criteria for nutrients are listed by aggregate ecoregion (fig. 5), which in Indiana are the Cornbelt and Northern Great Plains (CBNGP) for most of the State, the Mostly Glaciated Dairy Region

Table 3. Summary statistics for constituent concentrations in Indiana streams, 2000–10.

[n, number of samples; mg/L, milligrams per liter; POI, criteria applied at point of intake for public water supply; <, less than; not set, criteria not established; µg/L, micrograms per liter]

Constituent	Reporting limit	Mean	Minimum	25th percentile	Median	75th percentile	Maximum	n	Number censored	Percent censored	Indiana criteria[1]	National criteria[2]
Nitrate	0.1 mg/L	3.1	0.1	1.6	2.6	4.1	17	7,156	0	0	10 mg/L (POI)	ecoregion[3]
Organic nitrogen	0.1 mg/L	0.9	<0.1	0.5	0.8	1.1	16	7,260	79	1.1	not set	ecoregion[3]
Phosphorus	0.03 mg/L	0.19	<0.03	0.07	0.14	0.23	4.1	7,311	368	5.0	not set	ecoregion[3]
Suspended solids	4.0 mg/L	38	<4.0	8.0	17	42	1,480	7,286	652	8.9	not set	not set
Copper	1.0 µg/L	3.3	<1.0	1.8	2.5	3.8	108	6,619	281	4.2	25 - 33 µg/L[4]	9.0 µg/L
Iron	20 µg/L	1,300	20	250	560	1,400	44,800	7,334	0	0	not set	1,000 µg/L
Lead	1.0 µg/L	1.8	<1.0	<1.0	<1.0	1.7	160	6,549	3,794	57.9	6.7 - 9.5 µg/L[4]	2.5 µg/L
Zinc	6.0 µg/L	19	<6.0	<6.0	8.6	17	730	7,279	2,521	34.6	230 - 300 µg/L[4]	120 µg/L
Chloride	5.0 mg/L	45	5.0	25	35	51	615	7,331	0	0	414 - 467 µg/L[5]	230 µg/L
Sulfate	5.0 mg/L	59	7.3	33	48	68	723	7,314	0	0	1,678 to 2,059 mg/L 250 mg/L (POI)	not set
Hardness	30 mg/L	287	37	243	293	333	643	7,345	0	0	not set	not set
Dissolved solids	30 mg/L	394	85	314	377	438	1,740	7,326	0	0	750 mg/L (POI)	not set

[1] Indiana criteria are from the Indiana water-quality standards rules for surface water (Indiana Administrative Code, 2013).

[2] National criteria are from the national recommended fresh-water-quality criteria (U.S. Environmental Protection Agency, 2009 and references therein).

[3] The national recommended water-quality criteria for nutrients are listed by aggregate ecoregion (U.S. Environmental Protection Agency, 2000a, 2000b, and 2000c). The criteria for total nitrogen, including nitrate and organic nitrogen, are Cornbelt and Northern Great Plains (2.18 mg/L); Mostly Glaciated Dairy Region (0.54 mg/L); and Southeast Temperate Forested Plains and Hills (0.69 mg/L). The criteria for total phosphorus are Cornbelt and Northern Great Plains (0.076 mg/L); Mostly Glaciated Dairy Region (0.033 mg/L); and Southeast Temperate Forested Plains and Hills (0.037 mg/L).

[4] The Indiana water-quality standards rules for surface water (Indiana Administrative Code, 2013) provide an equation and a table for computing the dissolved concentration criteria for selected metals, based on the total recoverable metal concentration and a factor for the water hardness. For the dataset in this report, hardness values generally ranged from 243 mg/L (the 25th percentile) to 333 mg/L (the 75th percentile), and the equivalent hardness factors applied from the Indiana rule are 250 and 350 mg/L, respectively. The criteria are presented as a range computed with the two hardness factors.

[5] The Indiana water-quality standards rules for surface water (Indiana Administrative Code, 2013) provide an equation and a table for computing the chloride concentration criteria, based on factors for hardness and sulfate. For the dataset in this report, the hardness factors are 250 and 350 mg/L and the sulfate values generally ranged from 33 mg/L (the 25th percentile) to 68 mg/L (the 75th percentile); the equivalent sulfate factors are 25 and 50 mg/L, respectively.

[6] The Indiana water-quality standards rules for surface water (Indiana Administrative Code, 2013) provide an equation and a table for computing the sulfate concentration criteria, based on factors for hardness and chloride. For the dataset in this report, the hardness factors are 250 and 350 mg/L and the chloride values generally ranged from 25 mg/L (the 25th percentile) to 51 mg/L (the 75th percentile); the equivalent chloride factors are 25 and 50 mg/L, respectively.

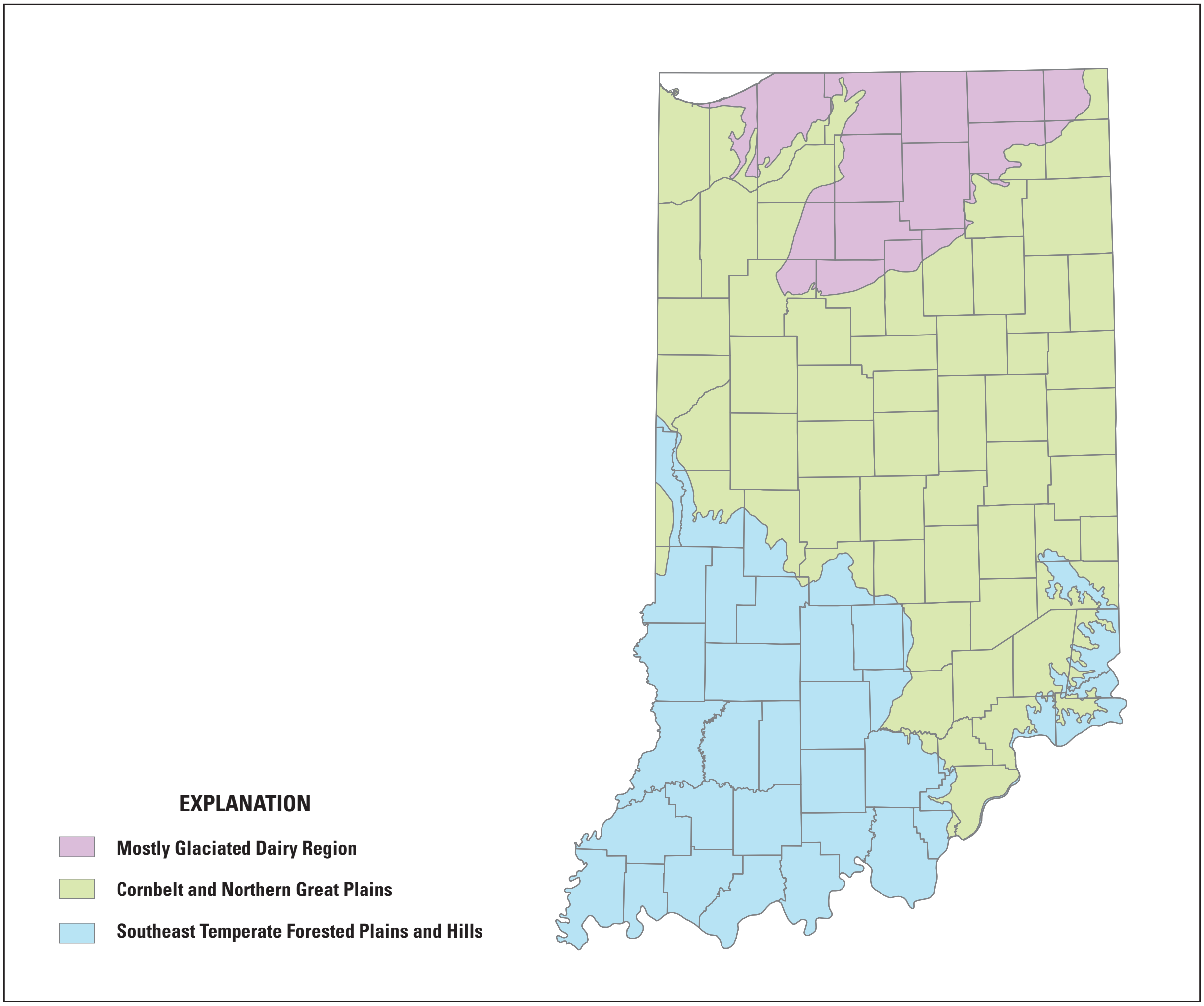

Figure 5. Aggregate ecoregions in Indiana.

(MGDR) for part of northern Indiana, and the Southeast Temperate Forested Plains and Hills (STFPH) for mostly southwestern Indiana (U.S. Environmental Protection Agency, 2000a, 2000b, and 2000c). The national recommended water-quality criteria for total nitrogen in rivers and streams are 2.18 mg/L for the CBNGP, 0.54 mg/L for the MGDR, and 0.69 mg/L for the STFPH. These criteria apply to the sum of nitrogen in the water, of which nitrate and organic nitrogen are parts. The national recommended water-quality criteria for phosphorus in rivers and streams are 0.076 mg/L for the CBNGP, 0.033 mg/L for the MGDR, and 0.037 mg/L for the STFPH.

Nutrient concentrations in this study generally were higher than standards and criteria (table 3). The national recommended criteria for total nitrogen in the ecoregions in Indiana were exceeded by more than one-half of the nitrate analyses in the study, since the statewide median nitrate concentration was 2.6 mg/L, compared to the highest national criterion of 2.18 mg/L for the CBNGP in Indiana. The national recommended criteria for total phosphorus in the ecoregions in Indiana was exceeded in most of the phosphorus analyses in the study, since the 25th percentile of all concentrations was 0.07 mg/L, compared to the highest national criterion of 0.076 mg/L for the CBNGP in Indiana.

Suspended solids are analyzed in water as the dry weight of sediment from a subsample of water. A total suspended solids concentration may equal a total suspended sediment concentration in which the entire sample is analyzed, especially when sand-size particles are more than 25 percent (Gray and others, 2000). However, total suspended solids is an approximation of suspended sediment and is descriptive of particulates and particulate-bound nutrient content in water. Neither an Indiana criterion nor a national recommended water-quality criterion is listed for suspended solids.

Metals

Metals that commonly occur in water are elements that are found in the earth's crust, although they can be present in wastewater. The metals in this study were from analysis of total recoverable metals, rather than dissolved metals; the Indiana water-quality standards are for dissolved metals. The Indiana rule[5] provides an equation and a table for computing the dissolved concentration criteria for selected metals, based on the total recoverable metal concentration and a factor for the water hardness. For the dataset in this report, hardness values generally ranged from 243 mg/L (the 25th percentile) to 333 mg/L (the 75th percentile) (table 3). The equivalent hardness values in the table from the Indiana rule are 250 and 350 mg/L. Based on the hardness of 250 and 350 mg/L,[6] a range of chronic aquatic criteria are listed for the total recoverable concentrations of the metals copper, lead, and zinc in this study.

Copper is used extensively by industry and is found in some wastewaters. Copper can be dissolved from water pipes and plumbing fixtures when water pH is less than 7. Copper is added to reservoirs, lakes, and ponds to slow the growth of algae. The Indiana chronic aquatic criterion for copper is 25 to 33 micrograms per liter (µg/L), to protect aquatic life from chronic toxic effects. The national recommended criterion continuous concentration for copper is 9.0 µg/L.

Copper concentrations in this study exceeded the 33 µg/L upper end of the range of Indiana water-quality standards for this dataset in 14 samples (0.2 percent). The maximum copper concentration was 108 µg/L and the 75th percentile was 3.8 µg/L, compared with the national recommended criterion of 9 µg/L.

Iron is a metallic element abundant in the earth's crust and is essential for the metabolism of plants and animals. The solubility of iron in water is determined by oxidation-reduction conditions and pH. Iron is present in organic wastes and wastewater from some industrial and manufacturing processes. The national recommended criterion continuous concentration is 1,000 µg/L. A criterion for iron is not listed in the Indiana rules. Iron concentrations in this study exceeded the 1,000 µg/L national recommended criterion in less than one-half the analyses. The median was 560 µg/L, and the 75th percentile was 1,400 µg/L.

Lead can be released into the air from burning coal and smelting ores, and it was once an additive in gasoline. Wet and dry deposition of lead in the air has dispersed lead into the environment. Lead is used in batteries and other manufacturing and can be present in some wastewaters. The Indiana chronic aquatic criterion for lead is 6.7 to 9.5 µg/L, to protect aquatic life from chronic toxic effects. The national recommended criterion continuous concentration for lead is 2.5 µg/L.

Lead concentrations in this study exceeded the 9.5 µg/L upper end of the range of Indiana water-quality standards for this dataset in 152 samples (2.3 percent). The maximum lead concentration was 160 µg/L and the 75th percentile was 1.7 µg/L, compared with the national recommended criterion of 2.5 µg/L.

Zinc is about as abundant in the earth's crust as copper or nickel, but it is more soluble in water. Zinc is used in brass and bronze, for galvanizing steel, and in paint and rubber. It is widely dispersed in the aquatic environment. The Indiana chronic aquatic criterion for zinc is 230 to 300 µg/L, to protect aquatic life from chronic toxic effects. For the Lake Michigan Basin in Indiana, the chronic aquatic criterion for zinc is 380 µg/L. The national recommended criterion continuous concentration for zinc is 120 µg/L.

Zinc concentrations in this study exceeded the 300 µg/L Indiana water-quality standard in 23 samples (0.3 percent). The maximum zinc concentration was 730 µg/L, and the 75th percentile was 17 µg/L. The top 4 percent of zinc concentrations exceeded the national recommended criterion of 120 µg/L.

Ions and Dissolved Solids

Ions are a group of constituents in this report that include the anions chloride, sulfate, and calcium carbonate hardness. Dissolved solids can be comprised of multiple ions.

Chloride is a major ion in water and the common ionic form of the element chlorine in water. Chlorine is used as a disinfectant for water and wastewater. Chloride salts are used to soften water and as road deicers. Deep subsurface water, such as water associated with oil and gas production, will have high chloride levels. The Indiana chronic aquatic criterion for chloride is set to protect aquatic life from chronic toxic effects. This chloride criterion is computed with an equation that includes hardness and sulfate concentration, and can be derived from a table in the Indiana rules[7] by use of a procedure similar to that used for metals. For the dataset in this report, the hardness values for the chloride criteria table are 250 and 350 mg/L. The data in this report have sulfate ranging from 33 mg/L (the 25th percentile) to 68 mg/L (the 75th percentile) (table 3). The equivalent sulfate values in the standards table are 25 and 50 mg/L. Based on these values of hardness and sulfate, the chloride criteria range from 414 to 467 mg/L. For the Lake Michigan Basin, the chloride criterion is 680 mg/L. The criterion for chloride in water at the point of intake for

[5] Indiana Administrative Code (2013) tables 6-2 and 6-3 for most of Indiana and tables 8-1 and 8-2 for the Great Lakes system.

[6] One of the 10 drainage basins in this study (the Lake Michigan Basin) is part of the Great Lakes system. The median hardness for the Lake Michigan Basin was 380 mg/L, equivalent to 400 mg/L in the table from the Indiana rules. For the Lake Michigan Basin, based on this hardness value, the criterion for copper is 29 µg/L and the criterion for zinc is 380 µg/L. A separate criterion for lead in the Great Lakes system is not listed in the Indiana rules.

[7] Indiana Administrative Code (2013) has a table for computing the chloride chronic aquatic criterion in 327 IAC2-1-6(a)(5)(E) for most of Indiana. For the Great Lakes system, a median sulfate of 150 mg/L and hardness of 400 mg/L were used with table 8-2b to compute the chloride aquatic criterion of 680 mg/L.

a public-water system in Indiana is 250 mg/L. The national recommended water-quality criterion for chloride is 230 mg/L.

Chloride concentrations in this study exceeded the 467 mg/L upper end of the range of Indiana water-quality standards for this dataset in 2 samples and exceeded 250 mg/L in 23 samples (0.3 percent). The maximum chloride concentration was 615 mg/L, and the 75th percentile was 51 mg/L.

Sulfate is a major ion in water and the common form of the element sulfur, often occurring as a complex ion with calcium or sodium. Sulfate levels are related to pH, and sulfate may contribute to acidic water. Wet deposition of sulfate in the air contributes to acid rain; natural processes and human activity affect the levels of sulfate in streams. The chronic aquatic criterion for sulfate is set to protect aquatic life from chronic toxic effects. This sulfate criterion is computed with an equation that includes hardness and chloride concentration, and can be derived from a table in the Indiana rules[8] by use of a procedure similar to that used for metals. For the dataset in this report, the hardness values for the sulfate criteria table are 250 and 350 mg/L. The data in this report have chloride ranging from 25 mg/L (the 25th percentile) to 51 mg/L (the 75th percentile) (table 3). The equivalent chloride values in the standards table are 25 and 50 mg/L. Based on these values of hardness and chloride, the sulfate criteria range from 1,678 to 2,059 mg/L. Sulfate criteria for water at the point of intake for a public-water system in Indiana is 250 mg/L.

Sulfate concentrations in this study exceeded the 2,059 mg/L upper end of the range of Indiana water-quality standards for this dataset in no samples and exceeded 250 mg/L in 67 samples (0.9 percent). The maximum sulfate concentration was 723 mg/L, and the 75th percentile was 68 mg/L.

Hardness is a term from the water-supply industry and comes from the metallic ions in the water, primarily calcium and magnesium. Hardness is generally the same as alkalinity, the ability of a solution to neutralize acid, and is represented as an equivalent of calcium carbonate. Hardness is dependent upon pH and affected by temperature. Natural processes and human activity affect the levels of hardness in streams. Hardness is important as a determinant of the potential for the solubility of some elements, such as metals. Some Indiana criteria, such as those for selected metals, chloride, and sulfate, are calculated with the water hardness, as described earlier in this report.

Dissolved solids include all the cations and anions in solution, which will be a different mixture in different water bodies. Excessive levels of dissolved solids are an indication of water pollution from various sources. The criterion for dissolved solids in water at the point of intake for a public-water system or point of withdrawal for an industrial water supply in Indiana is 750 mg/L.

Dissolved solids concentrations in this study exceeded the 750 mg/L Indiana water-quality standard in 215 samples (2.9 percent). The maximum dissolved solids concentration was 1,740 mg/L, and the 75th percentile was 438 mg/L.

Major Drainage Basins

The distribution of constituent concentrations among the 10 major drainage basins in Indiana was inspected by use of boxplots (fig. 6) and statistical analysis with the generalized Wilcoxon test (Helsel, 2004). The boxplots indicate whether the median concentration for the samples from a basin was higher or lower than the statewide median. Statistical analysis of the concentration distributions indicate basins that had a distribution significantly different from all other basins (indicated as a unique basin by an asterisk in the group label on fig. 6). Basins sharing the same group label (A, B, C, etc.) had concentration distributions that were not significantly different, and some basins belong to more than one group for some constituents. Basins with fewer sites had fewer samples but the statistical comparison was not biased by the number of samples per basin, which were more than 100 in all cases. Summary statistics for constituent concentrations, by basin (table 4), supplement the boxplots in figure 6.

The two Lake Michigan Basin sites had concentrations that were significantly different from all other basins for 10 of the 12 constituents, with concentrations of constituents higher than the medians of other basins and many times higher than the statewide median. The two Ohio River Basin sites had concentrations that were significantly different from all other basins for 5 of the 12 constituents, with concentrations of constituents lower than the medians of other basins and lower than the statewide median. The Patoka River Basin site had concentrations that were significantly different from all other basins for 4 of the 12 constituents. A progression of increasing median concentrations was observed from the 16 Upper Wabash River Basin sites downstream to the 8 Middle Wabash River Basin sites and the single Lower Wabash River Basin site for phosphorus, organic nitrogen, suspended solids, copper, iron, and lead. The median values were generally similar within these three basins for the other constituents. Lead had the most censored values, followed by zinc. More than one-half of the concentrations for lead and zinc were censored in samples from sites in the Ohio, Whitewater, and East Fork White River Basins.

[8] Indiana Administrative Code (2013) has a table for computing the sulfate chronic aquatic criteria in 327 IAC2-1-6(a)(6)(C) for most of Indiana.

***A*. Nutrients and suspended solids**

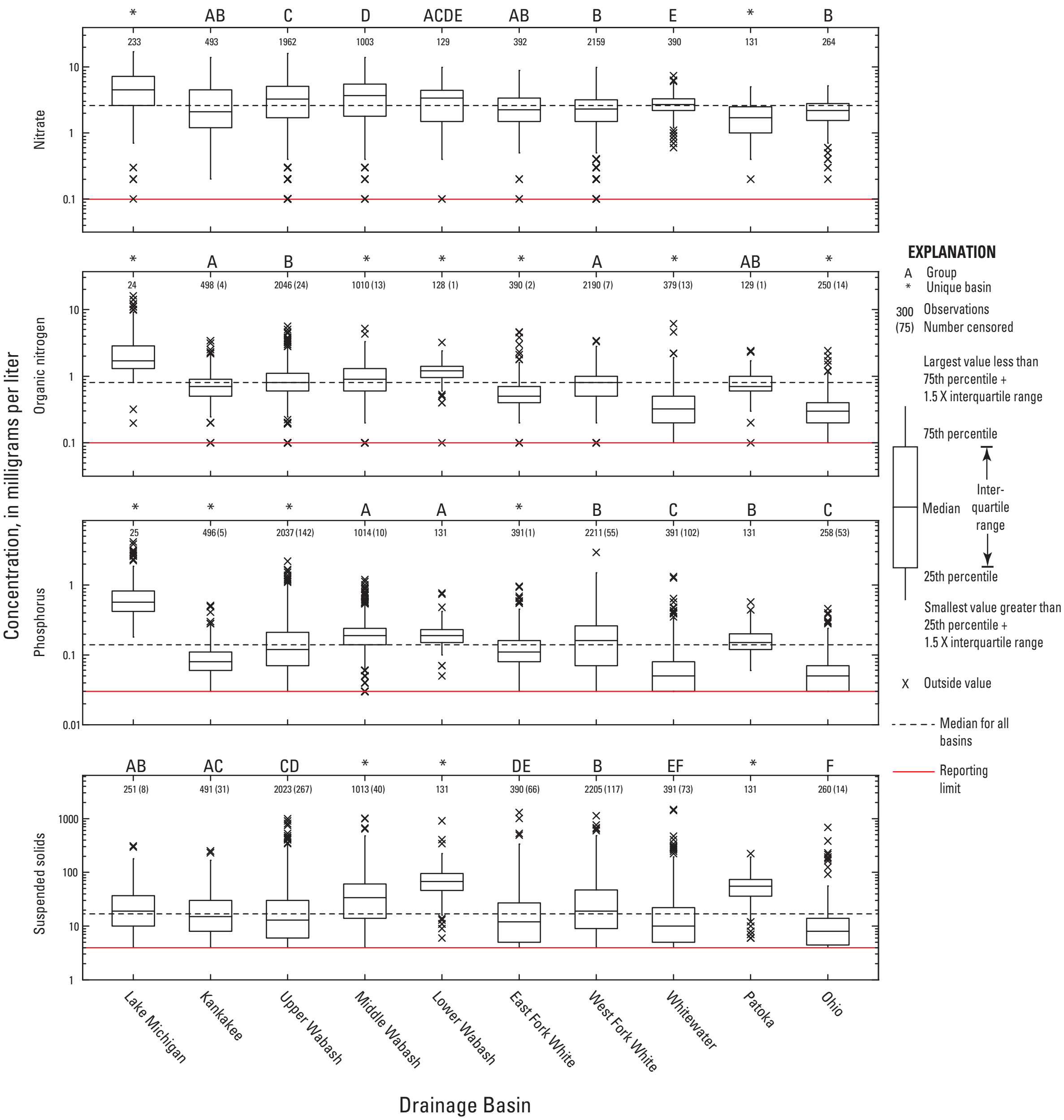

Figure 6. Distributions of concentrations for each constituent, by drainage basin. *A*, Nutrients and suspended solids. *B*, Metals. *C*, Ions and dissolved solids.

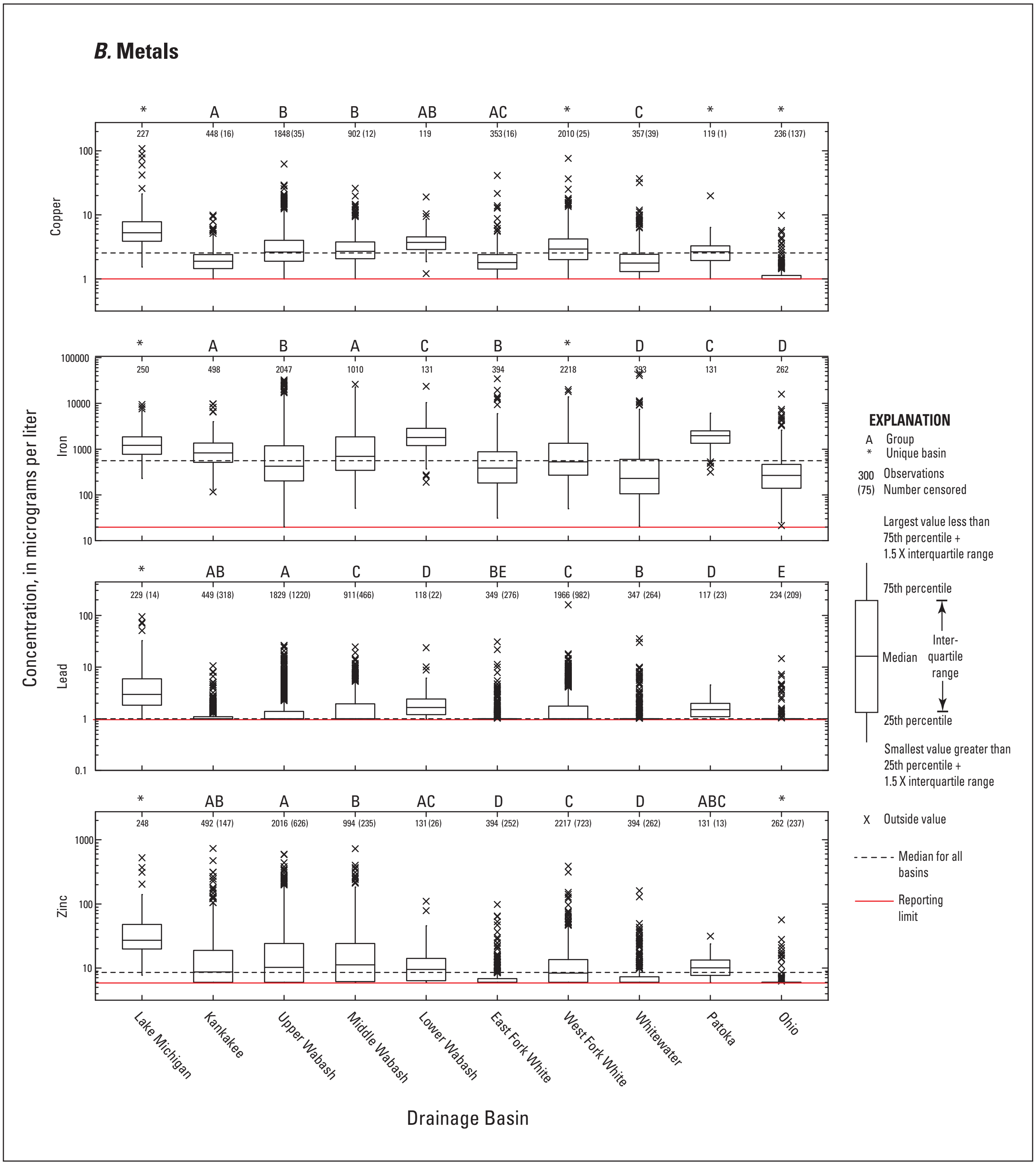

Figure 6. Distributions of concentrations for each constituent, by drainage basin. *A*, Nutrients and suspended solids. *B*, Metals. *C*, Ions and dissolved solids.—Continued

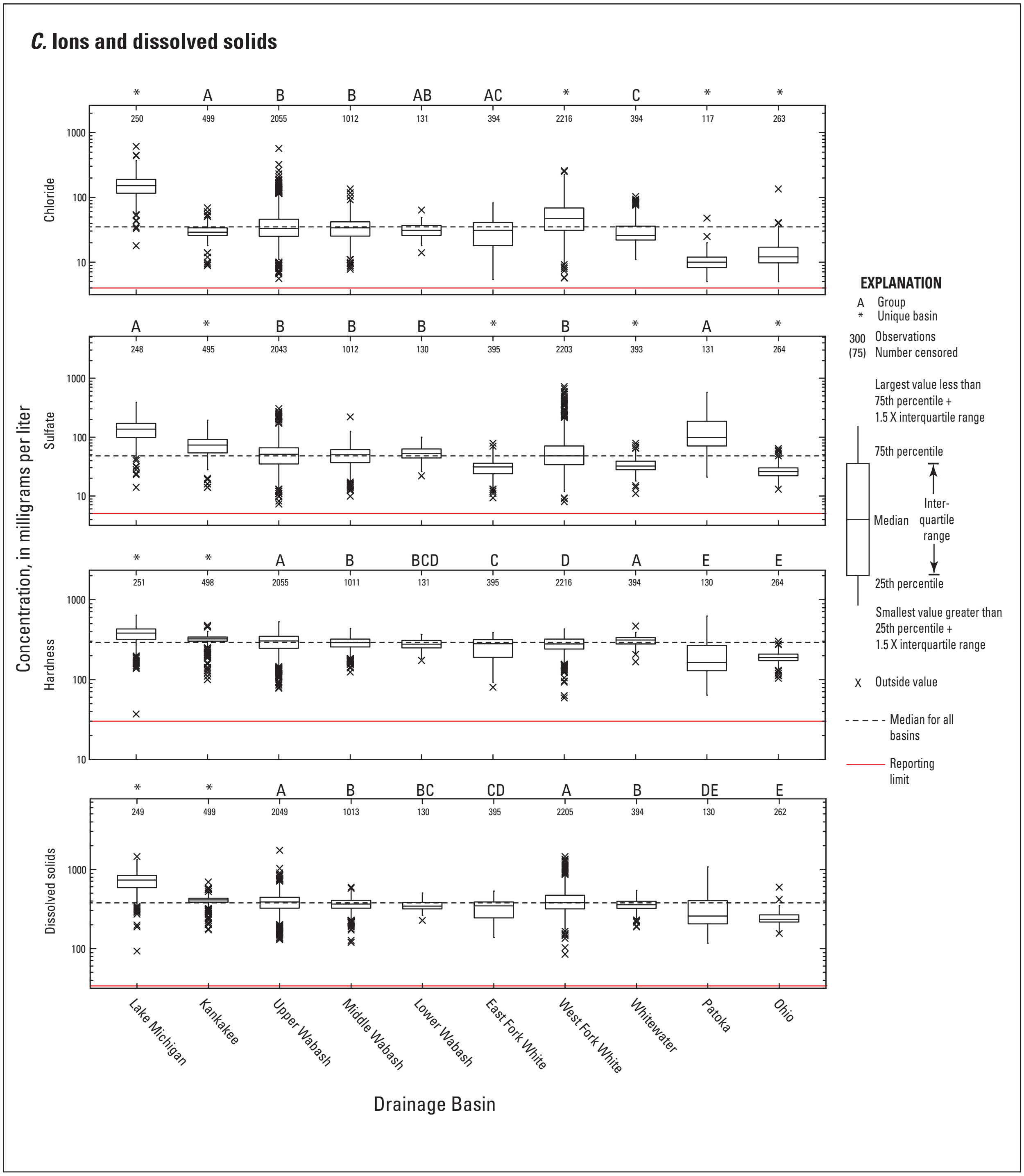

Figure 6. Distributions of concentrations for each constituent, by drainage basin. *A*, Nutrients and suspended solids. *B*, Metals. *C*, Ions and dissolved solids.—Continued

Table 4. Summary statistics for constituent concentrations in Indiana streams, 2000–10, by drainage basin.

[mg/L, milligrams per liter; minimum non-censored value listed although some constituents have censored values less than the reporting limit as listed in table 3; n, number of samples; R., River; <, less than; µg/L, micrograms per liter]

Nitrate							
Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n
Lake Michigan	5.3	0.1	2.6	4.5	7.2	17.0	233
Kankakee R.	3.2	0.2	1.2	2.1	4.5	14.0	493
Upper Wabash R.	3.6	0.1	1.7	3.3	5.1	16.0	1,962
Middle Wabash R.	3.9	0.1	1.8	3.7	5.5	14.0	1,003
Lower Wabash R.	3.2	0.1	1.5	3.4	4.4	9.9	129
East Fork White R.	2.5	0.1	1.5	2.3	3.4	8.9	392
West Fork White R.	2.4	0.1	1.5	2.3	3.2	9.9	2,159
Whitewater R	2.8	0.6	2.2	2.7	3.3	7.4	390
Patoka R.	1.9	0.2	1.0	1.7	2.5	5.0	131
Ohio R.	2.2	0.2	1.6	2.2	2.8	5.2	264
Total							7,156

Organic nitrogen									
Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n	Number censored	Percent censored
Lake Michigan	2.8	0.2	1.3	1.7	2.9	16.0	240	0	0
Kankakee R.	0.8	0.2	0.5	0.7	0.9	3.4	498	4	0.8
Upper Wabash R.	0.9	0.1	0.6	0.8	1.1	5.6	2,046	24	1.2
Middle Wabash R.	1.0	0.1	0.6	0.9	1.3	5.2	1,010	13	1.3
Lower Wabash R.	1.2	0.4	1.0	1.2	1.4	3.2	128	1	0.8
East Fork White R.	0.6	0.1	0.4	0.5	0.7	4.6	390	2	0.5
West Fork White R.	0.8	0.1	0.5	0.8	1.0	3.4	2,190	7	0.3
Whitewater R	0.5	0.1	0.2	0.3	0.5	6.1	379	13	3.4
Patoka R.	0.8	0.2	0.6	0.7	1.0	2.4	129	1	0.8
Ohio R.	0.4	0.1	0.2	0.3	0.4	2.4	250	14	5.6
Total							7,260	79	1.1

Phosphorus									
Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n	Number censored	Percent censored
Lake Michigan	0.71	0.18	0.42	0.57	0.82	4.14	251	0	0
Kankakee R.	0.09	0.03	0.06	0.08	0.11	0.51	496	5	1.0
Upper Wabash R.	0.17	0.03	0.07	0.12	0.21	2.19	2,037	142	7.0
Middle Wabash R.	0.21	0.03	0.14	0.19	0.24	1.2	1,014	10	1.0
Lower Wabash R.	0.20	0.05	0.15	0.19	0.23	0.77	131	0	0
East Fork White R.	0.14	0.03	0.08	0.11	0.16	0.96	391	1	0.3
West Fork White R.	0.21	0.03	0.07	0.16	0.26	2.94	2,211	55	2.5
Whitewater R	0.07	0.03	<0.03	0.05	0.08	1.32	391	102	26.1
Patoka R.	0.18	0.06	0.12	0.15	0.2	0.57	131	0	0
Ohio R.	0.07	0.03	0.03	0.05	0.07	0.46	258	53	20.5
Total							7,311	368	5.0

Table 4. Summary statistics for constituent concentrations in Indiana streams, 2000–10, by drainage basin.—Continued

[mg/L, milligrams per liter; minimum non-censored value listed although some constituents have censored values less than the reporting limit as listed in table 3; n, number of samples; R., River; <, less than; µg/L, micrograms per liter]

Suspended solids

Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n	Number censored	Percent censored
Lake Michigan	31	4.0	10	19	37	312	251	8	3.2
Kankakee R.	23	4.0	8	15	30	250	491	31	6.3
Upper Wabash R.	29	4.0	6	13	30	1,000	2,023	267	13.2
Middle Wabash R.	51	4.0	14	34	61	1,020	1,013	40	3.9
Lower Wabash R.	86	6.0	46	68	95	912	131	0	0
East Fork White R.	27	4.0	5	12	27	1,300	390	66	16.9
West Fork White R.	41	4.0	9	19	47	1,130	2,205	117	5.3
Whitewater R	28	4.0	5	10	22	1,480	391	73	18.7
Patoka R.	62	6.0	36	55	74	224	131	0	0
Ohio R.	15	4.0	5	8	14	688	260	50	19.2
Total							7,286	652	8.9

Copper

Indiana drainage basin	Mean (µg/L)	Minimum (µg/L)	25th percentile (µg/L)	Median (µg/L)	75th percentile (µg/L)	Maximum (µg/L)	n	Number censored	Percent censored
Lake Michigan	7.2	1.5	3.9	5.2	7.8	108.0	227	0	0
Kankakee R.	2.1	1.0	1.5	1.9	2.4	9.9	448	16	3.6
Upper Wabash R.	3.4	1.0	1.9	2.6	4.0	62.1	1,848	35	1.9
Middle Wabash R.	3.2	1.0	2.1	2.7	3.8	25.9	902	12	1.3
Lower Wabash R.	4.0	1.2	2.9	3.7	4.5	19.0	119	0	0
East Fork White R.	2.2	1.0	1.4	1.8	2.4	41.0	353	16	4.5
West Fork White R.	3.4	1.0	2.0	2.9	4.2	76.0	2,010	25	1.2
Whitewater R	2.3	1.0	1.3	1.8	2.4	36.7	357	39	10.9
Patoka R.	2.9	1.1	1.9	2.6	3.3	19.8	119	1	0.8
Ohio R.	1.0	1.0	<1.0	<1.0	1.1	9.8	236	137	58.1
Total							6,619	281	4.2

Iron

Indiana drainage basin	Mean (µg/L)	Minimum (µg/L)	25th percentile (µg/L)	Median (µg/L)	75th percentile (µg/L)	Maximum (µg/L)	n
Lake Michigan	1.58	0.23	0.78	1.21	1.85	9.46	250
Kankakee R.	1.09	0.12	0.52	0.83	1.36	9.79	498
Upper Wabash R.	1.35	0.02	0.20	0.42	1.18	32.60	2,047
Middle Wabash R.	1.52	0.05	0.35	0.70	1.86	26.10	1,010
Lower Wabash R.	2.40	0.19	1.20	1.79	2.85	23.50	131
East Fork White R.	0.97	0.03	0.18	0.39	0.88	34.50	394
West Fork White R.	1.14	0.05	0.27	0.53	1.34	19.90	2,218
Whitewater R	0.99	0.02	0.11	0.23	0.60	44.80	393
Patoka R.	2.11	0.31	1.34	1.96	2.50	6.08	131
Ohio R.	0.57	0.02	0.14	0.27	0.46	15.90	262
Total							7,334

Table 4. Summary statistics for constituent concentrations in Indiana streams, 2000–10, by drainage basin.—Continued

[mg/L, milligrams per liter; minimum non-censored value listed although some constituents have censored values less than the reporting limit as listed in table 3; n, number of samples; R., River; <, less than; µg/L, micrograms per liter]

Lead									
Indiana drainage basin	Mean (µg/L)	Minimum (µg/L)	25th percentile (µg/L)	Median (µg/L)	75th percentile (µg/L)	Maximum (µg/L)	n	Number censored	Percent censored
Lake Michigan	5.1	1.0	1.8	3.0	5.9	94.0	229	14	6.1
Kankakee R.	<1.0	1.0	<1.0	<1.0	1.1	318.0	449	318	70.8
Upper Wabash R.	1.3	1.0	<1.0	<1.0	1.4	26.2	1,829	1,220	66.7
Middle Wabash R.	1.6	1.0	<1.0	<1.0	1.9	24.6	911	466	51.2
Lower Wabash R.	2.1	1.0	1.2	1.7	2.4	23.7	118	22	18.6
East Fork White R.	<1.0	1.0	<1.0	<1.0	<1.0	30.7	349	276	79.1
West Fork White R.	1.5	1.0	<1.0	<1.0	1.8	160.0	1,966	982	49.9
Whitewater R	1.1	1.0	<1.0	<1.0	<1.0	35.5	347	264	76.1
Patoka R.	1.7	1.0	1.1	1.5	2.0	4.5	117	23	19.7
Ohio R.	<1.0	1.0	<1.0	<1.0	<1.0	14.6	234	209	89.3
Total							6,549	3,794	57.9

Zinc									
Indiana drainage basin	Mean (µg/L)	Minimum (µg/L)	25th percentile (µg/L)	Median (µg/L)	75th percentile (µg/L)	Maximum (µg/L)	n	Number censored	Percent censored
Lake Michigan	38.3	7.7	19.9	27.2	48.1	524.0	248	0	0
Kankakee R.	20.8	6.0	4.4	8.7	18.9	730.0	492	147	29.9
Upper Wabash R.	24.5	6.0	4.6	10.3	24.1	596.0	2,016	626	31.1
Middle Wabash R.	22.8	6.0	6.2	11.2	24.2	725.0	994	235	23.6
Lower Wabash R.	12.3	6.0	6.4	9.6	14.1	110.0	131	26	19.8
East Fork White R.	5.9	6.0	2.5	4.3	6.9	98.3	394	252	64.0
West Fork White R.	11.0	6.0	5.1	8.4	13.6	389.0	2,217	723	32.6
Whitewater R	6.4	6.0	1.9	3.8	7.3	161.0	394	262	66.5
Patoka R.	10.9	6.1	7.7	10.1	13.4	31.4	131	13	9.9
Ohio R.	<6.0	6.3	<6.0	<6.0	<6.0	56.5	262	237	90.5
Total							7,279	2,521	34.6

Chloride							
Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n
Lake Michigan	158	18	116	152	190	615	250
Kankakee R.	30	9	26	29	34	69	499
Upper Wabash R.	40	6	25	33	46	570	2,055
Middle Wabash R.	34	8	25	34	42	135	1,012
Lower Wabash R.	32	14	26	31	37	64	131
East Fork White R.	31	5	18	31	41	82	394
West Fork White R.	55	6	31	47	69	260	2,216
Whitewater R	33	11	22	26	36	103	394
Patoka R.	11	5	8	10	12	48	117
Ohio R.	14	5	10	12	17	135	263
Total							7,331

Table 4. Summary statistics for constituent concentrations in Indiana streams, 2000–10, by drainage basin.—Continued

[mg/L, milligrams per liter; minimum non-censored value listed although some constituents have censored values less than the reporting limit as listed in table 3; n, number of samples; R., River; <, less than; µg/L, micrograms per liter]

Sulfate							
Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n
Lake Michigan	142	14	99	137	172	388	248
Kankakee R.	74	14	54	73	91	194	495
Upper Wabash R.	55	7	35	51	66	305	2,043
Middle Wabash R.	50	10	37	50	61	220	1,012
Lower Wabash R.	54	22	44	53	63	100	130
East Fork White R.	31	9	24	31	36	79	395
West Fork White R.	63	8	34	48	71	723	2,203
Whitewater R	35	11	28	32	39	79	393
Patoka R.	136	21	71	99	185	580	131
Ohio R.	27	13	22	26	30	64	264
Total							7,314

Hardness							
Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n
Lake Michigan	370	37	319	383	432	643	251
Kankakee R.	318	100	303	324	341	477	498
Upper Wabash R.	296	78	246	304	347	530	2,055
Middle Wabash R.	287	124	257	291	321	435	1,011
Lower Wabash R.	276	174	249	277	308	367	131
East Fork White R.	256	80	190	282	317	390	395
West Fork White R.	280	59	241	279	321	430	2,216
Whitewater R	308	167	279	314	337	468	394
Patoka R.	206	64	129	165	266	623	130
Ohio R.	191	104	174	189	208	303	264
Total							7,345

Dissolved solids							
Indiana drainage basin	Mean (mg/L)	Minimum (mg/L)	25th percentile (mg/L)	Median (mg/L)	75th percentile (mg/L)	Maximum (mg/L)	n
Lake Michigan	718	93	589	731	839	1,450	249
Kankakee R.	407	173	386	411	433	693	499
Upper Wabash R.	393	130	323	389	443	1,740	2,049
Middle Wabash R.	365	120	324	366	406	595	1,013
Lower Wabash R.	351	227	317	345	382	505	130
East Fork White R.	322	138	245	346	388	530	395
West Fork White R.	413	85	318	381	472	1,450	2,205
Whitewater R	362	188	321	358	396	542	394
Patoka R.	315	117	205	258	404	1,076	130
Ohio R.	243	156	216	235	266	595	262
Total							7,326

Trends in Concentrations

Statistically significant trends in constituent concentrations have been summarized statewide and geographically. Increases and decreases in concentrations over time are described as the numerical difference and percentage difference in median flow-adjusted concentrations from 2000 compared with 2010. Where appropriate, general observations about non-significant increases and decreases have been added. A total of 684 trend analyses were made and 250 statistically significant trends were identified—167 downward trends and 83 upward trends.

Nutrients and Suspended Solids

Nitrate concentrations showed significant trends at 16 sites (figs. 7 and 1–1). Upward trends of 24.7 to 42.6 percent (0.3 to 1.3 mg/L) were identified at three sites in the West Fork White River Basin upstream from and inside the Indianapolis area. Downward trends were identified at 13 sites in 5 basins in the northern two-thirds of Indiana and ranged from −13.1 to −54.9 percent (−0.3 to −3.8 mg/L). When significant trends and non-significant changes in nitrate concentrations are considered, 74 percent of sites showed a decrease.

Organic nitrogen concentrations showed significant trends at 15 sites (figs. 7 and 1–2). Upward trends were identified at 10 sites in 5 basins, including 3 sites in the Kankakee River Basin and 3 sites in the Upper Wabash River Basin. Most of these upward trends ranged from 14 to 48 percent (0.1 to 0.2 mg/L) except for one Lake Michigan Basin site, which increased by 182 percent (3.1 mg/L). Downward trends of −16.4 to −28.0 percent (−0.1 to −0.4 mg/L) were identified at five sites in four basins. When significant trends and non-significant changes in organic nitrogen concentrations are considered, 53 percent of sites showed an increase.

Phosphorus concentrations showed significant trends at 16 sites (fig. 7 and 1–3). Upward trends of 21.7 to 28.1 percent (0.02 to 0.07 mg/L) were identified at one site in the Upper Wabash River Basin and at three sites in the West Fork White River Basin upstream from and inside the Indianapolis area. Downward trends of −14.1 to −38.7 percent (−0.02 to −0.07 mg/L) were identified at 12 sites in 7 basins statewide. When significant trends and non-significant changes in phosphorus concentrations are considered, 58 percent of sites showed a decrease.

Suspended solids concentrations showed significant trends at 13 sites (figs. 7 and 1–4). Upward trends of 34.9 to 91.0 percent (5.4 to 17.8 mg/L) were identified at three sites in the Middle Wabash River Basin and one site in the West Fork White River Basin. Downward trends of −27.6 to −50.3 percent (−2.9 to −20.5 mg/L) were identified at nine sites in six basins. When significant trends and non-significant changes in suspended solids concentrations are considered, 68 percent of sites showed a decrease.

Metals

Copper concentrations showed significant trends at 24 sites (figs. 8 and 1–5). Upward trends of 3.7 to 78.8 percent (0.04 to 2.1 µg/L) were identified at 13 sites in 6 basins. Copper increased at six sites in the Upper Wabash River Basin. Downward trends of −17.5 to −35.9 percent (−0.04 to −1.7 µg/L) were identified at 11 sites in 4 basins. Copper decreased at seven sites in the West Fork White River Basin. When significant trends and non-significant changes in copper concentrations are considered, 53 percent of sites showed an increase.

Iron concentrations showed significant trends at 19 sites (figs. 8 and 1–6). Upward trends of 30.1 and 101.3 percent (119.6 and 640.4 µg/L) were identified at two sites in two basins. Downward trends of −22.2 to −56.0 percent (−65.4 to −949.8 µg/L) were identified at 17 sites in 8 basins. Iron decreased at eight sites in the West Fork White River Basin. When significant trends and non-significant changes in iron concentrations are considered, 77 percent of sites showed a decrease.

Lead concentrations showed significant trends at 17 sites (figs. 8 and 1–7)[9]. Upward trends of 2.2 to 26.0 percent (0.02 to 0.27 µg/L) were identified at nine sites in five basins. Downward trends of −1.1 to −39.1 percent (−0.01 to −1.2 µg/L) were identified at eight sites in five basins. When significant trends and non-significant changes in lead concentrations are considered, 56 percent of sites showed a decrease.

Zinc concentrations showed significant trends at 21 sites (figs. 8 and 1–8).[10] Upward trends of 0.1 to 423 percent (0.01 to 17.2 µg/L) were identified at 11 sites in 5 basins. Some of the largest increases in zinc—130.1 to 423.0 percent (11.1 to 17.2 µg/L)—were noted at three sites in the Kankakee River Basin. Zinc increased at five sites in the Upper Wabash River Basin. Downward trends of −12.9 to −48.9 percent (−1.0 to −25.5 mg/L) were identified at 10 sites in 5 basins. When significant trends and non-significant changes in zinc concentrations are considered, 53 percent of sites showed a decrease.

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[9] The statistical trends technique used in this analysis is typically applied to data with less than approximately 10 percent censored values (Vecchia, 2003); 57.9 percent of lead values were censored.

[10] The statistical trends technique used in this analysis is typically applied to data with less than approximately 10 percent censored values (Vecchia, 2003); 34.6 percent of zinc values were censored.

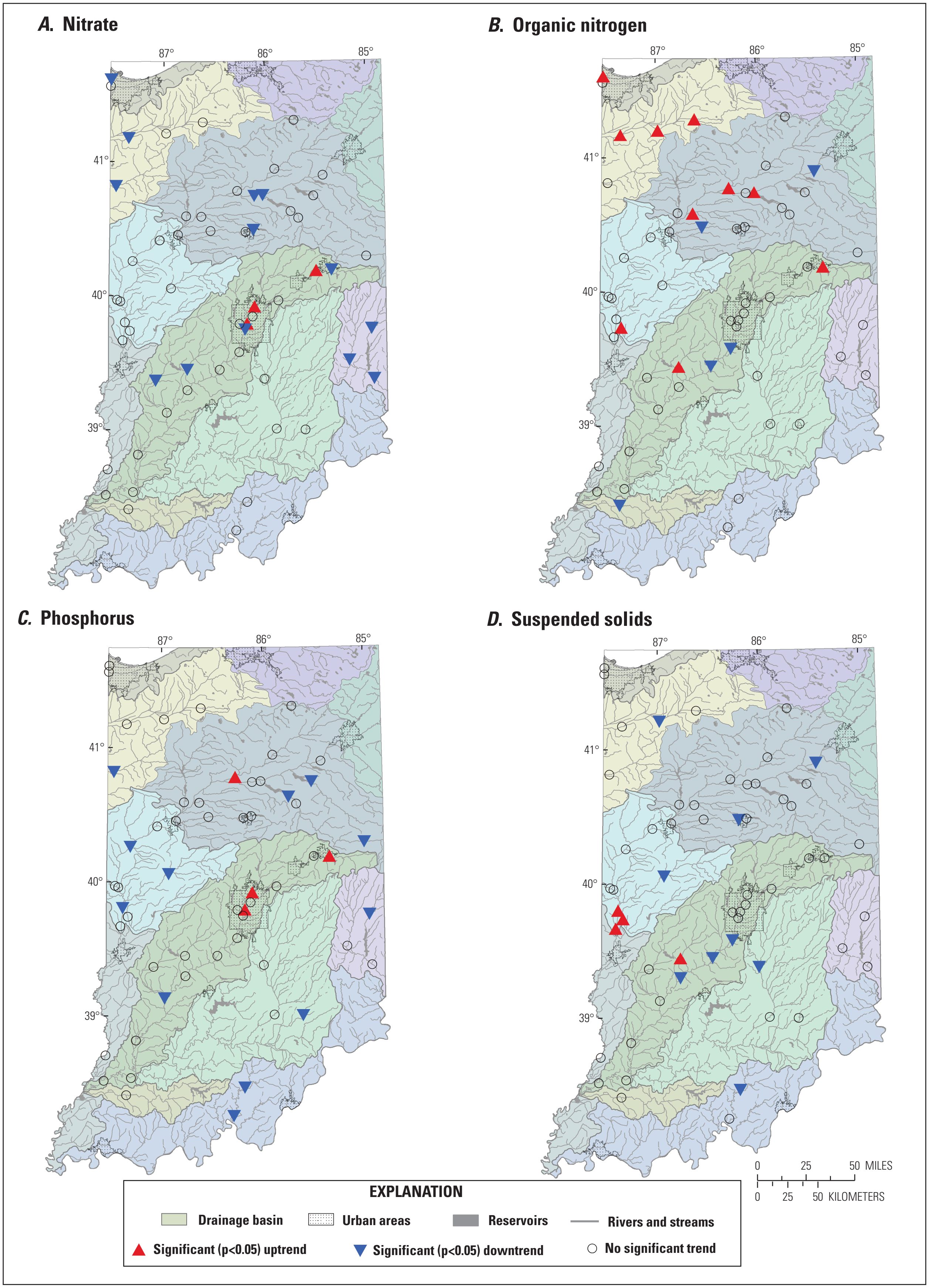

Figure 7. Sites with significant trends in concentrations of nutrients and suspended solids, 2000–10. *A*, Nitrate. *B*, Organic nitrogen. *C*, Phosphorus. *D*, Suspended solids.

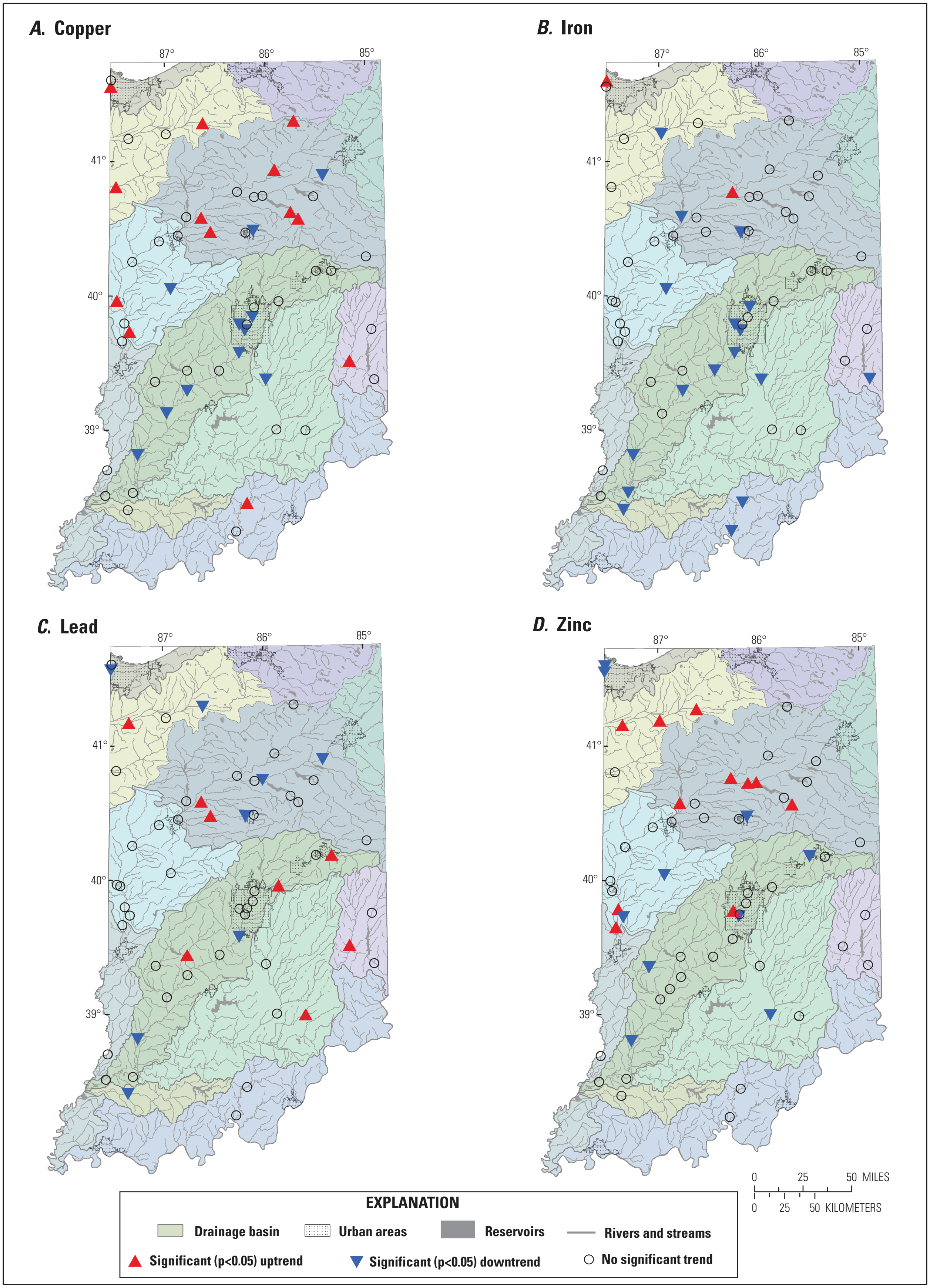

Figure 8. Sites with significant trends in concentrations of metals, 2000–10. *A*, Copper. *B*, Iron. *C*, Lead. *D*, Zinc.

Ions and Dissolved Solids

Chloride concentrations showed significant trends at 30 sites (figs. 9 and 1–9). Upward trends of 5.8 to 23.6 percent (1.3 to 11.2 mg/L) were identified at nine sites in four basins. Increases in chloride were noted at three sites in the Indianapolis area of the West Fork White River Basin. Downward trends were identified at 21 sites in 6 basins, ranging from −8.0 to −46.8 percent. The two largest decreases were −102.5 and −57.4 mg/L in the Lake Michigan Basin. Decreases in chloride were noted at eight sites in the Upper Wabash River Basin. When significant trends and non-significant changes in chloride concentrations are considered, 67 percent of sites showed a decrease.

Sulfate concentrations showed significant trends at 32 sites (figs. 9 and 1–10). Upward trends of 4.7 to 10.1 percent (1.4 to 8.9 mg/L) were identified at two sites in the Kankakee River Basin and one site in the Upper Wabash River Basin. Downward trends were identified at 29 sites in 6 basins, ranging from −6.3 to −57.1 percent. The largest decreases were −121.2 mg/L at one site in the Lake Michigan Basin and −31.2 mg/L at one site in the West Fork White River Basin. Decreases in sulfate were noted at 12 sites in the Upper Wabash River Basin. When significant trends and non-significant changes in sulfate concentrations are considered, 82 percent of sites showed a decrease.

Hardness concentrations showed significant trends at 22 sites (figs. 9 and 1–11). Upward trends of 5.7 to 18.8 percent (15.4 to 53.5 mg/L) were identified at 13 sites in 5 basins. Increases in hardness were noted at a group of four sites each in the Kankakee River and Middle Wabash River Basins. Downward trends of −5.2 to −16.0 percent (−17.5 to −38.2 mg/L) were identified at nine sites in three basins. Decreases in hardness were noted at four sites each in the West Fork White River and Upper Wabash River Basins. When significant trends and non-significant changes in hardness concentrations are considered, 53 percent of sites showed an increase.

Dissolved solids concentrations showed significant trends at 26 sites (figs. 9 and 1–12). Upward trends of 6.0 to 11.8 percent (20.9 to 43.5 mg/L) were identified at two sites in the Middle Wabash River Basin and at one site in the Kankakee River Basin. Downward trends were identified at 23 sites in 7 basins, ranging from −3.8 to −36.0 percent (−10.9 to −330.5 mg/L). The two largest decreases were noted at two sites in the Lake Michigan Basin. When significant trends and non-significant changes in dissolved solids concentrations are considered, 79 percent of sites showed a decrease.

Limitations and Considerations

This report describes water quality in Indiana based on concentration summaries and trend analysis of data from 57 FSMP sites representing 11 years. Therefore, this description of water quality in Indiana was limited by the geographic representativeness of the sites, parameters selected for the analysis, the time period of the analysis, and the FSMP network design. These limitations and potential consideration are described in the following discussion.

The Indiana FSMP provides a statewide set of sites on large streams with a generally consistent set of water-quality constituents analyzed in monthly water samples for multiple years, but all of the FSMP sites in Indiana were not included in this study for several reasons. The full network of 163 FSMP sites varies in completeness of annual water-quality records and the number of consecutive years with complete annual records. The network also varies in the number of constituents that were consistently analyzed each month and each year. Many of the sites in the network are not associated with a streamgage having a complete annual streamflow record, which is necessary for a flow-adjusted concentration trends analysis.

The FSMP sites are not a network designed to represent the major streams, drainage basins, and watersheds in Indiana. Rather, sites are mostly located downstream from areas with one or more permitted discharges of wastewater effluent, and sometimes they are paired with a FSMP site upstream of the discharges. Samples at FSMP sites may vary in their representativeness of stream-water quality because they were grab samples from the center of flow analyzed for total recoverable, not dissolved plus particulate fractions of a constituent. Grab samples generally are most representative when streams are well mixed across their width and depth. Depending upon streamflow conditions or the sample location, some constituents may not be uniformly distributed across the width and depth of a stream. Data for evaluating the representativeness of the water samples were not available for this study.

For purposes of this study, some FSMP sites were not included and the resulting geographic coverage was uneven across Indiana. The Maumee River and St. Joseph River Basins do not have sites represented in this study. The Lake Michigan, Ohio River, Patoka River, and Lower Wabash River Basins had 1 or 2 sites, compared with the Upper Wabash River and West Fork White River Basins that had 16 and 17 sites, respectively.

The summary statistics and 11-year trends in concentrations of 12 constituents presented in this report are tied to the scope of this initial study, but a number of other considerations are possible. (1) The study has established a data compilation and analysis process that can be applied for selected constituents for longer time periods at some sites. Longer time periods may show more than one trend at a site, with different directions and magnitude, unlike the single 11-year trends identified at sites in this study. (2) Constituent loads, the product of concentration and streamflow, were beyond the scope of this study, although data were compiled to make the calculation and analysis of loads possible. (3) Water-quality data for other Indiana streams and other constituents not included in this study are available from IDEM, USGS, and other sources, but a compilation and analysis of these other data were beyond the scope of this study. (4) Interpretation of the reasons and contributing factors for the trends in constituent concentrations

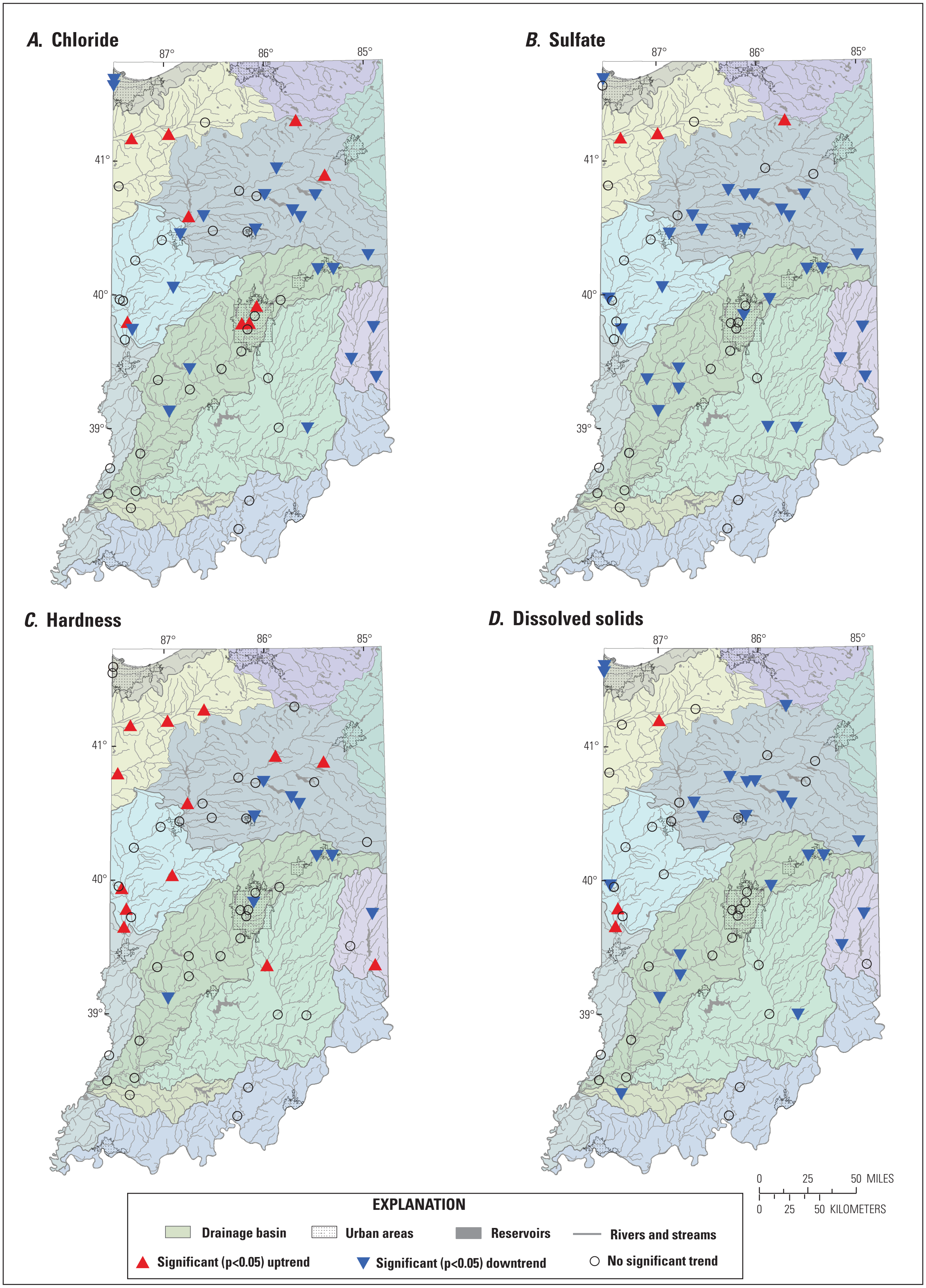

Figure 9. Sites with significant trends in concentrations of ions and dissolved solids, 2000–10. *A*, Chloride. *B*, Sulfate. *C*, Hardness. *D*, Dissolved solids.

and differences and similarities in constituent concentrations among drainage basins was beyond the scope of this study. Ancillary data that could be used to understand why and where constituent trends and differences were observed include information about permitted discharges of treated effluent and stormwater, nutrient application, atmospheric deposition, and land cover.

Regional Comparisons

Water quality in Indiana can be compared with findings from other regional studies during a similar time period. The following discussion provides a broader geographic context for some of the results of this study. Murphy and others (2013) reported a downward trend in nitrate concentrations for the Ohio River Basin (although the change in annual concentrations was small) and increasing nitrate concentrations in much of the Mississippi River and its tributaries for 2000–10. Similarly, nitrate generally declined in much of Indiana during this same period, which appears consistent with the results from this larger scale study. Lorenz and others (2008) reported trends in flow-adjusted concentrations in the Mississippi River Basin for 1975–2004, including a stream site in central Indiana. For this site, they found significant upward trends in nitrate and organic nitrogen, a non-significant increase in phosphorus, and a non-significant decrease in total nitrogen and total suspended sediment (similar to suspended solids). Sprague and others (2009) looked at trends in nutrients in major rivers of the U.S. for 1993–2003, including a stream site in central Indiana. For this site, they reported a significant downward trend in flow-adjusted nitrate concentrations and no significant change in phosphorus or total nitrogen concentrations.

Summary and Conclusions

Water-quality data from the Indiana Department of Environmental Management Fixed Station Monitoring Program (FSMP) were combined with streamflow data from collocated or nearby U.S. Geological Survey (USGS) streamgages. The final dataset for this study consisted of 86,110 concentration values for 12 constituents in 7,345 water samples from 57 FSMP sites for 11 years (January 1, 2000–December 31, 2010). The 12 constituents are the nutrients nitrate, organic nitrogen, and phosphorus; suspended solids; the metals copper, iron, lead, and zinc; the ions chloride and sulfate together with hardness as a measure of the calcium carbonate ion; and dissolved solids.

The parametric time-series model, QWTREND, was used to develop streamflow-adjusted constituent concentrations, to adjust for seasonal variance and serial correlation, and to identify trends independent of streamflow-related variability. A total of 684 trend analyses were made and 250 statistically significant trends were identified—167 downward trends and 83 upward trends. An additional 434 non-significant changes in constituent concentrations were noted for the study period. The number of significant trends compared with the total number of trend analyses per major drainage basin showed that the Kankakee River Basin had the most significant upward trends (37.5 percent). The most significant downward trends were in the Whitewater River Basin (−38.9 percent), the Lake Michigan Basin (−37.5 percent), and the Patoka River Basin (−33.3 percent).

Nutrient concentrations in this study generally were too high relative to standards and criteria. Although nitrate exceeded the Indiana water-quality standard in 1.2 percent of samples, the national recommended criteria for total nitrogen in the three ecoregions in Indiana were exceeded by more than one-half of the nitrate analyses in the study. Most of the phosphorus analyses in the study also exceeded the national recommended criteria for the three ecoregions in Indiana.

Copper, lead, zinc, chloride, sulfate, and dissolved solids concentrations were in acceptable ranges relative to standards and criteria in more than 97 percent of samples. Copper and lead exceeded the upper range of Indiana water-quality standards for this dataset in 0.2 and 2.3 percent of samples, respectively. Zinc exceeded the Indiana water-quality standard in 0.3 percent of samples and the top 4 percent of zinc concentrations exceeded the national recommended criteria. The Indiana water-quality standard for a public-water system intake was exceeded by chloride in 0.3 percent of samples, by sulfate in 0.9 percent of samples, and by dissolved solids in 2.9 percent of samples.

The two Lake Michigan Basin sites had the highest concentrations and were in a unique statistical group for 10 of the 12 constituents, with concentrations many times higher than the statewide median and higher than the medians of most other basins. The two Ohio River Basin sites had the lowest concentrations and were in a unique statistical group for 6 of the 12 constituents.

Nitrate concentrations showed significant trends at 16 sites—upward trends at 3 sites in the West Fork White River Basin upstream from and inside the Indianapolis area, Indiana, and downward trends at 13 sites in 5 basins in the northern half of Indiana. Organic nitrogen concentrations showed significant trends at 15 sites—upward trends at 10 sites in 5 basins and downward trends at 5 sites in 4 basins. Phosphorus concentrations showed significant trends at 16 sites—upward trends including 4 sites in the West Fork White River Basin upstream from and in the Indianapolis area and downward trends at 12 sites in 7 basins. Suspended solids concentrations showed significant trends at 13 sites—upward trends at 4 sites in 2 basins and downward trends at 9 sites in 6 basins.

Copper concentrations showed significant trends at 24 sites—upward trends at 13 sites in 6 basins and downward at 11 sites in 4 basins. Copper decreased at seven sites in the West Fork White River Basin; the two largest increases were in the Lake Michigan Basin. Iron concentrations showed significant trends at 19 sites—upward trends at 2 sites in 2 basins and downward trends 17 sites in 8 basins. Iron decreased at seven sites in the West Fork White River Basin. Lead concentrations showed significant trends at 17 sites—upward trends at 9 sites in 5 basins and downward trends at 8 sites in 5 basins. Significant increases in lead generally were small, and significant decreases generally were large. Zinc concentrations showed significant trends at 21 sites—upward trends at 11 sites in 5 basins and downward trends at 10 sites in 5 basins. Some of the largest increases in zinc were noted at three sites in the Kankakee River Basin; zinc increased at five sites in the Upper Wabash River Basin.

Chloride concentrations showed significant trends at 30 sites—upward trends at 9 sites in 4 basins and downward trends at 21 sites in 6 basins. Increases in chloride were noted at three sites upstream from and in the Indianapolis area of the West Fork White River Basin. The two largest decreases in chloride were at two sites in the Lake Michigan Basin. Decreases in chloride were noted at eight sites in the Upper Wabash River Basin. Sulfate concentrations showed significant trends at 32 sites—upward trends at 3 sites in 2 basins and downward trends at 29 sites in 6 basins. Decreases in sulfate were noted at 12 sites in the Upper Wabash River Basin. Hardness concentrations showed significant trends at 22 sites—upward trends at 13 sites in 5 basins and downward trends at 9 sites in 3 basins. Increases in hardness were noted at a group of four sites each in the Kankakee River and Middle Wabash River Basins. Decreases in hardness were noted at four sites each in the West Fork White River and Upper Wabash River Basins. Dissolved solids concentrations showed significant trends at 26 sites—upward trends at 3 sites in 2 basins and downward trends at 23 sites in 7 basins. The two largest decreases in dissolved solids were noted at two sites in the Lake Michigan Basin.

The interpretations of trends in water quality in Indiana streams described in this report were limited by the water-quality monitoring sites and samples that were analyzed. All 163 FSMP sites in Indiana were not included in this study because they were not near a USGS streamgage or they had incomplete data records. The geographic coverage of sites in this study was uneven among the major drainage basins in Indiana. The Maumee River and St. Joseph River Basins were not represented by sites. The objectives of this study limited the number of constituents and the number of years for which trends were analyzed.

In conclusion, the analysis of trends in streamflow-adjusted constituent concentrations at the FSMP sites in this study indicated a greater number of downward trends, signaling a potential pattern of improving statewide water quality. Two streams in the Lake Michigan Basin have shown substantial decreases in most constituents. The West Fork White River near Indianapolis showed increases in nitrate and phosphorus; the Kankakee River showed increases in copper, zinc, chloride, sulfate, and hardness. This initial study provides a basis for future investigations of the FSMP and streamflow data for Indiana.

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Appendix 1. Significant and non-significant trends for 12 constituents at 57 stream sites in Indiana, 2000–10

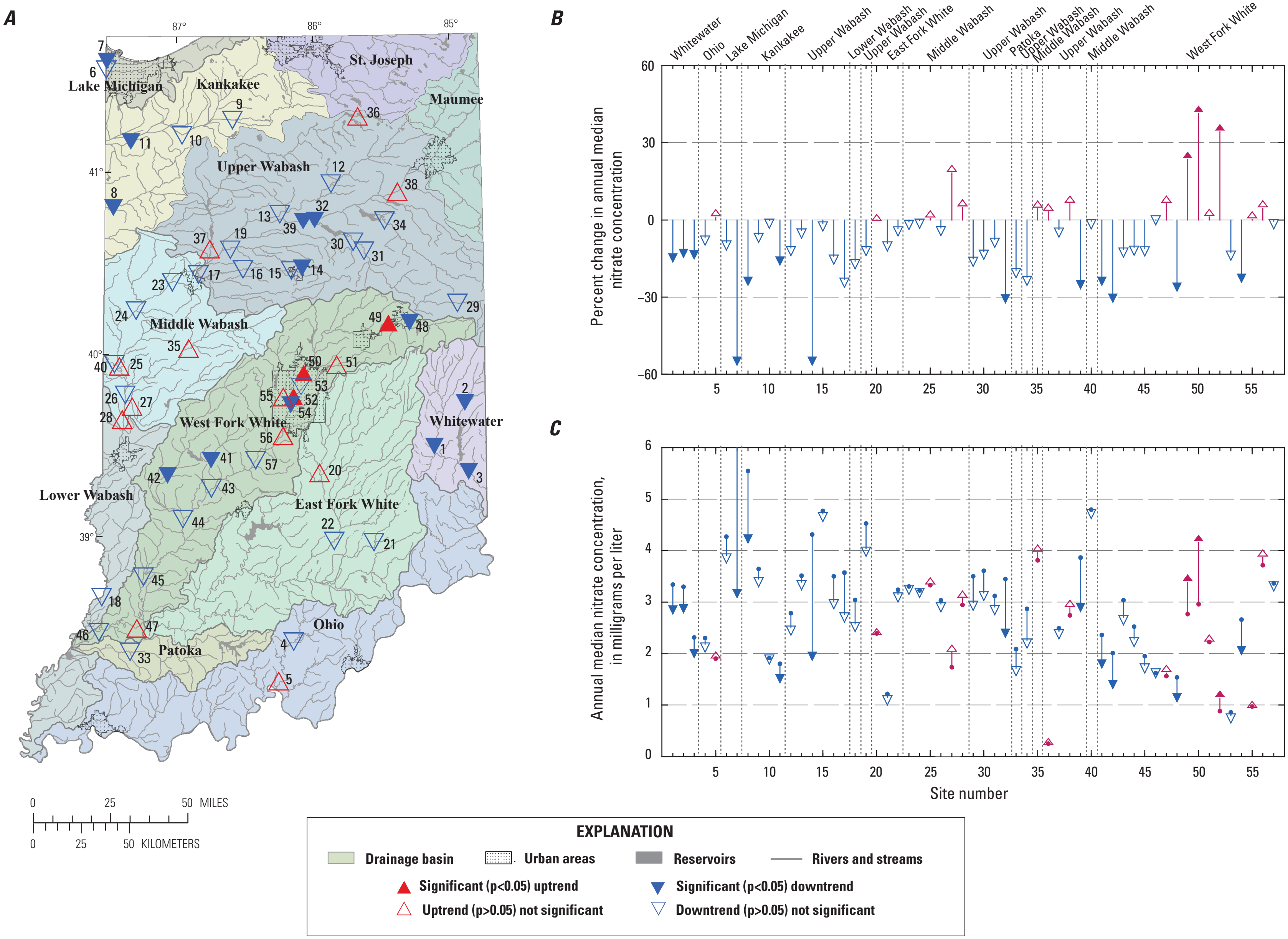

Figure 1–1. Significant and non-significant trends in nitrate at 57 stream sites in Indiana, 2000–10.

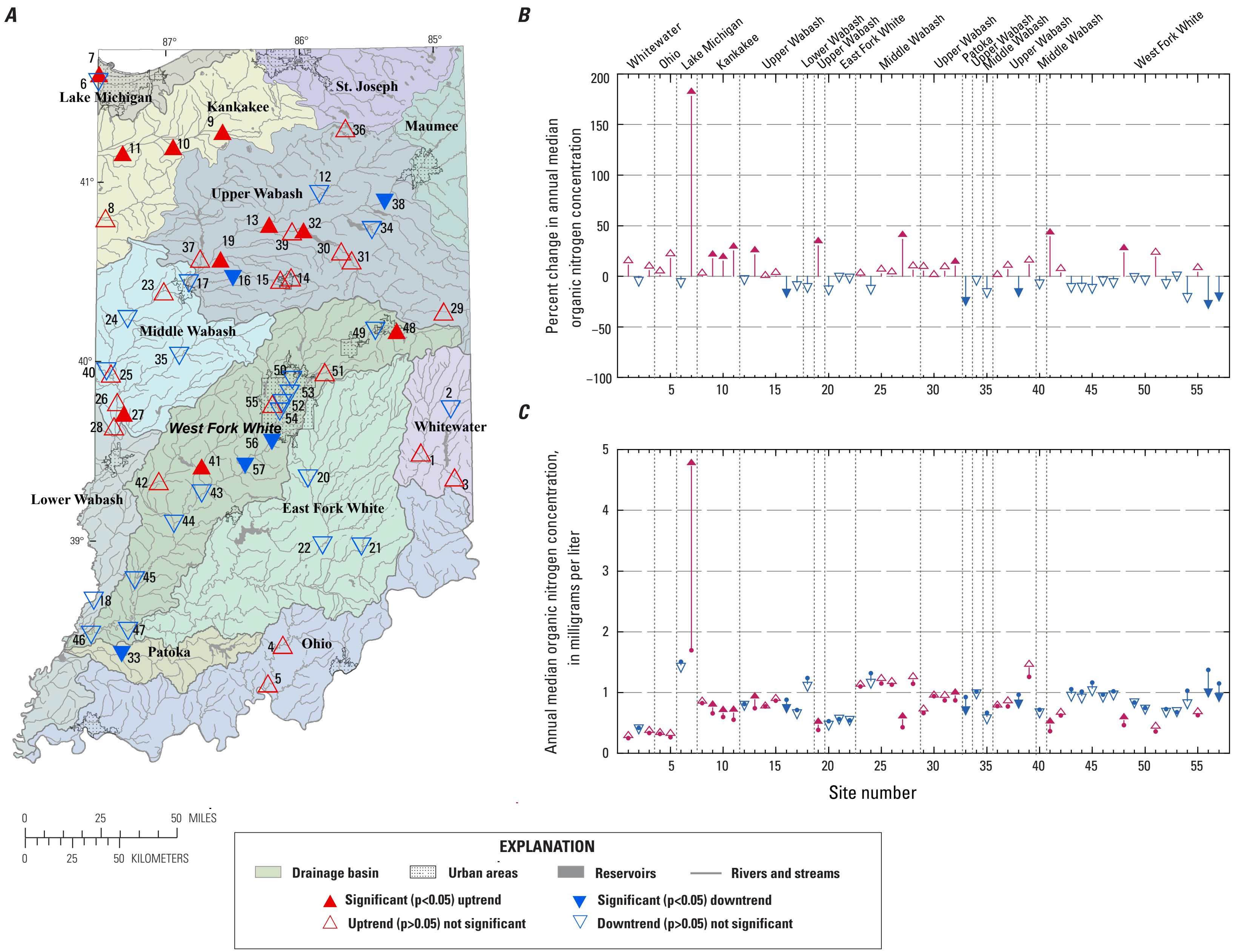

Figure 1–2. Significant and non-significant trends in organic nitrogen at 57 stream sites in Indiana, 2000–10.

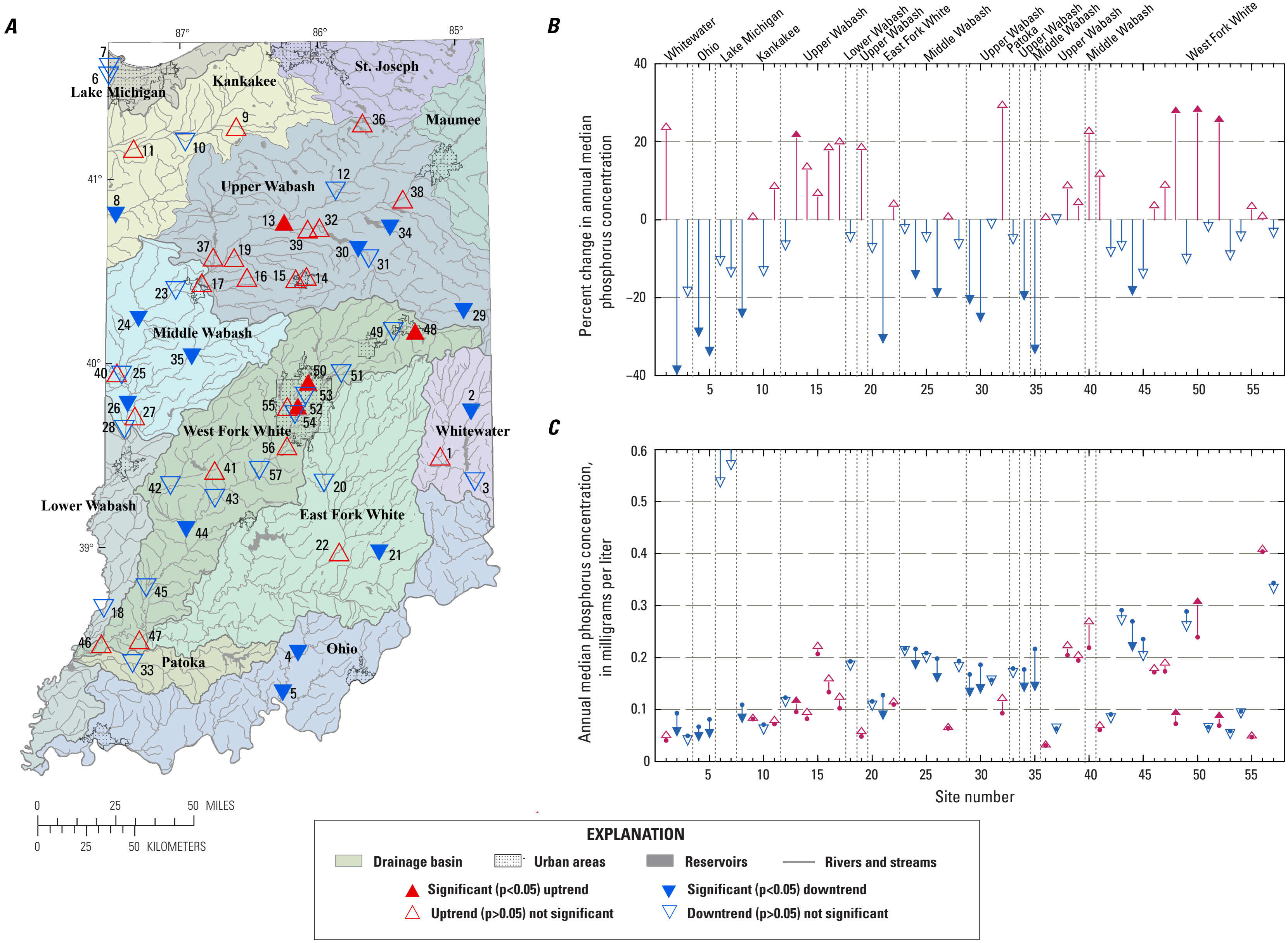

Figure 1–3. Significant and non-significant trends in phosphorus at 57 stream sites in Indiana, 2000–10.

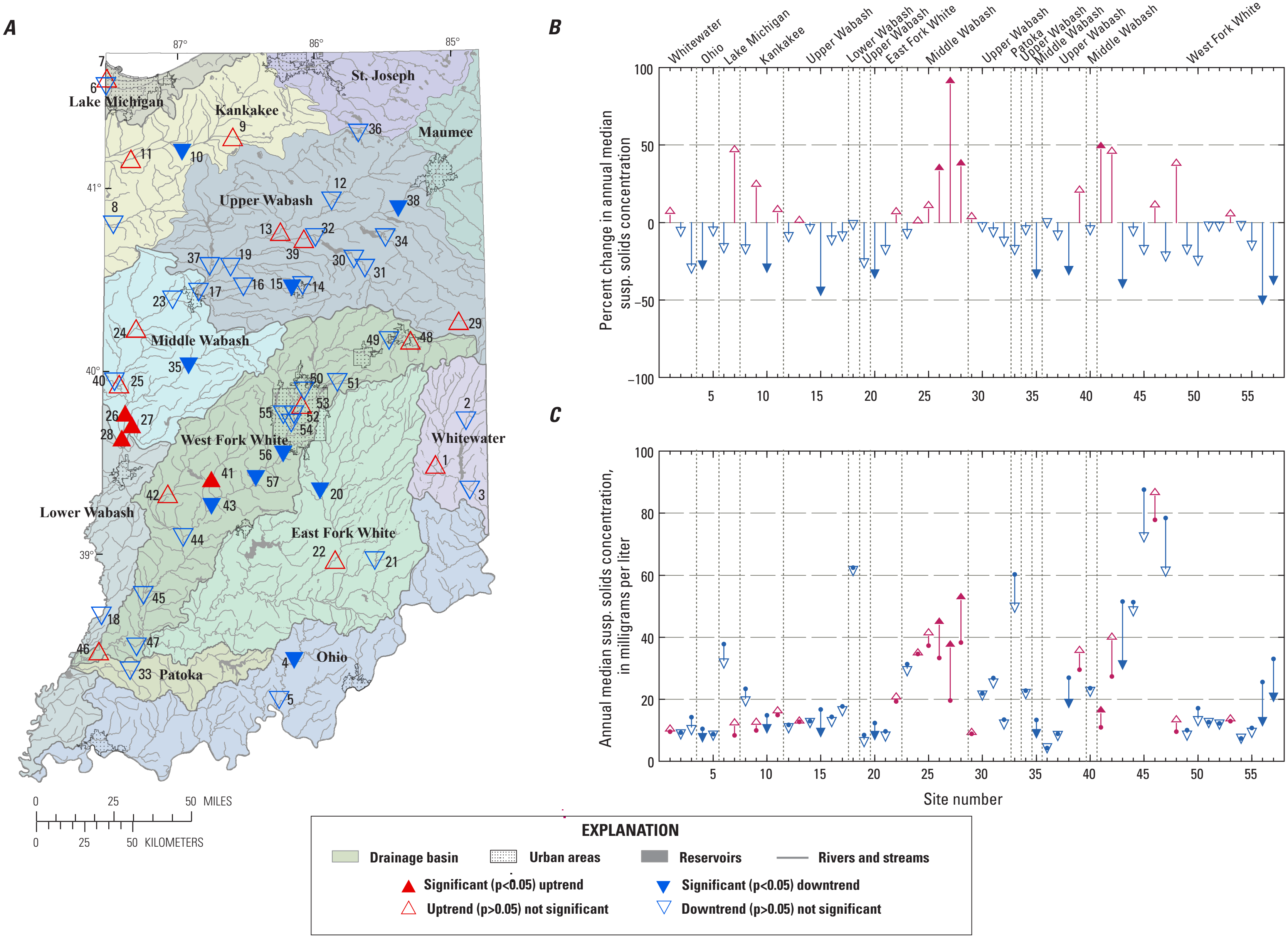

Figure 1–4. Significant and non-significant trends in suspended solids at 57 stream sites in Indiana, 2000–10.

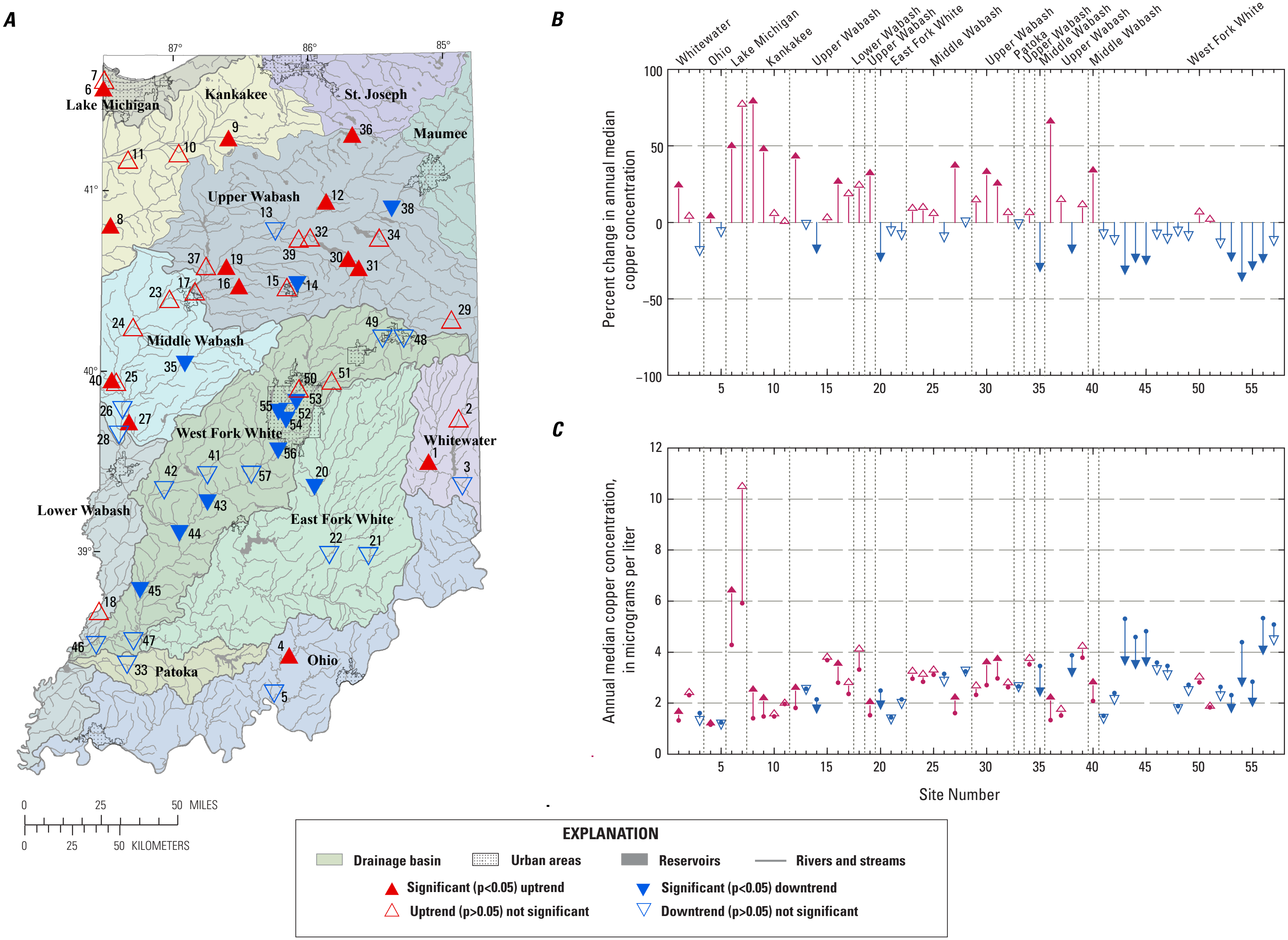

Figure 1–5. Significant and non-significant trends in copper at 57 stream sites in Indiana, 2000–10.

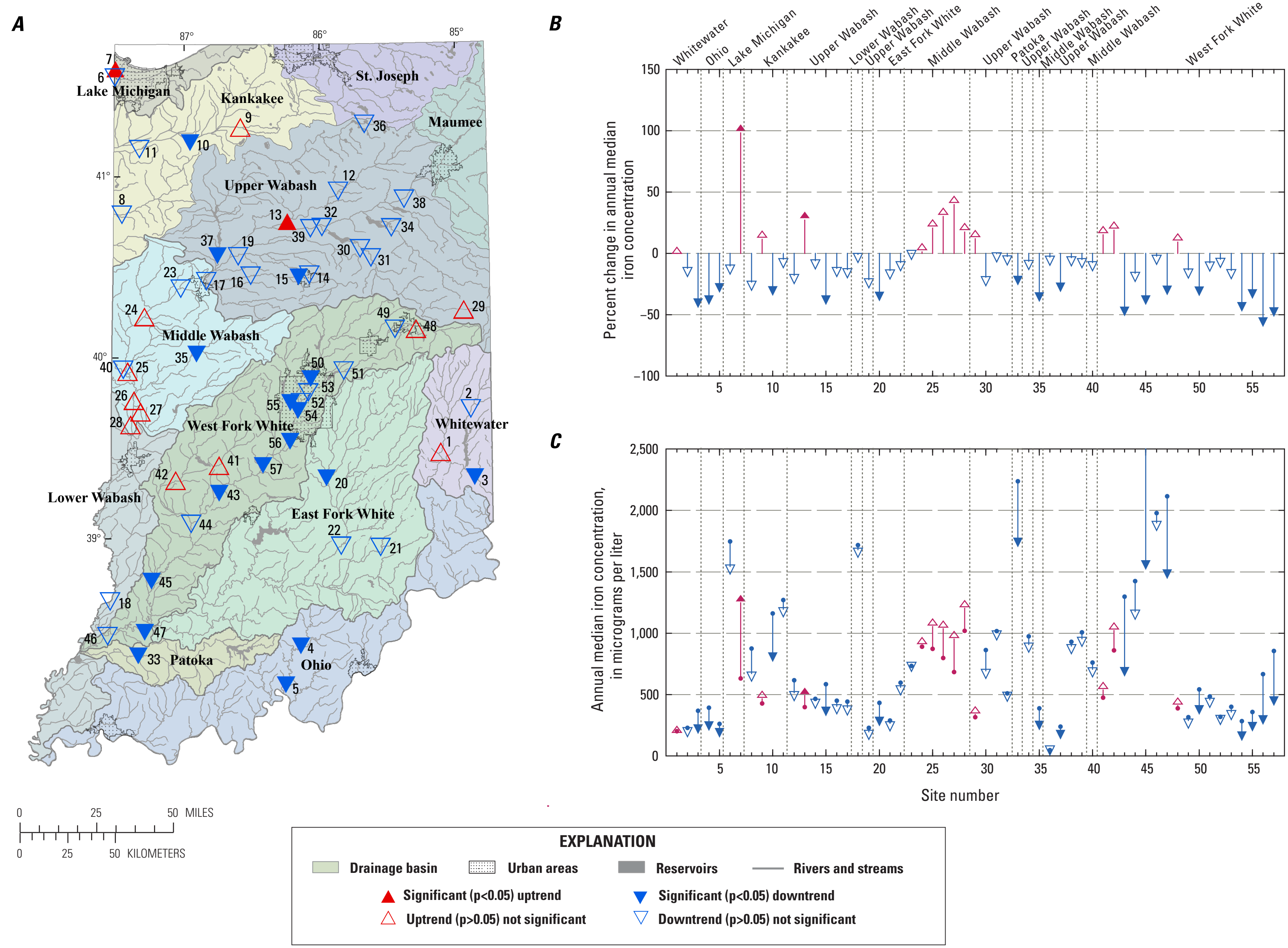

Figure 1–6. Significant and non-significant trends in iron at 57 stream sites in Indiana, 2000–10.

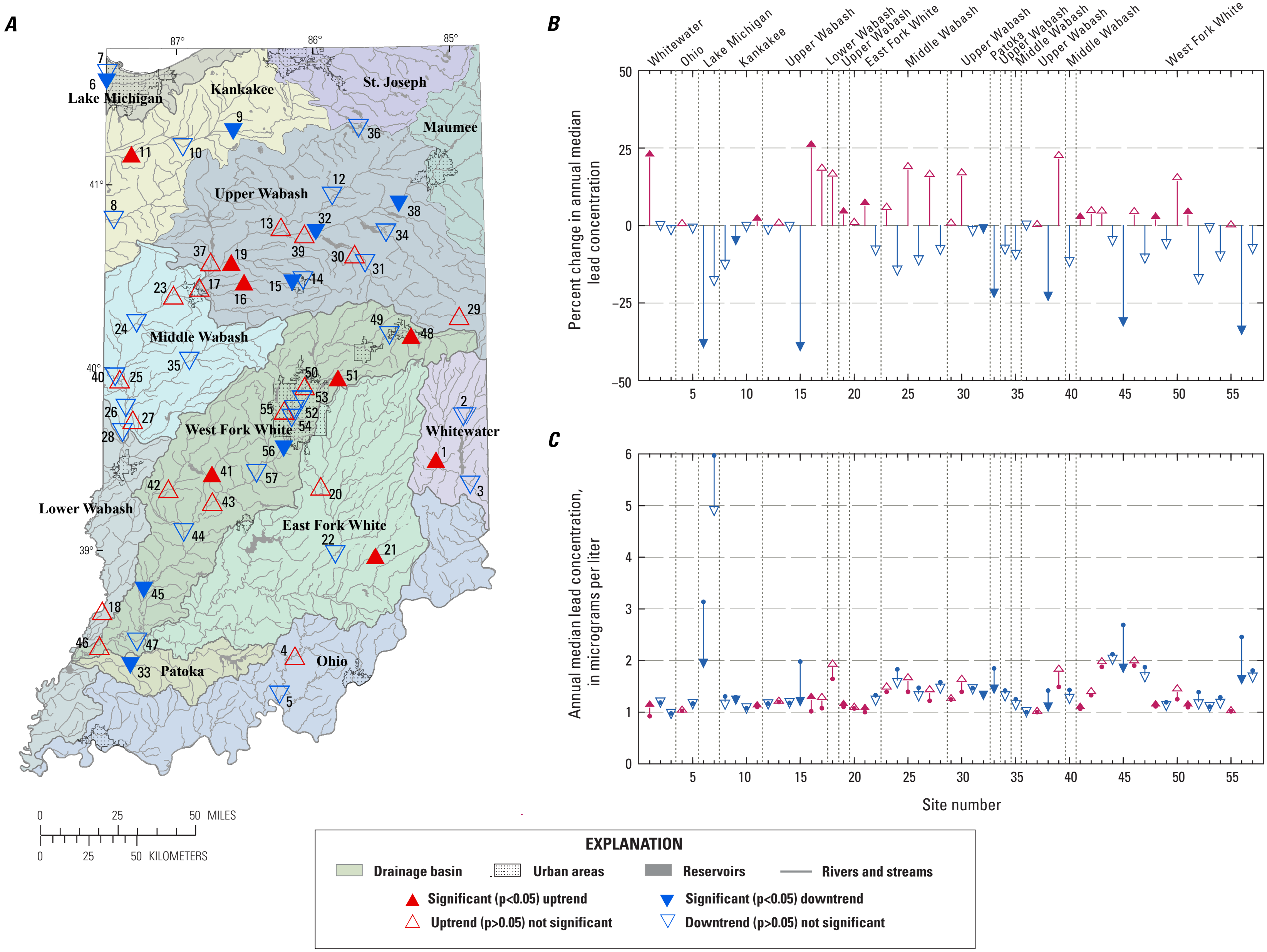

Figure 1–7. Significant and non-significant trends in lead at 57 stream sites in Indiana, 2000–10.

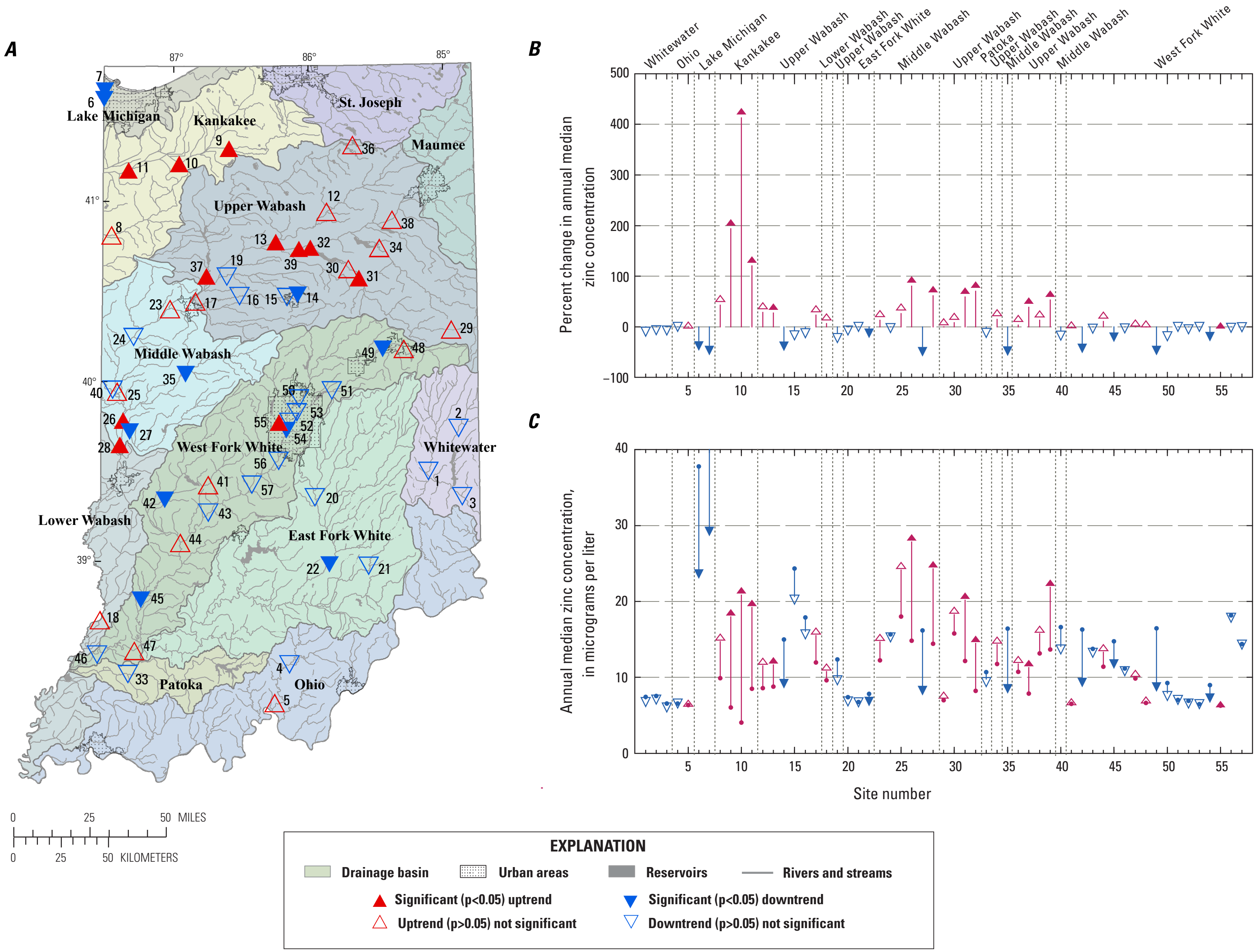

Figure 1–8. Significant and non-significant trends in zinc at 57 stream sites in Indiana, 2000–10.

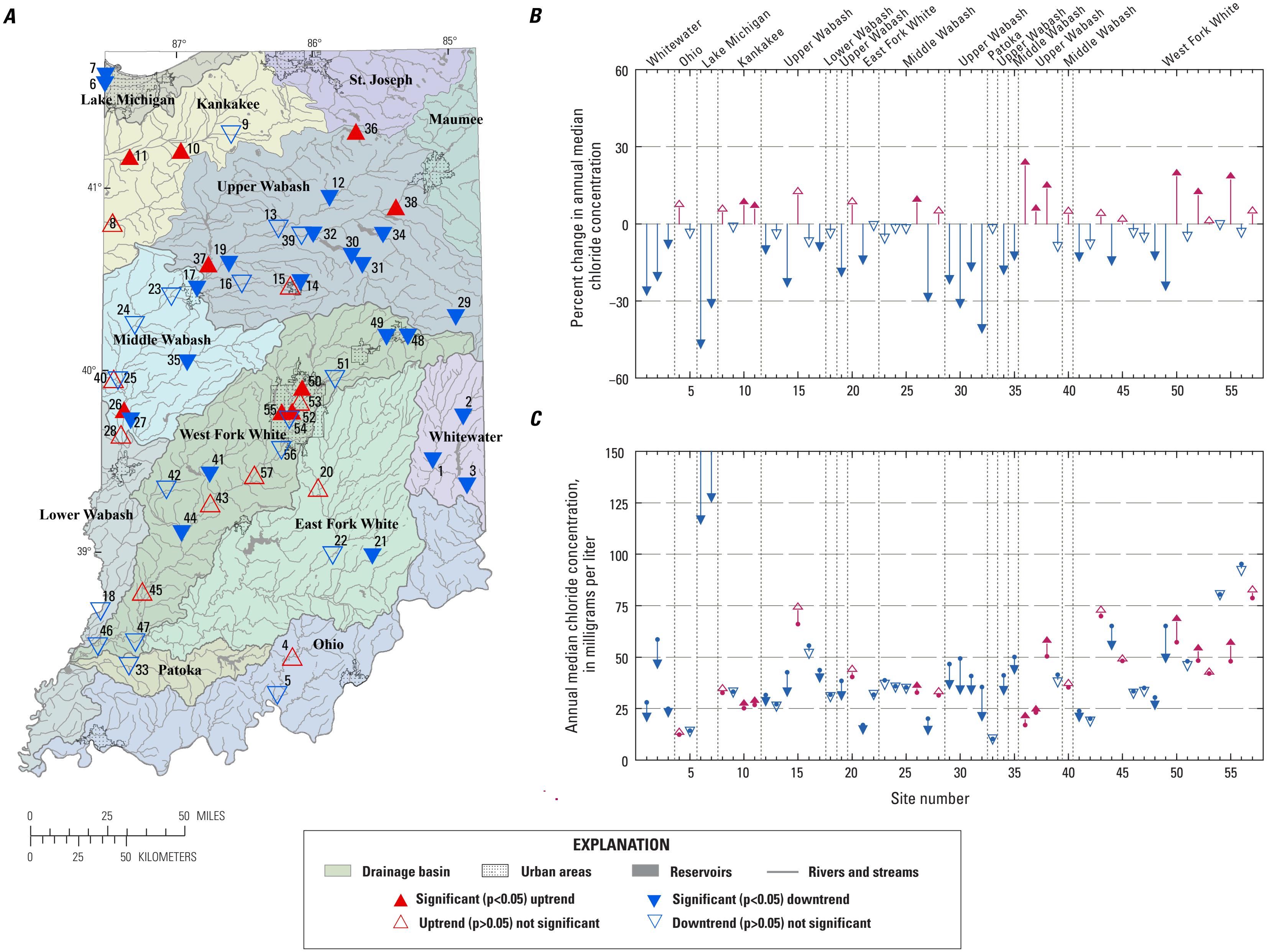

Figure 1–9. Significant and non-significant trends in chloride at 57 stream sites in Indiana, 2000–10.

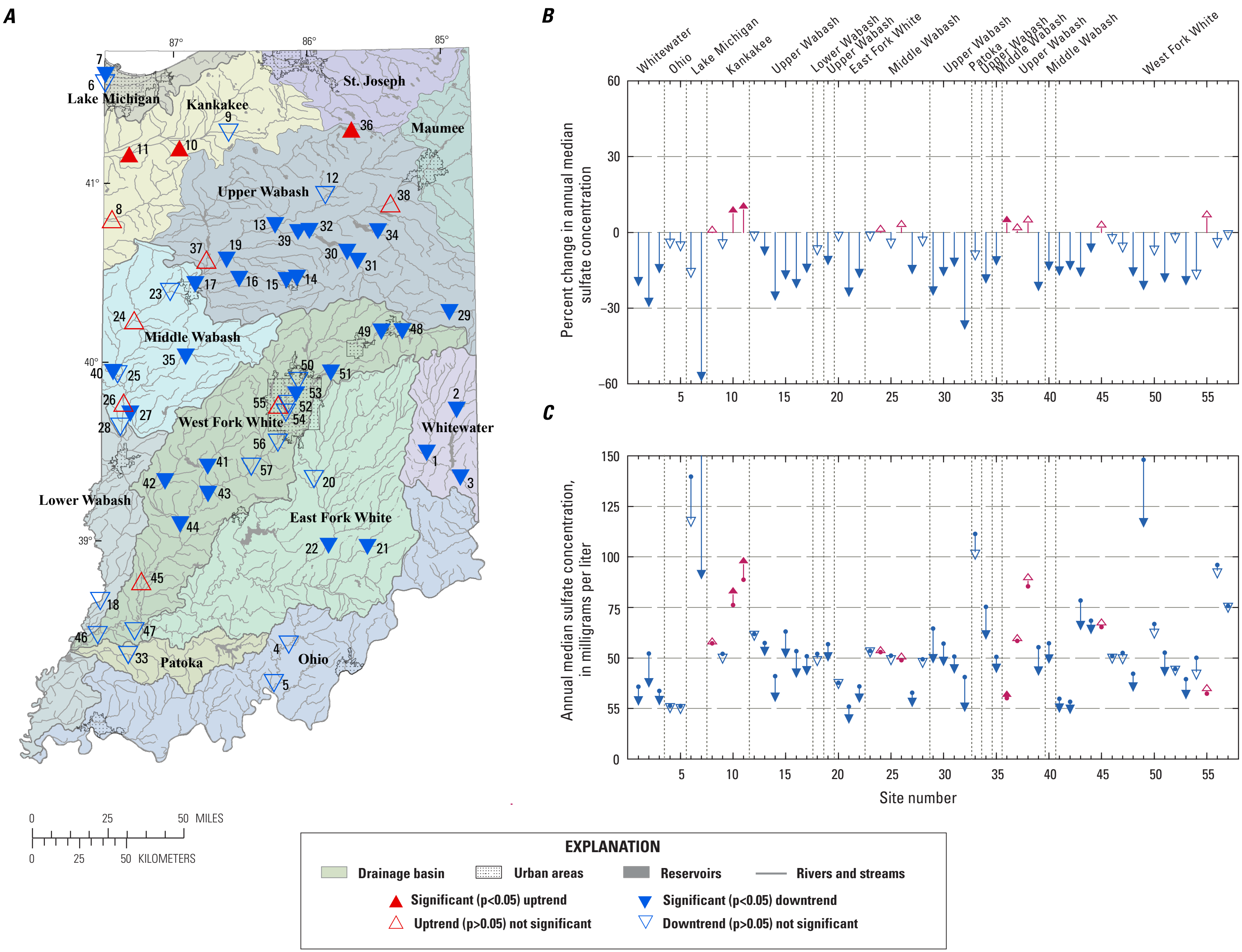

Figure 1–10. Significant and non-significant trends in sulfate at 57 stream sites in Indiana, 2000–10.

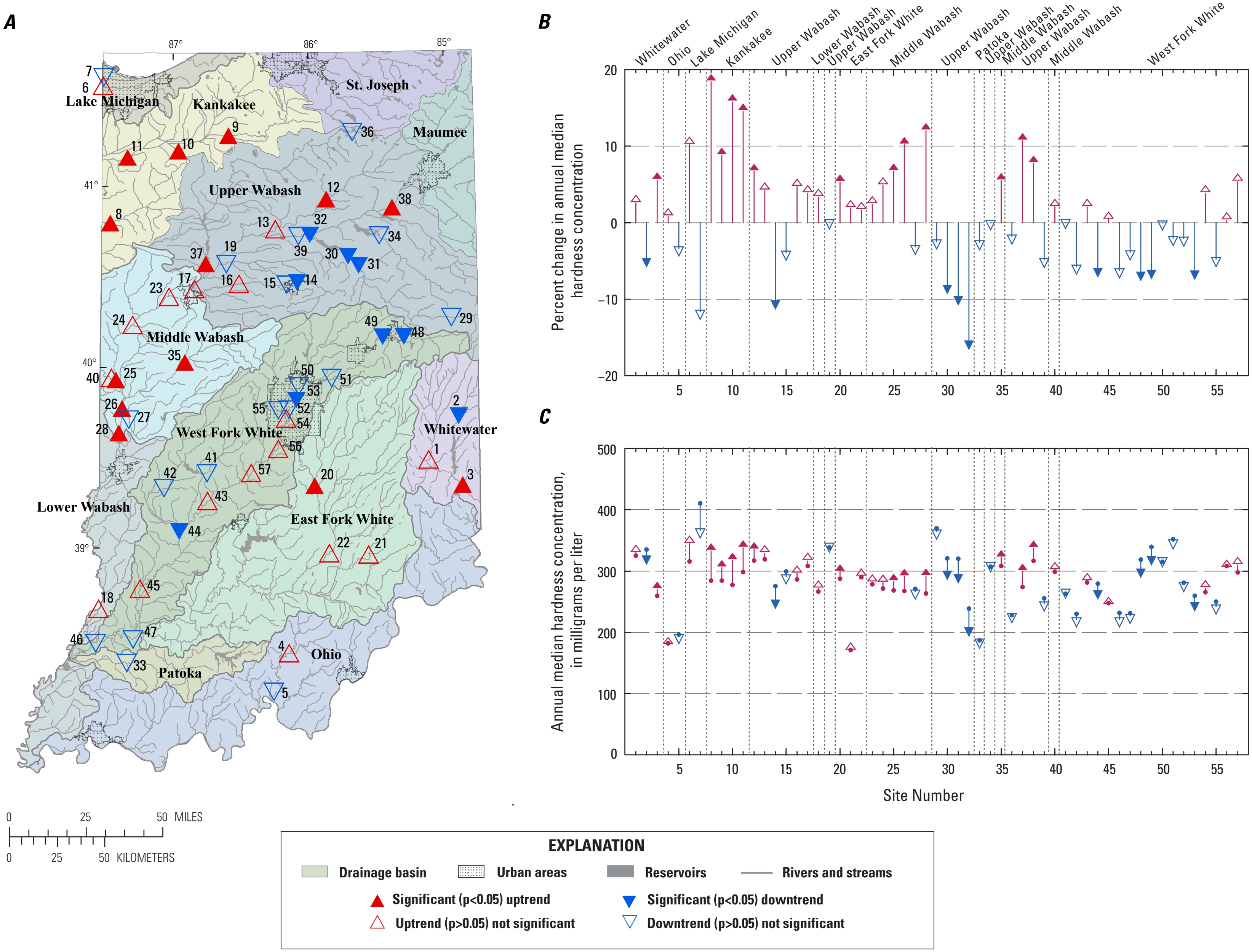

Figure 1–11. Significant and non-significant trends in hardness at 57 stream sites in Indiana, 2000–10.

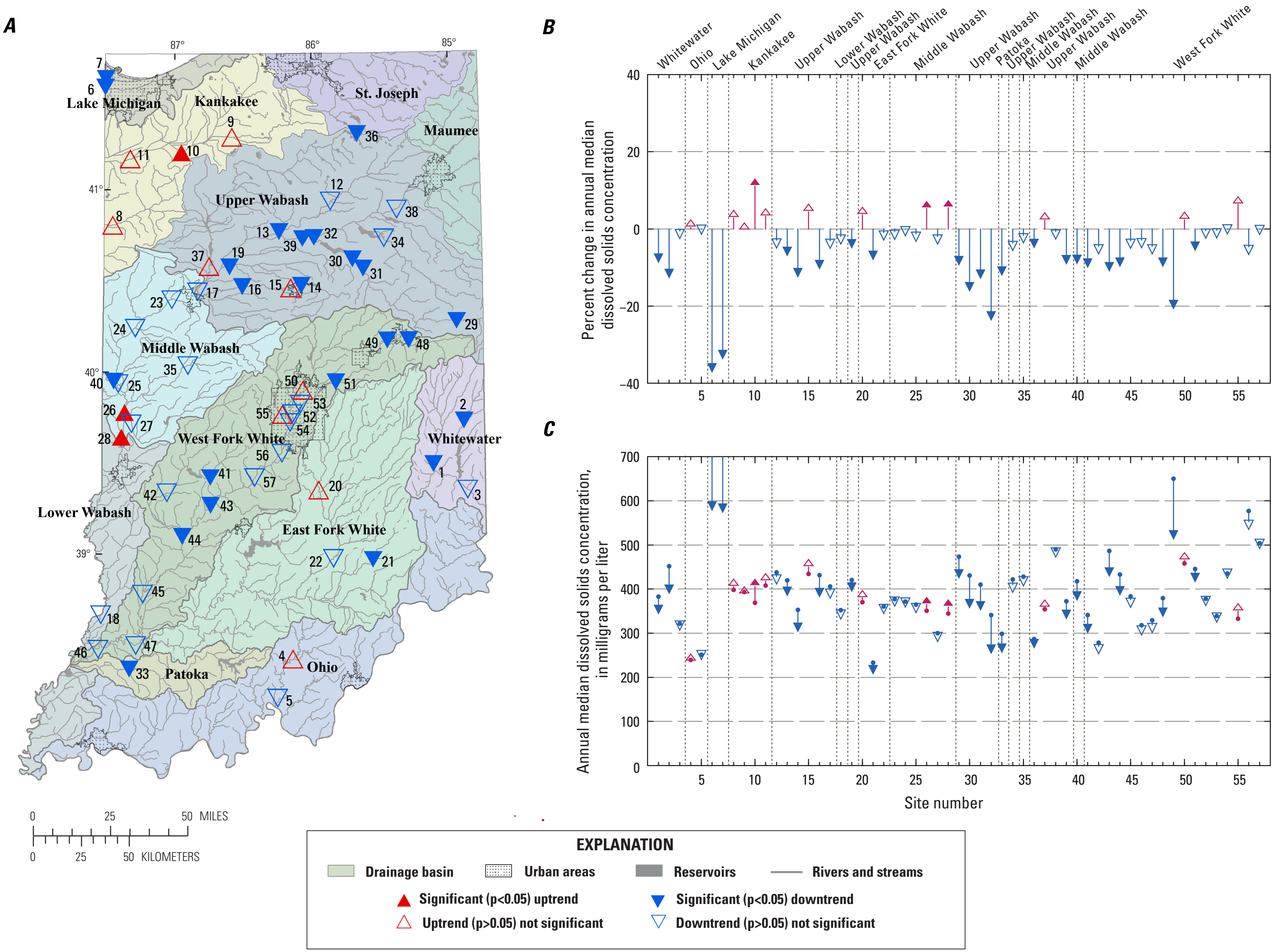

Figure 1–12. Significant and non-significant trends in dissolved solids at 57 stream sites in Indiana, 2000–10.

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