An Assessment for Optimization of Water-Quality Monitoring in Indiana, 2017

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[1], Indiana University-Purdue University at Indianapolis, [2], U.S Geological Survey Indiana-Kentucky Water Science Center, [3], Ohio River Valley Water Sanitation Commission, [4], Indiana Department of Environmental Management, [5], Marion County Public Health Department, [6], City of Elkhart, [7], Indiana University at Fort Wayne, [8], Purdue University, [9], U.S. Department of Agriculture – Agricultural Research Service, [10], Christopher Burke Engineering

Abstract

Background

The Indiana Water Monitoring Council (InWMC) was formed to "Maximize resources through improved communication, coordination, data sharing, and collaboration." Specifically, the InWMC:

1) provides a forum for communication among groups that are monitoring water resources,
2) promotes sharing of monitoring information including data, and effective procedures and protocols for sample collection, and
3) facilitates the development of collaborative monitoring strategies.

There are multiple federal, state, and local agencies and groups monitoring water quality within Indiana. Each group has its own mandate and reason for monitoring including status/assessment, trends, enforcement, compliance, or general research. Typically this work is done within the confines of each group and provides valuable information but lack of coordination can lead to duplication of efforts and important information may be overlooked from not sharing data. Even within the water monitoring community, there lacks a consistent or comprehensive understanding of existing active monitoring networks within Indiana.

This paper is intended for environmental managers, researchers, and interested citizens who seek data from Indiana sampling sites that have long periods of record. The goal of this paper is to (1) highlight the existing, ongoing river and stream water quality networks that provide data, and (2) identify potential areas or sites for expansion or reduction of the existing networks to better address monitoring needs. More specifically, this paper assesses whether Indiana:

a) has a good spatial coverage of water quality networks;
b) can determine the loads of important contaminants entering and leaving the state;
c) has all the necessary types of sampling sites, such as reference or least impacted sites, or sites to assess best management practices (BMPs);
d) has sampling sites sampled by multiple agencies that could be eliminated by one of the agencies to save costs, move funds to other pressing needs, or allow the agencies to work together to increase the coverage and quality of the data;
e) can determine trends at all important sampling locations for the greater Indiana network.

Additional historical water-quality sites are identified on the Indiana Water Monitoring Inventory compiled by Purdue University and found at the Indiana Water Monitoring Council website: http://www.inwmc.org/Default.aspx?pageId=319841

Existing Networks

Several water quality monitoring networks exist within Indiana that are sampled to satisfy the water management needs of the organization conducting the sampling. For this paper, a total of 13 agencies or groups are identified that sample at least quarterly for multiple classes of chemicals, including nutrients, pesticides, and suspended solids or sediment. Sites that are sampled only for *E. coli* are not included in these networks. These 13 groups include the Indiana Department of Environmental Management (IDEM), the U.S. Geological Survey's (USGS) National Water Quality Assessment (NAWQA) Program and National Stream Quality Accounting (NASQAN) networks, the U.S Department of Agriculture (USDA) Agricultural Research Service (ARS), the Ohio River Valley Water Sanitation Commission (ORSANCO), the cities of Indianapolis, Muncie, and Elkhart, several universities—Purdue University, Indiana University Purdue University Indianapolis (IUPUI), Manchester University, and Notre Dame University, the Marion County Public Health Department, and the St. Joseph River Watershed Initiative. All of these sites as well as active USGS streamflow gaging stations are identified in figure 1. A total of 300 sampling sites are included in these networks (Appendix 1). The intent is to add other agencies and groups to this document as they are identified.

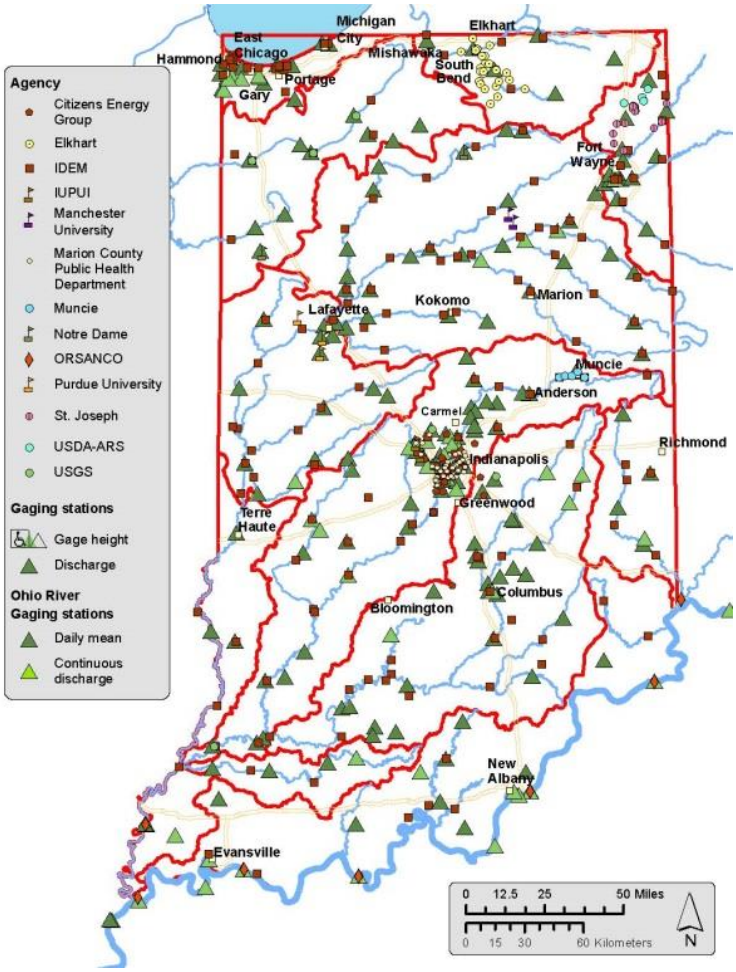


Figure 1. Location of existing water quality networks and USGS streamflow gages in Indiana.

Each of the agencies/groups described below have different reasons for continued monitoring over time. The reason for the monitoring influences how long they have monitored, what they monitor, and when they

monitor. Below is a description of the monitoring for each of the 13 agencies/groups shown in Fig. 1 and appendix 1.

State – Indiana Department of Environmental Management (IDEM)

IDEM is the primary state agency with Clean Water Act (CWA) authority to implement programs to protect and restore water quality. IDEM employs three different monitoring approaches including a fixed station network where sites do not change from year to year; a probabilistic approach, which is a stratified random method to site selection; and a targeted approach where the selection of sampling sites is based on specific monitoring objectives or decisions to be made. Since the focus of this paper is to identify long-term water quality networks, the fixed station network (FSN) is highlighted. IDEM's FSN, which began in 1957 with 49 sites located primarily at drinking water intakes and wastewater treatment plant outfalls, has expanded to 165 sites that are sampled monthly for nutrients, major ions, metals and other field parameters (Appendices 1 and X). For this paper, only 156 sites are included as the other nine sites are on canals or lakes. The original purpose of the FSN was to determine point source compliance and mixing zone effects. For the last decade or so, the data are primarily used to calibrate and verify waste load allocation models for National Pollutant Discharge Elimination System (NPDES) permits and, more recently, to determine water quality trends.

Federal – U.S. Department of Agriculture-Agriculture Research Service (ARS)

As one of the 14 Benchmark Watershed studies of the Conservation Effects Assessment Project (CEAP), ARS monitors eight stream sites (Appendices 1 and X) for discharge, nutrients, pesticides, and suspended sediment in the St. Joseph River Basin in northeast Indiana that will be used for process models nationally (fig. 3). All eight of these sites continue to be sampled in 2017 with three sampled since 2002, two since 2003, one since 2005, and two sites that have been moved but were sampled since 2002 and 2003, respectively. These sites include four edge of field and eight ditch/stream sites; only the eight ditch/stream sites are shown on the map. Field sites are sampled for nutrients, pesticides and suspended sediment, while ditch/stream sites are analyzed for nutrients and pesticides. Weather conditions and soil conditions are also monitored at 10 of these sites as well as four additional weather/soil moisture only sites.

Federal – United States Geological Survey (USGS)

The United States Geological Survey (USGS) has two long-term national monitoring networks designed to assess trends. The National Stream Quality Assessment Program (NASQAN) monitors large rivers and has two primary objectives which are to (1), address questions about the annual transport of selected constituents from selected large rivers to coastal waters of the United States and (2) address questions specific to the Mississippi-Atchafalaya River Basin related to hypoxia in the Gulf of Mexico. To accomplish this, all sites are co-located with USGS streamflow gages. NASQAN sites are sampled 14 times per year for nutrients, major ions, pesticides, suspended sediment, and dissolved organic carbon. Seasonal and annual loads of total and dissolved nutrients are determined from all the major subbasins within the Mississippi River Basin to the Gulf of Mexico to identify which sub-basins contribute the most nutrients. Because of the long period of record and colocation with streamflow gages, these sites allow for trend assessments. Annual loads and flow weighted concentrations are calculated and can be found at http://water.usgs.gov/nasqan/. There are four NASQAN sites that can be used to determine water quality conditions leaving the state of Indiana (fig 4).

The National Water Quality Assessment Program (NAWQA) has two sampling sites in Indiana; one site has been monitored since 1991--the White River at Hazleton (03374100)--and another site since 1993--Sugar Creek

at New Palestine (394340085524601). These sites are sampled 20-26 times per year for nutrients, pesticides, suspended sediment, and selected major ions. Additionally, the Sugar Creek site is sampled for biological communities (algae, invertebrates, and fish) and habitat; Sugar Creek has been sampled for ecological communities 19 times since 1993. Sugar Creek is an indicator of agricultural influences and is one of 11 agricultural sites within the NAWQA national study design. The White River site is a large river site and reflects all the upstream inputs.

Furthermore, the USGS has five sites that are sampled in collaboration with state groups. All of these sites are also monitored continuously for different parameters and include sites in Eagle Creek, School Branch, and the Kankakee River (3 sites). These sites are not shown on this map but can be found in the section on continuous monitored sites (Appendices 1 and X).

City – Citizens Energy Group – Environmental Stewardship (CEG)

In 2011, Citizens Energy Group purchased Indianapolis' Wastewater and Drinking Water operations. The city's monitoring programs accompanied the sale. The Citizens Energy Group monitors 27 sites with seven of those sites located on the White River and 20 sites on tributaries of the White River (Appendices 1 and X). Twelve of these sites have been monitored monthly since 1991 for nutrients, *E. coli*, and selected metals. An additional seven sites have been sampled monthly since 2004. The final six sites were started in 1998 (2 sites), 1999 (1 site) and 2004 (3 sites). A total of 17 of these 27 sites are colocated or close to a USGS streamflow gage (Appendices 1 and X). The most recent Stormwater NPDES permit, issued in 2013, includes additional site changes. Two sites were dropped due to overlap/no further interest, with two new sites and one old bacteria study site added to the sampling list. Additionally, CEG has eight sites that are continuously monitored for water quality parameters.

City - Muncie Bureau of Water Quality (MBWQ)

The City of Muncie Bureau of Water Quality (MBWQ) has sampled monthly five (appendix 1) sites since 1972 for nutrients, *E. coli*, selected metals and annually biological communities (invertebrates and fish). All five of those sites are on the White River (Appendices 1 and X). Three of the sites are monitored daily for ammonia and other parameters for which there are water quality standards. All five sites are co-located or within a ten percent drainage area ratio to USGS streamgages in order to determine loads.

City – Elkhart (ELK)

The City of Elkhart has monitored six sites since 1972 as part of its water quality assessments (Appendix 1 and X). Elkhart collects total suspended solids and *E.coli* weekly to monthly and nutrients quarterly at these sites. Additionally, the Elkhart County Health Department, in cooperation with the Greater Elkhart County Stormwater Partnership, samples 20 sites weekly during the growing season (May-September). These 20 sites do not meet the prerequisite of quarterly samples, but highlight sites that could be leveraged to add additional samples if needed. Elkhart also has an extensive biological sampling program that includes assessment of the fish and invertebrate communities.

University - Purdue University (PU)

Purdue University monitors three sites for nutrients in three small watersheds near West Lafayette (Appendices 1 and X). These sites are Elliot Ditch near Elston, IN (033356725), Little Wea Creek at South Raub, IN (03335673), and Little Pine Creek near Montmorenci, IN (033356786). These sites were sampled from

March 2009 to February 2015 for nutrients (nitrate + nitrite, total phosphorus), *E. coli*, and total suspended solids. These sites are co-located at USGS stream gages and also have continuous sensors for primary water quality parameters (pH, dissolved oxygen, temperature, and specific conductance).

University - Manchester University (MU)

Manchester University monitors two sites (Appendices 1 and X) for nutrients in the Middle Eel River Basin in northern Indiana as part of the Mississippi River Basin Initiative (MRBI). This study is a paired watershed study to test the implementation of agricultural BMPs to keep fertilizer and pesticides on the land and out of ground and surface waters. The two sites, PawPaw Creek and Beargrass Creeks, are sampled for total and dissolved nitrogen and phosphorus. Samples are collected six times a day in May and June during the prime runoff period for nutrients and pesticides and then weekly the rest of the year.

University – Indiana University-Purdue University at Indianapolis (IUPUI)

As part of the Healthy Watershed Initiative, the Center for Earth and Environmental Science (CEES) at Indiana University Purdue University (IUPUI) monitors within the School Branch watershed working closely with some of the most conservation-minded farmers in Indiana. CEES monitors stream, tile drain, and overland flow sites within this watershed. A bio-swale installation is monitored to test whether this BMP is effective at nutrient removal within a heavily tile drained region. Since 2014, CEES along with MCPHD, IDEM, NRCS, and the USGS are sampling at different scales within this watershed, which also includes a continuous multi-parameter sensor site, for the National Water Quality Initiative (NWQI). This NWQI monitoring work builds on the monitoring of 11 stream sites monitored by CEES from 2007-12. Two of the sites were sampled at the same location as MCPHD and IDEM (Appendices 1 and X). These two sites have been monitored between CEES, MCPHD, and IDEM since 1995.

University – Notre Dame University (UND)

Since 2006, the University of Notre Dame (UND) has monitored Shatto Ditch Watershed to quantify how water quality and channel stability have improved. To understand linkages between watershed-scale management practices and water quality, UND is measuring tile drain and stream water nutrient concentrations and loads by sampling 25 tile drains and 10 longitudinal stream sampling sites approximately every 14 days. In total, approximately 2,000 samples/year are collected. For each tile drain and stream grab sample, UND quantifies total suspended solids (TSS), nitrate-N, ammonium-N, total N, soluble reactive phosphorus (SRP), total phosphorus (TP), and dissolved organic carbon (DOC). Using Hydrolab Datasondes (Hach) at the watershed outlet, UND records turbidity, temperature, pH, and conductivity every 30 minutes. In addition to the grab sampling, UND has real-time nitrate sensors (Hach-Satlantic) and prototype phosphate sensors (developed in collaboration with Dublin City University, Ireland) at the outlet of the watershed (installed summer 2015—funded through USDA RCPP); sensors collect data every 10 minutes and are validated with grab sampling described above. Since 2015, two of the stream sites are co-located with USGS stream gages (Appendices 1 and X).

Regional - Ohio River Valley Water Sanitation Commission (ORSANCO)

ORSANCO is an interstate water pollution control agency located in Cincinnati, OH. ORSANCO monitors and assesses the Ohio River and selected interstate tributaries in the Ohio River basin. ORSANCO has seven fixed sampling sites within or on the border of Indiana (Appendices 1 and X). Several ORSANCO programs determine which parameters are sampled at each of those seven sites. Since 2001, the clean metals program samples at

five of those sites bimonthly for 17 metals and 14 nutrients and major ions. Since 1976 at six sites, 14 nutrients and major ions are sampled bimonthly. Since 2000, algae and nutrients are collected bimonthly at two sites. Since 1978 at two sites, the ODS (Organic Detection System) analyzes for 20-30 volatile organics, daily. ORSANCO has five continuous monitors in Indiana sampling at least every 30 minutes for DO, temperature, conductivity, turbidity, pH, and chlorophyll since 2009. Additionally, there are four sites where *E. coli* and fecal coliform are collected weekly, April – Oct. since 1992. Five sites are co-located or are close enough to USGS streamgages to determine loads.

County – Marion County Public Health Department (MCPHD)

The Marion County Public Health Department (MCPHD) has several programs to monitor water quality and assess trends within and around Marion County (Indianapolis). MCPHD monitors 40 sites within the county with staggered start dates, ranging from 1995 to 2016 (Appendices 1 and X). The ambient sampling program monitors 37 sites, which are sampled quarterly for nutrients, metals, volatile organic compounds, *E. coli*, and water quality parameters (DO, temp, pH, Spec. Cond, TDS). MCPHD's herbicide sampling program involves six sites, which are sampled weekly during the growing season (April-September) for nutrients, selected pesticides, metals, and water quality parameters. Most of these sites are also sampled five times per month for *E. coli* only. In addition, five of these sites are part of MCPHD's macroinvertebrate sampling program, which is conducted annually. Twelve sites are co-located or are close enough to USGS streamgages to determine loads. Sampling results are updated quarterly on the MCPHD's website at www.marionhealth.org.

Non-Governmental Organization – St. Joseph River Watershed Initiative (SJRWI)

The St. Joseph River, fed by a 694,400-acre watershed that drains parts of six counties in Michigan, Ohio, and Indiana, serves as a source of domestic water for more than 200,000 residents in the City of Fort Wayne and surrounding area. The confluence of the St. Joseph and St. Mary's rivers in Fort Wayne forms the Maumee River that empties into the western basin of Lake Erie at Toledo, Ohio. To support its mission and goals, the SJRWI has managed an extensive water quality monitoring program in the St. Joseph River Watershed since 1996. Currently, the Initiative samples 11 sites on tributaries to the St. Joseph River within 9 sub-watersheds throughout the St. Joseph River Basin (Appendices 1 and X). Water quality parameters measured and analyzed include, herbicides, *E. coli*, total phosphorus, nitrate, temperature, pH, dissolved oxygen and turbidity. Additionally, the SJRWI samples 14 other sites in Michigan and Ohio as part of the Tri-State Initiative.

Assessment of Indiana Monitoring Networks

Spatial Coverage and Co-location with Streamflow Gages

The large number of sites sampled by agencies and groups across the state shows good spatial coverage (fig. 1). However, the number of sites co-located with a stream gage to allow for the calculation of loads shows that some major watersheds lack collocation of streamflow and water monitoring (fig. 2). In particular, the Maumee River and Whitewater River watersheds could use additional monitoring. To address the spatial coverage throughout the state, this analysis will focus on the major river basin design of IDEM since it operates the largest monitoring network in the state.

Major River Basins

There are multiple ways of assessing the monitoring networks, such as ecoregions or where streams ultimately drain. However, since IDEM has the most sampling sites in the state, it makes sense to incorporate its existing study design to assess the monitoring networks in Indiana. IDEM uses 9 Major River Basins (MRBs) as the basis for its 9-year rotating basin probabilistic sampling design and this is the focus of this section (fig. 2). The MRBs that comprise IDEM's sampling strategy are: the (1) Great Lakes tributaries (St. Joseph to Lake Michigan, and Maumee to Lake Erie); the (2) Upper Wabash, (3) Middle Wabash, and (4) Lower Wabash; (5) Kankakee, (6) White and West Fork White; (7) East Fork White; (8) Whitewater, and (9) tributaries to the Ohio River. Another way to assess the spatial coverage of the water quality networks in Indiana is whether MRBs are co-located with a stream gage so that loads can be determined at pour points[1].

Important questions about Indiana monitoring:

(1) Can Indiana show the condition of waters entering and leaving the Major River Basins and the State?

(2) Can Indiana show trends in water quality?

(3) Can loads be determined at all the key pour points in Indiana?

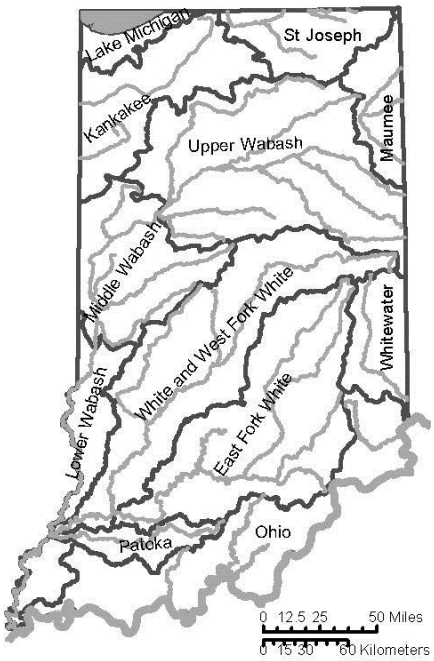


Figure 2. Map of the IDEM Major River Basins used in this assessment.

1) **West Fork White River** - The West Fork White River includes the cities of Indianapolis, Muncie, and Anderson but land use is dominated by row crop agriculture. There are a total of 102 sampling sites within this Major River Basin: 40 sites sampled by MCPHD, 28 sites sampled by IDEM, 24 sites sampled by Citizens Energy Group in Indianapolis, five sites sampled by Muncie Bureau of Water Quality, three sites by the USGS, and two sites by IUPUI-CEES within this Basin (fig. 3 and 3a). The IDEM site (WWL030-0003) is co-located with the USGS gage at White River near Edwardsport (03360500) and integrates all the West Fork White River above the confluence with the East Fork White River. The White River at Hazelton (03374100) site integrates both the West Fork and East Fork White River and is being sampled by IDEM as part of the FSN program and the USGS as part of the NAWQA/NASQAN programs. The impact of the City of Indianapolis on the White River is monitored by IDEM (WWU160-0004) and is co-located at the USGS gage at Centerton (033540000). Fall, Eagle, Crooked, and Mill Creeks and the Eel River are important tributaries in this Major River Basin.

[1]Encompassing the total area flowing into a given outlet or the bottom of a watershed.

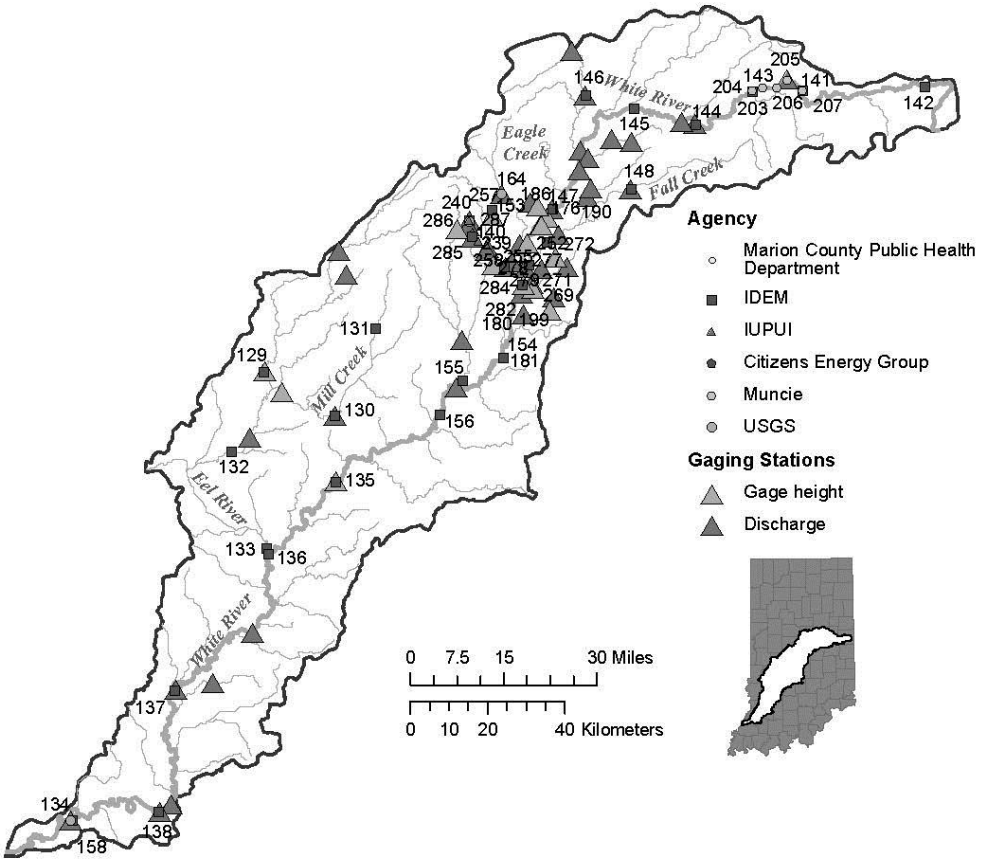


Figure 3. Map of the sites in the West Fork White River.

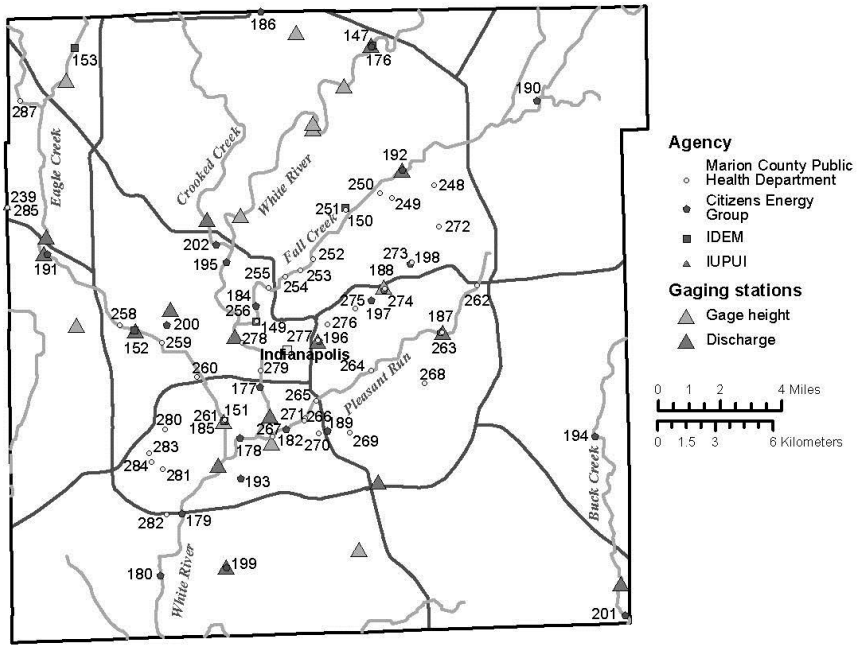


Figure 3a. Map of the sites in Marion County in the West Fork White River.

2) **East Fork White River –** This Major River Basin includes the City of Columbus but has less of an urban influence than the West Fork White River; it is dominated by row crop agriculture. There are a total of 23 sites within this Major River Basin: 19 sampled by IDEM; three by the Citizens Energy Group, and one USGS NAWQA site (fig. 4). Four of the sites are located at a USGS stream gage. There currently is not a site that is being sampled that would incorporate water quality conditions for this basin. The closest sampling site to the mouth is the IDEM site, East Fork White River at SR 57 (WEL170-0001), however there is not a gage close to this site. The East Fork White River at Shoals (03373500) is the closest gage to the mouth currently. To integrate all the East Fork White River above the confluence with the West Fork White River, a gage closer to the mouth or potentially sampling at Shoals would allow loads to be calculated for the East Fork White River. It was sampled by USGS NAWQA between 1993 and 1995. Sugar Creek and Muscatatuck River are important tributaries in this Major River Basin. The East Fork White River is formed at the confluence of the Driftwood and Flatrock Rivers and other important tributaries are Sugar Creek and the Muscatatuck and Big Blue Rivers.

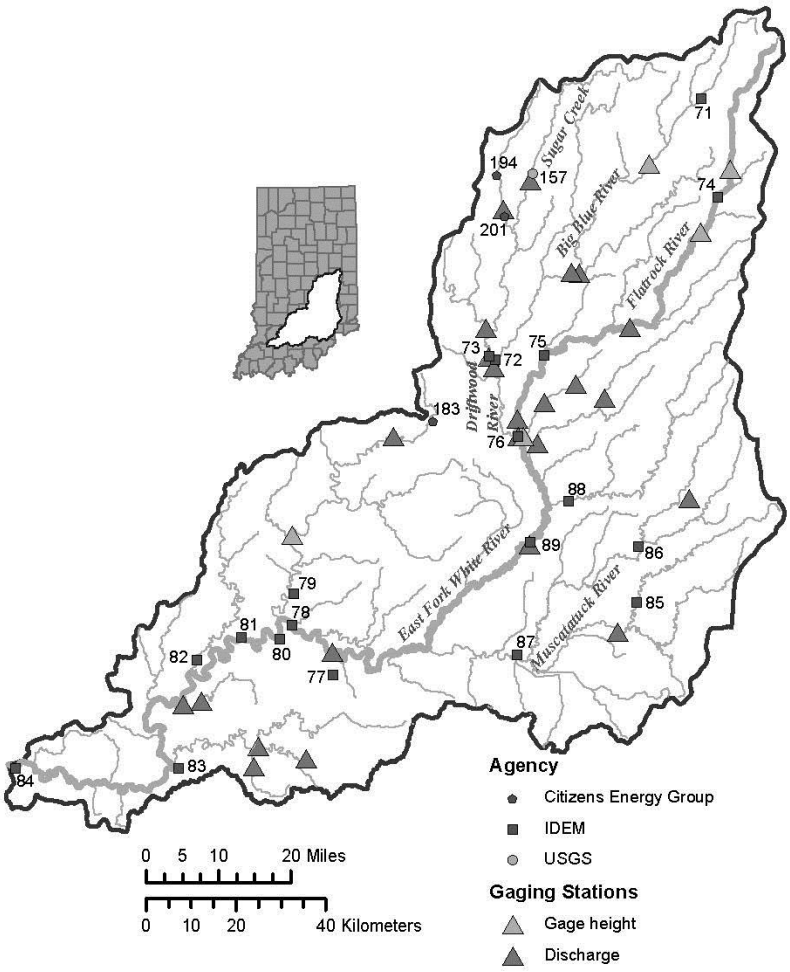


Figure 4. Map of the sites in the East Fork White River.

3) **Upper Wabash River –** There are a total of 38 sites sampled within this Major River Basin: 35 sites sampled by IDEM, two by Manchester University, and one by Notre Dame University within this Basin (fig. 5). Of the 38 sites, 16 are co-located at USGS stream gages. Wildcat Creek, and the Mississinewa, Eel, and Tippecanoe Rivers are three of the larger tributaries in this Major River Basin. There are no gaged sites that IDEM samples at the mouth of this Major River Basin, but the Wabash River at Lafayette (03335500), which is located in the Middle Wabash River Basin, is the site that integrates all the Wabash River in the Upper Wabash watershed.

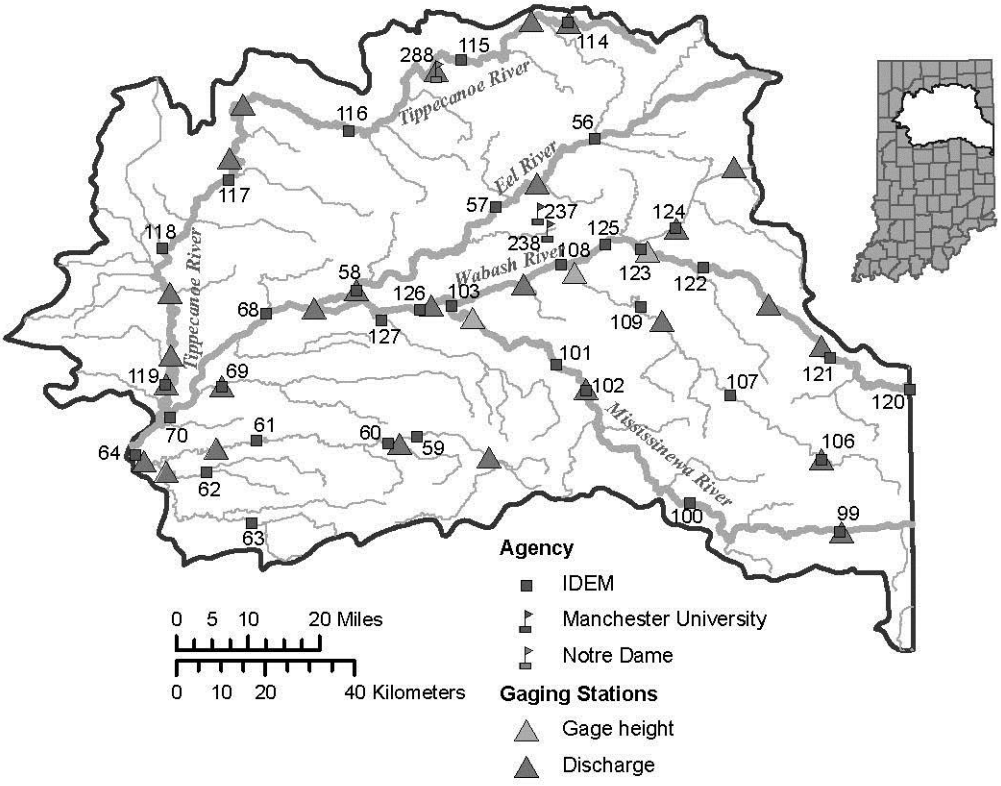


Figure 5. Map of the sites in the Upper Wabash River Basin.

4) **Middle Fork Wabash River -** There are a total of 16 sites within this Major River Basin: 13 sites sampled by IDEM and three by Purdue University (fig. 6). The IDEM site, map ID 97 (WLV200-0001), located at the USGS gage Wabash River at Terre Haute (03341500) is the site that integrates all the Wabash River in the Upper and Middle Wabash watersheds. Of the 17 sites, 11 are located at USGS gages. The Big Raccoon, Big Pine, and Sugar Creeks are important tributaries in this Major River Basin.

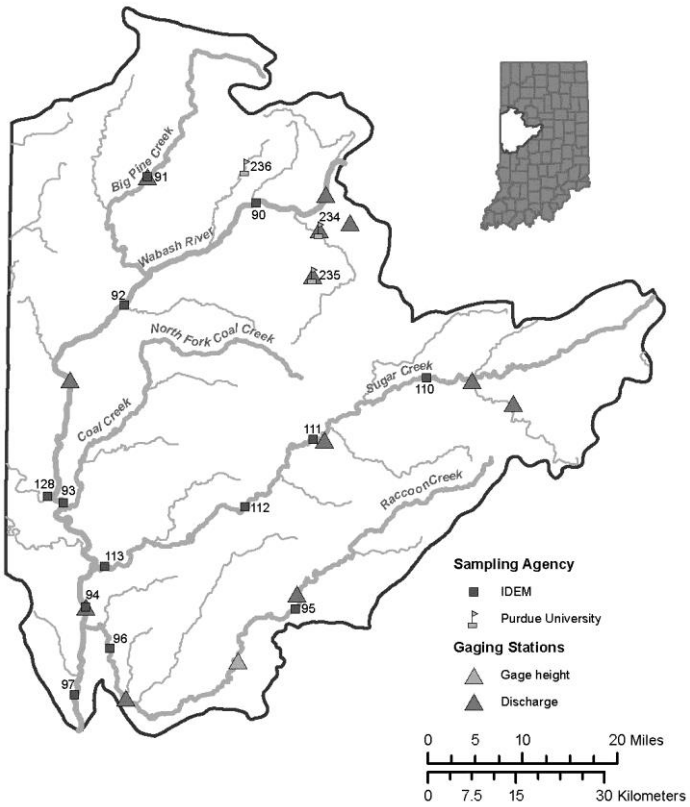


Figure 6. Map of the sites in the Middle Wabash River Basin.

5) **Lower Wabash River -** There are a total of five sites sampled in this Major River Basin: IDEM samples four sites; and USGS NASQAN and ORSANCO both sample the same site within this Basin (fig. 7). The Wabash River at New Harmony (03378500) is the site that integrates all the Wabash River above the confluence with the Ohio River. Currently, IDEM does not sample a gaged site to document water quality in the Wabash River as it leaves the state, but the NASQAN/ORSANCO data can be used. NASQAN has sampled this site since 1972. All of the tributaries in this Major River Basin are small but include Busseron, Big, Sulfur, and Turtle creeks and the Black River.

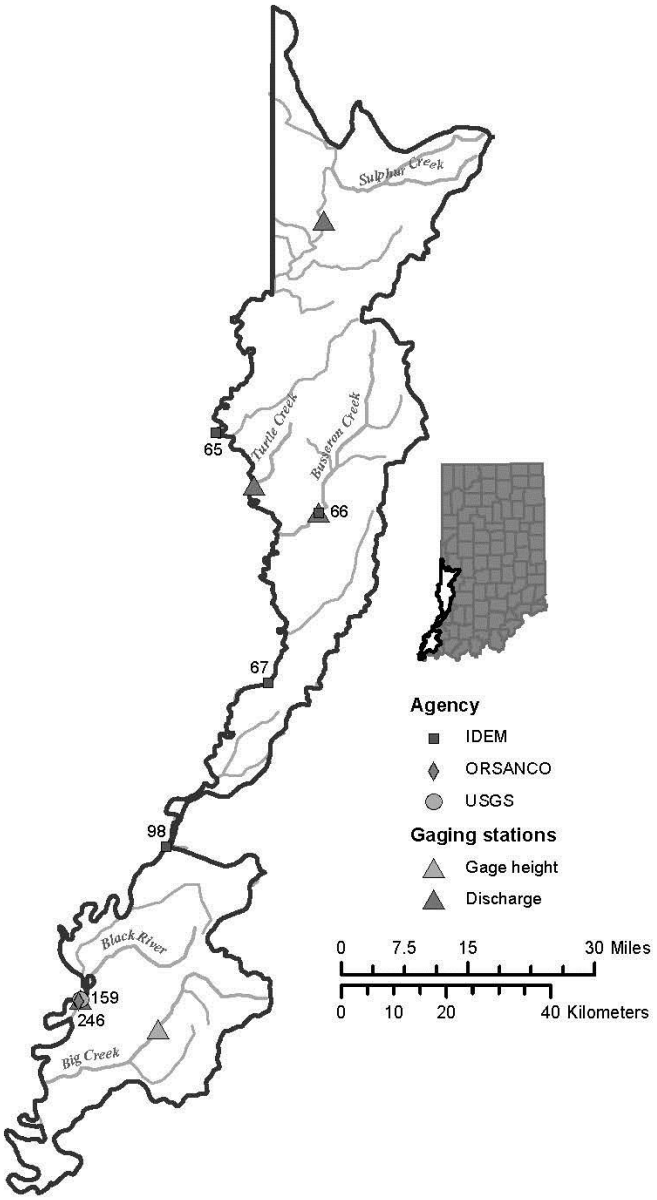
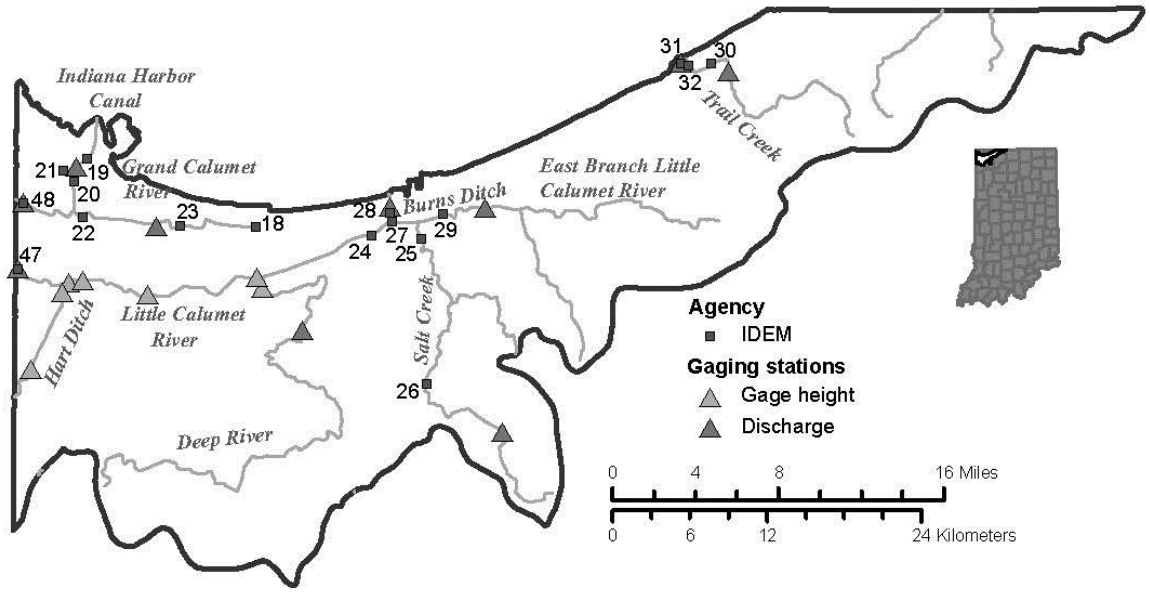


Figure 7. Map of the sites in the Lower Wabash River Basin.

6) **Great Lakes Tributaries -** There are a total of 80 sites within this Major River Basin: 31 sites drain into Lake Erie through the Maumee River. Of these 31 sites, 12 are sampled by IDEM, eight by ARS, and 11 by the St. Joseph River Basin Initiative; 17 drain into Lake Michigan and all 17 are sampled by IDEM (fig. 8a-c). Thirty-two drain into the St. Joseph River, with 6 sampled by IDEM and 26 by the City of Elkhart. Most (24) of the IDEM sites that drain into Lake Michigan are located at drinking water intakes. There are three IDEM sites located at USGS streamflow gages in the Maumee and another four sites within ten percent of the drainage areas, but none in the St. Joseph. Important tributaries in the Lake Michigan Basin include the Grand Calumet and Little Calumet Rivers, and the Trail and Salt Creeks; in the St. Joseph Basin, important tributaries include, St. Joseph, Elkhart, Little Elkhart and Pigeon rivers and Pigeon Creek; and in the Maumee River Basin, important tributaries include Cedar Creek and the St. Joseph and St. Mary's rivers.

a.


Indiana Harbor Canal
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East Branch Little Calumet River
Burns Ditch
Trail Creek
Little Calumet River
Hart Ditch
Salt Creek
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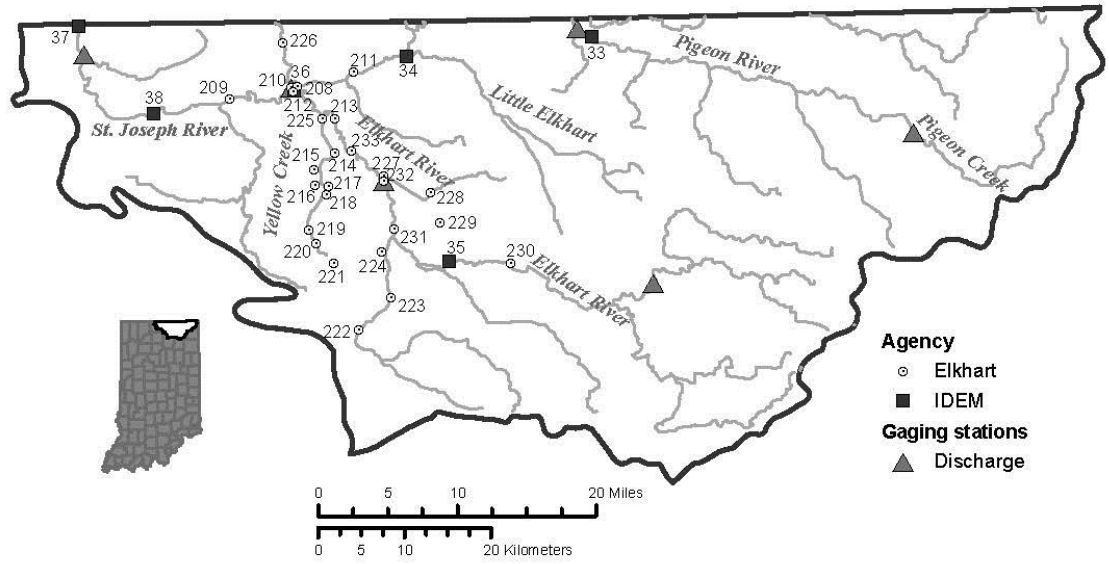
St. Joseph River
Yellow Creek
Elkhart River
Little Elkhart
Pigeon River
Pigeon Creek
Elkhart River
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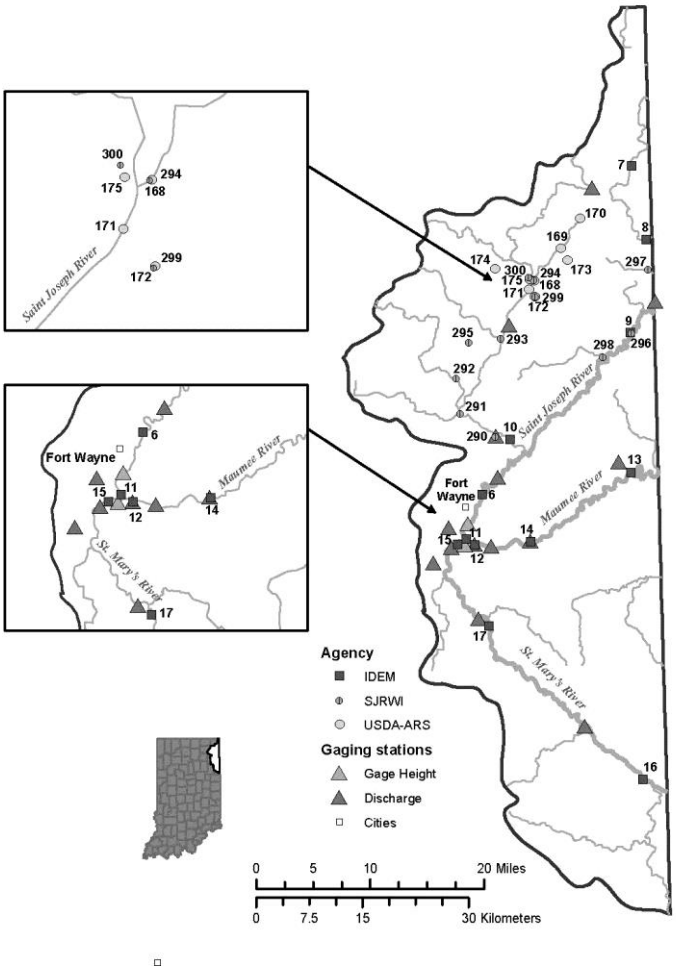

Figure 8. Map of the sites in the Tributaries to the Great Lakes which includes (a) Lake Michigan, (b) St. Joseph, and (c) Maumee Watersheds.

7) **Ohio River and Tributaries -** There are a total of seventeen sites sampled in this Major River Basin that drain into or are on the Ohio River (fig. 9). IDEM samples eight sites, most of them tributaries to the Ohio River. The largest of these include the East Whitewater River at Abington (03275600). ORSANCO samples six sites and the USGS three sites on the Ohio River; one of those sites, Ohio River at Cannelton, is sampled by ORSANCO and the USGS NASQAN program. Indian and Laughery Creeks, and the Blue and Little Blue Rivers are the larger tributaries in this Major River Basin. One important contributing watershed that currently is not being sampled is the Great Miami River, which flows along the border of Indiana and Ohio. Additionally, to ascertain water quality in the Ohio River before it enters Indiana, a site downstream of Cincinnati and the Great Miami Rivers would be helpful.

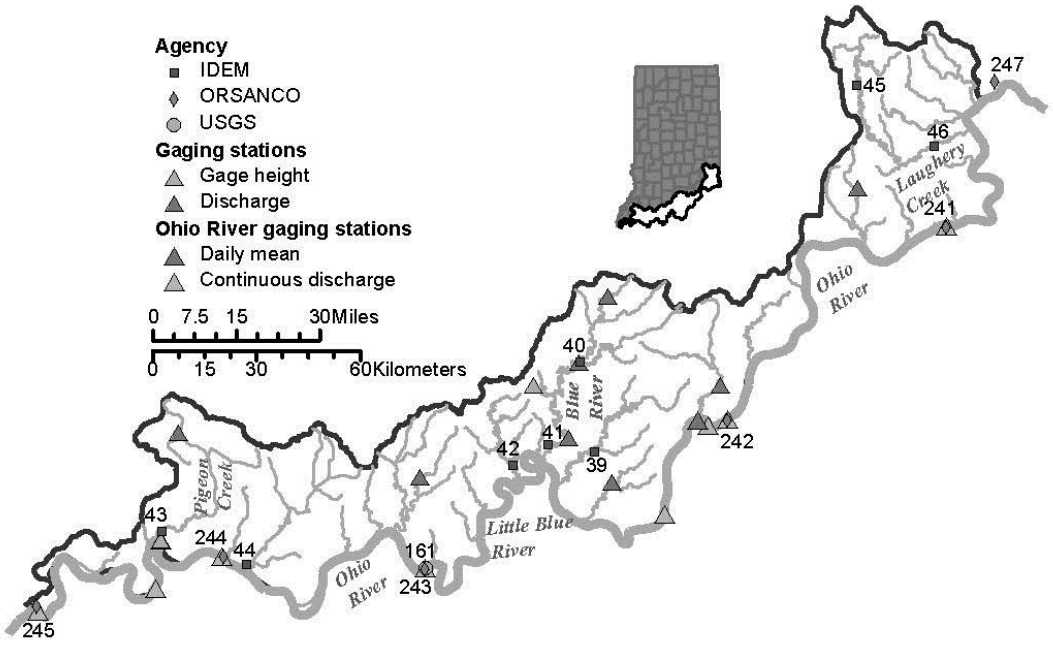

Figure 9. Map of the sites in the Ohio River Tributaries Basin.

8) **Patoka River -** There are two sites sampled by IDEM that are located within the Patoka watershed (fig. 10). The Patoka River at Winslow (03376300) is an IDEM site that is located near a USGS gage (7.9 percent difference). A primary water feature in this MRB is Patoka Lake which is an important drinking water reservoir. The Patoka River flows directly into the Wabash River on the western border between Indiana and Illinois.

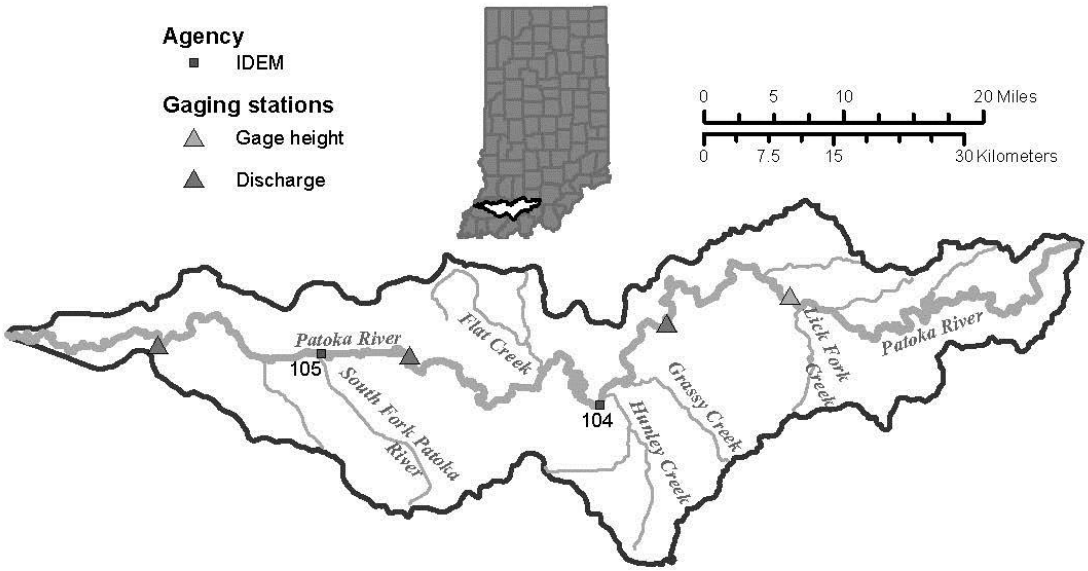

Figure 10. Map of the sites in the Patoka River Basin.

9) **Kankakee River -** There are a total of 11 sites sampled in this Major River Basin: seven by IDEM, three by the USGS, and one by Notre Dame (fig. 11). The Kankakee River flows into Illinois and the IDEM site, UMK110-0002, is located at the USGS stream gage Kankakee River at Shelby (05518000). The Yellow River and Iroquois Rivers are the important tributaries in the Major River Basin. The USGS has super gages (continuous multi-parameter sensors) at three sites, Kankakee River at Davis and three sediment gages in the Yellow River. The USGS has Nutrient Super gages at three Kankakee River sites, at Davis (05515500), at Dunn's Bridge (05517500), and at Shelby (05518000). Additionally, there are three sediment Super gages on the Yellow River.

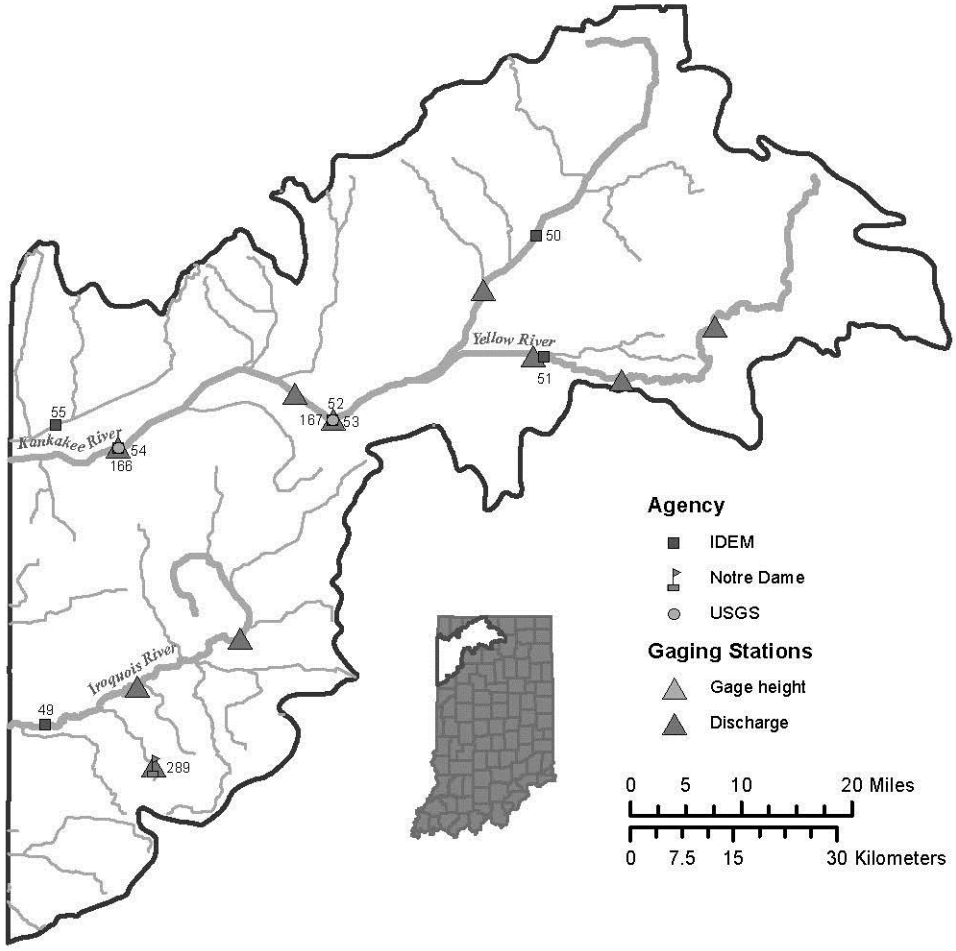

Figure 11. Map of the sites in the Kankakee River Basin.

10) **Whitewater River Basin -** There are a total of five sites sampled by IDEM in this Major River Basin (fig. 12). Near the Indiana-Ohio state line, the Whitewater River flows south into the Great Miami River, which flows into the Ohio River. There is one co-located sampling site with a USGS gage, the East Whitewater River at Abington (03275600). The Nolands Fork and Greens Fork and Whitewater and East Fork Whitewater Rivers are the main tributaries in this Major River Basin.

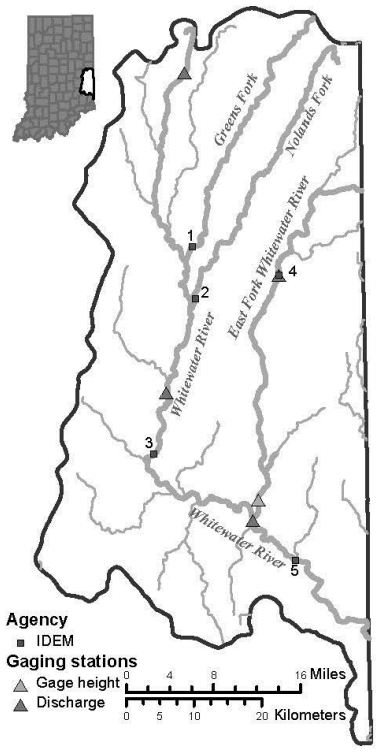

Figure 12. Map of the sites in the Whitewater River Basin.

Continuously monitored sites

All the networks within the State of Indiana are sampled at fixed frequency, typically monthly to bimonthly, to estimate the chemical conditions in the streams. Although statistically significant trends and a reasonable assessment of water chemistry can be determined with these sampling frequencies, the conditions between the times of discrete samples cannot be determined. Multi-parameter sensors allow for the continuous monitoring (interval frequency is changeable) of important chemical variables such as pH, dissolved oxygen (DO), specific conductance (SC), temperature, and turbidity, which can detail conditions within the stream. Additionally, some of these parameters can be used as surrogates for other important water quality variables. Continuous turbidity in conjunction with discrete phosphorus or suspended sediment sampling can be used to model continuous total phosphorus or suspended sediment concentrations. Continuous nitrate and orthophosphate sensors directly monitor peak concentrations of during runoff events.

Within Indiana, 25 sites are currently monitored continuously (Appendix 2 and fig. 13). The USGS monitors 12 sites, which include seven nitrate, three orthophosphate, and three sediment continuous sites. The Citizens Energy Group in Indianapolis and Purdue University monitors eight and three sites, respectively, for water quality parameters (pH, specific conductance, temperature, and dissolved oxygen). Since 2009, ORSANCO has continuously monitored DO and temperature at two sites. Additionally, at the J.T. Meyers site DO, SC, turbidity, and sestonic chlorophyll are collected.

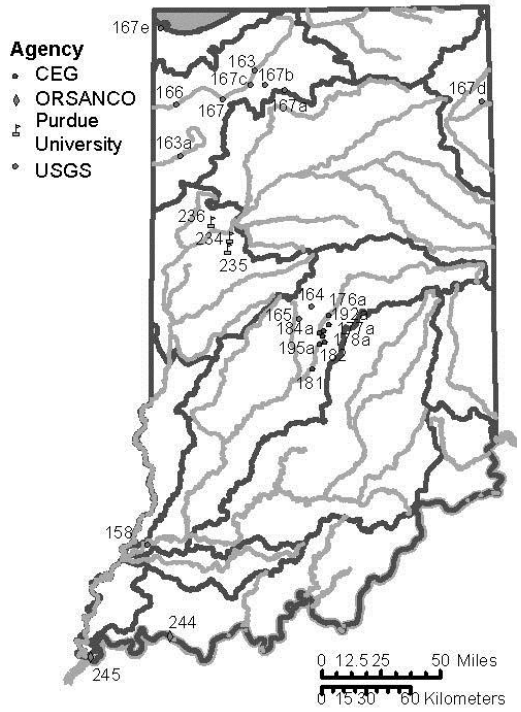

Figure 13. Map of sites currently being continuously monitored within Indiana.

Sites Capable to Determine Loads

To understand the mass of chemicals transported downstream, both concentration of the chemical and the amount of water in the stream, or discharge, need to be monitored. Concentrations of chemicals alone in streams can be misleading because if there are high concentrations of a chemical such as nitrate in a stream, yet very little water in the stream, the mass or "loads" of nitrate is very low. Therefore, it is important to have key sampling sites co-located with a streamflow gage or close enough so that loads can be determined. The best estimates of annual loads of chemicals occur when the sampling site is located at or close in proximity to the stream gage. In previous studies, a difference between drainage areas of the sampling site and the streamgage of 10 percent was considered close enough to determine loads. Within Indiana there are a total of 153 sites that are within 10 percent difference in drainage areas between the sampling site and the location of the streamflow gage (fig. 14 and appendix 3). For this paper, a total of 71 sites are between 0 and 1 percent difference, which is considered co-located and provides the best estimates for loads. There are 62 sampling sites with between 1-10 percent difference in drainage area ratios that provide good estimates of load. Any sites that have a greater than 10 percent difference in the drainage area ratio are less accurate but could probably be used for coarse estimates of loads. There are nine sampling sites between 10-15 percent and eight sampling sites between 15-20 percent differences in drainage ratios. There are three sampling sites that were slightly above 20 percent.

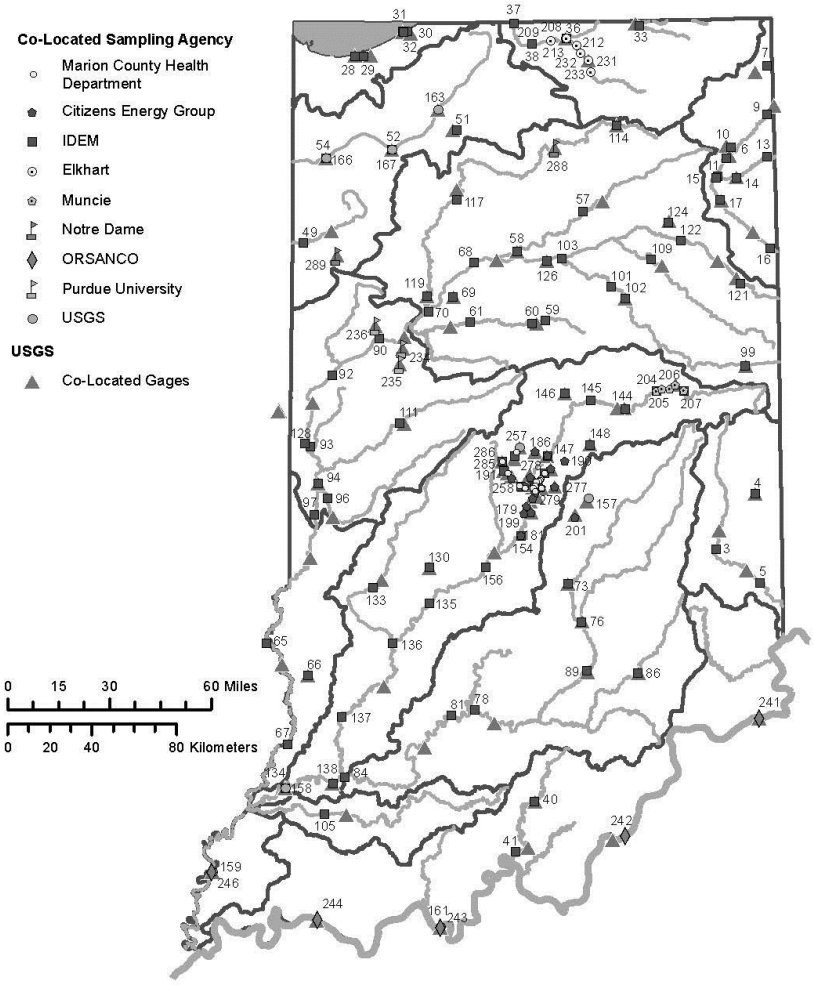

Figure 14. Location of sampling 153 sites co-located or close enough to USGS stream gages to calculate loads.

Land use

Land use within a watershed greatly affects the water quality within the streams. To understand water quality conditions within a stream, an understanding of the environmental setting and inputs within the watershed is needed. Land use and the degree to which hydro-modification[i] has occurred are the most important determinants of water quality. Increased forested lands within a watershed typically indicate better water quality conditions due to lack of disturbance. Urban areas tend to have the most impacted streams because of the many stressors associated with them. Agricultural lands have the widest range of water quality conditions—from very good to heavily impacted—depending upon the type of agriculture and the practices used within the watershed. Understanding land use and hydrology within our network watersheds is critical for both the research as well as management options to improve water quality.

Reference

None of the existing sampling sites in any of the networks qualify for "reference" or "least impacted." Many of the agencies collecting water quality data in their networks are tasked to compare water quality across sites. Which sites are most degraded and need environmental management? Are there high quality sites within Indiana? CWA Section 305(b) requires states to make water quality assessments and provide an Integrated

Report of water quality to the U.S. EPA, in even numbered years along with the CWA Section 303(d) List of Impaired Waters that includes waters that do not meet applicable state water quality standards or designated beneficial uses. Once this listing and ranking of impaired waters is completed, states are required to develop Total Maximum Daily Loads (TMDLs) for them according to the state's priority framework in order to achieve compliance with the water quality standards. To understand the biological condition of a stream or lake it is necessary to have a gradient of conditions from unimpacted—or "reference"—to heavily impacted conditions. The biological community composition changes along this gradient and can show the water quality conditions of the stream. As streams degrade through channelization, sedimentation, dredging, eutrophication, and invasive species among other stressors, the biological community changes through loss of sensitive species to the increase in species that can survive or out-compete other species due to the physical changes (low dissolved oxygen, increased algal biomass, increased sedimentation). Identifying "reference" or "least impacted" watersheds is important to be able to contrast other sampling sites within the state. Having a reference site or sites within the state included in the monitoring networks would benefit all monitoring entities.

There are parts of five ecoregions in Indiana including the Interior Plateau, Eastern Corn Belt and Plains, S. Michigan/N. Indiana Drift Plains, Huron/Erie Lake Plains, and Interior River Lowland. Because the level of agricultural or urban development varies across these ecoregions, the ability to find unimpacted sites is difficult and often the term "reference site" must be changed to "least impacted" to show the best available conditions in an ecoregion.

Recently, IDEM developed a *Sampling and Analysis Work Plan for Reference Site Monitoring Project*. The objective of this project is to identify and sample reference (least impacted) sites throughout Indiana to provide biological assemblage information with chemical and physical parameters that will be used to refine or validate the index of biotic integrity (IBI) metrics and biological criteria thresholds every ten years. The primary filter used in selecting reference sites is land use criteria such as percent of agricultural or urban areas, impervious surface area, human population density and distribution, road density and crossings, proportion of active mining activities, proportion of protected lands, and proximity to permitted facilities, confined feeding operations, and Superfund sites. In altered watersheds, chemical and in-stream physical habitat data may be used as a secondary filter to select reference sites and develop biological expectations for "least disturbed condition" (best available condition given widespread disturbance) rather than "minimally disturbed condition" (nearly absent human disturbance) or "historical condition" (prior to major industrialization, urbanization, and intense agricultural practices) (Stoddard et. al. 2006).
IDEM Office of Water Quality worked with the U.S. EPA and a contractor, Tetra Tech, in March 2015 to develop a framework and criteria for reference site selection. IDEM provided Tetra Tech with a list of 1,458 sites that were previously sampled for fish and/or macroinvertebrates between 2003 and 2013 for possible reference site selection. Using land use factors as the primary filter, Tetra Tech provided a list of 324 reference sites. IDEM narrowed down the list further by using in-stream chemical and physical data as a secondary filter. A minimum of 20 reference sites is required in each of the natural environmental gradient classifications (ecoregion, stream size, etc.) to develop linear regression models showing change in biological assemblage structure given certain explanatory variables; increasing the number of reference sites, however, reduces variability in calibrating the IBI and setting biological criteria thresholds (USEPA 2013, Tetra Tech personal communication). Based on the spatial distribution of the sites and available resources, IDEM is conducting site reconnaissance and sampling of reference sites with the goal of at least 20 reference sites

each year over the next ten years to refine biological indices, water quality criteria, and possibly develop other assessment indicators and thresholds. Sampling for this project began in April 2015.

Site #	AIMS Site Name	Stream Name and Location	County	Latitude (Decimal Degree)	Longitude (Decimal Degree)	Stream Order	Drainage Area (square miles)
1	WWE-04-0003	Big Walnut Creek @ 480 East	Putnam	39.72373	-86.76766	3	154.7
2	WSU010-0010	Spring Creek @ Lane on North side of SR 47 East of US 52	Boone	40.13118	-86.54585	2	12.2
3	WLV200-0002	Tributary of Norton Creek @ CR 1150 S Behind House at Big Rock	Vermillion	39.71557	-87.43329	1	1.1
4	WLV160-0038	Cornstalk Creek @ CR 1150 S	Montgomery	39.87289	-86.86082	1	20.5
5	WLV160-0020	Big Raccoon Creek @ At CR 775	Montgomery	39.94097	-86.75701	2	39.5
6	WLV160-0013	Big Raccoon Creek @ Lane off SR 236, east of US 231, Raccoon	Putnam	39.85464	-86.88629	3	123.6
7	WLV110-0006	Prairie Creek @ CR 170 W	Fountain	40.03438	-87.29816	2	13.7
8	WLV080-0015	Opossum Run @ Browns Hill Rd	Warren	40.19300	-87.45969	2	15.9
9	WLV070-0013	Big Shawnee Creek @ Green Bay Rd.	Fountain	40.25499	-87.19855	2	32.5
10	WLV060-0005	Big Pine Creek @ SR 55	Warren	40.30389	-87.26306	5	327
11	WLV010-0022	Burnett Creek @ Prophet St	Tippecanoe	40.50924	-86.84541	3	51
12	WBU030-0060	North Branch Otter Creek @ Fontanet Rd	Vigo	39.56961	-87.24176	3	25.8

Table 1. List of 2016 potential reference sites for the Western Central Basin.

Characterization of land use

Indiana is a heavily agricultural state and the environmental setting for the sampling sites reflects this characterization. Overall, the median land use is 68.0 percent agriculture, 9.3 percent urban, and 7.5 percent forest (table 4). Of the 312 sampling sites, 105 sites have greater than 75 percent agriculture within the watershed and 208 sites have greater than 50 percent agriculture. Many studies use 25 percent as a cutoff of a watershed to be considered urban and there are 57 sites following this rule; furthermore, there are 30 sites above 60 percent and 20 sites above 90 percent urban land use. All, except one site with 60 percent urban land use, are smaller watersheds (less than 70.7 square kilometers). Once the percent urban is relaxed to 25 percent, larger watersheds can be found. There are 11 sites with at least 50 percent forest in the watershed and 38 sites with 25 percent forest. Some of these heavily forested watersheds could be potential reference sites. Many of these forested sites tend to be larger sites, such as the Ohio and White River watersheds.

	Drainage area	Grass/ Pasture	Row Crop	Agriculture	Urban	Forest	Wetland
	(mi2)			in percent			
Number	298	199	199	275	275	275	274
Minimum	0.14	0.0	0.0	0.0	2.7	0.1	0.0
Median	240.5	4.6	63.2	72.2	9.6	7.6	0.0
Mean	3354	6.4	55.5	62.1	20.7	12.8	1.0
Maximum	203,100	37.8	94.0	94.0	99.9	73.9	10.2

Table 2. Land use and environmental characterization of the 312 sampling sites in Indiana.

Sites with duplicate sampling

Each agency collects water quality data for different reasons based upon its water management objectives or mandates. These mandates range from regulatory, such as IDEM which has specific quality assurance and chain-of-custody requirements, to research level, such as the USGS or the universities. Each agency collects different parameters and uses different labs which often have different reporting levels for these parameters. However, sites with multiple agencies collecting data at the same location indicate a redundancy that could be addressed to allow agencies to put funds to use at other sites. Additionally, these agencies could work together to:

1) expand the frequency of sampling;
2) coordinate some replicate samples so the data could be used for their respective needs; or
3) increase the amount of quality assurance so that the data could be used by other agencies to improve the quality and quantity of available data for analysis.

There are a total of 18 sampling sites that are monitored by at least two agencies and one site where three agencies sample (table 3, appendix 4, and fig. 15). In particular, the Citizens Energy Group and Marion County Public Health Department (MCPHD) have five co-located sites; MCPHD and IDEM have four sites co-located; IDEM and USGS have three co-located sites; and ORSANCO and USGS have two co-located sites.

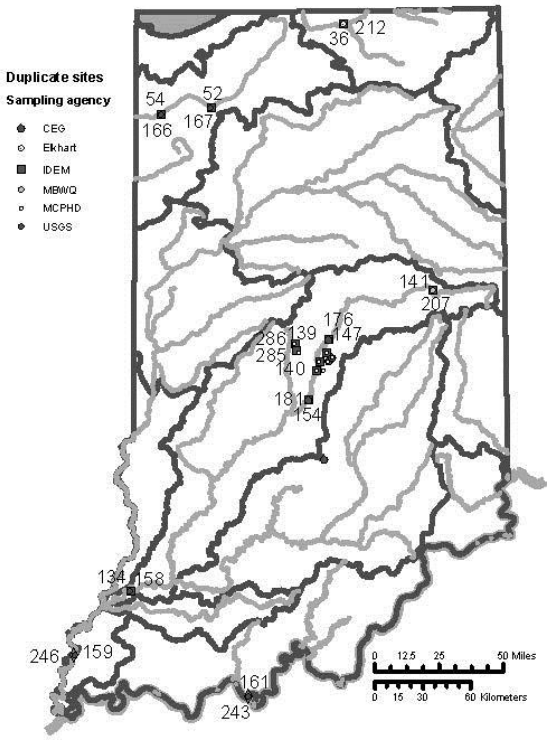

Figure 15. Map of sampling sites sampled by multiple agencies/ groups within Indiana. Marion County sites not shown because of space.

Site	Agencies (Map ID)
1) Wabash River at New Harmony, IN	ORSANCO (246), USGS-NASQAN (159)
2) Ohio River at Cannelton, KY	ORSANCO (243), USGS-NASQAN (161)
3) White River at Nora (82nd St.)	IDEM (147), CEG (176)
4) White River at Hazelton	USGS-NAWQA (158), IDEM (134)
5) White River at Waverly (SR 144)	IDEM (154), CEG (181)
6) White River at Memorial Dr.	IDEM (141), Muncie (207)
7) Eagle Creek at Raymond St.	CEG (185), MCPHD (261), IDEM (151)
8) Pogues Run at 21st St.	CEG (188), MCPHD (274)
9) Pogues Run at Rural St.	CEG (197), MCPHD (275)
10) Pogues Run at Emerson Ave.	CEG (198), MCPHD(273)
11) Bean Creek at Garfield Park	CEG (183), MCPHD (271)
12) Fall Creek at Keystone Ave.	IDEM (150), MCPHD (251)
13) Fall Creek at Stadium Dr.	IDEM(149), MCPHD (256)
14) Elkhart River SR 120 (Jackson St.)	IDEM (36), ELK (212)
15) School Branch at Maloney Road	MCPHD (286), IDEM (139)
16) School Branch at Raceway Road	MCPHD (285), IDEM (140)
17) Kankakee River at Dunn's Bridge	IDEM (52), USGS (167)
18) Kankakee River at Shelby	IDEM (54), USGS (166)

Table 3. List of sampling sites sampled by multiple agencies/groups within Indiana.

Efficacy of Best Management Practices

Indiana ranks in the top ten of states in agricultural production; however, the production of crops and animals leads to non-point source runoff of nutrients and other agricultural compounds that affect water quality. There is a renaissance of late with the development of BMPs that work in the heavily tile drained areas of Indiana to keep more of the nutrients and sediment on the land and out of streams and groundwater. A primary research focus has become the ability to track improvements in water quality associated with these various BMPs, especially on an edge-of-field (EOF) approach. These studies are of importance to many of our agencies and are critical to understanding potential solutions to improve water quality in Indiana and downstream.
There are a total of ten EOF sampling sites ongoing in Indiana from 2016 (fig. 16 and table 4). Some use a paired watershed approach to highlight differences between land use and BMPs within the watersheds like Manchester University (map IDs 5,6) and Purdue University (map IDs 1-3) sites. An effort is made to have one watershed incorporate key BMPs. Some studies monitor important transport pathways including tile drains, overland flow, and streamflow to document which pathways are important for each form of nutrient or contaminant. The amount of water that passes through each pathway is measured so that loads can be calculated. For these studies BMPs, are changed part way through the study so that changes can be documented. The two Notre Dame sites (map ID 9,10), one USGS site (map ID 8), and the multiagency site (map ID 7) are examples of this second type of study.

Map Number	Site number	Site name	Network	Latitude	Longitude	Drainage Area mi^2	Multiparameter (pH, DO, T, SC, turbidity) Y/N	Nitrate Y/N	Orthophosphate Y/N	Sediment Y/N	Autosampler Y/N	Best Management Practices
1	03335673	LITTLE WEA CREEK AT SOUTH RAUB, IN	EOF	40.30143	-86.92362	17.4	Y	N	N	N	N	
2	033356725	ELLIOTT DITCH NEAR ELSTON, IN	EOF	40.37087	-86.90945	18.0	Y	N	N	N	N	
3	033356786	LITTLE PINE CREEK NEAR MONTMORENCI, IN	EOF	40.46726	-87.05807	24.2	Y	N	N	N	N	
4	F34	Cedar Creek at CR 34	CEAP	41.40454	-85.01421	111	N	N	N	N	N	
5	MU-BC	Beargrass Creek	EOF	40.93357	-85.77831	4.0	N	N	N	N	N	
6	MU-PP	Paw Paw	EOF	40.89861	-85.75300	2.5	N	N	N	N	N	
7	03353420	SCHOOL BRANCH AT CR750N AT BROWNSBURG, IN	NWQI	39.88435	-86.35647	4.7	Y	Y	Y	Y	Y	Cover crops, N and P Priority basin
8	04183038	BLACK CREEK NEAR HARLAN, IN	GLRI	41.18329	-84.86966	12.4	Y	N	N	Y	Y	Cover crops, P Priority basin
9	03331224	Shatto Ditch at County Route 19 near Mentone, IN	EOF	41.22166	-86.04537	4.7	Y	Y	N	N	N	Cover crops, 2 stage ditch
10	05524546	Hunter Ditch at County Route 24 and 600E at Goodland, IN	EOF	40.76566	-87.27689	10.2	Y	Y	N	N	N	Cover crops, 2 stage ditch

Table 4. Site location information for the 10 Edge of Field sampling sites in Indiana.

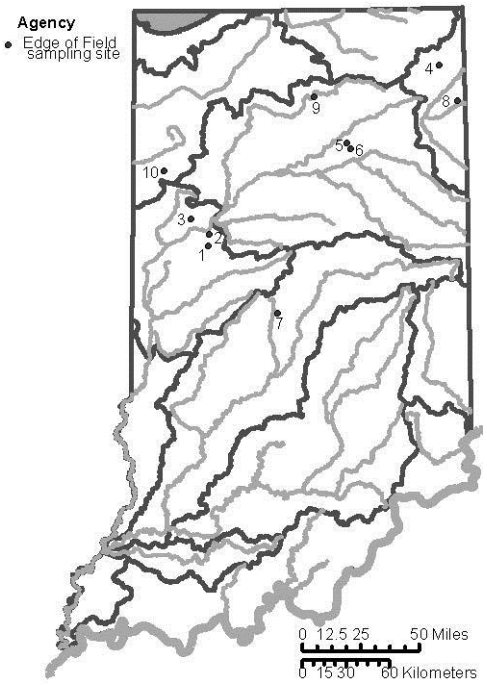

Figure 16. Site location of Edge of Field studies in Indiana

Potential sites with existing USGS stream gages

If additional sampling sites are needed within Indiana, one potential way to keep costs down is to leverage existing USGS stream gages. Some of these stream gages are only stage (water level) and another cost effective change may be to upgrade to a full discharge stream gage. This map identifies the current 232 USGS stream gages in Indiana and on the Ohio River. Specific information on each gage is located in Appendix 7. A new assessment by the InWMC is underway to analyze the optimization of the stream gages in Indiana.

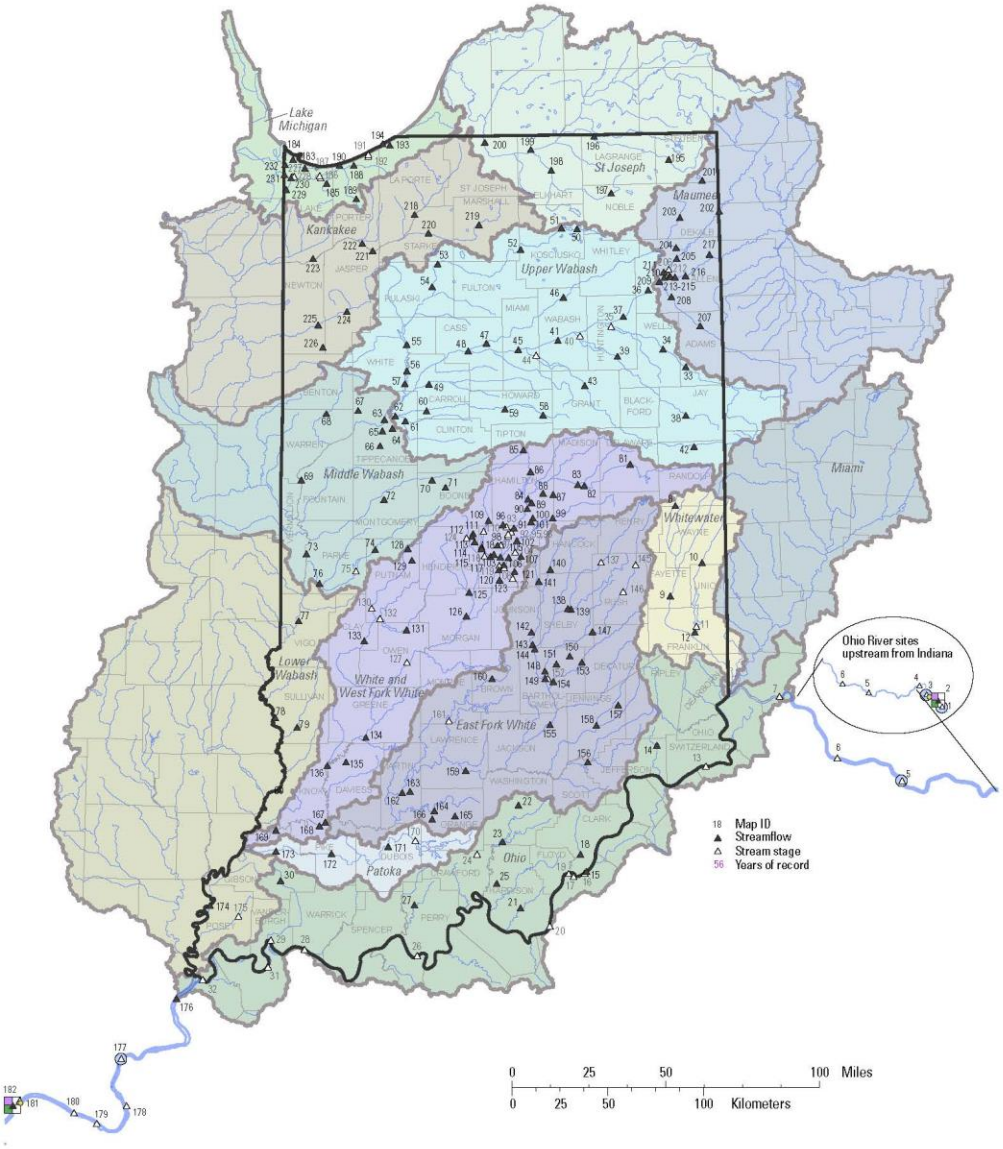

Figure 17. Location of existing USGS stream gages in Indiana.

Recommendations

1) **Ensure that all major streams/rivers entering and leaving Indiana borders have water quality monitoring done at co-located stream gages so loads and trends can be determined.** For the Ohio River this would require coordination with the States of Ohio and Kentucky so that major tributaries that drain into the Ohio River are sampled.
    a. **The Maumee River basin needs a sampling site co-located with a streamflow gage at the downstream point of the basin to determine loads leaving the basin.** The Harmful Algal Bloom issue in Lake Erie as well as sedimentation makes this a priority site. The USGS has a stream gage—Maumee River at Antwerp, OH, 0418350—approximately seven river miles from the border that could be leveraged for streamflow.
    b. **Work with other states to ensure that sampling on streams and rivers that cross borders are being sampled.** In Indiana, the Wabash, Maumee, St. Mary's, Kankakee, and Great Miami Rivers are examples where interstate collaboration would help both states.
2) **Ensure that all major streams/rivers entering and leaving Major River Basins have water quality monitoring done at co-located stream gages so loads and trends can be determined.** Currently the East Fork White River does not have a co-located stream gage and water-quality monitoring site. A potential site would be the East Fork White River at Shoals, Indiana.
3) **Stream sites that are sampled by multiple agencies/groups should work together to determine a more efficient plan that could save money, time, and improve sample quality and quantity.** Annual meetings to share data and quality assurance data would be helpful to improve the coverage and quality of data collected in Indiana. Included in this would be some side-by-side sampling with samples being sent to all agencies labs for comparison.
4) **Work with national agencies such as USGS and USEPA to increase the number of "Super Gages" in Indiana.** The focus would be on key streams and rivers such as the Maumee, White, Wabash, and Kankakee Rivers. Having continuous, real-time measurements of nutrients and sediment would help both state regulatory, as well as regional and national efforts. A Super Gage at the downstream site of Indianapolis would help delineate point and non-point driven influences.
5) **Work with national agencies such as USGS and USEPA to identify potential reference sites that could be included in national monitoring networks such as the Hydrologic Benchmark Network.** IDEM has identified potential reference sites within the Cornbelt Ecoregion and is in the process of confirming the ecological integrity of these sites.
6) **Identify reference or "least impacted" sites for the different ecoregions within Indiana.** Incorporate several sites as part of the Fixed Sampling Network within Indiana. Include yearly ecological sampling at these reference sites as well.
7) **Publish summaries of all state data annually or regularly.** A review and release of all water quality data would identify potential water quality issues.
8) **Accumulate the reporting levels for important parameters from all the sampling agencies.** Once reporting levels are known for each agency and group, a consistent minimum reporting level could be determined.
9) **Continue to update this paper and list of sampling sites periodically and showcase it on the Indiana Water Monitoring Council website.** Recent discussions within the Maumee River watershed have identified sampling done by the City of Fort Wayne and the Tri-state Initiative that could be added to the list in the future. There likely is other sampling being done that has not been identified.