Lower Wabash River Nutrients and Continuous Monitoring Project

April, 2015

Ohio River Valley Water Sanitation Commission
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Cincinnati, Ohio 45230
www.orsanco.org

Executive Summary

Encompassing a drainage area of approximately 33,000 square miles, the Wabash River is the second largest tributary to the Ohio River and the largest drainage in Indiana. The Wabash River flows into the Ohio near the upstream end of Smithland pool at Ohio River mile 848.0, at the border of Indiana and Illinois.

The Ohio River is a major source of nutrients contributing to the hypoxic zone in the Gulf of Mexico. Previous studies have shown that the Wabash River is the largest contributor of nutrients to the Ohio River. Also, the Ohio River has failed to meet the water quality standard for dissolved oxygen (DO) downstream of the Wabash River. The goals of the lower Wabash continuous monitoring project were:

1. To estimate the total annual load of total nitrogen and total phosphorous exiting the Wabash River.
2. To determine the Wabash River's contribution and causes of low dissolved oxygen levels in the Ohio River Smithland pool.

To accomplish these goals, a monitoring station was placed on the Wabash River at New Harmony, Indiana and operated continuously since August of 2010. In January of 2012, the project was extended until 2015. This report focuses on the 3 year extension of the project. A datasonde was used to measure DO, temperature, pH, conductivity, turbidity, and chlorophyll-*a* every 30 minutes. Every two weeks, water samples were collected and analyzed for nitrate/nitrite, Total Kjeldahl Nitrogen, ammonia, total phosphorus, biochemical oxygen demand (BOD), and total suspended solids. Monitoring stations were also placed on the Ohio River, both upstream and downstream of the Wabash River confluence. Sampling devices at these locations were operated from July through October, the critical period for dissolved oxygen. The same basic water quality parameters and sampling methods performed on the Wabash were also applied to the two Ohio River stations.

From January 2012 through December 2014 the Wabash River contributed 683,112 metric tons of nitrogen and 62,597 metric tons of phosphorus to the Ohio River.

During the 3 year study period the Smithland pool had a total of 17 days in which the DO standard was violated.

The Wabash River had a much higher BOD load than the Ohio River. This was identified as the likely cause of low dissolved oxygen problems in the Smithland Pool of the Ohio River.

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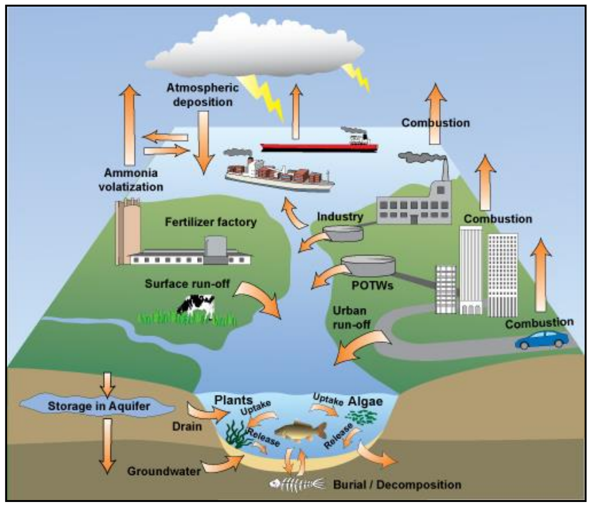
Introduction

The United States has made vast improvements to water quality since the Cuyahoga River fire sparked national interest in the issue in 1969. With that event, US Environmental Protection Agency (EPA) was formed and national legislature was passed to begin to increase the quality of some of our most precious natural resources. In 1972 the Clean Water Act, one of the first pieces of legislature passed by Congress, included a component focused on eliminating point source pollution. The National Pollution Discharge Elimination System (NPDES) requires anyone who wishes to discharge pollutants to a water body to obtain a permit; without such a permit, discharge is illegal (US EPA 2009). While these changes were critical to baseline improvements to our water resources, another type of pollution has replaced those point source discharges as a new major threat to lakes, rivers, and streams.

As development across the United States has increased, so has the amount of impervious surfaces and in turn, nonpoint source pollution. When it rains, water is unable to filtrate into the ground and runs across streets and driveways, picking up pollutants along the way. This type of pollution is much more difficult to abate and requires best management practices and watershed controls to decrease the amount of polluted runoff entering waterways. Stormwater runoff in urban regions is not the only source; pollutants including sediment and nutrients from farming areas have also proven to be detrimental to water quality (Cunjak 1996). Nutrients (nitrogen and phosphorus) have been identified as a major cause of impairment to waters of the United States (US EPA 2010). Excess nutrients can have impacts within the receiving stream and also in downstream waters as nutrients are exported from the system.



Many streams in the Mississippi River watershed are listed as impaired by excess nutrients in the system and do not reach their aquatic life use designation (Turner and Rabalais 2003). All of these streams lead to the Mississippi River and finally the Gulf of Mexico off the coasts of Louisiana and Texas. As a result of excess nutrients entering the northern Gulf of Mexico, a hypoxia zone now exists ranging from 8,000 to about 22,000 km^2 since 1985 (Hill, et al. 2011). These nutrients typically cause algal blooms, leading to large fluctuations in dissolved oxygen, falling below 2 mg O_2 per liter in the summer (Turner and Rabalais 2003) (Dodds 2006). The low dissolved oxygen levels lead to a "dead zone" which has adverse affects for aquatic life and their habitat. In 2008, the Gulf Hypoxia Action Plan identified the Ohio River as the largest contributor of both nitrogen and phosphorus to the Gulf of Mexico. A major tributary of the Ohio, the Wabash River, was identified in a 2005 ORSANCO study to be a significant source of nutrients to the Ohio, Mississippi, and Gulf of Mexico and is the focus of this report.

The Wabash River takes its headwaters in western Ohio and flows southwesterly for 474 miles before its confluence with the Ohio River. Encompassing a drainage area of approximately 33,000 square miles, the Wabash River is the second largest tributary to the Ohio River and the largest drainage in Indiana (Omernik and Gallant 1988). The basin includes portions of three states; Indiana, Illinois, and Ohio and two major tributaries, the White River and Little Wabash River. The watershed contains large segments of both the "Corn Belt" and major metropolitan areas including Indianapolis and Terre Haute. The upper basin drains the northern third of Indiana (Hrodey, Kalb and Sutton 2008). Major tributaries include the White River and the Little Wabash River which drain central Indiana and eastern Illinois, respectively (Figure 2). The population in the Wabash River watershed within the state of Indiana is approximately 3.56 million people (2000 Census Data), equating to almost 60% of the entire population of Indiana.

Nineteen high-lift locks and dams were installed on the Ohio River by the US Army Corps of Engineers for navigational purposes. These dams create a series of pools, each named for the downstream dam. The Wabash River flows into the Ohio at the upstream end of Smithland pool, located at Ohio River mile 848.0, at the border of Indiana and Illinois. The Smithland pool of the Ohio River is bounded on the upstream side by John T. Myers Locks and Dam at Ohio River Mile (ORM) 846.0 (just two miles upstream from the confluence with the Wabash River) and on the downstream end by Smithland Locks and Dam at ORM 918.5 (Figure 1).

In recent years, the Ohio River Valley Water Sanitation Commission (ORSANCO; the Commission) has noted a decrease in dissolved oxygen levels in Smithland pool. In 2008, the pool was listed as impaired in ORSANCO's Assessment of Water Quality Conditions. It is hypothesized that the Wabash River is the major contributor to this drop in oxygen levels. Additionally, the 2008 Indiana 303(d) list of impaired waters identified multiple sections of the Wabash River as impaired for nutrients. Large-scale agricultural practices present in the upper portion of the watershed have contributed to in-stream habitat loss and aquatic community degradation (Hrodey, Sutton and Frimpong 2009). ORSANCO investigated the contribution of the Wabash River to the Gulf of Mexico hypoxia zone and will continue its monitoring through 2014. The Commission used nutrient and other water quality parameters to estimate the total annual load of nitrogen and total phosphorus exiting the Wabash River. The contribution of the Wabash to low dissolved oxygen levels in Smithland pool has also been evaluated. A website has been established to provide continuous monitoring data to the public.

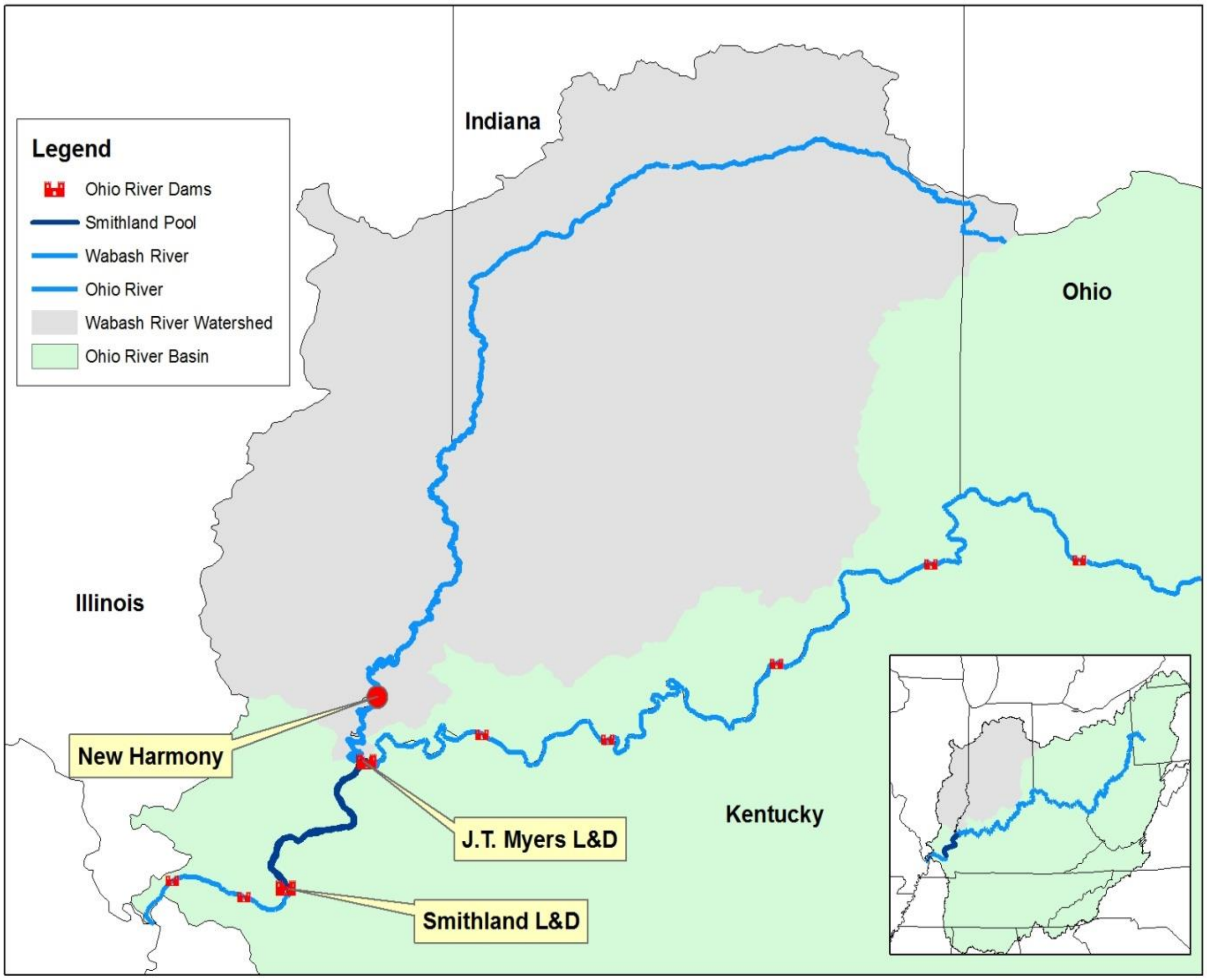


Figure 1: Project Area

Program Goals and Objectives

The overarching goal of this project is to determine the extent of the impact of the Ohio River to the Gulf of Mexico Hypoxia Zone. Objectives established by ORSANCO to achieve this goal are focused around the Wabash River, a major tributary to the Ohio and the longest free-flowing system east of the Mississippi. Reasons for this focus include the identification of the Wabash as already impaired for nutrients and observed low dissolved oxygen levels downstream of the confluence of the Wabash and Ohio Rivers. A 2005 study by ORSANCO identified the Wabash River as the single largest contributor of nitrogen and phosphorus to the Ohio River. In 2008, the Gulf Hypoxia Action Plan identified the Ohio River as the largest contributor of these same nutrients to the Gulf of Mexico.

Thus, the objectives of the project are as follows:

1. To estimate the total annual load of total nitrogen and total phosphorous exiting the Wabash River.
2. To determine the Wabash River's contribution and causes of low dissolved oxygen levels in the Ohio River Smithland pool.

In order to fulfill this mission, four tasks were identified in the approved scope of work:

Task: A
The Grantee shall collect water quality samples every two weeks from the Wabash River at the New Harmony Bridge. The Grantee shall analyze samples for nitrate/nitrite-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, biological oxygen demand, total suspended solids, chlorophyll-α, and algae species counts. The Grantee shall use the data collected to calculate a total annual load of nutrients from the Wabash River. The Grantee shall maintain a water quality datasonde at the New Harmony Bridge to measure temperature, pH, conductivity, turbidity, dissolved oxygen, and chlorophyll-α every 30 minutes. The Grantee shall conduct monitoring under the current QAPP, which is approved by IDEM.

Task: B
The Grantee shall maintain the project website, www.orsanco.org/wabash-river-project, to provide the public with project details and access to the data collected, including the calculated annual loads for total nitrogen and total phosphorus and a summary of all of the continuous monitoring data. The Grantee shall send a public notice to community news organizations throughout the project area each year informing them about the project.

Task: C

The Grantee shall submit an annual report of the project data for each of the three years of the project. The final annual report shall be submitted within two months of the final date of data collection.

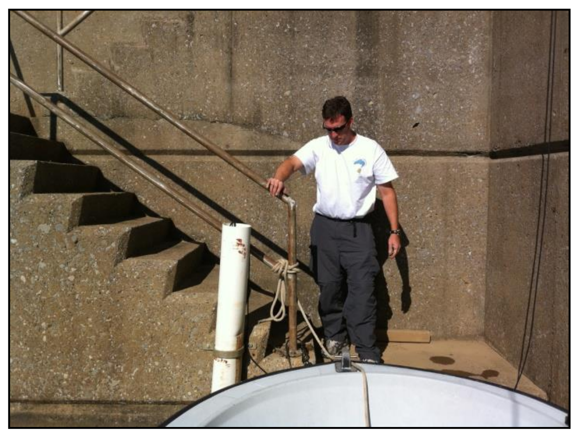
The following non-budgeted task(s) must be completed before final payment:

Task: D

The Grantee shall prepare and submit an electronic copy of a progress report to the State with each invoice, on at least a quarterly basis. A total of no less than 11 quarterly progress reports shall be prepared and submitted by the Grantee to the State. The Grantee shall prepare and submit two electronic copies of a final written summary project report to the State by the close of the project.

A datasonde was installed on the Wabash River on August 4, 2010 and continued to collect data until January 22, 2015. There were several periods when the datasonde did not operate. In April 2011 the system was damaged by lightning and in August 2014 the system was vandalized. However, more than four years of data were collected by the datasonde. Water samples were collected biweekly beginning in July of 2010. Due to river conditions it was not always possible to collect samples every two weeks. A total of 106 samples were collected during the two projects with 72 occurring during this final project. This report will focus on samples collected from 2012 through 2014.

Installation of the continuous monitor at New Harmony



Monitor on JT Myers Locks & Dam

Ohio River sampling stations are located at JT Myers Locks and Dam, and at Smithland Locks and Dam. Datasondes were placed on the lock walls of both dams from July to October during each year of the project (2012, 2013, 2014). Similar to methods used at the Wabash River, these datasondes collected data every 30 minutes and water quality samples were collected bi-weekly when datasondes were calibrated. In addition, samples were collected as part of ORSANCO's Bi-Monthly Sampling Program in the months of January, March, May, July, September, and November of each year. This provided a total of 40 samples from JT Myers and 39 from Smithland.

Land Use

The land use in the Wabash River watershed is dominated by agriculture, making up about 62% of the basin (Bukaveckas, et al. 2005) (Figure 2). In the southern portion of the watershed, 15% of the land cover is forest and urban land uses account for 13% of the total (Karns, Pyron and Simon 2006). The area surrounding the sampling station is primarily agricultural. Adjacent to the sampling station is the town of New Harmony, Indiana with a population of 916 (2000 Census Data). The town is served by a wastewater treatment plant which discharges to the Wabash River approximately 100 meters downstream of the sampling station. Harmonie State Park is also located downstream of the sampling site.

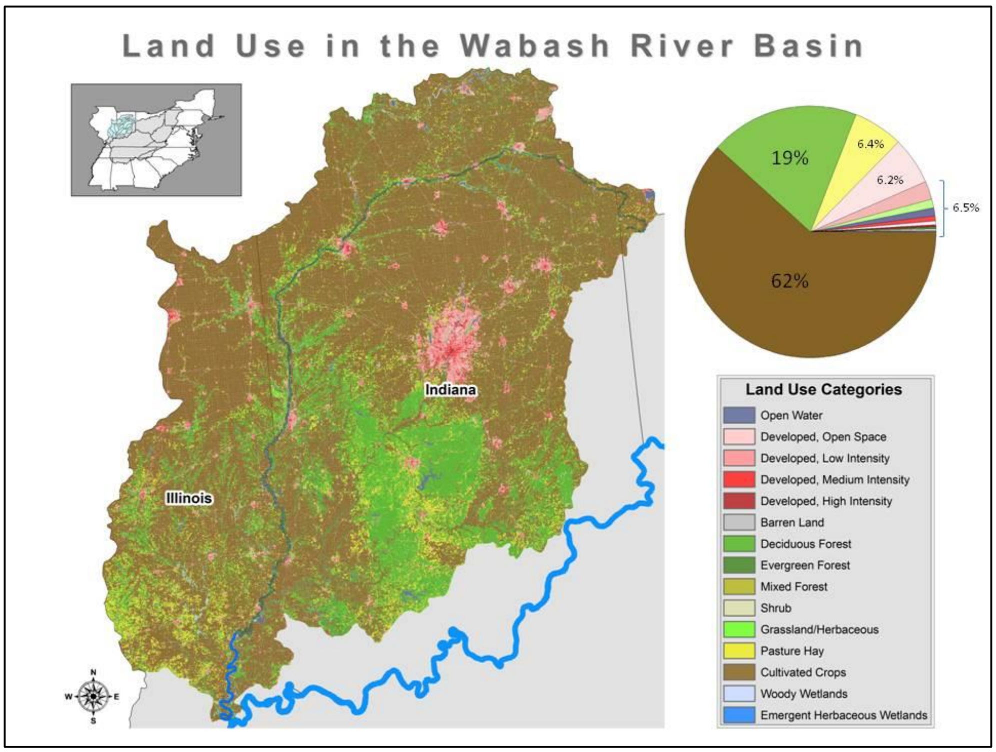


Figure 2: Wabash River Land Use (USGS, 2006)

Precipitation Catchment Land Use

The upper Wabash River is largely comprised of ground moraine and end moraine deposited during Wisconsinan glaciation (Fenneman 1946) and includes the Tipton Till Plain and the Northern Lake and Moraine region (Wayne 1956). Rolling hills and a generally flat landscape make up the topography of the upper basin (Karns, Pyron and Simon 2006). Glaciers did not extend to the lower reaches of the watershed, where entrenchment areas and elevation are now greatest (Fenneman 1946).

Approximately 100 cm of precipitation falls annually in the Wabash basin, ranging from 92 cm in the north to 112 cm in the south (Clark 1980). Long-term average temperatures in the watershed reach 25°C in July and 0°C in January, with an average annual temperature of 14°C (Karns, Pyron and Simon 2006).

Site Selection

The study area for this project includes the Wabash River and Smithland pool of the Ohio River. The first site is located at the New Harmony Bridge on Route 66 over the Wabash River at river mile 444.7. This location represents 88% of the Wabash drainage area, approximately 29,234 square miles. The exact sampling location is at 38°07’51.91” north latitude and 87°56’31.41’ west longitude at the eastern most pier of the bridge in the Wabash River. The surrounding land use is primarily agricultural. The small town of New Harmony, IN is located to the east and Harmonie State Recreation Area is immediately to the south. ORSANCO’s Bi-Monthly monitoring station on the Wabash was moved in 2013 from approximately 10 miles downstream, to the New Harmony Bridge. Data has been collected at this station every two months since 1988 and provided a historical background to serve as a comparison dataset. USGS has a new monitoring station on the Wabash at New Harmony, IN which is now active with flows calculated from 2000 to the present. This gauge provided flow volume which was used to calculate nutrient loadings. In previous reports, flow data was taken at the Mt. Carmel, IL gauge, approximately 16 miles upstream of New Harmony, IN. The Wabash River sampling point does not include the Little Wabash River, which represents approximately 3,200 square miles of the basin and is entirely within Illinois (ILRDSS, 2011).

The second site is located at the upstream end of the lock wall at JT Myers Locks and Dam in JT Myers pool at ORM 846.0. The Smithland pool begins below this dam and flows 72 miles from ORM 846.0 to 918.0. It is bounded on the western, downstream end by Smithland Locks and Dam and on the eastern, upstream end by JT Myers Locks and Dam. The Wabash River enters at ORM 848.0, just two miles downstream of JT Myers. Two other major tributaries enter the Ohio in Smithland pool, although they are significantly smaller than the Wabash River. The Saline River enters at ORM 867.3 and has a drainage area of 1,170 square miles, while the Tradewater River enters at ORM 873.5 with a drainage area of 1,000 square miles. The coordinates of this site are 37°47’30.25” north latitude and 87°59’13.10” west longitude. This site takes into account all of the Ohio River prior to entering Smithland pool. Serving as a control, nutrient samples will be taken at this site allowing ORSANCO to capture measurements in the Ohio River approximately one mile upstream of the influence of the Wabash.

A final sampling station is located at Smithland Locks and Dam. Samples collected at this station will help determine if the Wabash River is the cause of low DO in Smithland pool. The coordinates of this site are 37°09'30" north latitude and 88°25'34" west longitude.

Water Quality Sampling

Continuous monitoring of basic water quality parameters was completed using an YSI 6600 datasonde which was placed on the Wabash River at the New Harmony Bridge. This datasonde recorded dissolved oxygen (DO), temperature, pH, conductivity, chlorophyll-α, and turbidity at 30-minute intervals. Stream water grab samples were collected every two weeks on the Wabash River at the New Harmony, IN site. These samples were collected by boat during routine calibration of the datasonde. If the stage was above 10 feet, the water sample was collected from the bridge using a bailer sampling device and the datasonde unit was not calibrated. The samples were analyzed for total phosphorus, three species of nitrogen (Ammonia-Nitrogen, Total Kjeldahl Nitrogen, Nitrate/Nitrite-Nitrogen), biochemical oxygen demand (BOD), total suspended solids (TSS), algae identification, and chlorophyll. Planktonic algae were deemed the appropriate algae type for collection in rivers the size of the Ohio and Wabash. After collection, samples were placed on ice and transported to Cardinal Laboratories of Wilder, KY where they were analyzed for nutrients. Algae and chlorophyll samples were packaged into a separate cooler and shipped to BSA Environmental Services, Inc., of Beachwood, Ohio. Table 1 lists the analytical methods and detection limits. In accordance with the approved QAPP, blanks and duplicates were collected 10% of the time. All data was published to ORSANCO's website.

Table 1: Analytical Methods and Detection Limits

Parameters	Analytical Method	Method Detection Limit
Nitrate + Nitrite	353.2	0.02 mg/L
Total Kjeldahl Nitrogen	351.2	0.037 mg/L
Total Suspended Solids	SM 2540 D	0.6 mg/L
Ammonia Nitrogen	4500-NH3 D	0.004 mg/L
Total Phosphorus	365.1	0.007 mg/L
BOD	HACH10230	2.9 mg/L
Algae Analysis	10200-F.1 & F.2	NA
Chlorophyll	10200-H	1 ug/L

Datasonde units were also placed in the Smithland and JT Myers pools of the Ohio River. These devices only remained in place during summer months when critical conditions typically occur (June-October). These units were calibrated in the field every other week at each sampling event when water grab samples were collected.

Nutrient and flow data were used to calculate total annual loads for total nitrogen and total phosphorous for the Wabash and the Ohio immediately upstream of the Wabash. Flow data was obtained from the USGS gauging station located at New Harmony, IN (United States Geological Survey n.d.). Chlorophyll, algae, BOD, and TSS water quality data were used to determine the impact of the Wabash on low DO levels in Smithland.

Nutrient Load Calculations

LOADEST, a load estimator FORTRAN program developed by USGS, was used to calculate nutrient loads entering the Ohio River from the Wabash. With this program, ORSANCO developed a regression model for the estimation of nitrogen and phosphorus load using streamflow and nutrient data collected at the New Harmony, IN site. The regression model can then be used to estimate loads over a certain time period.

Three load estimation methods are used within the LOADEST program. Maximum Likelihood Estimation (MLE) introduces a bias correction factor that is necessary in the case of uncensored data. The primary load estimation method however, is referred to as Adjusted Maximum Likelihood Estimation (AMLE). While both regression methods assume normal distribution and constant variance within model residuals, AMLE eliminates the bias correction factor that is added in MLE and results in a “nearly unbiased” estimate of instantaneous load for censored datasets (Cohn 1988). Censored datasets include values that are below the laboratory detection limit. The third LOADEST estimation method, Least Absolute Deviation (LAD), is executed when data are not normally distributed with constant variance. Both nitrogen and phosphorous loads that were calculated in this report were done so using the AMLE method.

Within the LOADEST program, the most appropriate regression model can be selected automatically by using the automated model selection option. The best regression model is determined based on two statistics, the Akaike Information Criterion (AIC) and the Schwarz Posterior Probability Criterion (SPPC) (Judge and others, 1988). The model with the lowest AIC value is chosen to estimate stream loads and SPPC values are used if necessary for comparative purposes. Model details and fit (R^2 value) are provided below. Complete model outputs are provided in Appendix A.

Wabash River Nutrient Loads

The Wabash River model was developed using data from 106 samples that were collected over the course of the project. The calibrated model outputs a daily load for each sample year. Flow data was obtained from the USGS gauge at New Harmony, IN which now includes updated discharge data to 2010. The New Harmony gauge captures 88% (29,234 sq. mi.) of the Wabash River watershed. To generate the load for the entire watershed, the calculated load was multiplied by 1.136.

The flow data showed that the greatest discharge was during spring and lowest in late summer for each year (Figure 3). Annual discharge from 2001 through 2014 ranged from 7,418,609 cfs to 18,087,657 cfs. Table 2 shows the flows for each of the project years along with the total nitrogen and total phosphorus loads. As expected, loads are highest when flows are also high, which were in the spring of each year, and lowest in the late summer months when flows are also low.

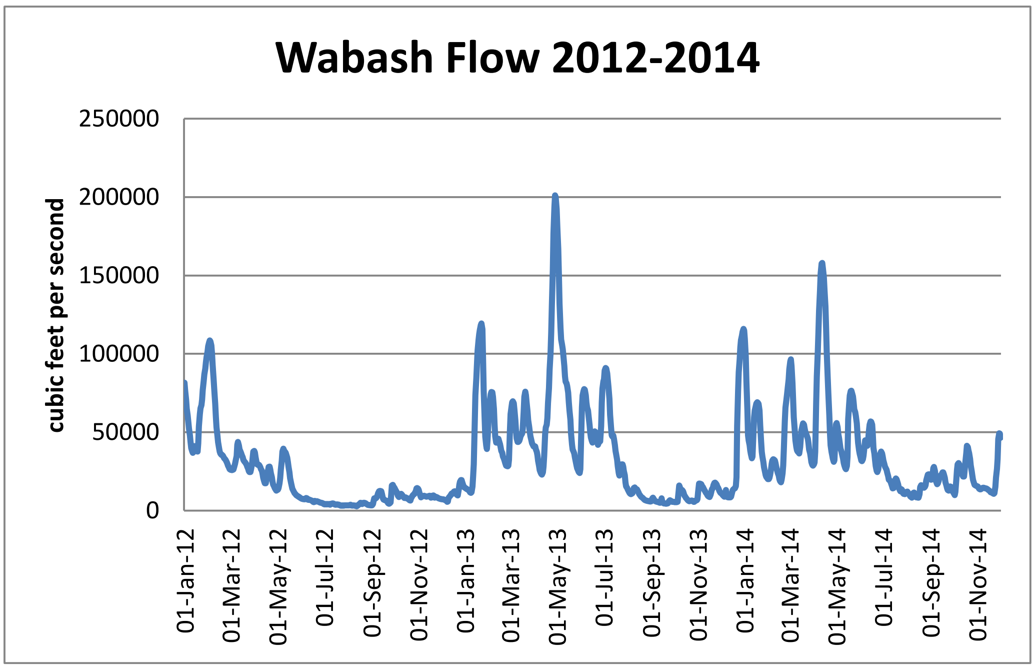


Figure 3: Mean Discharge

Table 2: Wabash River annual nutrient loads and flows

Year	TN (metric tons)	TP (metric tons)	Flow (cfs)
2012	68,377	4,811	7,418,609
2013	140,465	10,943	14,046,417
2014	131,710	9,176	13,249,938

LOADEST Model: Wabash River Nitrogen

Model #2 was selected for the load regression (PART Ia) and is used here:

Ln(Load) = a0 + a1 LnQ + a2 LnQ^2

where:
Load = constituent load (kg/day)
LnQ = Ln(Q) - center of Ln(Q)

AMLE Regression Statistics

R-Squared [%]: 92.11
Prob. Plot Corr. Coeff. (PPCC): 0.8239
Serial Correlation of Residuals: 0.2314

LOADEST Model: Wabash River Phosphorus

Model #7 was selected for the load regression and is used here:

Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime) + a5 dtime + a6 dtime^2

where:
Load = constituent load (kg/day)
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

AMLE Regression Statistics

R-Squared [%]: 91.07
Prob. Plot Corr. Coeff. (PPCC): 0.9954
Serial Correlation of Residuals: 0.0035

Ohio River (JT Myers) Nutrient Loads

The model for the Ohio River at JT Myers Locks and Dam was calibrated using information from 53 samples collected over the course of the project. It should be noted that the majority of these samples were collected during the summer months. ORSANCO's Bi-Monthly Sampling Program provided samples in January, March, May, July, September, and November from July 2010 through January 2015.

Flow data was available from the US Army Corps of Engineers Cascade model which has a node at JT Myers Locks and Dam (Figure 4). For the model year (2013) the flow was 52,933,850 cfs, while the previous 10 years ranged from 35,605,368 cfs – 87,999,200 cfs. This made the modeled year near the average since 2001 (Figure 6). The total nitrogen output was calculated at 236,941 metric tons while the total phosphorus output was 24,317 metric tons (Figures 7 and 8).

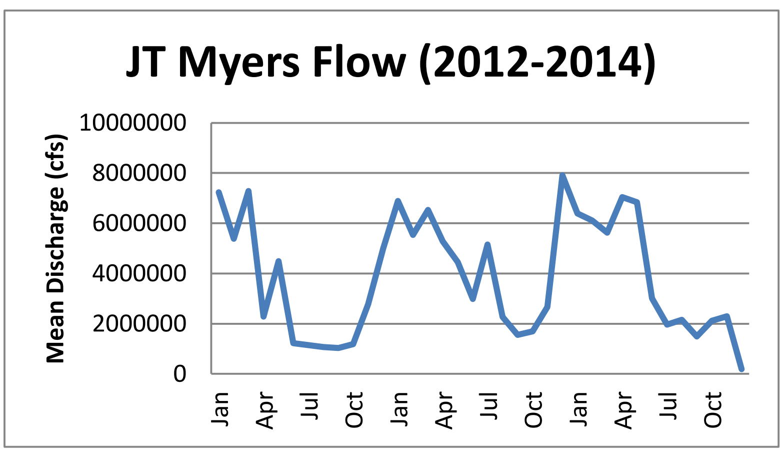


Figure 4: Mean Discharge at JT Myers

Table 2: Ohio River (JT Myers) annual nutrient loads and flows

Year	TN (metric tons)	TP (metric tons)	Flow (cfs)
2012	144,479	17,749	40,110,109
2013	236,941	24,318	52,933,850
2014	301,692	20,530	45,234,968

LOADEST Model: JT Myers Nitrogen

Model # 9 was selected for the load regression (PART Ia) and is used here:

$$Ln(Load) = a0 + a1\ LnQ + a2\ LnQ^2 + a3\ Sin(2\ \pi\ dtime) + a4\ Cos(2\ \pi\ dtime) + a5\ dtime + a6\ dtime^2$$

where:
- Load = constituent load [kg/d]
- LnQ = Ln(Q) - center of Ln(Q)
- dtime = decimal time - center of decimal time

AMLE Regression Statistics

R-Squared [%]: 98.06
Prob. Plot Corr. Coeff. (PPCC): 0.9946
Serial Correlation of Residuals: 0.0286

LOADEST Model: JT Myers Phosphorus

Model # 1 was selected for the load regression (PART Ia) and is used here:

$$Ln(Conc) = a0 + a1\ LnQ$$

where:
- Conc = constituent concentration
- LnQ = Ln(Q) - center of Ln(Q)

AMLE Regression Statistics

R-Squared [%]: 77.10
Prob. Plot Corr. Coeff. (PPCC): 0.9781
Serial Correlation of Residuals: -0.0597

Monitoring Results

Results of the sampling program are discussed individually below. Datasonde readings are provided in Appendix B. Sampling data is provided in Appendix C.

Dissolved Oxygen

In a river system, dissolved oxygen is put into the water by algae and macrophytic plants and by physical agitation of the water. Oxygen is consumed by bacteria breaking down organic matter (a measure of which is Biochemical Oxygen Demand) and by the nighttime respiration of algae. The State of Indiana water quality standard for DO outlines that the 24 hour average cannot be less than 5 mg/L, nor can there be an instantaneous reading less than 4 mg/L. There are several potential factors which can cause DO to drop below acceptable concentrations. For instance, a large input of organic material (i.e. sewage or manure) can increase the BOD which uses more oxygen than can be replenished. Another factor is that large concentrations of algae, although important for oxygen production during the day, use up so much oxygen at night that DO sags in a diurnal fluctuation, dropping below standards. A large diurnal flux (greater than 6 mg/L) has been shown to adversely affect fish communities (Heiskary and Markus 2003).

The Wabash River had 44 days during the study period in which the diurnal DO flux was greater than 6 mg/L, all of which occurred during late summer months. There were 6 days where the average DO was below the 5 mg/L water quality standard while 14 days had at least one DO measurement below the 4 mg/L instantaneous standard. Four of the fourteen days in which the 5 mg/L standard was violated were also days that the 4 mg/L standard was violated, for a total of 16 days of DO violations. The Ohio River station at JT Myers Locks and Dam had zero days with a DO flux of greater than 6 mg/L, zero days with an average DO below the 5 mg/L standard, and zero days with a measurement below the 4 mg/L instantaneous standard. The Smithland Locks and Dam station had one day with a DO flux of greater than 6 mg/L, zero days with an average DO below the 5 mg/L standard, and zero days with a measurement below the 4 mg/L instantaneous standard. A summary of these results is shown in Table 2.

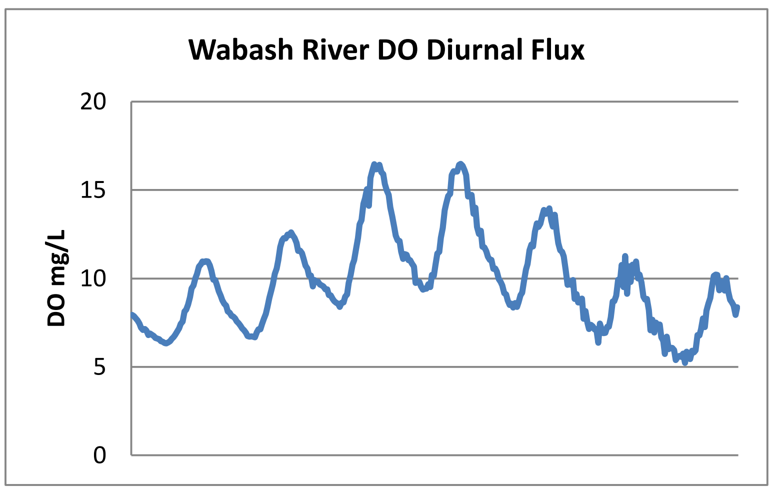


Table 3: DO Violations

Station	# days >6mg/L Flux	# days <5mg/L average	# days <4 mg/L instant
Wabash R.	81	25	66
JT Myers L&D	0	0	0
Smithland L&D	2	17	14

Algae

Algae were evaluated as an indicator of the impact of the Wabash River on the Ohio River. Specifically, the data were analyzed to determine if the Wabash River changed either the algae community or overall abundance.

A two way nested Analysis of Similarity was performed to evaluate each sampling event. For each of the 32 sampling events, the test compared the algae communities at the three sampling stations to determine their relative similarity. The test also generated a non-metric multidimensional scaling (NMDS) ordination plot to visually observe a 2-dimensional representation of the samples (Figure 5).

The results of this test indicate little variance (R=0.088) exists but there is a significant difference (p=0.004) between the three stations. However, some conclusions can be drawn from evaluating the locations in pairs; the two Ohio River stations are the most similar while the Wabash River station and the upstream Ohio River station seem to be the least related (Table 3). The relative magnitude of the pairwise p-values indicates that there is a marginal influence of the Wabash River algae on the Ohio River algae community.

The NMDS plot also shows a difference between the algae community in 2011 compared to both 2010 and 2012, which includes both the Wabash River and the Ohio River samples (Figure 9). Further statistical evaluation and a review of the laboratory show that this is not an artifact and is a true difference.

An analysis of the species was done to determine if this shift is toward or away from more pollution tolerant species. The Wilcoxon Rank-Sum test was used to evaluate the relative abundance of pollution tolerant algae by year. This test showed that there is no significant difference between the years with respect to pollution tolerance.

Table 4: Pairwise p Values

Station Pair	Similarity
JT Myers/Smithland	p=0.263
JT Myers/Wabash	p=0.004
Smithland/Wabash	p=0.150

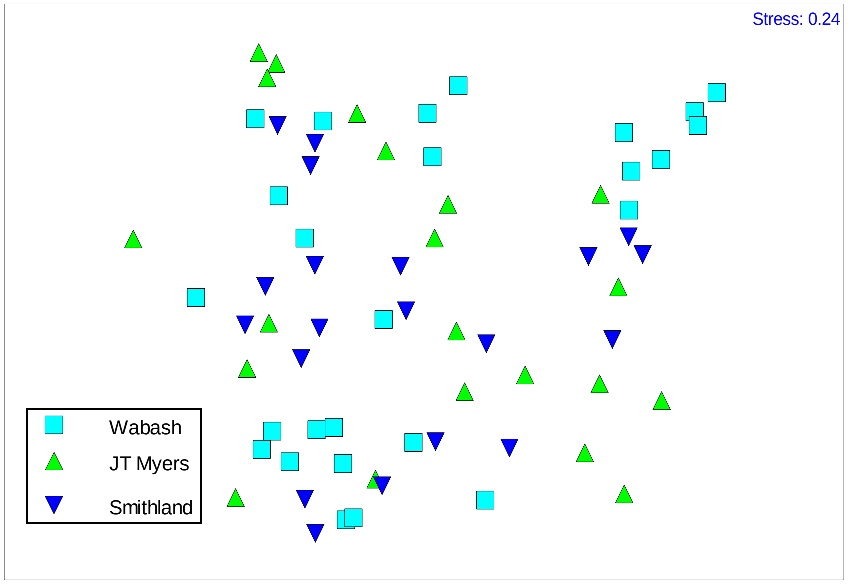


Figure 5: Algae community NMDS plot

Harmful Algae Blooms (HABs)

Algae are present in the Wabash River throughout the year. During optimal conditions some algae may rapidly proliferate causing a "bloom". During a bloom the algal concentration may go from a few thousand cells per milliliter (cells/ml) of water to hundreds of thousands or even millions of cells/ml. Algae blooms are most common in the summer although they may occur at most any time of the year.

Sampling on the Wabash River identified over 300 different species of algae. These algae are divided into 8 divisions with the most common being diatoms (Bacillariophyta), green algae (Chlorophyta) and blue-green algae (Cyanobacteria). The Cyanobacteria can produce toxins which can be harmful if ingested. For this reason an algae bloom which consists primarily of Cyanobacteria is considered a HAB.

Currently there are no drinking water or contact recreation standards for the toxins produced by algae. US EPA is expected to publish drinking water standards in spring 2015 with contact recreation standards planned for 2016-2017. Because of the lack of standards most States use the World Health Organization (WHO) Guidelines for managing recreational waters (see table 5 below)(WHO, 2003).

Table 5: WHO Guidelines for HABs

Guidance Level	**Concentration**	**How Guidance Level Derived**	**Health Risks**
Low probability of health effects	20,000 cells/ml	Human bathing epidemiological study	Short term- skin irritations, gastrointestinal illness
Moderate probability of health effects	100,000 cells/ml	Provisional drinking water guideline value for microcystin and other cyanotoxins	Potential for long term illness as well as short term health effects
High probability of health effects	Scum formation in areas where whole body contact occurs	Inference from oral animal lethal poisonings and human illness case histories	Potential for acute poisoning

During this project 70 samples were collected from the Wabash River and analyzed for algal concentration and community structure. On the Ohio River 21 samples were collected from both the JT Myers and Smithland sites. Table 6 shows the number and severity of HABs which occurred at each sampling station.

Table 6: # of HABs (2012-2014)

Station	Low Level	Moderate Level
Wabash River	12	2
JT Myers	1	0
Smithland	3	0

Chlorophyll *a*

Chlorophyll *a* is an overall measure of the concentration of algae. Chlorophyll samples were collected every two weeks in addition to nutrient samples. These samples were used to calibrate the datasonde chlorophyll *a* meters which collected readings every 30 minutes. Only the summer chlorophyll *a* measurements were used to compare the Wabash River with the Ohio River stations. This was evaluated to see if the Wabash River provided a large enough input of algae to cause blooms in the Smithland pool of the Ohio.

The mean chlorophyll *a* concentration for the Wabash River (2012-2014) was 40 µg/L, while the mean at JT Myers was 13 µg/L, and Smithland was 16 µg/L. Figure 6 compares the range of data at the three stations.

The data indicates that the Wabash River has a significantly greater abundance of algae than the Ohio River. However, there does not appear to be any long term effect on the Ohio River. Other studies have shown that algae on the Ohio are controlled by both flow and light penetration, so it is not unexpected that even relatively large inputs have no noticeable effect over the length of the Smithland pool (Sellers and Bukaveckas 2003).

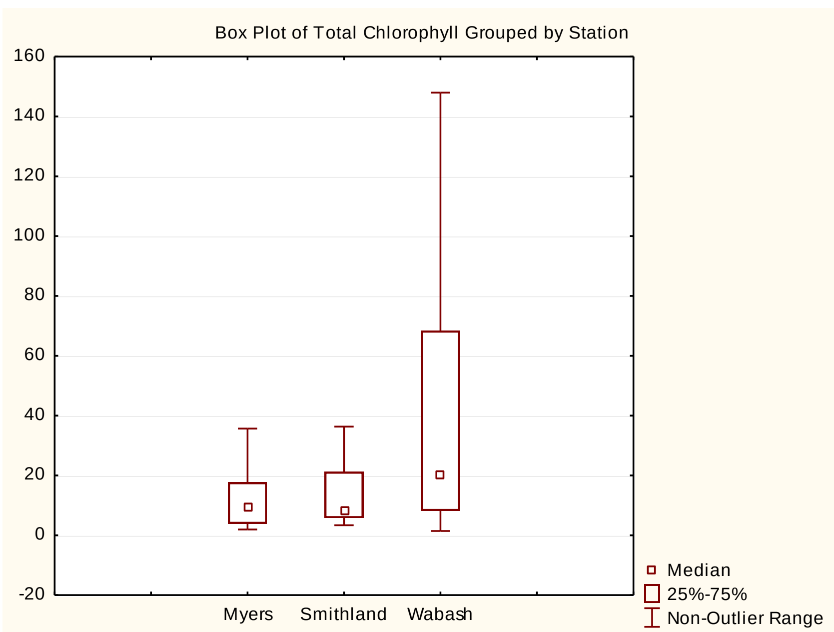


Figure 6: Comparison of Chlorophyll *a* Concentrations

Biochemical Oxygen Demand

ORSANCO uses a five-day biochemical oxygen demand (BOD_5) test to measure the amount of oxygen needed to aerobically break down organic material in the water column. Historically, BOD has been low in samples collected on the Ohio River with few samples above the detection limit (2 mg/L). This study concluded with similar results as previous surveys.

Both the JT Myers and Smithland stations had 3 detections out of 21 samples (14%). The Wabash River samples had a higher detection rate with 46 out of 70 samples above 2 mg/L (66%). Further analysis of the Wabash River samples demonstrated that the highest concentrations occurred during low flow periods while the lowest concentrations occurred during high flow periods (Figure 7). Comparing the BOD data to the chlorophyll data indicates that there is a correlation (Figure 8). After algae bloom they die off and are broken down by bacteria which consume oxygen in the process. This is the same process that causes the hypoxic zone in the Gulf of Mexico.

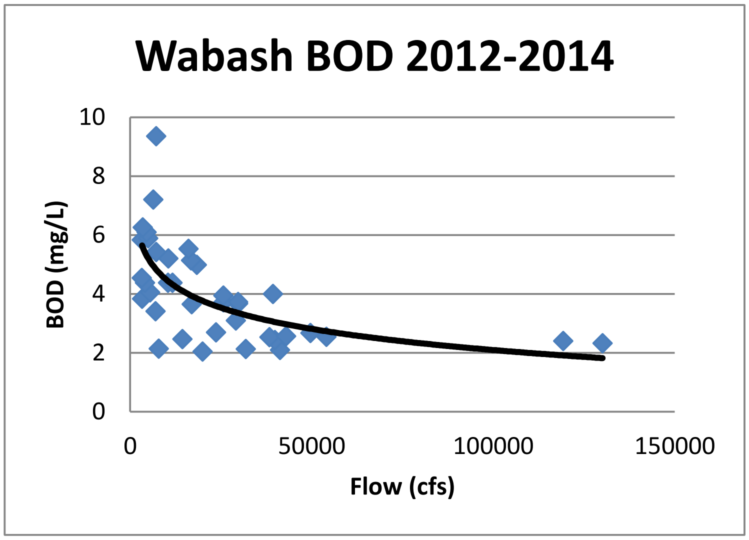


Figure 7: BOD vs. Flow

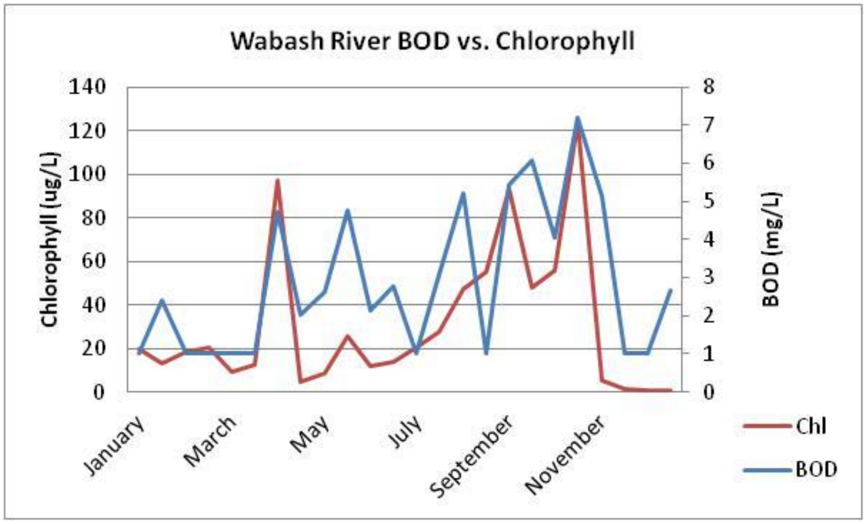


Figure 8: Comparison of Chlorophyll *a* and BOD Concentrations

Nutrients

Although US EPA is asking all states to develop numeric nutrient standards, there are currently few criteria against which to measure the results from this study. For nitrate/nitrite there is a drinking water standard of 10 mg/L; for ammonia there is a toxicity concentration for protection of aquatic life which is dependent on temperature and pH; as well as an Ohio River ammonia standard of 1 mg/L for drinking water. None of these standards were violated by the samples collected during this study. Total nitrogen was calculated by adding the TKN (organic nitrogen) and nitrate/nitrite (inorganic nitrogen) concentrations for each sample (Table 4).

Table 4: Nutrients Sampling Results

Station	Measure	Ammonia (mg/L)	TKN (mg/L)	NO3/NO2 (mg/L)	TN (mg/L)	TP (mg/L)
	Max	0.120	1.440	1.980	2.700	0.478
JT Myers	Min	<0.030	0.120	0.053	0.654	0.012
	Avg	0.067	0.522	1.003	1.533	0.104
	Max	0.230	2.920	5.400	7.070	0.793
Wabash R.	Min	<0.030	0.220	<0.050	0.735	0.056
	Avg	0.066	1.309	2.371	3.403	0.242
	Max	0.150	1.800	2.800	3.700	0.336
Smithland	Min	<0.030	0.110	0.388	0.590	0.012
	Avg	0.064	0.586	1.192	1.772	0.102

In general, the Wabash River concentrations were higher than Ohio River concentrations (see example data in Figures 9-12). However, Ohio River concentrations never dropped below a point that would limit algae growth. Thus, while the Wabash River is a source of nutrients it is unlikely that this input would cause algae blooms.

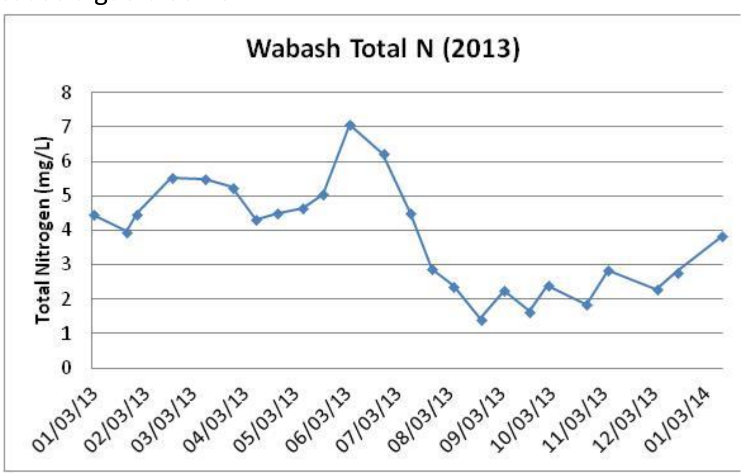


Figure 9: Wabash Total Nitrogen Concentration

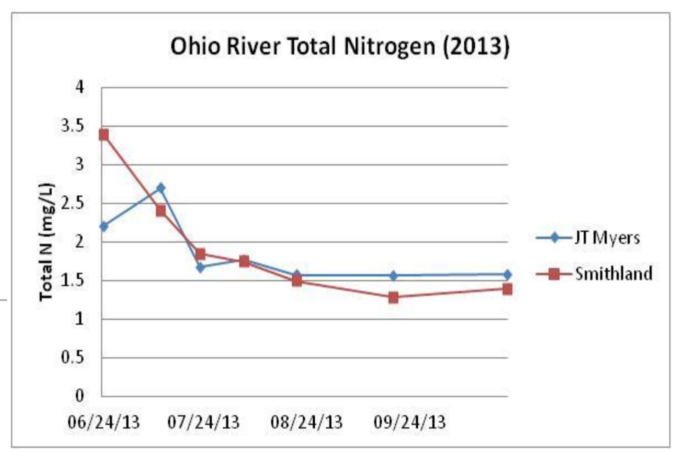


Figure 10: JT Myers, Smithland Total Nitrogen Concentration

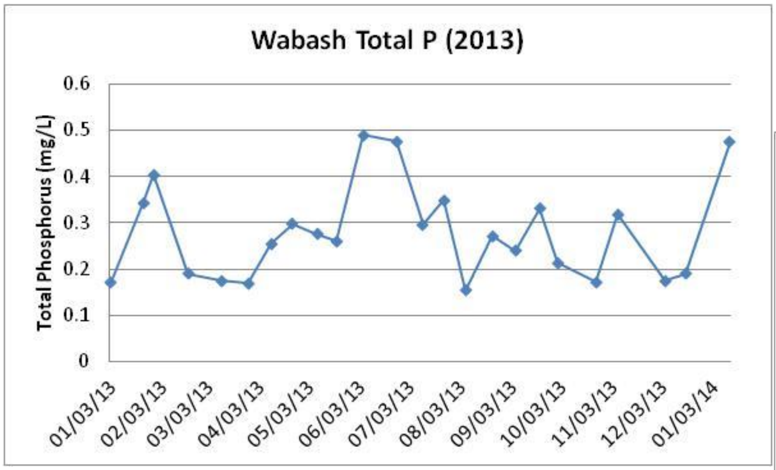


Figure 11: Wabash Total Phosphorus Concentration

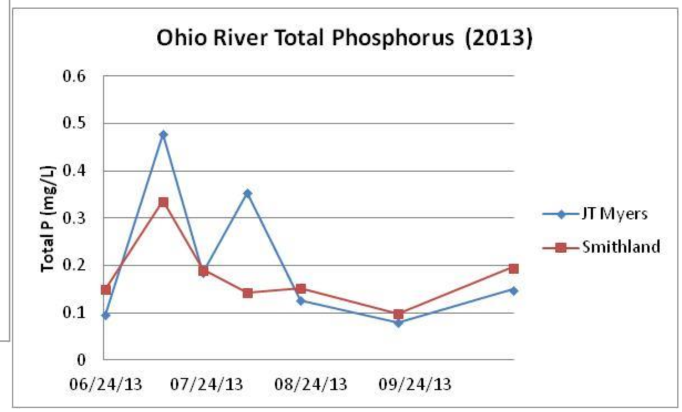


Figure 12: JT Myers, Smithland Total Phosphorus Concentration

One interesting result of the sampling was that during periods of extreme low flow conditions, generally September of each year, nitrate/nitrite dropped below the detection limit while TKN increased. In 2012 and 2014 TKN concentrations were correlated with chlorophyll, however in 2013 this was not the case (Figure 13). High chlorophyll concentrations in the late summer occurred during cyanobacteria blooms. This type of algae can fix atmospheric nitrogen into organic nitrogen, accounting for the high TKN concentrations during this period.

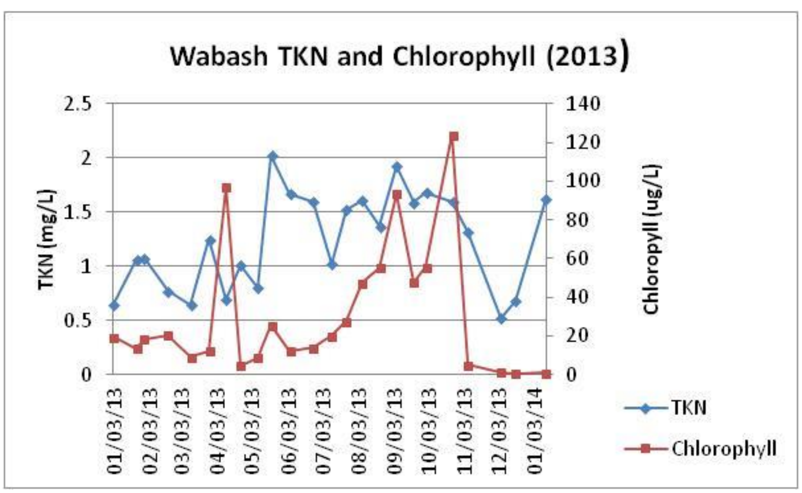


Figure 13: Comparison of Chlorophyll *a* and TKN Concentrations

Conclusions

The Wabash River continues to be a large source of both nitrogen and phosphorus to the Ohio River which is not surprising, considering its standing as the Ohio's second largest tributary. At its confluence with the Ohio, the Wabash represented for the study period:

- 23.6% of the drainage area
- 20.1% of the flow
- 33.3% of the nitrogen load (161,382 metric tons)
- 28.5% of the phosphorus load (13,344 metric tons)

One important objective of this study was to evaluate the Wabash River as a possible cause of low dissolved oxygen in the Smithland pool of the Ohio River. From 2013-2014 there were 17 days where dissolved oxygen levels in Smithland pool were below the 5 mg/L daily average standard and 14 days below the 4 mg/L instantaneous standard. All but 3 of these days coincided indicating a total of 20 days in which the Smithland pool failed to meet the DO standard.

Low DO levels in Smithland pool do not seem to be associated with a diurnal DO fluctuation, indicating that these results are not caused by an influx of algae. Based on chlorophyll *a* results, the Wabash River has much greater concentrations of algae, but this does not appear to affect the amount of algae on the Ohio River. Also, the algae community structure shows a limited effect of the Wabash River on that of the Ohio. Nutrient concentrations at the upper end of Smithland pool were never exhausted, indicating they are not a limiting factor of algae growth on the Ohio River.

The Wabash River provides a large load of BOD, but sampling results indicate very little BOD on the Ohio River. The concentration of BOD on the Wabash tends to be highest during low flow periods which is also when low DO levels are commonly observed on the Ohio River.

While organic materials are a necessary component of the stream ecosystem, an influx of these materials from wastewater treatment plants, agricultural or urban runoff, or animal feeding operations may put a considerable amount of stress on the aquatic community. When a large amount of organic material is introduced into an aquatic environment, microorganisms break down this material and in turn consume oxygen, increasing the biochemical oxygen demand (BOD). In streams, cyanobacteria have the ability to fix atmospheric inorganic nitrogen into organic nitrogen, thus increasing levels of Total Kjeldahl Nitrogen (TKN). However, in certain conditions, these algae reproduce exponentially, causing a bloom. Following this sudden increase in cyanobacteria, the algae eventually die, are consumed by bacteria, and again cause an increase in BOD.

BOD measurements in Smithland pool are collected at Smithland locks and dam, which is 70 miles downstream of the Wabash River. During low flow, the Ohio River can take greater than 10 days to cover this distance. It may be that the influx of BOD is consumed prior to arriving at the Ohio River sampling point, resulting in low DO measurements at Smithland locks and dam. This process is similar to the process that causes the hypoxic zone in the Gulf of Mexico.

Project Successes and Failures

The telemetry unit that provided real time data on the Wabash River was vandalized in August 2014. This caused the loss of 3 weeks of data as the unit overwrote previous downloaded data with corrupted data. The bridge on which the telemetry unit was mounted had been closed in 2013 due to structural deficiencies. With the bridge closed it was no longer possible to ensure the security of the unit so it was decided not to replace it. Therefore the final 6 months of the project real-time data was not available

There were two goals of this project:

1. To estimate the total annual load of total nitrogen and total phosphorous exiting the Wabash River.
2. To determine the contribution of the Wabash River to low dissolved oxygen levels in Smithland pool in the Ohio River.

Both of these goals were met by the project.

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APPENDIX A

LOADEST OUPUT

APPENDIX B

DATA FILES

APPENDIX C

Public Notices