Lower Wabash River Nutrients and Continuous Monitoring Project

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Ohio River Valley Water Sanitation Commission
5735 Kellogg Avenue
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 contribution of the Wabash River to low dissolved oxygen levels in Smithland pool in the Ohio River.

To accomplish these goals, a monitoring station was placed on the Wabash River at New Harmony, Indiana and operated continuously for 15 months. 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, and total suspended solids. On the Ohio River, monitoring stations were placed upstream and downstream of the Wabash River confluence and operated during the critical period for dissolved oxygen, July through October. The same sampling methods were also applied to the two Ohio River stations.

During the study period the Wabash River contributed 138,976 metric tons of nitrogen and 4,646 metric tons of phosphorus to the Ohio River.

The Smithland pool was below the DO water quality standard for 25 days during this study. Algae and nutrients did not appear to be the cause. Biochemical oxygen demand was identified as a possible cause with the apparent source of BOD related to point sources.

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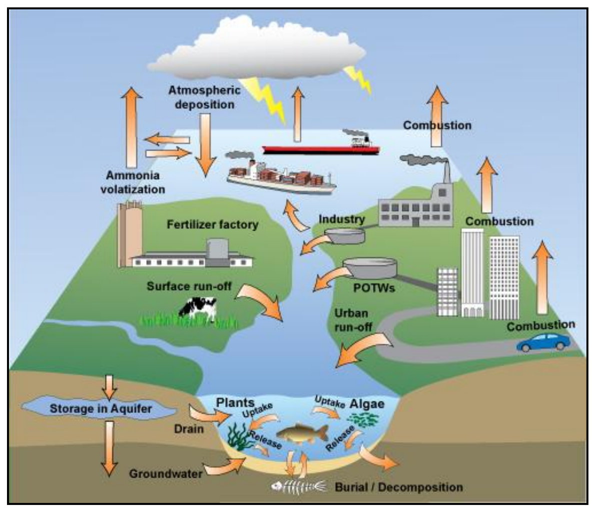
Introduction

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, the 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 our waterways. Stormwater runoff in urban regions is not the only dilemma; 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 speculated 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.

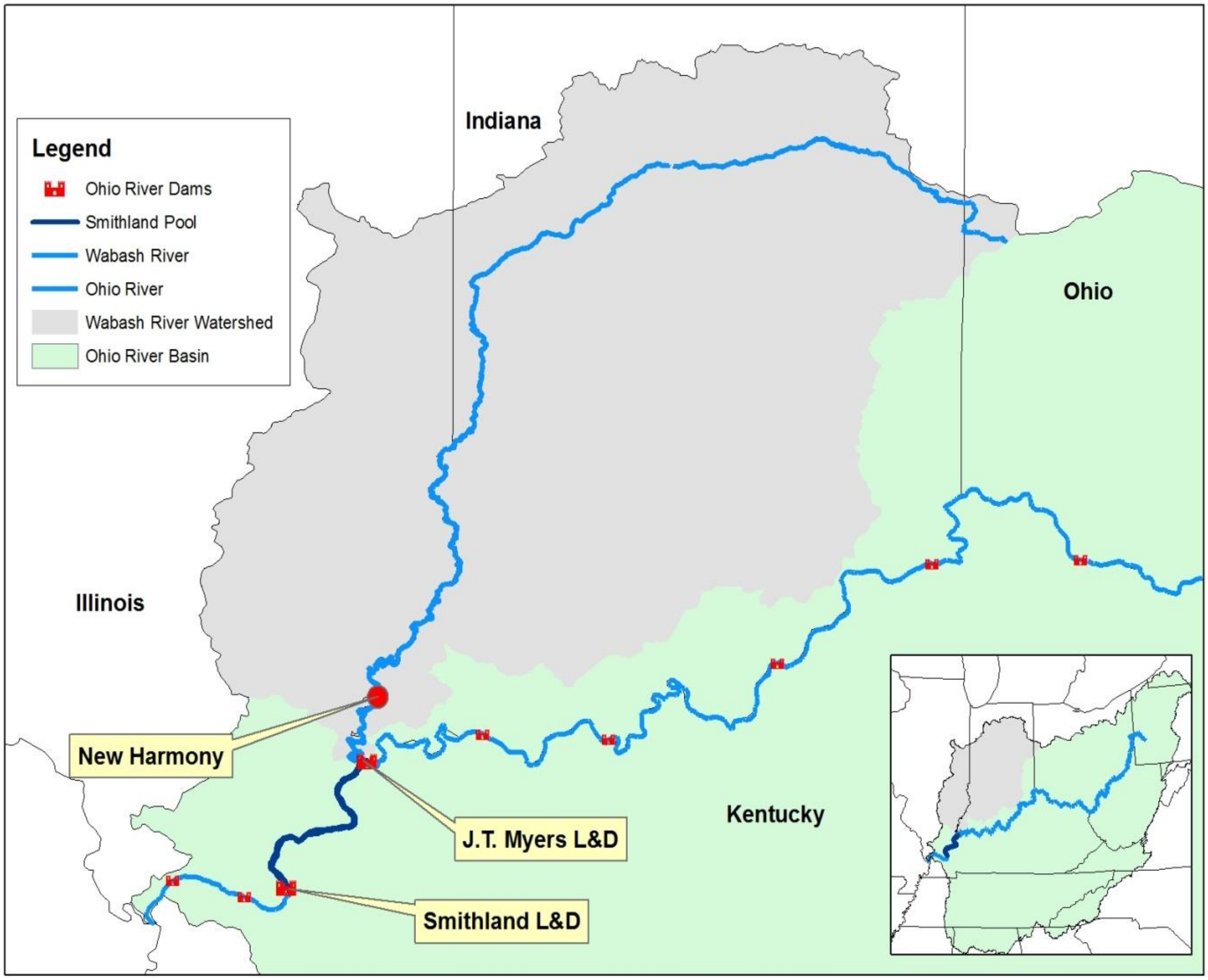


Figure 1: Project Area

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 contribution of the Wabash River to low dissolved oxygen levels in Smithland pool in the Ohio River.

In order to accomplish these goals, three tasks were identified in the approved scope of work:

Task: A

The Grantee shall install a continuous monitor on the Wabash River at the ORSANCO bimonthly monitoring station and measure dissolved oxygen, temperature, pH, conductivity, chlorophyll, depth, and turbidity. The Grantee shall collect samples every other week for one (1) year at the Wabash River Station and JT Myers Station (ORSANCO's Ohio River site immediately upstream of the Wabash River) for total nitrogen, total phosphorus, BOD, TSS, chlorophyll-a, and algae identification and counts. The Grantee shall conduct routine maintenance on the Wabash continuous monitor every other week.

The Grantee shall develop a Quality Assurance Project Plan (QAPP) for the monitoring activities and submit it to the State for approval at least one (1) month prior to initiating monitoring activities. The Grantee shall conduct all monitoring activities in accordance with the approved QAPP. Data shall be provided to the state in an EXCEL data file according to requirements provided in the QAPP.

Task: B

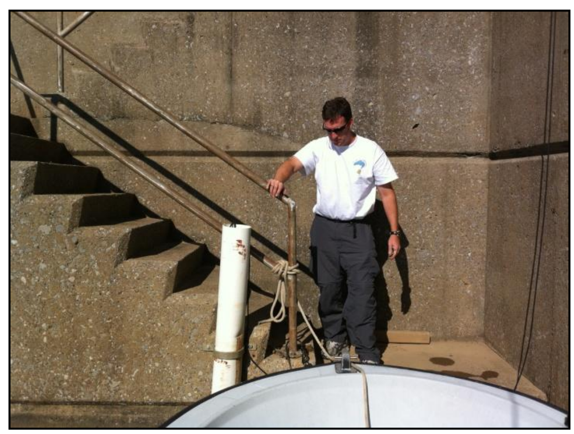
The Grantee shall develop a web site to keep the public informed about the project. The web site shall include a summary of all continuous monitoring data and annual total loads for total nitrogen and total phosphorus for the Wabash River Station. The Grantee shall issue a press release to make the public aware of the project and of the web site.

Task: C

The Grantee shall include all information used to estimate the total annual load of total nitrogen and total phosphorus exiting the Wabash River with conclusions in a final report. Additional information used to determine the impacts from the Wabash River on dissolved oxygen levels in the Ohio River Smithland pool shall also be included in the report. The Grantee shall submit two (2) electronic copies of the final report to the State.

A datasonde was installed on the Wabash River on August 4, 2010 and ran until September 30, 2011. Due to equipment failure in April/May 2011 the datasonde did not run continuously. However, more than a year of data was collected by the datasonde. Water samples were collected biweekly beginning on. Due to river conditions it was not always possible to collect samples every two weeks. A total of 28 samples were collected during this project.

Installation of the continuous monitor at New Harmony



Monitor on JT Myers Locks & Dam

In a change to the original scope, it was determined that project resources would be better allocated if data collection on the Ohio River was divided between the JT Myers and Smithland Locks and Dams. This would allow coverage of the Ohio River during the critical summer period at the expense of winter time coverage at JT Myers. Datasondes were placed on the lock walls of both dams from July 1, 2010 to November 1, 2010 and again from July 1, 2011 to September 30, 2011. 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 July, September, and November of 2010, and January, March, May, July, and September of 2011. This provided a total of 20 samples from JT Myers and 18 from Smithland.

With the submission of this final report all tasks associated with this grant will be complete.

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). 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 on the Indiana side of the river is the town of New Harmony 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.

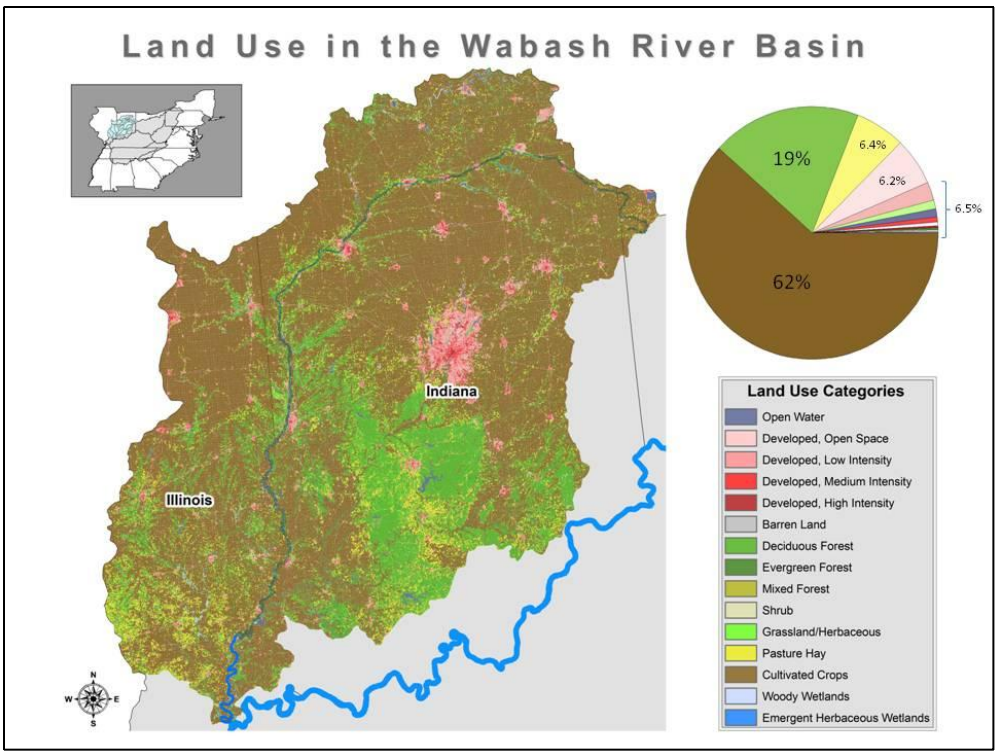


Figure 2: Wabash River Land Use (USGS, 2006)

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 Harmony State Recreation Area is immediately to the south. ORSANCO has an additional monitoring station on the Wabash approximately 10 miles downstream of the Route 66 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 monitoring station on the Wabash at Mt. Carmel, IL, approximately 16 miles upstream of New Harmony, IN. This station provided flow volume which was used to calculate nutrient loading. 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 Smithland pool at ORM 846.0. The Smithland pool 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 also be taken at this site allowing ORSANCO to capture measurements in the Ohio River approximately one mile upstream of the influence of the Wabash, just above Smithland. 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 Smithland and JT Myers pools. These devices only remained in place during the summer 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 Mt. Carmel, Illinois (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.

LOADEST Model: Wabash River Phosphorus

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

$$Ln(Conc) = a0 + a1\ LnQ + a2\ Sin(\pi\ dtime) + a3\ Cos(2\pi\ dtime) + a4\ dtime$$

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

AMLE Regression Statistics

R-Squared [%]: 87.46
Prob. Plot Corr. Coeff. (PPCC): 0.9925
Serial Correlation of Residuals: -.0660

LOADEST Model: Wabash River Nitrogen

Model # 6 was selected for the load regression (PART Ia) and is used here:

$$\text{Ln(Conc)} = a0 + a1\ \text{LnQ} + a2\ \text{LnQ}^2 + a3\ \text{Sin}(2\pi\ \text{dtime}) + a4\ \text{Cos}(2\pi\ \text{dtime})$$

where:

Conc = constituent concentration
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

AMLE Regression Statistics

R-Squared [%]: 98.04
Prob. Plot Corr. Coeff. (PPCC): 0.9915
Serial Correlation of Residuals: 0.1886

To develop the model for the Wabash River data from 30 samples collected over the course of the project were used. These samples were used to calibrate the model, but the output of the model was limited to one year (July 2010 to June 2011) in order to calculate an annual load. Flow data was obtained from the USGS gauge at Mt. Carmel, IL because the gauge at New Harmony only collects stage data, not discharge. The Mt. Carmel gauge captures 86.5% (28,635 sq. mi.) of the Wabash River watershed while the New Harmony gauge captures 88% (29,234 sq. mi.).

The flow data showed that the greatest discharge was during the spring months and lowest in late summer. Annual discharge from 2001 to 2011 ranged from 10,207,480 cfs to 17,737,490 cfs. The annual discharge for 2011 was 15,187,190 cfs, which is the second highest flow year of the previous ten years.

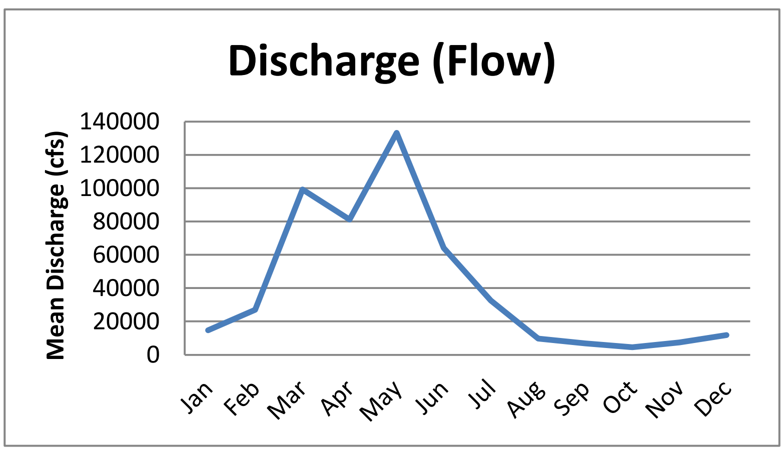


Figure 3: Mean Discharge

The calculated load was then was then multiplied by 1.156 to generate the load for the entire watershed as the available flow data only covered 86.5% of the watershed. This equates to a total nitrogen output of 138,976 metric tons and a total phosphorus output of 4,646 metric tons.

Nitrogen loads showed peaks in March and May while the highest phosphorus loads were in May. In general, both nitrogen and phosphorus loads were highest in the spring months when flows are typically highest and lowest in the late summer months when flows are lowest.

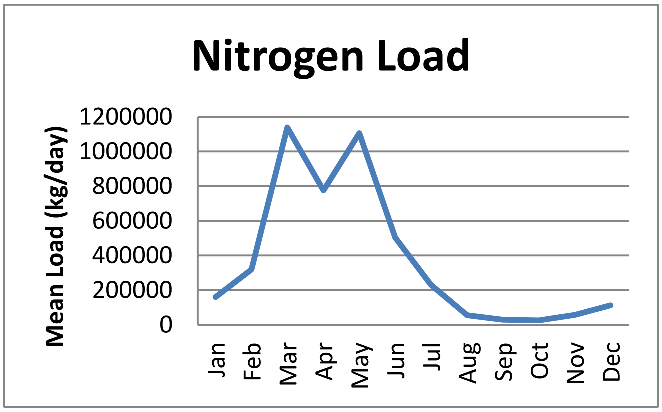


Figure 4: Monthly Nitrogen Load

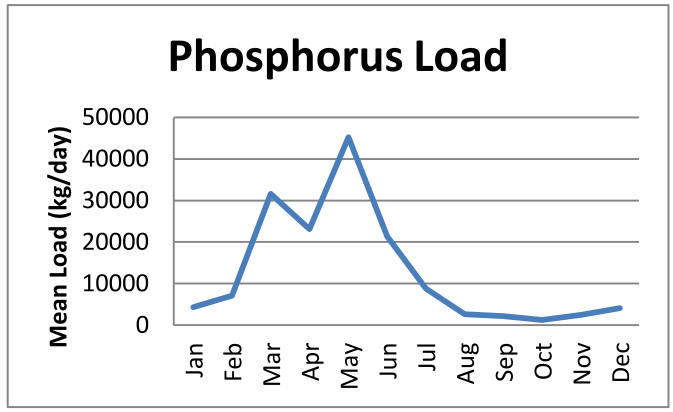


Figure 5: Monthly Phosphorus Load

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 [%]: 99.79
Prob. Plot Corr. Coeff. (PPCC): 0.9806
Serial Correlation of Residuals: -.3896

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 [%]: 87.12
Prob. Plot Corr. Coeff. (PPCC): 0.9804
Serial Correlation of Residuals: 0.1658

To develop the model for the Ohio River at JT Myers L&D we used 20 samples collected over the course of the project to calibrate the model. 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 November 2010, January 2011, March 2011, and May 2011.

Flow data was available from the US Army Corps of Engineers Cascade model which has a node at JT Myers L&D. For the model year the flow was 83,036,200 cfs, while the previous 10 years ranged from 50,373,500 cfs – 87,999,200 cfs. This made the modeled year the 3rd highest flow year in the decade.

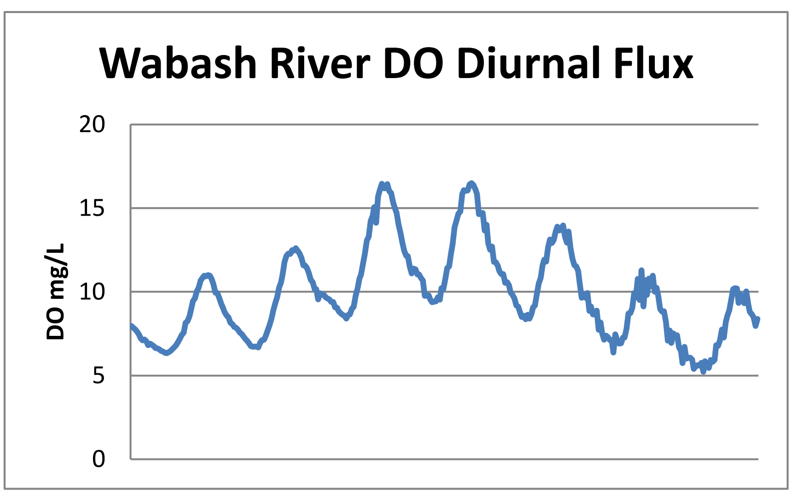
The total nitrogen output was calculated at 427,788 metric tons while the total phosphorus output was 39,377 metric tons.

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 21 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 zero days where the average DO was below the 5 mg/L water quality standard. Thirteen days had at least one DO measurement below the 4 mg/L instantaneous standard. The Ohio River station at JT Myers locks and dam had two days with a DO flux of greater than 6 mg/L, no days with an average DO below the 5 mg/L standard, and 12 days with a measurement below the 4 mg/L instantaneous standard. The Smithland locks and dam station had two days with a DO flux of greater than 6 mg/L, 25 days with an average DO below the 5 mg/L standard, and seven days with a measurement below the 4 mg/L instantaneous standard. A summary of these results is shown in Table 2.

For the Wabash River station, all of the instances of failing the water quality standard were associated with large diurnal fluxes indicating that they were caused by algae blooms. Conversely, for the Ohio River stations none of the days with measurements below the water quality standard were associated with diurnal DO fluxes indicating that these were not caused by algae blooms.

Table 2: DO Violations

Station	# days >6mg/L Flux	# days <5mg/L average	# days <4 mg/L instant
Wabash R.	21	0	13
JT Myers L&D	2	0	12
Smithland L&D	2	25	7

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 7).

The results of this test indicate little variance (R=0.034) exists and that there is no significant difference (p=0.176) 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.

Table 3: Pairwise p Values

Station Pair	Similarity
JT Myers/Smithland	p=0.875
JT Myers/Wabash	p=0.048
Smithland/Wabash	p=0.149

The NMDS plot also shows a difference between the communities from 2010 to 2011, which includes both the Wabash River and the Ohio River samples (Figure 7). 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.

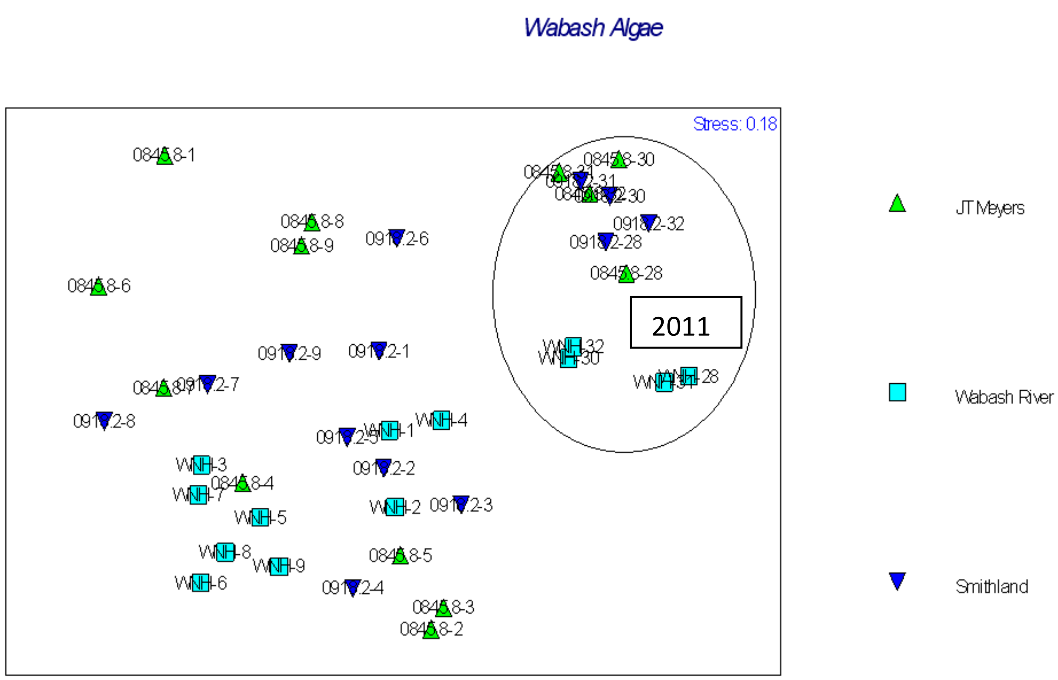


Figure 7: NMDS Plot

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 during the two summer periods was 84 µg/L while the mean at JT Myers was 23 µg/L and Smithland was 20 µg/L. Figure 8 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).

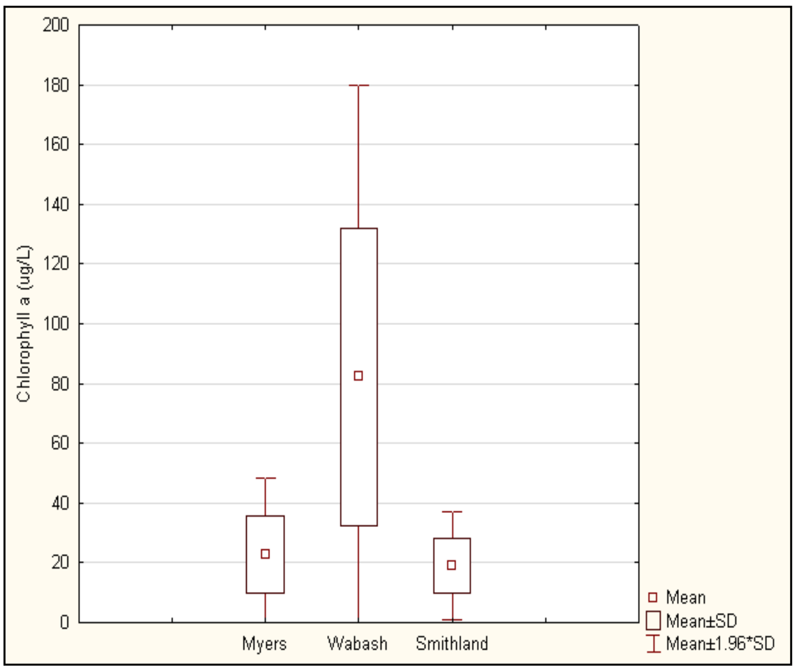


Figure 8: Comparison of Chlorophyll *a* Concentrations

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.

The JT Myers station had two detections out of 12 samples while the Smithland station had a single detection out of 12 samples (Figure 9). The Wabash River samples had a higher detection rate with 21 out of 30 samples above 2 mg/L. 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 10). This is a typical signature of a point source load into the river.

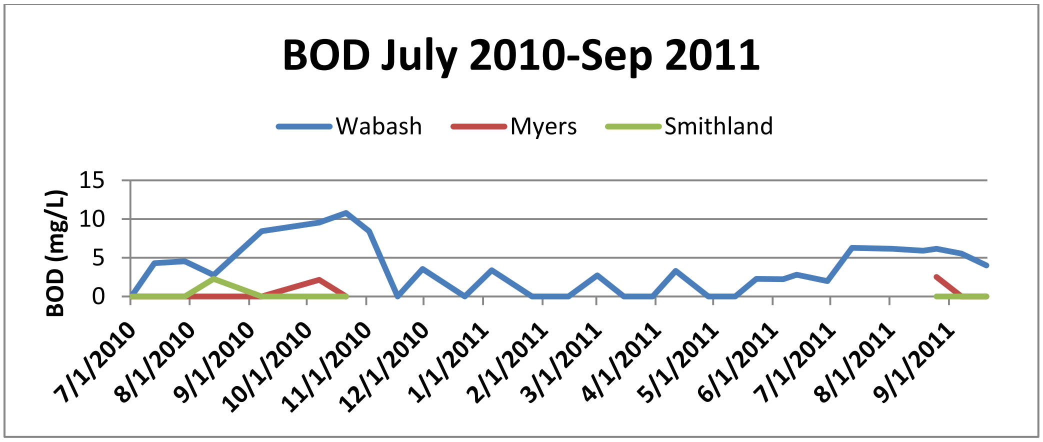


Figure 9: BOD Concentrations

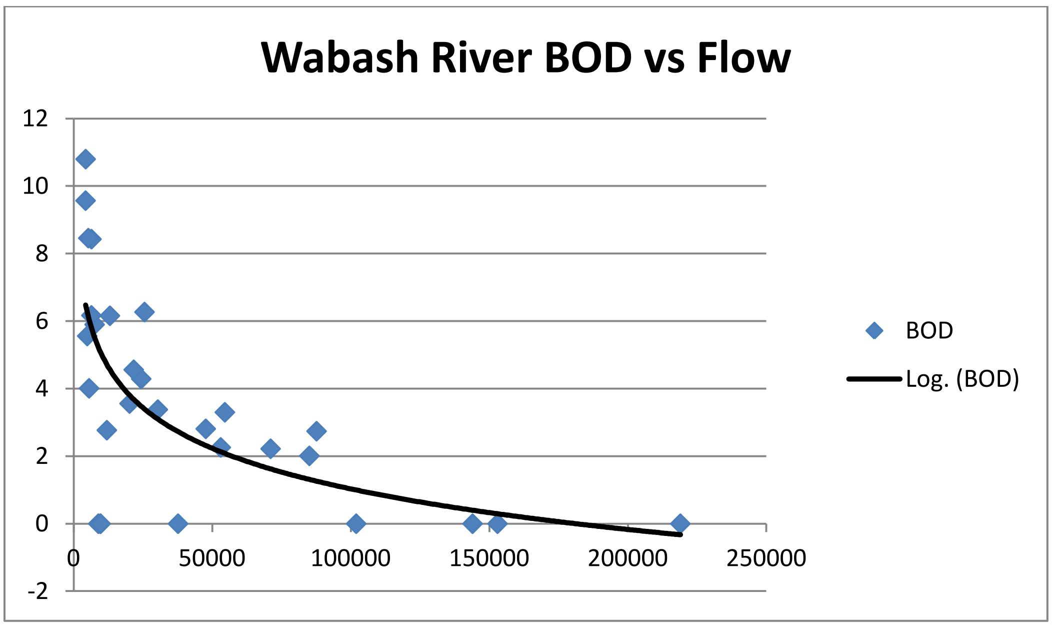


Figure 10: BOD vs. Flow

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.

A summary of the sampling results is shown in Table 4. Total nitrogen was calculated by adding the TKN (organic nitrogen) and nitrate/nitrite (inorganic nitrogen) concentrations for each sample.

Table 4: Nutrients Sampling Results

Station	Measure	Ammonia (mg/L)	TKN (mg/L)	NO3/NO2 (mg/L)	TN (mg/L)	TP (mg/L)
	Max	0.180	1.230	1.600	2.575	0.256
JT Myers	Min	0.015	0.449	0.462	1.161	0.029
	Avg	0.057	0.698	0.849	1.546	0.111
	Max	0.170	2.480	4.570	5.980	0.535
Wabash R.	Min	0.015	0.446	0.050	1.400	0.083
	Avg	0.056	1.424	1.793	3.217	0.207
	Max	0.120	1.320	1.660	2.940	0.217
Smithland	Min	0.015	0.407	0.479	1.023	0.043
	Avg	0.055	0.741	0.886	1.626	0.0989

In general, the Wabash River concentrations were higher than Ohio River concentrations (Figures 11-14). 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.

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. Comparable with BOD survey results, TKN concentrations were highest during low flow periods indicating that this load is from point source(s).

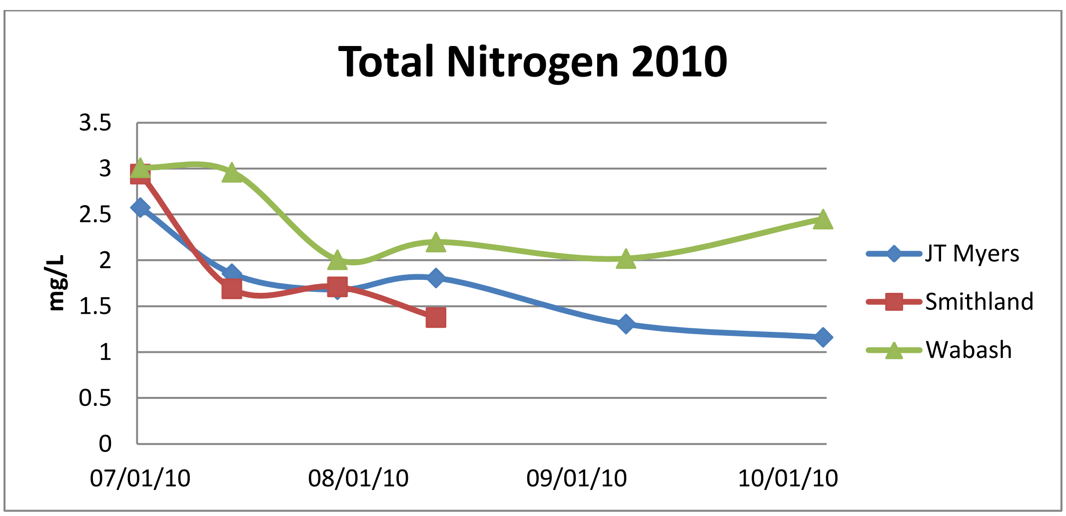


Figure 11: Total Nitrogen Concentrations, 2010

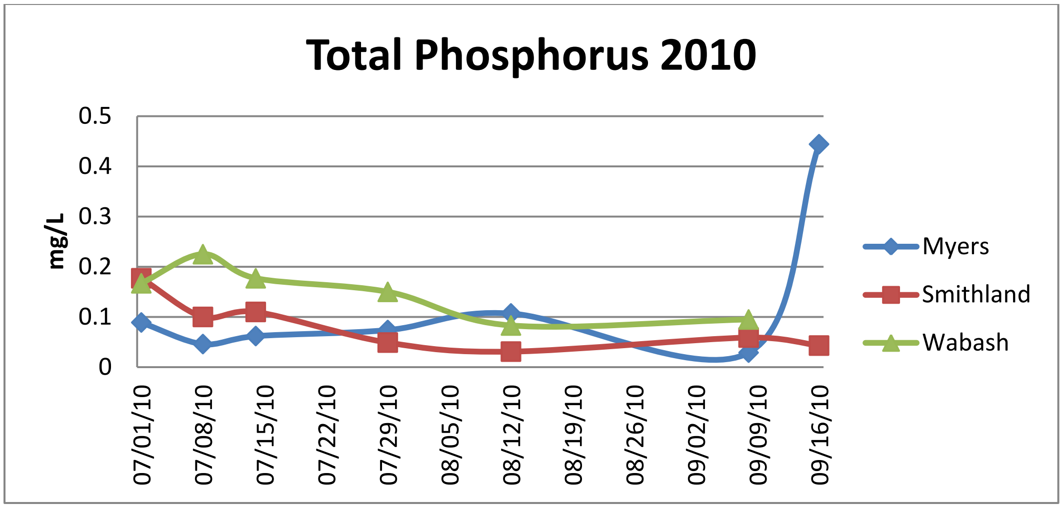


Figure 12: Total Phosphorus Concentrations, 2010

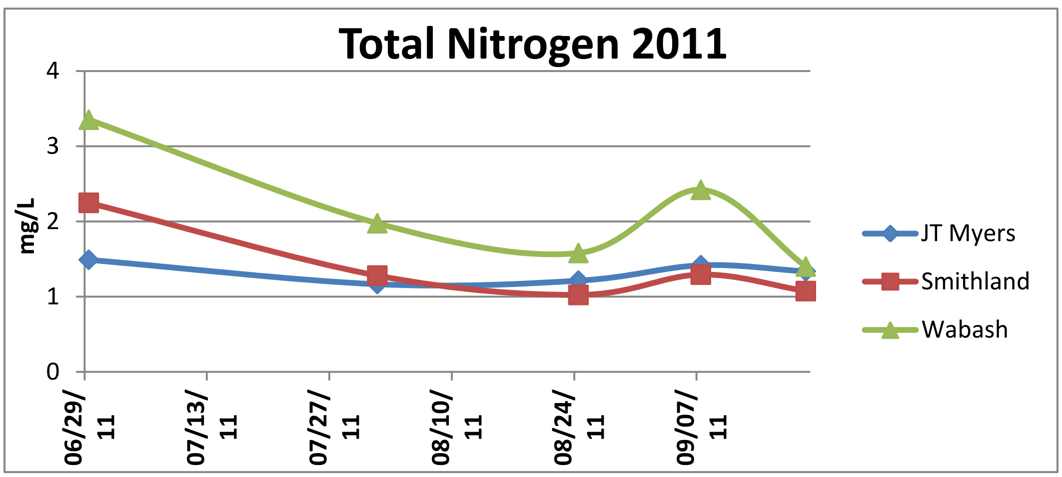


Figure 13: Total Nitrogen Concentrations, 2011

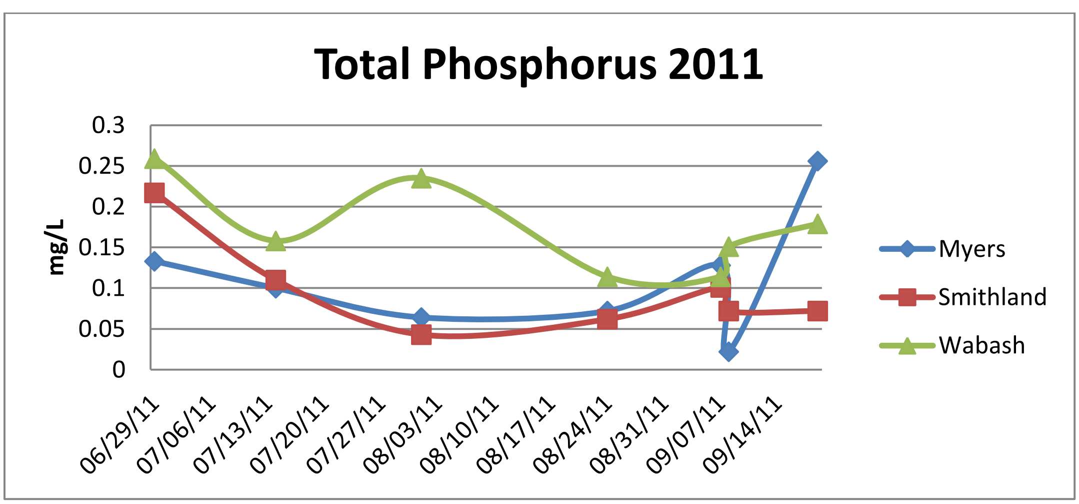


Figure 14: Total Phosphorus Concentrations, 2011

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
- 15.5% of the flow
- 24.5% of the nitrogen load (138,976 metric tons)
- 10.6% of the phosphorus load (4,646 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. Over the course of the survey period, there were 25 days where dissolved oxygen levels in Smithland pool were below the 5 mg/L daily average standard and seven days below the 4 mg/L instantaneous 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. 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.

Both BOD and TKN (the organic fraction of nitrogen) show a classic pattern of coming from a point source or several point sources. For example, the New Harmony POTW outfall is located downstream of the sampling point. With no other known sources nearby, this would not appear to be a localized effect.

Project Successes and Failures

The single largest problem encountered over the course of this project was damage to the datasonde that occurred when lightning struck the bridge on which it was mounted. A review of grounding methods with the equipment manufacturer showed that the unit was properly grounded. This damage occurred while the Wabash River was at flood stage, making retrieval of the unit for repairs impossible until floodwaters receded. This resulted in the loss of data for six weeks.

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.

Future Projects

Because results of sampling can vary depending on the amount and timing of precipitation in a watershed, it is important to sample over several years to confirm the findings of a single survey season. Funding has been provided by IDEM to continue monitoring on the Wabash River for an additional three years. ORSANCO will continue sampling the Ohio River at John T. Myers locks and dam and Smithland locks and dam as part of its own regular sampling programs.

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APPENDIX A

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APPENDIX B

DATA FILES