Nutrient Mass Balance Study for Ohio’s Major Rivers

Division of Surface Water
Modeling, Assessment and TMDL Section

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Executive Summary

Since 2011, more than $3.6 billion has been allocated statewide to address both point source and nonpoint source nutrient reduction, drinking water treatment, home sewage treatment systems, and drinking and wastewater infrastructure improvements. Of that total, $2.2 billion has been spent in the Lake Erie basin.

The following is a list of statewide water quality improvement activities underway to address nutrients and harmful algal blooms.

1. **Statewide Nutrient Reduction Strategy**: Ohio’s environmental, agricultural and natural resource agencies worked together to create a statewide strategy to reduce nutrient loading to streams and lakes, including Lake Erie. The strategy was submitted to U.S. EPA Region 5 in 2013. Ohio EPA recently updated the strategy to address gaps identified through U.S. EPA’s review. The strategy and more information about the effort are available at [http://www.epa.ohio.gov/dsw/wqs/NutrientReduction.aspx](http://www.epa.ohio.gov/dsw/wqs/NutrientReduction.aspx).

2. **Water Quality Bill**: Senate Bill 1 became effective July 3, 2015, requires major publicly owned treatment works (POTWs) to conduct technical and financial capability studies to achieve 1.0 mg/L total phosphorus; establishes regulations for fertilizer or manure application for persons in the western basin; designates the director of Ohio EPA as coordinator of harmful algae management and response and requires the director to implement actions that protect against cyanobacteria in the western basin and public water supplies; prohibits the director of Ohio EPA from issuing permits for sludge management that allow placement of sewage sludge on frozen ground; and prohibits the deposit of dredged material in Lake Erie on or after July 1, 2020, with some exceptions.

3. **Agriculture Water Quality Bill**: SB 150, effective August 21, 2014, requires that beginning September 31, 2017, fertilizer applicators must be certified and educated on the handling and application of fertilizer and authorizes a person who owns or operates agricultural land to develop a voluntary nutrient management plan or request that one be developed for him or her.

4. **State Budget Bill**: HB 64, effective June 30, 2015, requires the development of a biennial report on mass loading of nutrients delivered to Lake Erie and the Ohio River from Ohio’s point and nonpoint sources. A summary of the bill is available at [https://www.legislature.ohio.gov/legislation/legislation-summary?id=GA131-HB-64](https://www.legislature.ohio.gov/legislation/legislation-summary?id=GA131-HB-64). This report fulfills this requirement for 2016.

5. **Great Lakes Restoration Initiative Demonstration and Nutrient Reduction Projects**: Nine grants totaling over $12 million were awarded to Ohio. Highlights include: first saturated buffer installed in Ohio; 53 controlled drainage structures installed; 52 whole farm conservation plans developed; 7,500 acres of cover crops planted; and 29 storm water, wetland and stream restoration projects in Cuyahoga County.

6. **Ohio Clean Lakes Initiative**: In 2012 the Departments of Natural Resources, Agriculture and Ohio EPA created the Ohio Clean Lakes Initiative. The Ohio General Assembly provided more than $3.5 million for projects to reduce nutrient runoff in the Western Lake Erie Basin beginning in 2013.

"Western basin" is defined in this Senate Bill as consisting of the following 11 watersheds: Ottawa watershed, HUC 04100001; River Raisin watershed, HUC 04100002; St. Joseph watershed, HUC 04100003; St. Mary’s watershed, HUC 04100004; Upper Maumee watershed, HUC 04100005; Tiffin watershed, HUC 04100006; Auglaize watershed, HUC 04100007; Blanchard watershed, HUC 04100008; Lower Maumee watershed, HUC 04100009; Cedar-Portage watershed, HUC 04100010; and Sandusky watershed, HUC 04100011.
7. **Healthy Lake Erie Fund**: In 2014 the Ohio General Assembly, provided $10 million to the Healthy Lake Erie Fund to reduce the open lake placement of dredge material into Lake Erie. These sediments often contain high levels of nutrients or other contaminants so finding alternative use or disposal options is a priority.

8. **Western Basin of Lake Erie Collaborative Plan**: This agreement between Ohio, Michigan and Ontario will serve as a precursor to the Great Lakes Water Quality Agreement Domestic Action Plan. The Collaborative establishes an implementation plan with the goal to achieve a 40% reduction for total and dissolved reactive phosphorus from entering Lake Erie by 2025.

9. **Targeted Funding to Ohio Drinking Water and WWTPs**: More than $150 million was made available starting in 2014 to help public water systems keep drinking water safe and to help wastewater treatment plants reduce the amount of phosphorus they discharge into the Lake Erie watershed. As of June 2016, more than $61 million had been awarded for this work and most of the remainder has been allocated for specific projects.

10. **Directors’ Agricultural Nutrients and Water Quality Working Group**: A collaborative working group consisting of experts from Ohio EPA, ODA and ODNR developed the group’s 2012 report, which contains a number of recommendations to be implemented during the next several years. For example, the report recommends ways for farmers to better manage fertilizers and animal manure and also provides the state with the means to assist farmers in the development of nutrient management plans and to exert more regulatory authority over the farmers who are not following the rules. The report is available at [http://www.agri.ohio.gov/topnews/waterquality/docs/FINAL_REPORT_03-09-12.pdf](http://www.agri.ohio.gov/topnews/waterquality/docs/FINAL_REPORT_03-09-12.pdf).


12. **Ohio Point Source and Urban Runoff Workgroup**: Businesses, municipalities and Ohio EPA came together to initiate the “Point Source and Urban Runoff Workgroup” in 2012 to identify actions that can be taken immediately to reduce phosphorus loadings from WWTPs, industrial discharges and urban storm water. The group’s full report is available at [http://epa.ohio.gov/portals/35/documents/point_source_workgroup_report.pdf](http://epa.ohio.gov/portals/35/documents/point_source_workgroup_report.pdf).

**Background and Purpose**

Excess nutrients (nitrogen and phosphorus) stimulate algal growth affecting water quality in both the near and far field. This study computes annual total nitrogen (N) and phosphorus (P) loads originating from Ohio watersheds draining to Lake Erie and the Ohio River. The watersheds covered in this study include the Maumee, Portage, Sandusky, Cuyahoga, Great Miami, Scioto and Muskingum watersheds. Loads were allocated to major contributor groups, for example, municipal wastewater, combined sewer overflows (CSO), home sewage treatment systems (HSTS) and nonpoint sources.

The study was prompted by the need to identify the most environmentally beneficial and cost-effective mechanisms for nutrient reduction. The nutrient mass balance will serve as a baseline and will aid in tracking progress to goals established by the 2012 Great Lakes Water Quality Agreement and the Gulf of Mexico Hypoxia Task Force 2008 Action Plan. Finally, Ohio EPA is required by Ohio law [ORC 6111.03] to complete this nutrient accounting on a two-year basis.

**Methods/Approach**

The current (2016) edition computes loading totals on a water-year (WY) basis – for each of water years 2013 and 2014. *Data from water years 2013 -14 are the most recent and complete data sets available and is the reason they are used in this initial baseline report.* Watersheds selected for analysis were limited to those with daily water quality monitoring needed for an accurate estimate of annual load. These watersheds include the Maumee, Portage, Sandusky and Cuyahoga of the
Lake Erie system and the Great Miami, Scioto and Muskingum of the Ohio system – seven in total and comprising 63 percent of Ohio’s land area.

Total load at a ‘pour point’ was computed from water chemistry and flow by the National Center for Water Quality Research and the U.S. Geological Survey, respectively. A pour point is a location on a river or stream where the total load is known. Loads from sources permitted by the National Pollutant Discharge Elimination System (NPDES) were estimated using self-monitoring data for wastewater and combined sewer overflows, referred to as NPDES loads. Loads for home sewage treatment systems (HSTSS) were derived from Ohio Department of Health regional estimates (ODH 2013) of HSTS type and failure rate and GIS analysis of U.S. census data, referred to as HSTS load. The total nonpoint source load was computed as the difference between the pour point load and the NPDES and HSTS loads upstream of the pour point, assuming no load loss from NPDES and HSTS from source to outlet. The nonpoint source load from the area downstream of the pour point is estimated based on the yield of the upstream nonpoint source.

Variables:

The timing, location, duration and amounts of precipitation, especially rainfall, can be a significant variable influencing stream discharges that affect source loads, especially from nonpoint sources, although point sources may also be affected. This variable is addressed under the section 3.1 subsection Relationship of Annual Water Yield to Annual load.

Just before and since WY 13-14, a significant amount of state and federal dollars have been allocated to nutrient reduction and nutrient management efforts at both the point and nonpoint level in a number of the watersheds referenced in this report, especially those in the western Lake Erie basin. Programs are underway to track potential water quality improvements resulting from these practices. Attempts will be made to factor these and ongoing nutrient management efforts into the 2018 Nutrient Mass Balance Report. A compilation of these programs and policy changes related to nutrient management for both point source and nonpoint sources are listed in the Introduction under Past Studies and Associated Work.

Important Findings

The Scioto and Maumee watersheds generated the highest annual total P load for both water years (2013 and 2014) – an average of 2200 metric tons per annum (mta). The Muskingum watershed, though the largest area among the seven, was only the fourth highest total P load contributor – an average of 1500 mta. In-stream reservoirs and high proportion of natural land cover may be contributing to lower total P loading in the Muskingum watershed.

When examining the sources of total P load, nonpoint sources were the highest contributors to the phosphorus load in the Sandusky (93 percent of its total load), Maumee (88 percent) and Portage (85 percent) watersheds. The highest proportions of NPDES load are in the Ohio River basin – led by the Muskingum watershed (42 percent of its total load and 630 mta). The Great Miami and Scioto watersheds are a close second, in terms of percent, at 31 (463 mta) and 30 (672 mta) percent of their total loads. The Ohio River basin has very few total P wastewater limits in contrast to wastewater in the Lake Erie basin. The Cuyahoga watershed also showed a high proportion of NPDES load relative to total P load (27 percent and 100 mta), owing to an urban, population-dense watershed.

The role of HSTS was moderately less than NPDES loads—occupying an average of 5 percent of the total P load. When considering the contribution of CSOs to the total P load, they accounted for an average of 3 percent of the total load and 20 percent of the NPDES load. Sandusky watershed had the largest percentage of CSO load to NPDES load (over 50 percent). When compared to total load, Cuyahoga watershed had the largest CSO contribution (just over 10 percent).

For total N load, the results are very similar to those found for total P load – the Maumee watershed ranked highest and produced an average of 41,000 mta. The Muskingum watershed ranked second highest in total N load producing an average of 21,700 mta, and owing to the large watershed area. More prevalent in the Muskingum watershed, discharge from coal-fueled power plants contributed to an average of 28 percent of the total NPDES N load (about 6.5 percent of the total N load). When considering all three Ohio River watersheds together, the total N load was over 61,500 and 72,000 mta for 2013 and 2014, respectively.
In terms of sources of total N load and their relative proportions, NPDES load generally occupied the same percentage of total load within the Ohio River basin (around 18 percent) and within the Lake Erie basin (around 8 percent and excluding the Cuyahoga) watersheds. We found the Cuyahoga watershed to be an anomaly – producing an average of 60 percent of the total N load. For the three other Lake Erie watersheds, nonpoint source load dominated the total N load (90 percent). For the Ohio River watersheds, nonpoint sources contributed an average of 78 percent of the total N load.

Home sewage system load was a smaller proportion (3 percent overall) of the total N load compared to the same for total P. This lesser role was also apparent for CSOs. The contribution of CSOs was an average of just under 2 percent of the total N load and just under 14 percent of the NPDES load. Sandusky watershed, as in total P load, had the largest percentage of CSO load to NPDES load (about 35 percent). Cuyahoga watershed again had the largest CSO contribution to total load (5.5 percent).

When standardizing the total nonpoint source load by area, the highest annual yields were found in the Sandusky watershed – for both for total P (average of 1.5 lb/acre) and total N (23 lb/acre). The Portage watershed also produced a high annual total P nonpoint source yield (almost 1 lb/acre). When standardizing the human-sewage load (NPDES plus HSTS loads) by population count, the highest annual per capita total P yields occurred in the Muskingum (almost 1.2 lb/person), Portage (over 0.9), and Great Miami and Scioto (both just under 0.9) watersheds. Notably, three of these four watersheds are in the Ohio River basin, owing to fewer P limits for major wastewater treatment facilities. For total N, annual per capita yields were similar across all seven watersheds (average just under 9 lb/person).

**Recommendations for Further Action**

The next edition will compute loadings for the subsequent two water years and begin to identify trends in total loading and sources of loads. Future editions of this study will consider other monitored watersheds, expanding beyond these seven watersheds, and assessing the additional load generated by the remaining 40 percent of Ohio’s land area. These other watersheds, though not monitored daily, will need to have a sufficient monitoring frequency and capture of storm events to generate reliable load estimates. Refinement of the subcomponents of nonpoint source load including agriculture, residential development, urban areas and industry will be pursued.
1 Introduction

The objectives of this study are to determine nutrient (nitrogen and phosphorus) loads and the relative proportions of point source and nonpoint source contributions to Lake Erie and the Ohio River on an annual basis from seven major watersheds in Ohio. Excess nutrients stimulate algal growth, and when in excess, subsequently affect the physical, chemical and biological health of aquatic systems. To calculate total loads, we identified load sources originating from all known major contributors (for example, municipal wastewater, industrial wastewater, nonpoint sources). The current (2016) edition computes loading totals on a water-year\(^2\) basis – each of water years 2013 and 2014 (wy13 and wy14). Data from water years 2013 - 14 are the most recent and complete data sets available and is the reason they are used in this initial baseline report.

There are numerous benefits to performing such a study. One benefit is that identifying load sources provides information for determining the most environmentally beneficial and cost-effective mechanisms for nutrient reduction. For example, if nonpoint nutrients are found to be the major contributor of downstream total phosphorus load, then focusing remediation on point source nutrients would neither be prudent or efficient. The study will also serve national and regional U.S. goals manifested by the 2012 Great Lakes Water Agreement Annex 4 (nutrients) and the Gulf of Mexico Hypoxia Task Force 2001 Action Plan. Annex 4 goals address both nuisance algal blooms and hypoxia in Lake Erie. Results could also aid in the management of nuisance algal blooms for the Ohio River.

The need to understand total nutrient load and sources for Ohio was earlier recognized by the Point Source and Urban Runoff Nutrient Workgroup (Ohio EPA, 2012; pp 8-9, 16-17), developed as part of Ohio EPA’s Nutrient Reduction Strategy. The state legislature then considered this recommendation from the work group and subsequently codified it into a statutory requirement [ORC 6111.03 (U)]. The requirement was passed by the Ohio General Assembly in June 2015 and states that Ohio EPA shall “study, examine, and calculate nutrient loading from point and nonpoint sources in order to determine comparative contributions by those sources, and report every two years”. The study watersheds must include data on ambient water quality and streamflow and point source discharges. Subsequent studies carried out biennially will be used to document nutrient loading trends.

For the 2016 edition of the nutrient mass balance study, watersheds were selected based on availability of discharge and water quality. They were expected to be major contributors of nutrient load to the Lake Erie and the Ohio River systems. The watersheds are monitored for water quality on a daily (and sometimes more frequent) basis by the National Center for Water Quality Research (NCWQR) at Heidelberg University (Ohio). Sub-hourly discharge is monitored by the U.S. Geological Survey for all seven watersheds. These sources of data were critical in developing a meaningful procedure for a biannual analysis of loading sources. These watersheds include the Maumee River, Portage River, Sandusky River and Cuyahoga River of the Lake Erie system and the Great Miami River, Scioto River and Muskingum River of the Ohio River system (Figure 1).

The total area of these seven watersheds comprises 63 percent of the total area of Ohio. All sources outside the state boundary and within the watershed area were included in the analysis. Any pollutant source draining directly or indirectly (i.e., through connecting tributaries) to the mainstem river segment of these basins was included in the 2016 edition; direct discharges to Lake Erie or the Ohio River were not included but will be in subsequent editions. Some of the data sources used to define source loads were taken from Ohio Department Health survey of home septic systems and the National Pollution Discharge self-monitoring program.

Future editions of this study will consider other monitored watersheds. These other watersheds, though likely not monitored daily, will need to have a sufficient monitoring frequency and capture of moderate- to high-flow events to allow reasonable calculations. Also, Ohio EPA will be investigating ways to replace the currently-defined, gross nonpoint source load with more refined representations of agricultural and urban/suburban nutrient loads in future editions.

A major assumption in identifying sources of loads and computing total load at the outlet to a major system such as Lake Erie is that no loss in load occurs from source to outlet. Nutrient load losses may occur from assimilation into the floodplain, river or stream substrate or plant uptake (both macrophytes and algae). However, the assumption of no load loss is reasonable when accounting for total nutrient quantity (for example, total phosphorus) over a 12-month period. On a water year basis, this assumption is acceptable

\(^2\) A water year (wy) is a 12-month period that starts on October 1 of each year and is named for the year of its September-ending date. The beginning of a water year differs from the calendar year so that precipitation and its associated subsequent runoff are accounted for in the same 12-month period. Late autumn and winter snowfall that may accumulate in the ensuing months will not drain and discharge until the following spring (or summer) snowmelt.
because sources and sinks of nutrients tend to reconcile to the same total load over longer time intervals such as a year. Other more permanent losses may arise from denitrification (for nitrogen) in floodplain and stream bank soils or from fish harvest; future editions may quantify these components, too.

Figure 1 — Map of nutrient mass balance watersheds and associated pour points.
Past Studies and Associated Work
The focus in Lake Erie and other Great Lakes has been on phosphorus and its corresponding blue-green algae blooms, while the focus on the Gulf of Mexico nutrient loading has been toward nitrogen loads and hypoxia of the northern Gulf of Mexico (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2001).

Several historical and ongoing studies characterizing total nutrient loads from Great Lakes tributaries have been conducted for various reporting periods (Dolan 1993; Dolan and Richards, 2008). The earliest study of Lake Erie loadings was conducted by the Pollution from Land Use Activities Reference Group in 1978 (PLUARG, 1978).

A detailed analysis of Lake Erie total phosphorus loadings was presented by Dolan and McGunagle (2005). Both direct and watershed loadings were considered. For unmonitored tributaries, a unit-area load was used to estimate the total load. The 2005 work was advanced for all of the Great Lakes and updated in 2008 by Dolan and Chapra (2012a, 2012b), and is planned to continue. We anticipate that this 2016 Ohio effort will aid in more frequent updates to Lake Erie and Great Lake total load accounting.

The earliest studies on hypoxia in the Gulf of Mexico addressed nitrogen loads (Goolsby and Battaglin, 2001; Scavia et al., 2003, Aulenbach et al., 2007) as recommended by 2001 Action Plan (see above). However, more recent assessments (2007, 2013) of hypoxia causes suggest a dual nutrient strategy and call for concurrent nitrogen and phosphorus reductions (U.S. Environmental Protection Agency Science Advisory Board, 2008).

2 Methods

2.1 Overall Loading Calculation
The mass balance equation used to calculate watershed loading is presented as Equation 1 below.

\[
Total Load = NPDES + HSTS + NPS_{upst} + NPS_{dst} \quad (1)
\]

The load discharged by entities with National Pollutant Discharge Elimination System (NPDES) permits, which are within the regulatory authority of Ohio EPA, is represented as the point source load (named NPDES) in Equation 1. Household Sewage Treatment System (HSTS) contributions are estimated separately. The nonpoint source (NPS) loads are separated into two categories: nonpoint source, which is calculated upstream from the pour point (NPS_{upst}) and nonpoint source, calculated downstream of the pour point (NPS_{dst}). The timing, location, duration and amounts of precipitation, especially rainfall, can be a significant variable influencing stream discharges that affect source loads, especially from nonpoint sources, although point sources may also be affected. This variable is addressed under the section 3.1 subsection Relationship of Annual Water Yield to Annual load.

2.2 Point Source Loading
The NPDES program requires permittees to report operational data to Ohio EPA via discharge monitoring reports (DMR). All facilities are required to report flow volume. To varying degrees, nutrient concentrations are also monitored and reported. This is dependent on factors such as reasonable potential of elevated concentrations and facility size. The varied reporting from different facilities requires that loads be estimated using a method which is flexible and can account for missing data. Equation 2 estimates the generic loading from an NPDES permitted facility.

\[
Annual Load = Q(\text{in} \ MG) * [\text{Nutrient}] * cf \quad (2)
\]

In Equation 2, Q represents a facility’s flow volume in million gallons (MG). The cf stands for the conversion factor used to convert MG and nutrient concentration from milligrams per liter into kilograms per day, which is 3.78541.

To estimate the nutrient concentration, denoted [Nutrient], in Equation 2, each facility is placed into one of four groups, depending on the type of plant and available nutrient monitoring data. The groups and approaches for calculating nutrient concentrations are: 1) industrial facilities reporting nutrient concentrations – use the median concentration of nutrients reported during the calculation period; 2) industrial facilities not reporting nutrient concentrations – assume a de minimis nutrient concentration set equal to 0; 3) sewage treatment facilities reporting nutrient concentrations – use the median nutrient concentration from the calculation period;
and 4) sewage treatment facilities not reporting nutrient concentrations – use the median nutrient concentration of facilities in the same class. These classes are defined in Table 1.

### Table 1 — Facility classes by design flow.

<table>
<thead>
<tr>
<th>Group</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrials</td>
<td>All Industrial Permits</td>
</tr>
<tr>
<td>Major</td>
<td>Sewage Treatment and ADF ≥ 1.0 mgd</td>
</tr>
<tr>
<td>Class 2</td>
<td>Sewage Treatment and 1.0 mgd &gt; ADF ≥ 0.5 mgd</td>
</tr>
<tr>
<td>Class 3</td>
<td>Sewage Treatment and 0.5 mgd &gt; ADF ≥ 0.25 mgd</td>
</tr>
<tr>
<td>Class 4</td>
<td>Sewage Treatment and 0.25 mgd &gt; ADF ≥ 0.1 mgd</td>
</tr>
<tr>
<td>Class 5</td>
<td>Sewage Treatment and ADF &lt; 0.1 MGD</td>
</tr>
</tbody>
</table>

ADF = Average Design Flow

Nutrient loads in this report are estimated as total phosphorus (total P) and total nitrogen (total N). Facilities with phosphorus monitoring typically report total P, which can be used directly for loading estimates. However, to determine total N, estimates are needed for ammonia, nitrite + nitrate and organic N. Most facilities, however, are only required to report ammonia and nitrite + nitrate with limited data available for organic N. Organic N is estimated as the difference between Total Kjeldahl Nitrogen (TKN) and ammonia. A statewide analysis of paired TKN and ammonia samples from NPDES sewage treatment facilities from wy11 – wy15 (9,110 samples) was performed to provide an estimate of organic N. There was little variation for different sized facilities so the median of the statewide dataset of 1.37 mg/L was used for an organic N estimate for all sewage treatment facilities.

Wet-weather events often result in increased wastewater flows within collection networks, either by design in combined sewer communities or as increased flows to sanitary sewers through inflow and infiltration (I&I). The result of increased flows is reduced treatment at the plant (usually a bypass of secondary treatment), wastewater bypasses at the plant headworks (raw bypasses), overflows of combined sewers (CSOs) and overflows of sanitary sewers (SSOs). Note that SSOs are only included when overflow volume is reported. Loads are estimated at NPDES facilities reporting discharge for these wet-weather events at assigned stations. This report uses a wet-weather loading nutrient concentration of 2.19 mg/L for total P (Northeast Ohio Regional Sewer District, personal communication, 9/27/2012) and 20 mg/L for total N (U.S. Environmental Protection Agency, 2004; Tchobanoglous et al., 2003) at stations designated as SSOs, CSOs and raw bypasses. This value for total P concentration was also used in the Ohio Phosphorus Task Force I loading analysis for CSOs (Ohio EPA, 2010, p. 34). For bypasses that go through primary treatment, 15 percent nutrient removal is assumed to account for some total P removal through settling and sludge removal.

Estimates of NPDES loading are reported both as lumped in type groups in order to facilitate discussion of nutrient contributions from different types of facilities. Understanding the contributions of plants of different sizes and relative influence of wet-weather loading could help guide implementation efforts.

One watershed analyzed in the mass balance study, the Maumee, included NPDES sources that are outside of the state of Ohio. Data on monthly loads was available from the Integrated Compliance Information System (ICIS) maintained by U.S. EPA. These monthly loads were summed for each facility within the watershed and are reported as out-of-state (OOS) NPDES loads. This load contains a CSO load estimate where the overflow volumes reported for combined sewer systems were assumed to have the same concentration as those within Ohio.

#### 2.3 HSTS Loads

The population served by HSTS is estimated using a GIS analysis of census data (US Census, 2010), combined with an assessment of populations that are likely served by sewer systems of NPDES permitted facilities. The populations served by NPDES facilities are estimated using two methods. The first is that census designated places (CDPs) are assessed as sewered or not. The second method is applied to NPDES sewage treatment facilities that are not associated with a CDP. In this case, the population served by the facilities is estimated by determining the average flow for facilities associated primarily with households and then dividing by 70.1 gal/day/person (Lowe et al., 2009). For example, facilities serving mobile home parks and subdivisions were included while facilities serving highway rest stops and recreation facilities were excluded. The HSTS population is then estimated to be the remaining
population when NPDES CDP population and non-CDP NPDES population are subtracted from the total population. Equation 3 explains this overall method.

$$Load_{HSTS} = Pop_{HSTS} \times Nut_{yield}$$

$$\times \left[ \text{percentPop}_{\text{discharge}} \times DR_{\text{discharge}} + \text{percentPop}_{\text{onsite-working}} \times DR_{\text{onsite-working}} + \text{percentPop}_{\text{onsite-failed}} \times DR_{\text{onsite-failed}} \right]$$ (3)

where,

$$Pop_{HSTS} = \text{Total population served by HSTS in watershed (persons)}$$

$$Nut_{yield} = \text{Annual yield of nutrient per person (lb/yr/person)}$$

$$\text{percentPop}_{\text{discharge}} = \text{percent of population served by discharging HSTS}$$

$$DR_{\text{discharge}} = \text{nutrient delivery ratio for discharging systems}$$

$$\text{percentPop}_{\text{onsite-working}} = \text{percent of population served by onsite working HSTS}$$

$$DR_{\text{onsite-working}} = \text{nutrient delivery ratio for onsite working systems}$$

$$\text{percentPop}_{\text{onsite-failing}} = \text{percent of population served by onsite failing HSTS}$$

$$DR_{\text{onsite-failing}} = \text{nutrient delivery ratio for onsite failing systems}$$

Literature was reviewed to estimate the per capita nutrient yield in household wastewater. A study by Lowe and others (2009) reported a median nutrient yield as 0.511 kg-P/capita/year and 3.686 kg-N/capita/year. In a similar effort to this mass balance study, the Minnesota Pollution Control Agency (MPCA) estimated the annual per capita nutrient yield to be 0.8845 kg-P/capita/year and 9.1 kg-N/capita/year (Wilson and Anderson, 2004). The MPCA study used estimated values based on different household water use activities while the Lowe study reported statistics on data measured on actual systems. The Lowe study median concentrations were used because the methodology uses actual sampling data of septic tank effluents.

Phosphorus delivery ratios for three different system types were estimated from a literature review. One system type is properly operating soil adsorption systems. In these systems, wastewater percolates through the soil matrix where physical, chemical and biological processes treat pollutants. Phosphorus is usually considered to be effectively removed in these systems. Beal and others (2005) reviewed several studies and reported several findings including: >99 percent P removal, 83 percent P removal and slow P movement to ground water. In a nutrient balance study, MPCA assumed that HSTS with soil adsorption systems removed phosphorus at 80 percent efficiency (MPCA, 2004). For this study, 80 percent efficiency will be used because the studies reviewed by Beal used fresh soil columns and did not consider a reduction in efficiency with system age.

Another category of systems included in the mass balance study is soil adsorption systems that are failing to function as designed. Failure of systems is caused by a myriad of problems, so literature values are not available for phosphorus removal. For this mass balance study, the assumption is made that failing systems still involve some level of soil contact — therefore total P removal will be between a direct discharge and that of a soil adsorption system. The value used for the mass balance study was 40 percent total P removal for failing soil adsorption systems, or half that is assumed for properly working systems.

A third group of HSTS is systems that are designed to discharge. These systems use mechanical treatment processes to treat wastewater and discharge directly to streams. Similar to septic tanks, they are designed to remove suspended solids but sludge removal is limited to periodic pumping. Lowe and others (2009) studied septic tank influent and effluent and determined that there was a 6 percent reduction in total P. This study will use the same 6 percent reduction observed by Beal.

Nitrogen delivery ratios are different from phosphorus delivery ratios and, like phosphorus, are estimated using a literature review. Soil type and flow path affect the delivery of nitrogen from soil adsorption systems. Beal and others (2005) reviewed several studies and reported nitrogen removal from 0 – 80 percent. For this mass balance study, 40 percent removal of nitrogen in working soil

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State of Ohio Nutrient Mass Balance Study
adsorption systems is used. Again, since failing soil adsorption systems are considered failing for many reasons, they are not well studied relative to removal efficiency of different pollutants. However, since soil contact and lateral water movement are still involved, this nutrient mass balance study will use the same 40 percent removal efficiency used for working soil adsorption systems. Discharging HSTS are not designed to remove sludge from the system. Rather, they mineralize organic material and therefore the median nitrogen outflow of septic tanks is not significantly different from the inflow (Lowe, 2009). For this reason, the discharging HSTS will not be considered as providing any reduction of total N in the mass balance study.

The final component needed to estimate HSTS loading is the relative proportion of system types, split into three categories: 1) working soil adsorption systems; 2) failing soil adsorption systems; and 3) systems designed to discharge. The Ohio Department of Health (ODH) is the state agency tasked with regulating the treatment of household sewage. ODH completed a survey of county health districts in 2012 and published the results as an inventory of existing HSTS in the state by Ohio EPA district. The district with the largest influence on a watershed is used to determine the relative proportions of different system types (Table 2).

<table>
<thead>
<tr>
<th>Ohio EPA District</th>
<th>Working Soil Adsorption (%)</th>
<th>Failing Soil Adsorption (%)</th>
<th>Discharging (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>41.5</td>
<td>26.5</td>
<td>32</td>
</tr>
<tr>
<td>Northeast</td>
<td>44</td>
<td>27</td>
<td>29</td>
</tr>
<tr>
<td>Central</td>
<td>42.8</td>
<td>25.2</td>
<td>32</td>
</tr>
<tr>
<td>Southwest</td>
<td>64</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>Southeast</td>
<td>61.2</td>
<td>10.8</td>
<td>28</td>
</tr>
</tbody>
</table>

2.4 Nonpoint Source Loading

Central to estimating the nonpoint source load is a monitoring point where near continuous data is collected by the NCWQR. This data results in the ability to calculate a very accurate annual load at that location, referred to in this study as a ‘pour point’. The nonpoint source load is separated into two categories, the nonpoint source load upstream of the pour point (NPS$_{up}$) and the nonpoint source downstream of the pour point (NPS$_{dn}$). There are different assumptions made to estimate the nonpoint source load up and down stream of the pour point. The nonpoint source load upstream of the pour point (NPS$_{up}$) is estimated as the residual load at the pour point. The residual load is the difference between the total pour point load and the sum of the NPDES and HSTS loads upstream of the pour point. The nonpoint source load downstream of the pour point (NPS$_{dn}$) is estimated as the product of the yield from upstream nonpoint source load and the downstream area. The upstream yield is the NPS$_{up}$ divided by the total watershed area upstream of the pour point.

It was important to separate the two types of nonpoint source loads (NPS$_{up}$ and NPS$_{dn}$) because the load downstream is estimated with the assumption of having the same areal yield as the upstream load. Yield equivalency is a weaker assumption than that of mass conservation. Watersheds with a larger proportion of drainage area downstream from the pour point are subject to more influence from the assumption of yield equivalency. The percent of total area downstream of the pour point, from highest to lowest, for the seven watersheds is: Scioto (41); Great Miami (30); Portage (27); Cuyahoga (13); Sandusky (12); Muskingum (8); and Maumee (4). Therefore, the nonpoint source load calculation is weaker for the Scioto and Great Miami than the Muskingum and Maumee watersheds. The yield assumption is compounded when the land use distribution between up and downstream of the pour point is quite different.

A key assumption of the mass balance method is conservation of mass throughout the watershed. While this adds ease in computation over large areas having limited or no data on assimilative capacity, it is also seen as a weakness. Consequently, the nonpoint source load includes both nonpoint sources and sinks of nutrients. Nutrient sources included within the nonpoint source estimate include: agricultural sources, storm water from developed lands, MS4 (municipal separate storm sewer system) areas, mining activities, natural sources and others. The nutrient sinks would include: wetlands (total P and total N), biomass (total P and...
total N), sedimentation (total P), atmospheric losses (total N) and others. Some of the nutrients assimilated within nonpoint sinks are undoubtedly from point sources or HSTS. The mass balance method overestimates the annual delivery of the load from these sources to the outlet by the unknown amount of assimilation.

3 Results and Discussion

3.1 Statewide Analysis

Total phosphorus loading is presented as total load grouped by major source, nonpoint source yields calculated, and per capita yield (Figure 2); all values are reported on an annual basis. The tabular results used to create Figure 2 are in Appendix B. Besides nutrient loads, which relate to the overall goal of the study, yields have also been reported to standardize the load by watershed area and human population count. Thus, a yield represents the intensity of the load; both are computed for the same timeframe. The categories of sources are: 1) HSTS; 2) total NPDES; 3) nonpoint source upstream of the pour point; and 4) nonpoint source downstream of the pour point. The annual nonpoint source yield is computed as the annual nonpoint source load divided by the watershed area; both are calculated at the pour point. The annual per capita yield is the sum of NPDES and HSTS loads divided by the total population residing in the watershed; both are calculated at the watershed outlet. The per capita yield thus represents the human waste-sourced nutrient load. The total N loads are presented similarly (Figure 3).

More detailed discussion of relative differences within each watershed will appear in Sections 3.2-3.8. The following discussion focuses on differences in total and relative load among the seven watersheds with respect to watershed area, annual water yield, nonpoint source nutrient yield, per capita nutrient yield and population density.

Watershed Area

In order to compare across watersheds of vastly different areas, the size of the watershed should be considered when examining loading totals. Generally speaking, watersheds with greater drainage area have the potential to produce the largest nonpoint source load (Figures 2 and 3). It is important to note watershed area when comparing total loads from watersheds that have much different areas. For example, an exception to this relationship is the Muskingum watershed. The Muskingum has the largest drainage area of any of the seven watersheds yet yields a smaller total load than the Maumee, Scioto and Great Miami watersheds. Other watershed characteristics are responsible for these differences and are discussed further as follows.

Relationship of Annual Water Yield to Annual Load

Load is calculated as the product of flow and concentration. The water yield is a means of presenting the annual discharge normalized by watershed area. The annual discharge is affected primarily by fluctuations in precipitation from year to year and regional precipitation patterns. The typical yield for each watershed is presented in Table 3 as the median of the last 20 years of discharge data (14 years for the Muskingum). The typical water yield was generally lowest for the northwest Ohio (13.5 – 14.0 in) compared to the Ohio River watershed (15.4 – 17.3 in) but highest in the Cuyahoga watershed (21.6 in). The loading impact of these differences in a typical year would be equivalent loads occurring at lower nutrient concentrations but at a higher water yield. The two water years studied in this project are typical for all seven watersheds as their value falls within the inter-quartile range (not shown).

Total nonpoint loads from a watershed are usually highly correlated to stream discharge; thus, a year with greater discharge and water yield would usually result in a greater load. For total P load from wy13 to wy14, all watersheds, except for Maumee, experienced the same directional change as its water yield from wy13 to wy14 (compare Tables 3 and 4). Note that for the Sandusky watershed this was a decrease, while the other watersheds saw an increase of both water yield and load. For the Maumee watershed, the annual discharge for wy14 was 16 percent higher compared to wy13, yet the loading decreased by 10 percent (Tables 3 and 4; Figures 2 and 3). The observation from the Maumee River total P loading suggests that timing and intensity of large precipitation events, especially as they relate to the timing of agricultural activities, are important components of nonpoint source nutrient loading. Data for agricultural activities such as fertilizer application were not available, so specific nonpoint source influences could not be ascribed to this observation.
When extending this discussion to total N load, the relationship of increased water yield and increased N load is not as straightforward. Total N load increases with increasing water yield for all three Ohio River watershed systems (Tables 3 and 4); these three watersheds also have the largest increase in water yield from wy13 to wy14 (Table 3). For the four Lake Erie watershed systems, total N load decreases from wy13 to wy14 (Table 4); but water yield, while increasing (except for Sandusky), is a much smaller increase relative to the Ohio River systems (Table 3). Other factors, besides change in water yield, may explain the change in total N load for the Lake Erie system.

### Table 3 — Annual water yield (in), median long-term water yield (in) and relative percent difference (RPD, percent) for the seven watersheds calculated at the pour point (PP) of each.

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Drainage Area at PP (sq. mi.)</th>
<th>Median Water Yield (1996-2015, in)</th>
<th>Water Yield (wy13, in)</th>
<th>Water Yield (wy14, in)</th>
<th>RPD (from wy13 to wy14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maumee</td>
<td>6,330</td>
<td>13.9</td>
<td>12.1</td>
<td>14.0</td>
<td>16%</td>
</tr>
<tr>
<td>Portage</td>
<td>428</td>
<td>13.5</td>
<td>13.3</td>
<td>15.6</td>
<td>17%</td>
</tr>
<tr>
<td>Sandusky</td>
<td>1,251</td>
<td>14.0</td>
<td>18.1</td>
<td>17.2</td>
<td>-5%</td>
</tr>
<tr>
<td>Cuyahoga</td>
<td>707</td>
<td>21.6</td>
<td>21.2</td>
<td>22.4</td>
<td>6%</td>
</tr>
<tr>
<td>Great Miami</td>
<td>2,685</td>
<td>17.3</td>
<td>13.8</td>
<td>18.4</td>
<td>33%</td>
</tr>
<tr>
<td>Scioto</td>
<td>3,854</td>
<td>15.6</td>
<td>14.0</td>
<td>17.6</td>
<td>26%</td>
</tr>
<tr>
<td>Muskingum</td>
<td>7,420</td>
<td>15.4(^a)</td>
<td>14.9</td>
<td>18.7</td>
<td>26%</td>
</tr>
</tbody>
</table>

\(^a\): median computed from 2002-2015.

### Table 4 — Annual total phosphorus and total nitrogen loads (by water year) and relative percent difference (RPD, percent) for the seven watersheds examined in this study. Load and drainage area calculated at the outlet of each watershed.

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Drainage Area at Outlet (sq. mi.)</th>
<th>Total P Load (mta)</th>
<th>Total N Load (mta)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wy13</td>
<td>wy14</td>
<td>RPD (from wy13 to wy14)</td>
</tr>
<tr>
<td>Maumee</td>
<td>6,568</td>
<td>2,295</td>
<td>2,062</td>
</tr>
<tr>
<td>Portage</td>
<td>585</td>
<td>168</td>
<td>219</td>
</tr>
<tr>
<td>Sandusky</td>
<td>1,420</td>
<td>711</td>
<td>615</td>
</tr>
<tr>
<td>Cuyahoga</td>
<td>808</td>
<td>327</td>
<td>402</td>
</tr>
<tr>
<td>Great Miami</td>
<td>3,889</td>
<td>1,266</td>
<td>1,798</td>
</tr>
<tr>
<td>Scioto</td>
<td>6,509</td>
<td>2,036</td>
<td>2,426</td>
</tr>
<tr>
<td>Muskingum</td>
<td>8,044</td>
<td>1,360</td>
<td>1,666</td>
</tr>
</tbody>
</table>
Figure 2 — Total phosphorus loading and nonpoint source yields as estimated using simplified nutrient balance methods. The nonpoint source yield is calculated as the residual load at the pour point divided by the area upstream of the pour point. Per capita yield is defined as the sum of NPDES and HSTS loads divided by the total number of people residing in the watershed; both are calculated at the watershed outlet.
Figure 3 — Total nitrogen loading and nonpoint source yields as estimated using simplified nutrient balance methods. The nonpoint source yield is calculated as the residual load at the pour point divided by the area upstream of the pour point. Per capita yield is defined as the sum of NPDES and HSTS loads divided by the total number of people residing in the watershed; both are calculated at the watershed outlet.
Nonpoint Source Nutrient Yield
The Muskingum watershed shows the lowest nonpoint source nutrient yields (see grey bar in Figures 2 and 3) – for both water years. The Great Miami and Scioto watershed also had slightly lower yields than those observed in Lake Erie drainage. In the Muskingum and Scioto watersheds, the presence of large run-of-river reservoirs may be a confounding factor for nonpoint source yields. In-stream reservoirs trap nonpoint source sediment with associated nutrients and prevent their movement downstream to the pour point.

Further, natural land cover (comprising wetlands, forest, shrub and herbaceous land) comprised more than 46 percent of the Muskingum total watershed area (Figure 4). These types of land covers are not large generators of nonpoint nutrient loads. The Cuyahoga watershed was a low generator of nonpoint source N yield (Figure 3). Natural land cover was also high for the Cuyahoga watershed and comprised more than 42 percent of its total area.

In the remaining five watersheds, natural land typically comprised only 10-15 percent of the total watershed area. The Sandusky, Portage and Maumee watersheds, where agricultural land comprises the majority of watershed area, exhibited the highest nonpoint source yields for both water years, especially for total N (Figures 2 and 3). The highest total P yield for both water years was the Sandusky watershed, and considerably above the second highest.

Per Capita Nutrient Yield
As mentioned previously, the per capita yield is the sum of NPDES and HSTS loads divided by the total population. The per capita yield thus represents the human waste-sourced nutrient load. For total P (see blue bar in Figure 2), per capita yield is generally highest for the Ohio River watersheds. In these watersheds, the NPDES load from major WWTPs, for the most part, is not subject to a total P concentration limit. The Cuyahoga watershed exhibits the lowest per capita total P yield, a primarily urban watershed with a low percentage of the population served by HSTS and high percentage served by major NPDES WWTPs. The remaining Lake Erie watersheds (Maumee, Sandusky and especially the Portage in wy14) have moderately high per capita total P yield. These watersheds have rural and small town populations containing HSTS and non-major WWTPs, respectively, not subject to total P concentration limits in their discharges. Differences in total N per capita yield (see blue bar in Figure 3), are less apparent among the study watersheds, though the Portage watershed has the highest yield relative to the remaining six watersheds.

Figure 4 — Distribution of major land use and land cover categories by major watershed (shown as percent of total watershed area). Land use/cover data taken from National Land Cover Dataset for year 2011 (NLCD 2011; Homer et al., 2015).
Population Density
The Cuyahoga watershed exhibits the highest population density among the seven watersheds (Table 5). It is nearly four times greater than the density of the next highest watershed. The Great Miami and Scioto watersheds exhibit the next highest population density. When exploring the highest relative contribution of total NPDES and HSTS load to total watershed load (for wy13, Table 6), the Cuyahoga watershed has the highest total N load (68 percent of total load). No other watershed is close to this percent contribution of NPDES and HSTS to total N load. However, the Cuyahoga is third place, percentwise, in total P load contributed by NPDES and HSTS; here the Muskingum (59 percent) and Great Miami (44 percent) are highest contributors of these sectors to total P load (Table 6).

Table 5 — Population density calculated as the total watershed population divided by total watershed area.

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Total Population (# persons)</th>
<th>Population Density (persons/sq. mi.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maumee</td>
<td>1,086,242</td>
<td>165</td>
</tr>
<tr>
<td>Portage</td>
<td>67,181</td>
<td>115</td>
</tr>
<tr>
<td>Sandusky</td>
<td>130,088</td>
<td>92</td>
</tr>
<tr>
<td>Cuyahoga</td>
<td>1,005,298</td>
<td>1,244</td>
</tr>
<tr>
<td>Great Miami</td>
<td>1,359,723</td>
<td>350</td>
</tr>
<tr>
<td>Scioto</td>
<td>1,939,124</td>
<td>298</td>
</tr>
<tr>
<td>Muskingum</td>
<td>1,462,086</td>
<td>182</td>
</tr>
</tbody>
</table>

Relative Loadings
There are differences in relative contributions of total P and total N when comparing loads originating from HSTS, NPDES and nonpoint sources to the total load in different watersheds (Figures 2 and 3). Among the seven basins, the proportional loadings differ when comparing the same source of total P and total N within each watershed (Table 6). For example, in the Cuyahoga watershed NPS plays a greater role in total P load than total N load. The opposite is true for the Great Miami and Scioto watersheds.

There are also differences in relative importance of sources among the basins for each of total P and total N (Figures 2 and 3; Table 4). The primary difference in relative contributions of total P and total N loads from NPDES sources is between Ohio River and Lake Erie drainage basins. Relative to total N, NPDES loads have lower total P contributions, at least for the Lake Erie basin. A likely cause is the NPDES limit on total P for major WWTPs located in the Lake Erie drainages in Ohio. Major WWTPs managing for phosphorus to meet NPDES limits typically exceed reduction efforts to assure compliance, further reducing their load. Baker and others (2006) also noted the reason for monitored differences in nutrient concentration between Ohio River and Lake Erie drainages was due to total P limits on major WWTPs discharging in Lake Erie drainages.

Finally, those watersheds with higher population density (Table 5) also exhibit higher proportion of NPDES load (Table 6) and this is true for both total P and total N.
Table 6 — Total phosphorus and total nitrogen contributions from household sewage treatment systems (HSTS), NPDES permitted sources (NPDES) and nonpoint sources (NPS) relative to the total load at the watershed outlet (expressed as percent). Values reported for wy13.

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Total P (percent of total)</th>
<th>Total N (percent of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HSTS</td>
<td>NPDES</td>
</tr>
<tr>
<td>Maumee</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Portage</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Sandusky</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Cuyahoga</td>
<td>11</td>
<td>29</td>
</tr>
<tr>
<td>Great Miami</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td>Scioto</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>Muskingum</td>
<td>10</td>
<td>49</td>
</tr>
</tbody>
</table>
3.2 Maumee River
The Maumee River drains 6,568 sq. mi. in northwestern Ohio, southeastern Michigan and northeastern Indiana (Figure 5). The National Center for Water Quality Research (NCWQR) maintains a water quality sampling station at a USGS gaging station in Waterville, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 6,297 sq. mi. and 271 sq. mi. downstream of the pour point.

Agricultural production dominates the landscape in the watershed, which includes the fertile drained lands of the Great Black Swamp. There is a notable shift in land use in the areas up and downstream of the pour point as the river enters the Toledo metropolitan area downstream of Waterville. Downstream of the pour point, the proportion of agricultural production reduces from 79 percent to 49 percent whereas both high/low intensity development and natural lands increase in proportion.

Total P loads from the Maumee River were 2,295 metric tons per year (mta) in wy13 and 2,062 mta for wy14 (Figure 6 and Table 7). Total N loads from the Maumee River were 43,698 mta in wy13 and 37,853 mta for wy14 (Figure 7 and Table 7).
Figure 7 — Total nitrogen loads for the Maumee River. Loads are presented in three major categories: 1) Household sewage Treatment Systems (HSTS); 2) NPDES permitted loads (Total NPDES) – includes CSOs; and 3) Nonpoint source (NPS).

There was a slight decrease in loading of both total P and total N from wy13 to wy14 (Table 7). Load is the product of flow and concentration. The annual flow is presented as water yield (flow volume divided by watershed area) and the concentration is presented as the FWMC. The two years had a water yield of 12.1 in (wy13) and 14.0 in (wy14) at the Waterville pour point. The median water yield from 1996 – 2015 at this location was 13.9 in. The water yield for wy13 was on the dry end of the 20-year period falling on the boundary of the lower quartile of annual yields. The change in annual load between the two years was small, because while the water yield increased the flow-weighted mean concentration (FWMC) decreased. The FWMC averages the nutrient concentration based on streamflow and is most appropriate for loading discussions. Annual FWMC may vary in streams for many reasons, including: timing of agricultural activities relative to precipitation events, rainfall intensity, overall magnitude of a storm (large storms move more than a series of small storms) and others. The result, demonstrated in the Maumee River, was a year with less discharge having greater nutrient loading.

Table 7 — Changes in flow-weighted mean concentration (FWMC), total load and water yield for wy13 and wy14. Water yield is annual discharge normalized by watershed area (in units of inches). FWMC and annual discharge are calculated at the pour point and do not include downstream drainage area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wy13</th>
<th>wy14</th>
<th>RPD from wy13 to wy14 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Yield (in)</td>
<td>12.1</td>
<td>14.0</td>
<td>↑16</td>
</tr>
<tr>
<td>20-yr Median Water Yield (in)</td>
<td>13.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>0.42</td>
<td>0.33</td>
<td>↓22</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>2,295</td>
<td>2,062</td>
<td>↓10</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>8.02</td>
<td>5.88</td>
<td>↓27</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>43,698</td>
<td>37,853</td>
<td>↓13</td>
</tr>
</tbody>
</table>
The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N in wy13 are presented in Figure 8. As was readily observed in Figures 6 and 7, the nonpoint source is the largest proportion of the load in the Maumee River at 87 and 89 percent, respectively, for total P and total N. The NPDES sources comprised 9 percent of the total P and 10 percent of the total N load. The NPDES sources are further broken down into source categories corresponding to plant type and size. The majority of the NPDES load (total P – 47 percent; total N – 58 percent) is from major WWTPs. The second largest NPDES contribution is from out of state sources at 28 percent of the NPDES total P load and 33 percent of the NPDES total N load. HSTS are the remaining 4 percent of the annual total phosphorus load and 1 percent of the total N load. In wy14 the total load decreased as a result of decreased NPS load resulting in slight increases in the relative contribution of NPDES sources and HSTS.

![Pie chart showing the relative contribution of nonpoint source, total NPDES, and HSTS loads for total P and total N in wy13.](image_url)

**Figure 8** — Total phosphorus and nitrogen load from different sources relative to total load for the Maumee watershed in wy13. NPDES sources: Major WWTP – sewage treatment >1.0 mgd, Class 2 – sewage treatment 0.5-1.0 mgd, Class 3 – sewage treatment 0.25-1.0 mgd, Class 4 – 0.1-0.25 mgd, Class 5 – <0.1 mgd.

The Maumee River is a critical source of Western Lake Erie Basin (WLEB) nutrient loading (Dolan and McGunagle, 2005). Other studies have supported the Ohio EPA finding that nonpoint sources dominate the load in the Maumee watershed. Scavia and others (2016) calculated a conservative mass balance of phosphorus loading in the Maumee River averaged over nine years. They estimated 7 percent of total P load was from point sources, 3 percent from HSTS and the remainder was from other nonpoint nutrient inputs, which is similar to the total P proportions found in the Ohio EPA study. Using NCWQR data, Baker and others (2006) attributed high FWMCs relative to time-weighted mean concentrations to the dominance of nonpoint source loading. The FWMC weights the sample concentration by flow in addition to time. Therefore, when the concentration is higher at high flows the FWMC increases. If the concentrations are higher at low flows, which occur more frequently than high flows, the time-weighted concentration increases. Since point sources have a greater impact to
concentration at low flows and nonpoint sources at high flows, the comparison of the FWMC and the time-weighted mean concentration can identify the influence of different sources on a stream. Nutrient reduction efforts currently being pursued in the Maumee River Basin have emphasized the importance of nonpoint source nutrient reductions and this study supports that approach.
3.3 Portage River

The Portage River drains 585 sq. mi. in northwest Ohio (Figure 9). It is the smallest watershed considered in this study. The National Center for Water Quality Research (NCWQR) maintains a water quality station at a USGS gaging station in Woodville, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 428 sq. mi. and 157 sq. mi. downstream of the pour point.

Agricultural production dominates the landscape, with 81 percent of the total land area being dedicated to agricultural production. Natural areas and low intensity development were similar to each other at 8.4 percent and 8.7 percent respectively. The area downstream of the pour point had similar land use with the largest change being a reduction in agricultural lands of 11 percent, which was replaced largely by natural areas increasing by 10 percent.

Total P loads from the Portage River were 168 metric tons per year (mta) in wy13 and 219 mta for wy14 (Figure 10 and Table 8). Total N loads from the Portage River were 3,882 mta in wy13 and 3,068 mta for wy14 (Figure 11 and Table 8).
Figure 11 — Total nitrogen loads for the Sandusky River. Loads are presented in three major categories: 1) Household Sewage Treatment Systems (HSTS); 2) NPDES permitted loads (Total NPDES) – includes CSOs; and 3) Nonpoint source (NPS).

There was an increase in loading for both total P and total N from wy13 to wy14 (Table 8). Load is the product of flow and concentration. The annual flow is presented as water yield (flow volume divided by watershed area) and the concentration is presented as the FWMC. The two years had a water yield of 13.3 in (wy13) and 15.6 in (wy14) at the Woodville pour point. The median water yield from 1996 – 2015 at this location was 13.5 in. The FWMC averages the nutrient concentration based on streamflow and is most appropriate for loading discussions. Annual FWMC may vary in streams for many reasons, including: timing of agricultural activities relative to precipitation events, rainfall intensity, overall magnitude of a storm (large storms move more than a series of small storms) and others. For total P, both water yield and FWMC increased, producing an increase in annual load; however, for total N, while water yield increased, only a slight increase in annual load resulted because it was offset by a decrease in FWMC.

Table 8 — Changes in flow-weighted mean concentration (FWMC), total load and water yield for wy13 and wy14. Water yield is annual discharge normalized by watershed area (in units of inches). FWMC and annual discharge are calculated at the pour point and do not include downstream drainage area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wy13</th>
<th>wy14</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Yield (in)</td>
<td>13.3</td>
<td>15.6</td>
<td>↑17</td>
</tr>
<tr>
<td>20-yr Median Water Yield (in) – 13.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>0.32</td>
<td>0.36</td>
<td>↑12</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>168</td>
<td>219</td>
<td>↑30</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>7.63</td>
<td>5.19</td>
<td>↓32</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>3,882</td>
<td>3,068</td>
<td>↓21</td>
</tr>
</tbody>
</table>
The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N in wy13 are presented in Figure 12. The figure shows the nonpoint source is the largest proportion of the load in the Portage River at 84 and 90 percent for total P and total N, respectively. The NPDES sources comprised 11 and 8 percent of the total P and total N loads, respectively. The NPDES sources are further broken down into categories corresponding to plant type and size. The single largest load contributor is major WWTPs (total P – 34 percent; total N – 72 percent). CSOs and class 2 WWTPs (0.5 – 1.0 mgd) are also large total P load contributors contributing 22 and 27 percent of the total NPDES loads, respectively. HSTS are the remaining 6 percent of the annual total P load and 3 percent of the annual total N load. A pie-chart is not presented for wy14, but the total P load increased as a result of an increase in NPS load (Figures 10 and 11) resulting in decreases in the relative contribution of NPDES sources and HSTS. The relative loading of total N followed the opposite trend of total P because the NPS load decreased between wy13 and wy14.

![Pie charts showing total P and total N loads](image)

**Figure 12** — Total phosphorus and nitrogen load from different sources relative to total load for the Portage watershed in wy13. NPDES sources: Major WWTP – sewage treatment >1.0 mgd, Class 2 – sewage treatment 0.5-1.0 mgd, Class 3 – sewage treatment 0.25-1.0 mgd, Class 4 – sewage treatment 0.1-0.25 mgd, Class 5 – sewage treatment <0.1 mgd.

The Portage River is considered a priority watershed for nutrient reduction to the western basin of Lake Erie (Annex 4 of the 2012 Great Lakes Water Quality Agreement). However, because of its relatively small size (less than 10 percent of the area of the Maumee River watershed) it has been studied less. However, the results of this study show that the Portage watershed had high nonpoint source yields and elevated per capita nutrient yields. Therefore, the Portage River is highlighted as an important part of nutrient reductions to the western basin of Lake Erie.
3.4 Sandusky River

The Sandusky River drains 1,420 sq. mi. in north central Ohio (Figure 13). The National Center for Water Quality Research (NCWQR) maintains a water quality station at a USGS gaging station in Fremont, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 1,251 sq. mi. and 170 sq. mi. downstream of the pour point.

Agricultural production dominates the landscape, with 80 percent of the total land area being dedicated to agricultural production. Natural areas are the second leading land use at 11 percent and the remainder are developed lands. The land use distribution downstream of the pour point is similar to that upstream of the pour point, where the largest change is less than 3 percent for any given land use.

Total P loads from the Sandusky River were 711 metric tons per year (mta) in wy13 and 615 mta for wy14 (Figure 14 and Table 9). Total N loads from the Sandusky River were 11,407 mta in wy13 and 8,356 mta for wy14 (Figure 15 and Table 9).

Figure 13 — Project area represented in the Sandusky River mass balance. The pour point along with up and downstream drainage areas are shown.
There was a decrease in loading for both total P and total N from wy13 to wy14 (Table 9). Load is the product of flow and concentration. The annual flow is presented as water yield (flow volume divided by watershed area) and the concentration is presented as the FWMC. The two years had a water yield of 18.1 in (wy13) and 17.2 in (wy14) at the Fremont pour point. The median water yield from 1996 – 2015 at this location was 14.0 in. The FWMC averages the nutrient concentration based on streamflow and is most appropriate for loading discussions. Annual FWMC may vary in streams for many reasons, including: timing of agricultural activities relative to precipitation events, rainfall intensity, overall magnitude of a storm (large storms move more than a series of small storms) and others. The change in annual load for total N and total P between the two years was due to a decrease in annual discharge and an accompanying decrease in FWMC.
Table 9 — Changes in flow-weighted mean concentration (FWMC), total load and water yield for wy13 and wy14. Water yield is annual discharge normalized by watershed area (in units of inches). FWMC and annual discharge are calculated at the pour point and do not include downstream drainage area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wy13</th>
<th>wy14</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Yield (in)</td>
<td>18.1</td>
<td>17.2</td>
<td>↓5</td>
</tr>
<tr>
<td>20-yr Median Water Yield (in)</td>
<td>–</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td><strong>Total P</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>0.41</td>
<td>0.38</td>
<td>↓9</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>711</td>
<td>615</td>
<td>↓14</td>
</tr>
<tr>
<td><strong>Total N</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>6.66</td>
<td>5.12</td>
<td>↓23</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>11,407</td>
<td>8,356</td>
<td>↓27</td>
</tr>
</tbody>
</table>

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N in wy13 are presented in Figure 16. This figure shows that the nonpoint source is the largest proportion of the load in the Sandusky River at 94 and 96 percent, respectively, for total P and total N. The NPDES sources comprised 4 and 3 percent of the total P and total N loads, respectively. The NPDES sources are further broken down into categories corresponding to plant type and size. The single largest NPDES load contributor is from CSOs for total P, comprising 42 percent of the NPDES total P load. The major WWTPs contributed a similar amount of total P as the Class 2 facilities (0.5 – 1.0 mgd) for total P at 28 and 23 percent, respectively. For total N the largest NPDES load contributor is from major WWTPs, comprising 57 percent of the NPDES total N load. CSOs made up the largest portion of the remaining NPDES total N loads at 33 percent of the annual load. Discharge limits for phosphorus are the reason that the major WWTPs are not the leading NPDES source in both categories. HSTS are the remaining 2 percent of the annual total P load and 1 percent of the annual total N load. A pie-chart is not presented for wy14, but the total load decreased as a result of a decrease in NPS load (Figures 14 and 15) resulting in increases in the relative contribution of NPDES sources and HSTS.
Figure 16 — Total phosphorus and nitrogen load from different sources relative to total load for the Sandusky watershed in wy13. NPDES sources: Major WWTP – sewage treatment >1.0 mgd, Class 2 – sewage treatment 0.5-1.0 mgd, Class 3 – sewage treatment 0.25-1.0 mgd, Class 4 – sewage treatment 0.1-0.25 mgd, Class 5 – sewage treatment <0.1 mgd.

The Sandusky River is a central Lake Erie basin tributary and is targeted for a 40 percent reduction in annual loads to curb central basin hypoxia as well as a 40 percent reduction of spring total and dissolved phosphorus to curb nearshore cyanobacteria blooms (Annex 4 of the 2012 Great Lakes Water Quality Agreement). The NCWQR is located in Tiffin, Ohio in the center of the Sandusky River watershed and the river has been central to many of their loading studies. A NCWQR study estimated that only 4 percent of the annual phosphorus export in the Sandusky River was from point sources (Baker, 2006). Baker and others (2006) also presented a FWMC for total P as being the highest amongst the watersheds the Ohio EPA mass balance study. Also, the Ohio EPA mass balance study identified the Sandusky River as having the highest nonpoint source total P yields among the seven watersheds studied. Further, the highest relative loading of total P and total N attributed to nonpoint sources in this study were in the Sandusky River watershed. The results identified highlight the importance of nonpoint source loadings in a watershed that has 80 percent of its land use dedicated to agricultural production.
3.5 Cuyahoga River

The Cuyahoga River drains 808 sq. mi. in northeast Ohio (Figure 17). The National Center for Water Quality Research (NCWQR) maintains a water quality station at a USGS gaging station in Independence, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 707 sq. mi. and 101 sq. mi. downstream of the pour point.

Natural areas and low intensity development dominate the land use of the Cuyahoga watershed at 38 percent and 36 percent, respectively. Downstream of the pour point there was a notable shift in land use with a reduction of natural and agricultural areas to largely low and high intensity development, 56 percent and 36 percent, respectively.

Total P loads from the Cuyahoga River were 327 metric tons per year (mta) in wy13 and 402 mta for wy14 (Figure 18 and Table 10). Total nitrogen loads from the Cuyahoga River were 6,163 mta in wy13 and 5,971 mta for wy14 (Figure 19 and Table 10).

Figure 17 — Project area represented in the Cuyahoga River mass balance. The pour point along with up and downstream drainage areas are shown.

Figure 18 — Total phosphorus loads for the Cuyahoga River. Loads are presented in three major categories: 1) Household Sewage Treatment Systems (HSTS); 2) NPDES permitted loads (Total NPDES) – includes CSOs; and 3) Nonpoint source (NPS).
There was an increase in loading for both total P and total N from wy13 to wy14 (Table 10). Load is the product of flow and concentration. The annual flow is presented as water yield (flow volume divided by watershed area) and the concentration is presented as the FWMC. The two years had a water yield of 21.2 in (wy13) and 22.4 in (wy14) at the Independence pour point. The median water yield from 1996 – 2015 at this location was 21.6 in. The FWMC averages the nutrient concentration based on streamflow and is most appropriate for loading discussions. Annual FWMC may vary in streams for many reasons, including: timing of agricultural activities relative to precipitation events, rainfall intensity, overall magnitude of a storm (large storms move more load than a series of small storms) and others. The increase in annual load for total P between the two years was due to an increase in annual discharge and an accompanying increase in FWMC. A similar increase would have been expected for the total N loads in wy14, however, a decrease in NPDES loading downstream of the pour point was larger than the increase in nonpoint source load.

Table 10 — Changes in flow-weighted mean concentration (FWMC), total load and water yield for wy13 and wy14. Water yield is annual discharge normalized by watershed area (in units of inches). FWMC and annual discharge are calculated at the pour point and do not include downstream drainage area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wy13</th>
<th>wy14</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Yield (in)</td>
<td>21.2</td>
<td>22.4</td>
<td>↑6</td>
</tr>
<tr>
<td>20-yr Median Water Yield (in) – 21.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>0.23</td>
<td>0.27</td>
<td>↑17</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>327</td>
<td>402</td>
<td>↑23</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>2.79</td>
<td>2.84</td>
<td>↑2</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>6,163</td>
<td>5,971</td>
<td>↓3</td>
</tr>
</tbody>
</table>

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N in wy13 are presented in Figure 20. The figure shows the nonpoint source is the largest proportion of the total P load in the Cuyahoga River at 60
percent and second largest component for the total N load at 32 percent. The NPDES sources comprised 29 percent of the total P load and 62 percent of the total N load. The NPDES sources are further broken down into categories corresponding to plant type and size. The single largest NPDES load contributor is from major WWTPs for total P and total N, comprising 56 and 91 percent of the total P and total N loads, respectively. CSOs were the second leading NPDES contributor of both nutrients, at 40 percent of the NPDES total P load and 9 percent of the NPDES total N load. HSTS are the remaining 14 percent of the annual total P load and 7 percent of the annual total N load. A pie-chart is not presented for wy14, but the proportion of NPDES total N and P load decreased as a result of an increase in NPS load (Figures 18 and 19).

![Pie chart of nutrient load sources](image)

**Figure 20** — Total phosphorus and nitrogen load from different sources relative to total load for the Cuyahoga watershed in wy13. NPDES sources: Major WWTP – sewage treatment >1.0 mgd, Class 2 – sewage treatment 0.5-1.0 mgd, Class 3 – sewage treatment 0.25-1.0 mgd, Class 4 – sewage treatment 0.1-0.25 mgd, Class 5 – sewage treatment <0.1 mgd.

The Cuyahoga River is one of the most urbanized watersheds in Ohio with more than 1,200 people/sq. mi., nearly four times greater than any other watershed in this study. The relative point source loading is consequently among the highest of the seven watersheds studied. However, the relative loading of total P is much lower than that of total N, an indication of phosphorus limits at the WWTPs discharging greater than 1.0 mgd. Even with the flow contribution of point sources to, the time-weighted mean concentration of total phosphorus (indicative of high low flow phosphorus concentrations) was lower than that of the Scioto and Great Miami rivers (Baker et al., 2006).
3.6 Great Miami River

The Great Miami River drains 3,889 sq. mi., excluding drainage area of the Whitewater River, in southwest Ohio and southeast Indiana (Figure 21). The National Center for Water Quality Research (NCWQR) maintains a water quality station at a USGS gaging station in Miamisburg, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 2,685 sq. mi. and 1,204 sq. mi. downstream of the pour point.

Agricultural land use dominates the Great Miami River watershed, with 68 percent of the land being in agricultural production. Downstream of the pour point, the largest shift in land use was from agricultural production to natural areas.

Total P loads from the Great Miami River were 1,266 metric tons per year (mta) in wy13 and 1,798 mta for wy14 (Figure 22 and Table 11). Total N loads from the Great Miami River were 18,638 mta in wy13 and 20,805 mta for wy14 (Figure 23 and Table 11).
There was an increase in loading for both total P and total N from wy13 to wy14 (Table 11). Load is the product of flow and concentration. The annual flow is presented as water yield (flow volume divided by watershed area) and the concentration is presented as the FWMC. The two years had a water yield of 13.8 in (wy13) and 18.4 in (wy14) at the Miamisburg pour point. The median water yield from 1996 – 2015 at this location was 17.3 in. The FWMC averages the nutrient concentration based on streamflow and is most appropriate for loading discussions. Annual FWMC may vary in streams for many reasons, including: timing of agricultural activities relative to precipitation events, rainfall intensity, overall magnitude of a storm (large storms move more than a series of small storms) and others. The change in annual load for total P between the two years was due to an increase in annual discharge coupled with an increase in the FWMC. However, while total N loading still increased between the two years the magnitude was smaller because the FWMC decreased between the two years.

Table 11 — Changes in flow-weighted mean concentration (FWMC), total load and water yield for wy13 and wy14. Water yield is annual discharge normalized by watershed area (in units of inches). FWMC and annual discharge are calculated at the pour point and do not include downstream drainage area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wy13</th>
<th>wy14</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Yield (in)</td>
<td>13.8</td>
<td>18.4</td>
<td>↑33</td>
</tr>
<tr>
<td>20-yr Median Water Yield (in) – 17.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>0.37</td>
<td>0.39</td>
<td>↑6</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>1,266</td>
<td>1,798</td>
<td>↑42</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>5.31</td>
<td>4.42</td>
<td>↓17</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>18,638</td>
<td>20,805</td>
<td>↑12</td>
</tr>
</tbody>
</table>

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N in wy13 are presented in Figure 24. The figure shows the nonpoint source is the largest proportion of the total P and total N load in the Great Miami River at 56 and 80 percent, respectively. The NPDES sources comprised 38 percent of the total P load and 17 percent
of the total N load. The NPDES sources are further broken down into categories corresponding to plant type and size. The single largest NPDES load contributor is from major WWTPs for total P and total N, comprising 88 and 91 percent of the total P and total N loads, respectively. Industrial facilities were the second leading NPDES contributor of both nutrients, at 7 percent of the NPDES total P load and 4 percent of the NPDES total N load. HSTS are the remaining 6 percent of the annual total P load and 3 percent of the annual total N load. A pie-chart is not presented for wy14, but the total N and P load increased as a result of an increase in NPS load (Figures 22 and 23) resulting in a decrease in the relative contribution of NPDES sources and HSTS.

The Great Miami River has been studied as a contributor of nutrients to the Gulf of Mexico. A National Oceanic and Atmospheric Administration (NOAA) study (Goolsby, 1999) found the watershed had both total P and dissolved phosphorus yield among the 5 highest out of 42 watersheds studied in the Mississippi-Atchafalaya River basin. A NCWQR study found the Great Miami River to have the highest soluble reactive phosphorus concentrations and the highest time weighted average total P concentration amongst 10 streams studied in Ohio (Baker, 2006). A study by the Miami Conservancy District highlighted that the dissolved orthophosphate was the dominant form of phosphorus in their samples at 63 percent of the total P and that total P concentrations increased at both high and low flows (MCD, 2012). These studies demonstrate an increased prevalence of NPDES sources for TP, supporting the findings of the Ohio EPA mass balance efforts.
3.7 Scioto River

The Scioto River drains 6,509 sq. mi. in central and south central Ohio (Figure 25). The National Center for Water Quality Research (NCWQR) maintains a water quality station at a USGS gaging station in Chillicothe, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 3,854 sq. mi. and 2,655 sq. mi. downstream of the pour point.

Agricultural land use dominates the Scioto watershed, with 58 percent of the land being in agricultural production. Downstream of the pour point, the largest shift in land use was from agricultural production to natural areas.

Total P loads from the Scioto River were 2,036 metric tons per year (mta) in wy13 and 2,426 mta for wy14 (Figure 26 and Table 12). Total nitrogen loads from the Scioto River were 22,943 mta in wy13 and 27,971 mta for wy14 (Figure 27 and Table 12).
There was an increase in loading for both total P and total N from wy13 to wy14 (Table 12). Load is the product of flow and concentration. The annual flow is presented as water yield (flow volume divided by watershed area) and the concentration is presented as the FWMC. The two years had a water yield of 14.0 in (wy13) and 17.6 in (wy14) at the Chillicothe pour point. The median water yield from 1996 – 2015 at this location was 15.6 in. The FWMC averages the nutrient concentration based on streamflow and is most appropriate for loading discussions. Annual FWMC may vary in streams for many reasons, including: timing of agricultural activities relative to precipitation events, rainfall intensity, overall magnitude of a storm (large storms move more than a series of small storms) and others. The change in annual load for total P and total N between the two years was due to an increase in annual discharge with a slight decrease in the FWMC.

**Table 12 — Changes in flow-weighted mean concentration (FWMC), total load and watershed discharge for wy13 and wy14. Discharge in inches normalized by watershed area.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wy13</th>
<th>wy14</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Yield (in)</td>
<td>14.0</td>
<td>17.6</td>
<td>↑26</td>
</tr>
<tr>
<td>20-yr Median Water Yield (in)</td>
<td>15.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>0.40</td>
<td>0.37</td>
<td>↓7</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>2,036</td>
<td>2,426</td>
<td>↑19</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>4.13</td>
<td>3.94</td>
<td>↓5</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>22,943</td>
<td>27,971</td>
<td>↑26</td>
</tr>
</tbody>
</table>

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N in wy13 are presented in Figure 28. The nonpoint source contributed 66 percent of the annual total P load and 81 percent of the annual total N load. The figure shows the NPDES sources are the contributed 30 percent of the total P and 16 percent of the total N loads. The NPDES sources are further broken down into categories corresponding to plant type and size. The single largest NPDES load contributor is from major WWTPs for total P and total N, comprising 93 and 92 percent of the total P and total N loads,
respectively. All other components of the NPDES load were less than 5 percent of the annual NPDES total P or N loads. HSTS are the remaining 4 percent of the annual total P load and 3 percent of the annual total N load. A pie-chart is not presented for wy14, but the total N and P load increased as a result of an increase in NPS load (Figures 26 and 27). However, a similar increase in NPDES load resulted in little change in the relative contributions for TP and TN.

![Pie charts showing the percentage of total phosphorus and nitrogen load from different sources.](image)

**Figure 28 — Total phosphorus and nitrogen load from different sources relative to total load for the Scioto watershed in wy13. NPDES sources: Major WWTP — sewage treatment >1.0 mgd, Class 2 — sewage treatment 0.5-1.0 mgd, Class 3 — sewage treatment 0.25-1.0 mgd, Class 4 — sewage treatment 0.1-0.25 mgd, Class 5 — sewage treatment <0.1 mgd.**

The Scioto River is the second largest watershed in Ohio that drains to the Ohio River. Baker and others (2006) found a time-weighted mean contribution of total phosphorus that was greater than the flow-weighted mean. They suggest that this occurs with an increased influence from point sources. This supports the Ohio EPA study identifying a high influence of point sources.
3.8 Muskingum River

The Muskingum River drains 8,044 sq. mi. primarily in northeast and southeast Ohio (Figure 29). The National Center for Water Quality Research (NCWQR) maintains a water quality station at a USGS gaging at McConnelsville, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 7,420 sq. mi. and 624 sq. mi. downstream of the pour point.

Natural and agricultural land use dominates the Muskingum River watershed, with 48 percent and 40 percent respectively. Downstream of the pour point, the largest shift in land use was from agricultural production to natural areas.

Total phosphorus loads from the Muskingum River were 1,360 metric tons per year (mta) in wy13 and 1,666 mta for wy14 (Figure 30 and Table 13). Total N loads from the Muskingum River were 19,963 mta in wy13 and 23,456 mta for wy14 (Figure 31 and Table 13).
Figure 3 — Total nitrogen loads for the Muskingum River. Loads are presented in three major categories: 1) Household Sewage Treatment Systems (HSTS); 2) NPDES permitted loads (Total NPDES) – includes CSOs; and 3) Nonpoint source (NPS).

There was an increase in loading for both total P and total N from wy13 to wy14 (Table 13). Load is the product of flow and concentration. The annual flow is presented as water yield (flow volume divided by watershed area) and the concentration is presented as the FWMC. The two years had a water yield of 14.9 in (wy13) and 18.7 in (wy14) at the McConnelsville pour point. The median water yield from 1996 – 2015 at this location was 15.4 in. The FWMC averages the nutrient concentration based on streamflow and is most appropriate for loading discussions. Annual FWMC may vary in streams for many reasons, including: timing of agricultural activities relative to precipitation events, rainfall intensity, overall magnitude of a storm (large storms move more than a series of small storms) and others. The change in annual load for total P and total N between the two years was due to an increase in annual discharge with a slight decrease in the FWMC.

Table 13 — Changes in flow-weighted mean concentration (FWMC), total load and water yield for wy13 and wy14. Water yield is annual discharge normalized by watershed area (in units of inches). FWMC and annual discharge are calculated at the pour point and do not include downstream drainage area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wy13</th>
<th>wy14</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Yield (in)</td>
<td>14.9</td>
<td>18.7</td>
<td>↑26</td>
</tr>
<tr>
<td>14-yr Median Water Yield (in) – 15.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>0.18</td>
<td>0.17</td>
<td>↓3</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>1,360</td>
<td>1,666</td>
<td>↑23</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWMC (mg/L)</td>
<td>2.42</td>
<td>2.26</td>
<td>↓6</td>
</tr>
<tr>
<td>Annual Load (mta)</td>
<td>19,963</td>
<td>23,456</td>
<td>↑17</td>
</tr>
</tbody>
</table>

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N in wy13 are presented in Figure 32. The nonpoint source contributed 41 percent of the annual total P load and 25 percent of the annual total N load. The figure shows the NPDES sources contributed 49 percent of the total P and 25 percent of the total N loads. The NPDES sources are further broken down into categories corresponding to plant type and size. The single largest NPDES load contributor is from major WWTPs for total P and total N, comprising 84 and 63 percent of the total P and total N loads,
respectively. Industrial facilities were the second highest source of NPDES total P and total N load with 9 and 30 percent, respectively. HSTS are the remaining 10 percent of the annual total P load and 7 percent of the annual total N load. A pie-chart is not presented for wy14, but the total N and P load increased as a result of an increase in NPS load (Figures 30 and 31) resulting in a decrease in the relative contribution of NPDES sources and HSTS. This decrease resulted in a shift from NPDES sources to nonpoint sources as the leading total P contributor.

![Pie charts showing the percentage of total P and total N load from different sources](image)

**Figure 32** — Total phosphorus and nitrogen load from different sources relative to total load for the Muskingum watershed in wy13. NPDES sources: Major WWTP – sewage treatment >1.0 mgd, Class 2 – sewage treatment 0.5-1.0 mgd, Class 3 – sewage treatment 0.25-1.0 mgd, Class 4 – sewage treatment 0.1-0.25 mgd, Class 5 – sewage treatment <0.1 mgd.

The Muskingum River has the highest proportion of natural areas of any watershed in this study. It was also the stream with the lowest nonpoint source yield for both total P and total N. Industrial sources of total P and total N were a larger proportion of the total load than any other watershed.
4 Summary and Future Work

Nutrient loads (total P and total N) were estimated and divided into major contributing sources for seven watersheds in Ohio, covering 63 percent of the land area of Ohio. This study noted several factors that influence watershed loading, including: watershed size; annual water yield; nonpoint source yield; land use; per capita yield; and population density. These factors help describe the total load from a watershed and also the breakdown of sources contributing to those loads. It is not in the scope of this work to recommend nutrient reductions relative to different sources identified in the loading analysis. The seven watersheds studied varied both in total loads contributed relative to the watershed size and the relative role of each of their sources. Understanding these differences will help inform future decisions as nutrient reduction efforts are pursued to meet the goals of national and international agreements for the Gulf of Mexico and Lake Erie.

Pursuant to the requirements of ORC 6111.03 (U), Ohio EPA is required to update this work biannually and coinciding with the release of the Integrated Report\(^3\). External feedback on our approach and results produced valuable suggestions for future editions of the biennial nutrient balance report. Specific items are shown in Table 14 and include relative priority and the party that can help address it. In general, future editions will strive to cover more land area, including some areas that are not currently monitored with the same level of detail as the seven watersheds in the current version. This may require new means to estimate loads that could require an expanded work effort. Note that all new efforts listed in Table 14 are contingent on funding, labor support, and institutional cooperation.

Future editions will consider any new information that becomes available for attributing loads to appropriate sources. Some particular areas where refined information would improve the ability to estimate loads would be CSOs, HSTS and the breakdown of nonpoint source loads. The total P and total N concentration data for CSOs that are currently available came from studies in the early 1990s; newer studies would improve the estimates for CSO loading. HSTS accounting is limited by the lack of available data describing the system locations and types. Much of this information does exist at the county level, if this data was compiled into a common format it could be used to refine future versions of this report. Assessing the NPS runoff from developed areas compared to natural and agricultural areas is not possible in the current version. Defining the relative contributions from NPS sources will require better monitoring and modeling data that quantifies the loading from the different sources. If data becomes available for any of the defined needs, Ohio EPA will consider it in future developments of the nutrient mass balance effort.

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\(^3\) *Integrated Water Quality Monitoring and Assessment Report* which satisfies the Clean Water Act requirements for both Section 305(b) for biennial reports on the condition of the State’s waters and Section 303(d) for a prioritized list of impaired waters.
Table 14 — Proposed additions and modifications to the biennial nutrient balance approach including priority and potential parties to accomplish same objective. Priority is a goal defined by each subsequent report cycle (e.g., priority 1 goal is the 2018 report).

<table>
<thead>
<tr>
<th>Objective</th>
<th>Priority</th>
<th>Primary Role</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial Extent</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expand LE watersheds – Vermilion R, Huron R, Grand R (at most for wy 2017 and beyond^a)</td>
<td>1</td>
<td>Mass balance effort – OEPA Pour-point monitoring – NCWQR and USGS</td>
</tr>
<tr>
<td>Expand OR watersheds – Hocking R, Little Miami R, Mahoning R (at most for wy 2017 and beyond^a)</td>
<td>1</td>
<td>OEPA, other – based on funding</td>
</tr>
<tr>
<td>Expand LE watersheds – Black R, Toussaint Ck, Rocky R, Chagrin R</td>
<td>2</td>
<td>OEPA, USGS WQ monitoring, other – based on funding</td>
</tr>
<tr>
<td>Expand OR watersheds – Wabash R (Ohio portion), Mill Ck (Cincinnati)</td>
<td>2</td>
<td>OEPA, other – based on funding</td>
</tr>
<tr>
<td>Include direct NPDES discharges to LE and OR; compute for wy 2013-2021</td>
<td>3</td>
<td>OEPA</td>
</tr>
<tr>
<td><strong>Methodology / Approach</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Begin portrayal of loading trends and to include wy 2013-2017</td>
<td>1</td>
<td>OEPA</td>
</tr>
<tr>
<td>Determine appropriate load estimator and apply to new watersheds (see above) with less frequent WQ monitoring^a</td>
<td>1</td>
<td>OEPA</td>
</tr>
<tr>
<td>Report proportion of failing and direct-discharge HSTS by individual county, when necessary, in selected watersheds</td>
<td>1</td>
<td>OEPA, ODH, support from individual counties</td>
</tr>
<tr>
<td>Determine population count on central sewer using sewer district maps where areawide planning agencies exist</td>
<td>2</td>
<td>Ohio areawide planning agencies, OEPA</td>
</tr>
<tr>
<td><strong>Data Input / Parameterization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve estimate of CSO total P and total N concentrations</td>
<td>1</td>
<td>Ohio municipalities, AOMWA</td>
</tr>
<tr>
<td>Separate NPS load estimation into agricultural and urban/suburban components; estimate urban component from field monitoring</td>
<td>2</td>
<td>OEPA, Ohio areawide planning agencies, ODA, Ohio Farm Bureau</td>
</tr>
<tr>
<td>Differentiate NPS agricultural component by nutrient source (i.e., organic manure vs. synthetic fertilizer)</td>
<td>3</td>
<td>OEPA, ODA, Ohio Farm Bureau, county SWCD</td>
</tr>
</tbody>
</table>

**Notes:**

a. Depending on availability of frequent and timely chemical sampling and flow data.

**Abbreviations:**

LE=Lake Erie, OR=Ohio River, R=river, Ck=Creek, IR=Integrated Report, WQ=water quality, AOMWA=Association of Ohio Metropolitan Wastewater Agencies, CSO=combined sewer overflow, ODH=Ohio Department of Health, USGS=US Geological Survey, NCWQR=National Center for Water Quality Research, ODA=Ohio Department of Agriculture, SWCD=soil and water conservation district
Acknowledgements

The following Ohio EPA staff were instrumental in preparing this document:

Data Analysis and Report Preparation: Dale White, Josh Griffin, Bill Schumacher, Sarah Becker

Reviewers: Cathy Alexander, Brian Hall, Dan Dudley, Sandra Kosek-Sills (Ohio Lake Erie Commission), Bob Miltner, Paul Gledhill, and Gregg Sablak

Technical support and review was also offered by staff from Ohio Department of Natural Resources, Ohio Department of Agriculture, Ohio Department of Health, Association of Ohio Metropolitan Wastewater Agencies, Ohio Farm Bureau, National Center for Water Quality Research, U.S. Geological Survey (Ohio Water Science Center) and The Nature Conservancy (Ohio Chapter).
References Cited


Appendix A - Spring Nutrient Loading for Selected Lake Erie Tributaries
The 2012 Great Lakes Water Quality Agreement (GLWQA) via the Nutrients Annex Subcommittee (Annex 4; herein Annex) and their Objectives and Targets Task Team set specific loading targets for priority Lake Erie tributaries. Three of the watersheds in this study have priority spring season loading targets set forth by the Annex: Maumee, Portage and Sandusky. Each of these watersheds has a targeted 40 percent reduction of spring total and dissolved reactive phosphorus relative to 2008 levels. Since the load is influenced by the total flow, the Annex also suggests that achieving a 40 percent reduction from the 2008 value in flow weighted mean concentration (FWMC) would meet the loading targets. The Annex defines the spring season different from the typical seasonal spring using instead the March 1 – July 31 time-frame. All loading and FWMC calculations were done using a calculation tool developed by the National Center for Water Quality Research (NCWQR). The tool used NCWQR’s water quality data and streamflow from the corresponding USGS gaging station. Since the mass balance analysis in the main report does not allow for speciation to sources for dissolved reactive phosphorus, these targets will not be presented. Further the Annex proposed tracking progress towards the targets at the pour points in the mass balance study. For this reason, the loads downstream of the pour points are not included in this appendix.

Maumee River

For the Maumee River, the 2008 spring total phosphorus load was 1438 metric tons (MT) with the 40 percent reduction resulting in a target of 860 MT. The spring loads for 2013 and 2014 were 1244 MT and 1183 MT, respectively. These values are presented on Figure A1. The FWMC’s for 2008 base year and two spring seasons are also presented in Figure A1. For the spring of 2013 and 2014, the loads exceeded the target by 31 and 27 percent, respectively. The FWMC exceeded the target by 45 percent in 2013 and 30 percent in 2014. These observations identify that the targets were not met in either year but loads are declining; however, there is not enough information in this report to suggest that any temporal trend exists.

Figure A1. Maumee River spring load and flow weighted mean concentrations (FWMC) using water quality data from the NCWQR and streamflow from the USGS gage at Waterville, Ohio. Point source and HSTS loads are presented separately for the two years covered in the nutrient mass balance report, but not for the 2008 base year. A 2008 base year and targets from the recommendations of the Annex 4 (Nutrients) Objectives and Targets Task Team of the GLWQA of 2012 are also presented.
Portage River

Continuous monitoring of nutrient concentrations did not begin in the Portage River until 2010, after the index year of 2008. Consequently, the spring loads cannot be compared to a target without a different approach to estimate the 2008 load. Figure A2 presents the spring loads for both 2013 and 2014. The spring load for 2013 was 69.5 MT corresponding to a FWMC of 0.32 mg/L. The spring load for 2014 was 64.8 MT corresponding to a FWMC of 0.36 MT. Trends in total load cannot be determined from two years of information; further, targets could not be set based on lack of 2008 water quality monitoring data.

Figure A2. Portage River spring load and flow weighted mean concentrations using water quality data from NCWQR and streamflow from the USGS gage at Woodville, Ohio. Point source and HSTS loads are presented separately for the two years.
Sandusky River

The 2008 spring total phosphorus load was 350 MT with the 40 percent reduction resulting in a target of 210 MT. The spring loads for 2013 and 2014 were 369 MT and 227 MT, respectively. These values are presented on Figure A3. The flow weighted mean concentrations (FWMC) are also presented in Figure A3. For the spring of 2013 and 2014, the loads exceeded the target by 43 and 7 percent, respectively. The FWMC exceeded the target by 43 percent in 2013 and 42 percent in 2014. These observations identify that the targets were not met in either year, though they are close to meeting in 2014. Loads are declining; however, there is not enough information in this report to suggest that any temporal trend exists.

Figure A3. Spring load and flow weighted mean concentrations at the Fremont USGS gage on the Sandusky River. Point source and HSTS loads are presented separately for the two years covered in the nutrient mass balance report but not for the 2008 base year. Targets based on the 2008 base year are also identified.
Appendix B – Summary Tables for Mass Balance Calculations
Table B1. Loading components and mass balance calculations for the Maumee River watershed.

<table>
<thead>
<tr>
<th>Source</th>
<th>yr13 TP Load (mta)</th>
<th>yr13 TN Load (mta)</th>
<th>yr14 TP Load (mta)</th>
<th>yr14 TN Load (mta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading Upstream of the Pour Point</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major WWTP</td>
<td>33.2</td>
<td>829.0</td>
<td>41.0</td>
<td>813.1</td>
</tr>
<tr>
<td>Class 2</td>
<td>8.7</td>
<td>35.9</td>
<td>9.0</td>
<td>40.1</td>
</tr>
<tr>
<td>Class 3</td>
<td>6.7</td>
<td>31.3</td>
<td>8.7</td>
<td>32.5</td>
</tr>
<tr>
<td>Class 4</td>
<td>4.9</td>
<td>70.5</td>
<td>5.8</td>
<td>15.7</td>
</tr>
<tr>
<td>Class 5</td>
<td>4.3</td>
<td>34.0</td>
<td>7.2</td>
<td>38.9</td>
</tr>
<tr>
<td>Industrial</td>
<td>12.1</td>
<td>54.4</td>
<td>12.0</td>
<td>52.7</td>
</tr>
<tr>
<td>Wet Weather</td>
<td>10.9</td>
<td>99.2</td>
<td>17.1</td>
<td>156.4</td>
</tr>
<tr>
<td>OOS NPDES</td>
<td>34.4</td>
<td>1160.9</td>
<td>36.3</td>
<td>1271.6</td>
</tr>
<tr>
<td>OOS Wet Weather</td>
<td>26.7</td>
<td>243.8</td>
<td>28.5</td>
<td>260.4</td>
</tr>
<tr>
<td>Total NPDES</td>
<td>142.0</td>
<td>2559.0</td>
<td>165.6</td>
<td>2681.5</td>
</tr>
<tr>
<td>HSTS</td>
<td>80.7</td>
<td>582.2</td>
<td>80.7</td>
<td>582.2</td>
</tr>
<tr>
<td>NPS = Total load - NPDES load - HSTS load</td>
<td>2134.5</td>
<td>40348.2</td>
<td>1919.3</td>
<td>34568.6</td>
</tr>
</tbody>
</table>

| Loading Downstream of the Pour Point |                    |                    |                    |                    |
| NPDES Sources          |                    |                    |                    |                    |
| Major WWTP             | 68.4               | 1667.3             | 60.3               | 1860.0             |
| Class 2                | 1.7                | 12.9               | 1.6                | 11.6               |
| Class 3                | 0.0                | 0.0                | 0.0                | 0.0                |
| Class 4                | 0.0                | 0.0                | 0.0                | 0.0                |
| Class 5                | 0.2                | 1.3                | 0.8                | 2.3                |
| Industrial             | 0.0                | 0.2                | 0.0                | 0.1                |
| Wet Weather            | 4.7                | 43.2               | 4.3                | 38.8               |
| Total NPDES            | 75.0               | 1724.8             | 66.9               | 1912.8             |
| NPS calculated based on upstream yield | 3.5 | 25.0 | 3.5 | 25.0 |
| HSTS                  | 82.2               | 1600.3             | 72.0               | 1346.4             |

| Total Loading          |                    |                    |                    |                    |
| NPDES Sources          |                    |                    |                    |                    |
| Major WWTP             | 101.7              | 2496.3             | 101.3              | 2673.1             |
| Class 2                | 10.4               | 48.8               | 10.5               | 51.7               |
| Class 3                | 6.7                | 31.3               | 8.7                | 32.5               |
| Class 4                | 4.9                | 70.5               | 5.8                | 15.7               |
| Class 5                | 4.6                | 35.3               | 8.0                | 41.2               |
| Industrial             | 12.1               | 54.6               | 12.0               | 52.8               |
| Wet Weather            | 15.6               | 142.4              | 21.4               | 195.2              |
| OOS NPDES              | 34.4               | 1160.9             | 36.3               | 1271.6             |
| OOS Wet Weather        | 26.7               | 243.8              | 28.5               | 260.4              |
| Total NPDES            | 217.1              | 4283.8             | 232.5              | 4594.3             |
| HSTS                  | 84.2               | 607.2              | 84.2               | 607.2              |
| NPS                   | 1994.0             | 38807.3            | 1745.0             | 32651.3            |
| Total                 | 2295.3             | 43698.3            | 2061.7             | 37852.8            |
Table B2. Loading components and mass balance calculations for the Portage River watershed.

<table>
<thead>
<tr>
<th>Source</th>
<th>yr13 TP Load (mta)</th>
<th>yr13 TN Load (mta)</th>
<th>yr14 TP Load (mta)</th>
<th>yr14 TN Load (mta)</th>
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<td><strong>Loading Upstream of the Pour Point</strong></td>
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<tr>
<td>NPDES Sources</td>
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<td></td>
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<td>192.4</td>
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<td>16.2</td>
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<td>Class 3</td>
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<td>Class 4</td>
<td>0.3</td>
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<td>0.3</td>
<td>5.6</td>
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<td>Class 5</td>
<td>0.5</td>
<td>4.4</td>
<td>0.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wet Weather</td>
<td>3.7</td>
<td>33.7</td>
<td>7.0</td>
<td>63.6</td>
</tr>
<tr>
<td>Total NPDES</td>
<td>12.3</td>
<td>254.5</td>
<td>15.9</td>
<td>300.8</td>
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<td>HSTS</td>
<td>5.6</td>
<td>54.4</td>
<td>5.6</td>
<td>54.4</td>
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<tr>
<td><strong>NPS = Total load - NPDES load - HSTS load</strong></td>
<td></td>
<td></td>
<td>121.1</td>
<td>2854.6</td>
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<td>Total (NCWQR)</td>
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<td>NPS</td>
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<td>Unit Area NPS UPST (mta/ha)</td>
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<td>0.017356</td>
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<td><strong>Loading Downstream of the Pour Point</strong></td>
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<tr>
<td>NPDES Sources</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Major WWTP</td>
<td>0.5</td>
<td>37.0</td>
<td>0.4</td>
<td>34.2</td>
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<td>Class 2</td>
<td>4.3</td>
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<td>17.0</td>
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</tr>
<tr>
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<td>1.9</td>
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<tr>
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<tr>
<td>Industrial</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wet Weather</td>
<td>0.5</td>
<td>4.9</td>
<td>0.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Total NPDES</td>
<td>6.8</td>
<td>65.2</td>
<td>7.0</td>
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</tr>
<tr>
<td>HSTS</td>
<td>2.1</td>
<td>20.1</td>
<td>2.1</td>
<td>20.1</td>
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<tr>
<td><strong>NPS calculated based on upstream yield</strong></td>
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<td></td>
<td>38.2</td>
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<td>NPS</td>
<td>141.3</td>
<td>3487.6</td>
<td>188.2</td>
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</tr>
<tr>
<td><strong>Total Loading</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPDES Sources</td>
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</tr>
<tr>
<td>Major WWTP</td>
<td>6.5</td>
<td>229.4</td>
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<td>240.4</td>
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<td>31.8</td>
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<tr>
<td>Class 3</td>
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<td>9.0</td>
<td>1.9</td>
<td>8.7</td>
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<td>Class 4</td>
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</tr>
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<td>Class 5</td>
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<td>0.9</td>
<td>6.7</td>
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<tr>
<td>Industrial</td>
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<td>0.0</td>
</tr>
<tr>
<td>Wet Weather</td>
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<td>38.6</td>
<td>7.3</td>
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<td>74.5</td>
<td>7.7</td>
<td>74.5</td>
</tr>
<tr>
<td>NPS</td>
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<td>3487.6</td>
<td>188.2</td>
<td>2629.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>187.3</td>
<td>4201.4</td>
<td>241.7</td>
<td>3432.2</td>
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</table>
### Table B3. Loading components and mass balance calculations for the Sandusky River watershed.

<table>
<thead>
<tr>
<th>Source</th>
<th>yr13 TP Load (mta)</th>
<th>yr13 TN Load (mta)</th>
<th>yr14 TP Load (mta)</th>
<th>yr14 TN Load (mta)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loading Upstream of the Pour Point</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPDES Sources</td>
<td></td>
<td></td>
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<td></td>
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### Non-Point Source Unit Area Loading

| Unit Area NPS UPST (mta/ha) | 0.001804 | 0.02959 | 0.00155 | 0.021318 |

| Loading Downstream of the Pour Point |                    |                    |                    |                    |
| NPDES Sources |                    |                    |                    |                    |
| Major WWTP    | 2.6                | 62.8               | 1.3                | 48.3               |
| Class 2       | 0.0                | 0.0                | 0.0                | 0.0                |
| Class 3       | 0.0                | 0.0                | 0.0                | 0.0                |
| Class 4       | 0.0                | 0.0                | 0.0                | 0.0                |
| Class 5       | 0.1                | 0.6                | 0.1                | 0.7                |
| Industrial    | 0.0                | 0.0                | 0.0                | 0.0                |
| Wet Weather   | 9.8                | 89.6               | 10.8               | 98.3               |
| Total NPDES   | 12.5               | 153.0              | 12.2               | 147.3              |
| HSTS          | 1.8                | 17.5               | 1.8                | 17.5               |

| NPS calculated based on upstream yield |                    |                    |                    |                    |
| HSTS                                   | 1.8                | 17.5               | 1.8                | 17.5               |
| NPS                                    | 79.8               | 1309.1             | 68.6               | 943.2              |

### Total Loading

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<th>yr14 TP Load (mta)</th>
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Table B4. Loading components and mass balance calculations for the Cuyahoga River watershed.

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<td>Total (NCWQR)</td>
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**Non-Point Source Unit Area Loading**

| Unit Area NPS UPST (mta/ha) | 0.000941 | 0.000941 | 0.001249 | 0.0010499 |

**Loading Downstream of the Pour Point**

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<th>yr14 TN Load (mta)</th>
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**Total Loading**

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Table B5. Loading components and mass balance calculations for the Great Miami River watershed.

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### Table B6. Loading components and mass balance calculations for the Scioto River watershed.

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<th>TP Load (mta)</th>
<th>TN Load (mta)</th>
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