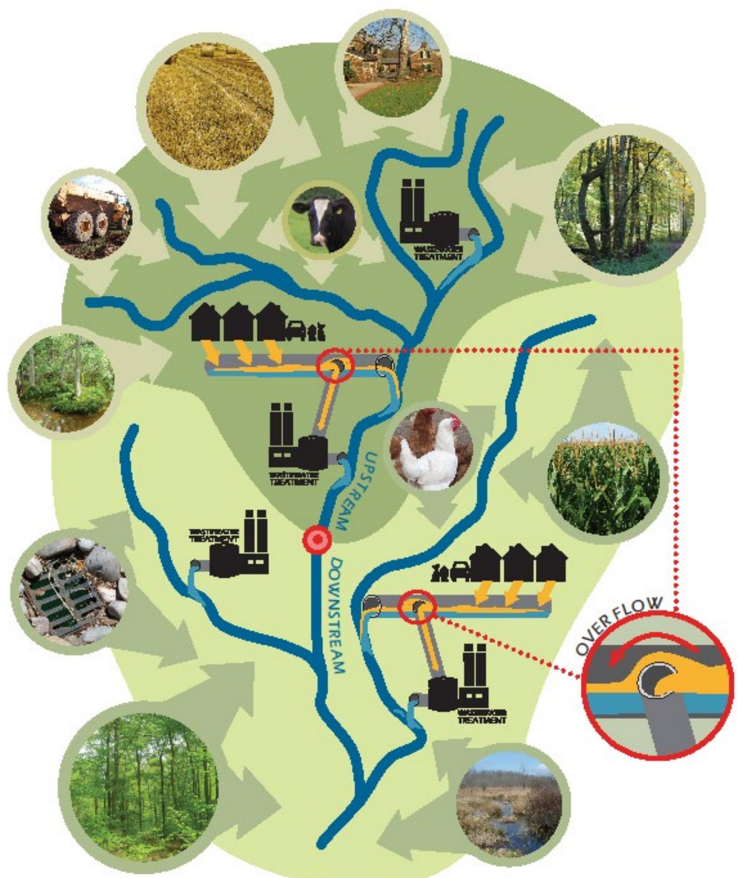
Ohio Environmental Protection Agency

Nutrient Mass Balance Study for Ohio's Major Rivers 2022



Division of Surface Water
Modeling and Assessment Section
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Table of Contents

Executive Summary

Background and Purpose

This nutrient mass balance study computes annual total nitrogen (N) and phosphorus (P) loads by watershed throughout the state of Ohio. By summarizing loads by nutrient and watershed, Ohio EPA is able to comprehensively evaluate and identify excess nutrient sources, thereby creating a framework for nutrient reduction focused activities. Areas of high relative loading contributions are determined in order to help prioritize allocating resources and implementation practices. This study, along with the other data related to current and past nutrient loadings, can serve as a tool to focus research, investment, and policy/legislation decisions to curb phosphorus and nitrogen loading in both the Lake Erie watershed and the Ohio River basin.

Watersheds included in this report are the Maumee, Portage, Cedar-Toussaint, Sandusky, Huron, Old Woman Creek, Vermilion, Cuyahoga, Great Miami, Scioto, Muskingum, Little Miami/East Fork Little Miami (LMR/EFLMR), and Hocking. New in the current (2022) edition are the Hocking and Little Miami watersheds.

Altogether, the watersheds included in the 2022 study comprise 72.59 percent of Ohio's land area. This 2022 edition computes loadings for the subsequent two water years; a total of nine years for most watersheds.

Loads are allocated to three broad contributing sources: nonpoint source (NPS); point sources; and household sewage treatment systems (HSTS). Point source loads are determined based on detailed self-monitoring by regulated point sources with individual National Pollution Discharge Elimination System (NPDES) permits. HSTS includes loads calculated as being discharged from household sewage waste treatment systems. Nonpoint source includes nutrients from the remainder of sources; mostly consisting of general land uses. These include urban/suburban developed lands, agricultural land, and natural/unimproved areas.

As an ongoing effort to respond to feedback and promote consistency in reporting across efforts to manage nutrients in Ohio, the following changes have occurred since the 2020 edition of this report:

1) Updated population served by HSTS, total population, land area, and land use area (from original 2016 values)
2) Inclusion of the Little Miami and Hocking watersheds.

Substantial state and federal dollars continue to be allocated to nutrient reduction and nutrient management efforts to address both point and nonpoint sources in many of the watersheds referenced in this report, especially those in the Western Lake Erie Basin (WLEB). Monitoring programs are underway to track potential water quality improvements resulting from these practices. There is an expected lag between implementation and observed load reductions at monitoring gages as the effects of legacy practices diminish with time.

A compilation of the programs and policy initiatives related to nutrient management for both point source and nonpoint sources are included in Ohio's Nutrient Reduction Strategy found here: ***epa.ohio.gov/divisions-and-offices/surface-water/reports-data/nutrient-pollution-finding-solutions***.

Important Findings

Findings of interest include which watersheds contribute the highest absolute loads of phosphorus and nitrogen, what are the relative contributions of each source category, and which watersheds have the highest yield (quantity per unit area).

The Maumee and Scioto watersheds generated the highest annual total P load when averaged for the five most recent water years in the study (2017-2021) – an average of 2,843 and 2,423 metric tons per annum (mta), respectively. The Muskingum watershed, though the largest area among the watersheds, was only the fourth highest total P load contributor – an average of 1,499 mta. In-stream reservoirs and a high proportion of natural land cover may be contributing to lower total P loading in the Muskingum watershed.

Water year 2019 was an extremely wet year which resulted in maximum total P and total N loads for most watersheds in this study across the period of record. The nonpoint source yield for both nutrients was also the greatest in water year 2019 for most watersheds. These results further documented the fact that hydrology drives a large share of the total loads, as 2020 and 2021 loads resumed to a lower average, as observed prior to 2019.

When examining the sources of total P load, nonpoint sources were the highest contributors to the phosphorus load in the Huron (95 percent of its total load), Vermilion (95 percent), Sandusky (93 percent), Portage (91 percent), and Maumee (90 percent) watersheds. These are all within the Lake Erie watershed. The Cuyahoga, also within the Lake Erie watershed but with substantially different watershed characteristics, had the lowest relative contribution of total P from nonpoint sources.

The highest proportions of total P NPDES load was in the Cuyahoga River basin (43 percent), one of Ohio's most urban watersheds. The rest of the watersheds with the highest NPDES proportions are in the Ohio River basin – Muskingum (26 percent), Great Miami (31 percent), and Scioto (27 percent).

Loading from home sewage treatment systems (HSTS) was less than NPDES loads – an average of all watersheds of 6.1 percent of the total P load, without adjusting for watershed size. The relative proportions of HSTS total P load was highest in the Hocking watershed (14 percent) and Cuyahoga watershed (9 percent) and lowest in the western Lake Erie watersheds (all with five year averages at 3 percent). Note that the new watersheds in this analysis, which includes the Hocking, only examines the loads from water year 2021 while all this summary considers an average of available data for the last five years (2017-2021) for all other watersheds.

For total N load, the patterns of load magnitude are similar to those found for total P load – the Maumee watershed ranked highest delivering an average of 42,461 mta. The Scioto watershed's average is the second highest in total N load at 26,820 mta.

Regarding the total N relative proportions of load sources, NPDES load generally delivered the same percentage of total load across watersheds within the Ohio River basin at around 15 percent. Within the Lake Erie basin, NPDES loads were around seven percent (excluding the Cuyahoga watershed). The Cuyahoga watershed was an anomaly, with NPDES supplying an average of 79 percent of the total N load. For the other Lake Erie watersheds, nonpoint source load dominated the total N load at greater than 89 percent. For the Ohio River watersheds with five years of record, the nonpoint sources contributed an average of 80 percent of the total N load. Nonpoint sources contributed around two thirds of the nitrogen for the one water year with the Hocking and LMR watersheds.

Similar to total P, HSTS was generally the smallest contributing load source for total N, averaging 3.7 percent across the watersheds. This is an increase of 0.7 percent from the previous contribution estimated in the 2020 Mass Balance report. This increase is attributed to improvements in the methodology for calculating populations served by HSTS. In this report, HSTS loads range from a low of one percent in the Portage watersheds to a high of 14 percent for the one year of analysis in the Hocking watershed.

Nonpoint source yields for total P varied from a low of 0.25 pounds per acre to a high of 1.48 pounds per acre. The watersheds with the highest nonpoint source yields had the highest proportion of the area dedicated to agricultural production. These highest nonpoint yields were in NW Ohio where nearly 80% of the land area is utilized for agriculture. Similar results were shown for total N when normalized for watershed area; the lowest nonpoint yields were observed in the Muskingum watershed.

When the human-waste sourced loads (NPDES + HSTS) were standardized by the contributing population in the watershed, the total P yields were higher in the Ohio River basin – averaging 0.77 pounds per person (for the three watersheds with five years data) compared to 0.42 pounds per person in the Lake Erie basin. This highlights the existing requirement for major NPDES wastewater treatment plants in the Lake Erie basin to treat total P, while fewer Ohio River basin plants have phosphorus treatment requirements. The human-waste sources of total N were not notably different across the watersheds – averaging 6.2 pounds per person.

Future Actions

The next edition (2024) will provide computed loadings for the subsequent two water years (a total of eleven years).

Additional opportunities to improve calculations for 2024 include: increasing the accuracy of the population contributing to wastewater treatment plant loads, the re-evaluating the organic N estimate for wastewater treatment facilities, and improving wet-weather nutrient concentration estimations as additional data allow.

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. Excess nutrients stimulate algal growth, and affect the physical, chemical, and biological health of aquatic systems. The current (2022) edition extends the analysis from eleven major watersheds in the previous edition (published in 2020; Ohio EPA 2020) to thirteen by adding the Hocking and Little Miami watersheds.

To calculate total loads, load sources originating from all known major contributors (municipal wastewater, industrial wastewater, HSTS, nonpoint sources) were identified. The current (2022) edition computes loading totals on a water-year[1] basis – nine total for water years 2013 through 2021 (designated herein as wyNN where NN is the water year, for example, wy18).

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) (Great Lakes Water Quality Agreement, 2015) and the Gulf of Mexico Hypoxia Task Force 2008 Action Plan (U.S. Environmental Protection Agency (U.S. EPA), 2008). 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 and in other parts of Ohio with near field impacts.

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." To carry out this directive, the study watersheds must include data on ambient water quality, streamflow and point source discharges. Subsequent studies carried out biennially will be used to document nutrient loading trends.

Nine watersheds of significant size and nutrient loading potential in Ohio 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). Two watersheds nutrient loading is measured on a regular basis by USGS. Sub-hourly discharge (stream flow) is monitored by the USGS for all eleven watersheds (USGS data are reported via their National Water Information System, ***waterdata.usgs.gov/nwis***). These sources of data were critical in developing a meaningful procedure for a biennial analysis of loading sources. The watersheds include the Maumee River, Portage River, Sandusky River, Huron River, Old Woman Creek, and Cuyahoga River of the Lake Erie tributary system and the Great Miami River, Scioto River, Little Miami River (including the East Fork Little Miami River), Hocking River, and Muskingum River of the Ohio River tributary system.

[1] A water year (wy) is a 12-month period that starts on Oct. 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.

The additional drainage area for Lake Erie recognizes the increasingly important need to document contributions to the Ohio waters of the Western and Central basins of this Great Lake. The area referred to in this report as Cedar Toussaint (Lake Erie) is included basing nonpoint source loads on the monitoring of the adjacent Portage River. The Vermilion River (Lake Erie) is monitored for water quality and flow by the USGS. Thus, in total, the 2022 nutrient mass balance study examines nutrient loads from thirteen watersheds. Figure 1 shows these watersheds.

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 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. Additional research on in-stream processing/cycling of nutrients is discussed in the following citations - King et al., 2022, Casillas-Ituarte, 2020; Jarvie, 2011, 2012, and 2013; Marcê, 2009; Withers, 2008.

Past Studies and Associated Work

In Lake Erie, and other Great Lakes, most focus has been on phosphorus and corresponding blue-green algae blooms. In waters draining to the Gulf of Mexico, nitrogen loads and the resulting hypoxia of the northern Gulf of Mexico have garnered the most attention (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008).

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, Maccoux et al. 2016). 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) and subsequently updated in Maccoux and others (2016). Both direct to the lake 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 the Great Lakes and updated in 2008 by Dolan and Chapra (2012a, 2012b). Ongoing Lake Erie total phosphorus loads have since been annually updated using the referenced method by the Great Lakes Water Quality Agreement's Annex 4 Subcommittee and are reported on the ***eriestat.org*** website.

The past (2016, 2018, 2020) and current (2022) Ohio nutrient mass balance reports aid in these updates to Lake Erie and Great Lake total nutrient load accounting.

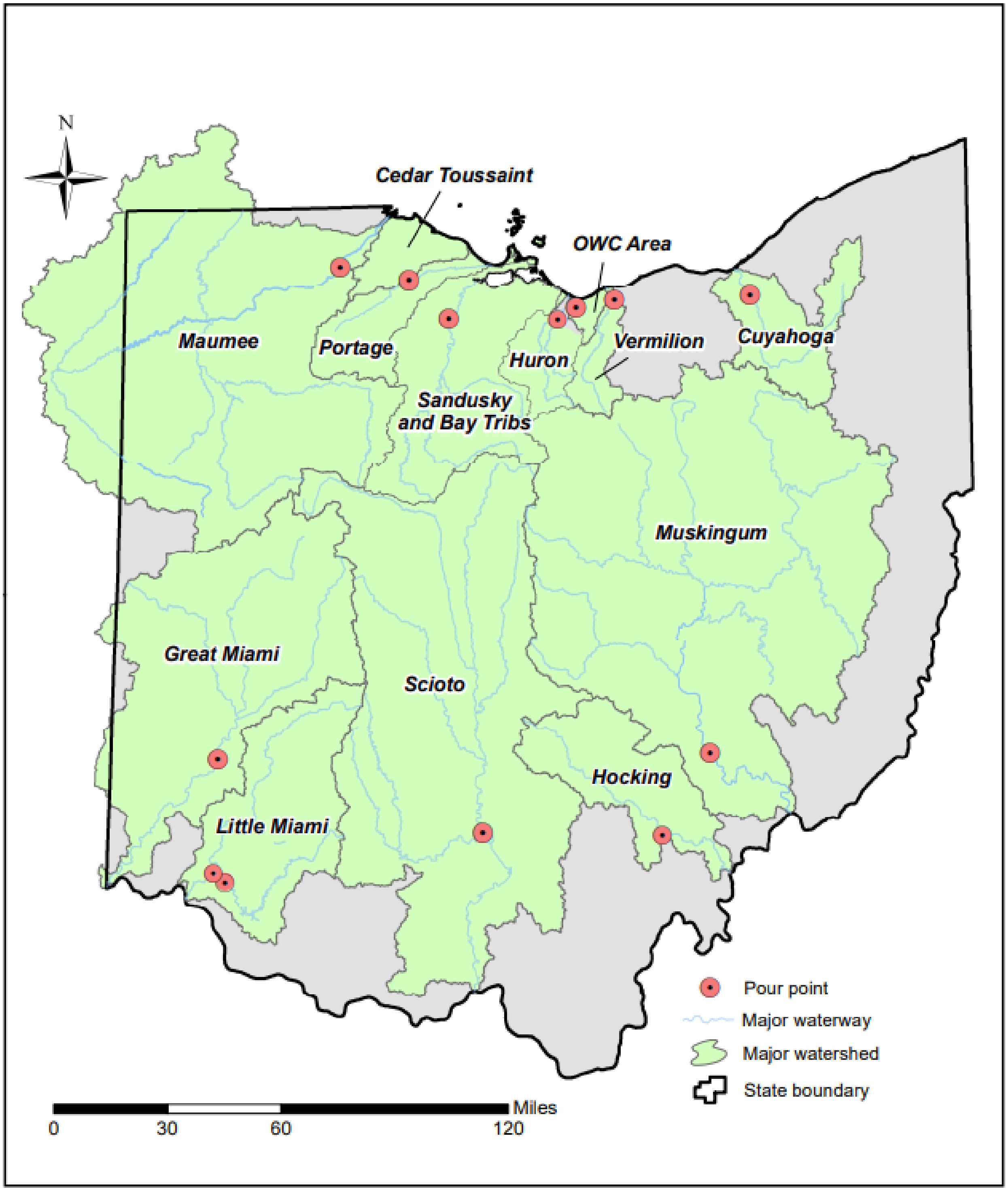


Figure 1 — Map of nutrient mass balance watersheds and associated pour points.

2 Methods

2.1 Overall Loading Calculation

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

$$Total\ Load = NPDES + HSTS + NPS_{upst} + NPS_{dst}\ (1)$$

The load discharged by entities with NPDES permits, which are within the regulatory authority of Ohio EPA, is represented as the point source load (named NPDES) in Equation 1. HSTS contributions are estimated separately. The 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, are important variables influencing stream discharges that affect source loads, especially from nonpoint sources, although point sources may also be affected. These variables are discussed in 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.

$$Annual\ Load = Q(in\ MG) * [Nutrient] * cf\ (2)$$

In Equation 2, Q represents a facility's flow volume in million gallons (MG). The conversion factor (cf) term, equal to 3.78451, is a conversion factor used to convert MG and nutrient concentration from milligrams per liter into kilograms per day.

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 from similar facilities. Nutrient concentrations were estimated for three size classes of municipal effluent and are defined in Table 1. Note that in the 2016 edition, five size classes of municipal effluent were defined. The simple breakdown shown here is more consistent with how Ohio EPA administers its NPDES program.

Table 1 — Facility classes by design flow.

Group	Type	Design Flow (mgd)
Industrials	All Industrial Permits	--
Major Municipal	Sewage Treatment	≥ 1.0
Minor Municipal	Sewage Treatment	0.1 to 1.0
Package Plant	Sewage Treatment	< 0.1

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. Of note, all major municipal facilities have monitoring requirements for total phosphorus. 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. In the approach used here, 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. Different sized facilities had similar data so a common 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 0.73 mg/L for total P, the median concentration of 131 samples reported from September 2014 to August 2017 by two sewer districts that are required to monitor TP at select CSO outfalls in their NPDES permit. For total N, 20 mg/L was used at stations designated as SSOs, CSOs and raw bypasses (U.S. Environmental Protection Agency, 2004; Tchobanoglous et al., 2003). For bypasses that pass through primary treatment, 15 percent removal is assumed to account for settling and sludge removal. For those that pass through secondary treatment, 40 percent removal is assumed. For this version of the report, additional effort was taken to account for wet-weather loading in the correct receiving watershed. This change only affected loading estimates for communities that have multiple discharges to various streams, e.g., large sewer districts like NEORSD.

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. Facilities identified as controlled dischargers were excluded from the OOS analysis because the data maintained in ICIS is an average of discharge on days a discharge occurred. There is no associated count of days that discharge occurred, resulting in gross overestimation of discharge volume. This load contains a CSO load estimate where the overflow volumes are reported, and combined sewer systems were assumed to have the same concentration as those within Ohio.

2.3 HSTS Loads

This version of the nutrient mass balance includes updates to the HSTS loading calculations. This is the first update to these loads since the original calculations first published in 2016. These new methods utilize the 2020 U.S. Census. The results from this update were only applied to the two new loading years, 2020 and 2021.

The population served by HSTS was updated in this iteration of the nutrient mass balance report via the geospatial reporting tool GIS. For this analysis, dasymetric mapping and raster data was utilized. The daysymetric system uses quantitative aerial data and creates boundaries that divide the mapped areas into zones of relative sameness (for example water features or forested area). This tool is very helpful when calculating populations and performing land use analysis. To estimate HSTS populations, a dasymetric density raster based on U.S. Census block data from 2020 was created to estimate the watershed area populations. An overlay of potentially sewered areas for Ohio was then created, based on sewered areas provided by areawide agencies, and census place boundaries of municipalities and incorporated areas with sewer services in areas not covered by areawide or regional agencies. Census place and municipal boundaries were adjusted to best match known sewered areas. Estimation of the population in unsewered areas was then calculated by subtracting the estimate of sewered area population from the estimate of total population in each watershed. For additional details on this methodology, see Appendix B.

The HSTS Load was then calculated using the equation below.

Equation 3 explains this overall method.

$$Load_{HSTS} = Pop_{HSTS} * Nut_{Yield} * \left[percentPop_{discharge} * DR_{discharge} + percentPop_{onsite-working} * DR_{onsite-working} + percentPop_{onsite-failed} * DR_{onsite-failed} \right] \quad (3)$$

where,

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

$\mathrm{Nut_{Yield}}$ = Annual yield of nutrient per person $\left(\frac{\frac{\mathrm{lb}}{\mathrm{year}}}{\mathrm{person}}\right)$

$\mathrm{percentPop_{discharge}}$ = percent of population served by discharging HSTS

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

$\mathrm{percentPop_{onsite-working}}$ = percent of population served by onsite working HSTS

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

$\mathrm{percentPop_{onsite-failing}}$ = percent of population served by onsite failing HSTS

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

The per capita nutrient yield in household wastewater was determined by literature review. 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 also estimated by literature review. One system type is properly operating soil absorption 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 absorption 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 absorption 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 in between the value of a direct discharge and a soil absorption 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 directly to a receiving stream. 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 six percent reduction in total P. This study will use the same six percent reduction observed by Lowe and others (2009).

Nitrogen delivery ratios are different from phosphorus delivery ratios and, like phosphorus, are estimated by literature review. Soil type and flow path affect the delivery of nitrogen from soil absorption systems. Beal and others (2005) reviewed several studies and reported nitrogen removal from 0 to 80 percent. For this mass balance study, 40 percent removal of nitrogen in working soil absorption systems is used. Again, since failing soil absorption 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, yet moderate, 40 percent removal efficiency used for working soil absorption systems. As noted above, discharging HSTS are not designed to remove sludge from the system. Rather, they mineralize organic material and therefore the median total 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 absorption systems; 2) failing soil absorption 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. In 2013, ODH published the results of a survey of county health districts in 2012 as an inventory of existing HSTS in the state by Ohio EPA district (Table 2). The district with the largest areal overlap with a watershed is used to determine the relative proportions of different system types.

Table 1 — Proportions of total HSTS systems grouped into categories for nutrient mass balance study. Adapted from the 2012 ODH statewide inventory (ODH, 2013).

Ohio EPA District	Working Soil Adsorption (%)	Failing Soil Adsorption (%)	Discharging (%)
Northwest	41.5	26.5	32
Northeast	44	27	29
Central	42.8	25.2	32
Southwest	64	14	22
Southeast	61.2	10.8	28

2.4 Nonpoint Source Loading

Central to estimating the nonpoint source load is a monitoring point, herein the pour point, where near-continuous data is collected by the NCWQR or USGS. Data collected at a fine temporal resolution results in the ability to calculate a very accurate annual load at that location. The nonpoint source load is separated into two categories based on the nonpoint source load upstream of the pour point (NPS_{up}) and that downstream of the pour point (NPS_{dn}). There are different assumptions made to estimate the nonpoint source load up- and downstream 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 the upstream nonpoint source load and the downstream area. The upstream yield is NPS_{up} divided by the total watershed area upstream of the pour point. In the Cedar Toussaint watershed where no pour point exists among any of the sub-basins, an NPS yield is applied from the adjacent Portage River watershed having a pour point load. Also, the Old Woman Creek area watershed's pour point monitoring is expanded to other adjacent Lake Erie frontal zones.

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 less precise assumption than that of mass conservation (discussed below). Watersheds with a larger proportion of drainage area downstream from the pour point are subject to more influence from the assumption of yield equivalency. Excluding the Cedar Toussaint and Old Woman Creek watersheds, the percent of total area downstream of the pour point, from highest to lowest, for the watersheds is: Scioto (41); Sandusky (32); Great Miami (30); Portage (27); Hocking (21); Cuyahoga (13); Little Miami (10); Huron (9); Muskingum (8); Maumee (4) and Vermilion (3). In the Old Woman Creek area watershed included in this report 75 percent of the area is either downstream of the pour point or in a different adjacent frontal Lake Erie watershed. Therefore, the nonpoint source load calculation is less precise for some watersheds versus others. Deviations in the yield assumption is compounded when the land use distribution between up and downstream of the pour point is considerably different.

A key assumption of the mass balance method is conservation of nutrient mass being transported through the watershed. While this adds ease in computation over large areas having limited or no data on assimilative capacity, it is also a simplifying function that could be improved in future methods. 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 runoff from developed lands; MS4 (municipal separate storm sewer system) areas; mining activities; natural sources and others. Nutrient sinks could include: wetlands (total P and total N); biomass – both terrestrial and aquatic (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. Because the point source and HSTS terms in Equation 1 are computed directly at their source and no assimilation is considered, the mass balance method will overestimate the annual delivery of the load from these sources.

2.5 Pour Point Load Estimation

Most wy13 through wy17 pour point loads were calculated by Ohio EPA for the 2018 Nutrient Mass Balance (NMB) report and are used in previous iterations of this report. Total P pour point loads for several Lake Erie watersheds during these water years have been updated by NCWQR. NCWQR made these calculations for publications for the Ohio Lake Erie Commission and Blue Accounting's ErieStat website. In order to be consistent with these calculated loads, this edition of the Nutrient Mass Balance is using those pour point values.

All of wy20 and wy21 loads, aside from the Vermillion River watershed, were provided to Ohio EPA by either NCWQR or the USGS depending on the entity collecting the data. Vermilion River pour point loads for these water years were estimated using a regression-based estimator, LOADEST (Runkel et al. 2004). This method used USGS monthly (and occasional sub-monthly) chemical concentrations and USGS daily flow. An estimate of daily load was based on the relationship of flow and concentration for days in which both were sampled. Using the regression analysis, the annual loads were estimated using the annual flow record.

Distributions due to the COVID-19 pandemic limited some resources for water quality monitoring in wy2020. Pour point data missing significant portions of monitoring was accounted for via LoadFlex or manual interpolation methods by the monitoring group.

2.6 Contributing Populations

Contributing population is defined in this report as the source population for nutrient loading to a watershed. This value varies from the total population living within a watershed's boundary as many wastewater treatment plants serve populations outside of the watershed where the plant discharges. This is important to differentiate when calculating per capita load as it relates to load calculations and sourcing.

To increase accuracy of contributing population data for the 2022 report, a new methodology was developed and utilized. Originally, for the 2016 – 2020 iterations of this report, spatial analysis in GIS was conducted to assign sewered populations on watershed divides to the watershed where the wastewater treatment plant discharged. For this report, the total population for each watershed is calculated as the summation of the HSTS populations (as described in Section 2.3) and population served by the watershed's wastewater treatment plants. The latter figure is available because NPDES permit applications require wastewater treatment plants to report the population served. A study conducted by the Toledo Metropolitan Area Council of Governments (TMACOG) in 2018 specifying HSTS breakdowns was also utilized for the Maumee watershed (TMACOG, 2018).

3 Results and Discussion

3.1 Statewide Analysis

The five most recent water years' average total phosphorus loading is presented as total load grouped by major source on Figure 2. Average nonpoint source and per capita yields are shown on Figure 3. The Huron River, LMR/EFLMR, and Hocking River basin results are not presented in Figures 2 and 3 because five years of data are not available to include these watersheds. The tabular results used to create Figures 2 and 3 are in Appendix A.

The categories of sources are: 1) HSTS; 2) total NPDES; and 3) nonpoint source. Besides nutrient loads, which relate to the overall goal of the study, yields are 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 annual nonpoint source yield is computed as the annual nonpoint source load divided by the watershed area; both numerator and denominator are calculated at the pour point. The annual per capita yield is the sum of NPDES and HSTS loads divided by the total human population contributing waste in the watershed; both are calculated at the watershed outlet. The per capita yield represents the *human sewage-sourced* nutrient load and for NPDES load, includes all population residing in the service (collection) area of each facility. The total N loads and yields are presented similarly (Figures 4 and 5, respectively).

More detailed discussion of relative differences *within* each watershed will appear in Sections 3.2-3.14. The following discussion focuses on differences in total and relative load *among* the watersheds throughout the state 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 absolute nonpoint source load (Figure 2 and Figure 4). It is therefore important to note watershed area when comparing total loads from watersheds that have much different areas. For example, the Maumee and Portage watersheds have similar physiographic and land use characteristics and therefore similar nutrient yields. However, the Maumee drains more than 10 times the area of the Portage. Thus, the Maumee's total load is vastly greater than the Portage.

An exception to this relationship is the Muskingum watershed. The Muskingum has the largest drainage area of any of the watersheds yet delivers a smaller total load than the Maumee, Scioto, or Great Miami watersheds. Watershed characteristics are responsible for these differences as discussed further below.

Watershed areas and land usages were updated for the 2022 iteration of this report. For more details on this methodology, see Appendix B.

Relationship of Annual Water Yield to Annual Load

Load is calculated as the product of flow and concentration, so it is important to understand the variability in flow and how it may affect load comparisons. Watersheds with higher drainage areas generally have higher flows so one way to compare watersheds by flow is to compute water yield. Water yield is the annual discharge normalized by watershed area and is expressed as height per unit time (for example, 14 inches per water year).

Annual streamflow discharge is primarily affected by fluctuations in precipitation from year to year and regional precipitation patterns. The typical water yield for each watershed is presented in Table 3 as the median of the last 20 years of discharge data, with some date range exceptions. The typical water yield was generally lower for northwest Ohio (13.9 – 15.4 in), compared to the Ohio River watershed (15.0 – 18.0 in), but highest in the Cuyahoga watershed (22.7). Hence, for equivalent nutrient yields across watersheds in a typical year, those with higher water yields will have lower flow-weighted mean concentrations (FWMC); the Cuyahoga watershed demonstrates this dilution effect.

Normal in hydrology is often defined as an event being within the inner-quartile range (25th – 75th percentile) of the observed dataset. Many of the water years for a given watershed fall within this range (Table 3). However, wy16 was dry statewide, with only the Scioto and Great Miami rivers barely exceeding their 25th percentile streamflow, and the remaining watersheds below their 25th percentile. The wettest year included in this analysis was wy19. All watersheds, except for the Vermillion, exceeded their 75th percentile in wy19.

When extending this discussion to loads, the total phosphorus load in wy16 is the lowest loading year for all watersheds, excluding the Scioto, whereas wy19 highest loading year for all (Table 4). The total nitrogen loadings reflected similar trends (Table 5). LMR and Hocking median and averages are not included on these tables due to too few years of observations. These observations highlight the importance of considering the annual flows when evaluating nutrient loads.

FWMC is a way to (partially) normalize the influence of flow from year to year. FWMC can be calculated in different ways, but it is equivalent to the annual load divided by the total annual flow. This provides a concentration that is somewhat dampened by the impact of flow when interpreting results. The somewhat qualifier is used because a positive relationship typically exists between flow and concentration. This tends to increase the FWMC in wet years. FWMC is calculated within Sections 3.2-3.14 to discuss inter-annual variability for each of the specific regions examined.

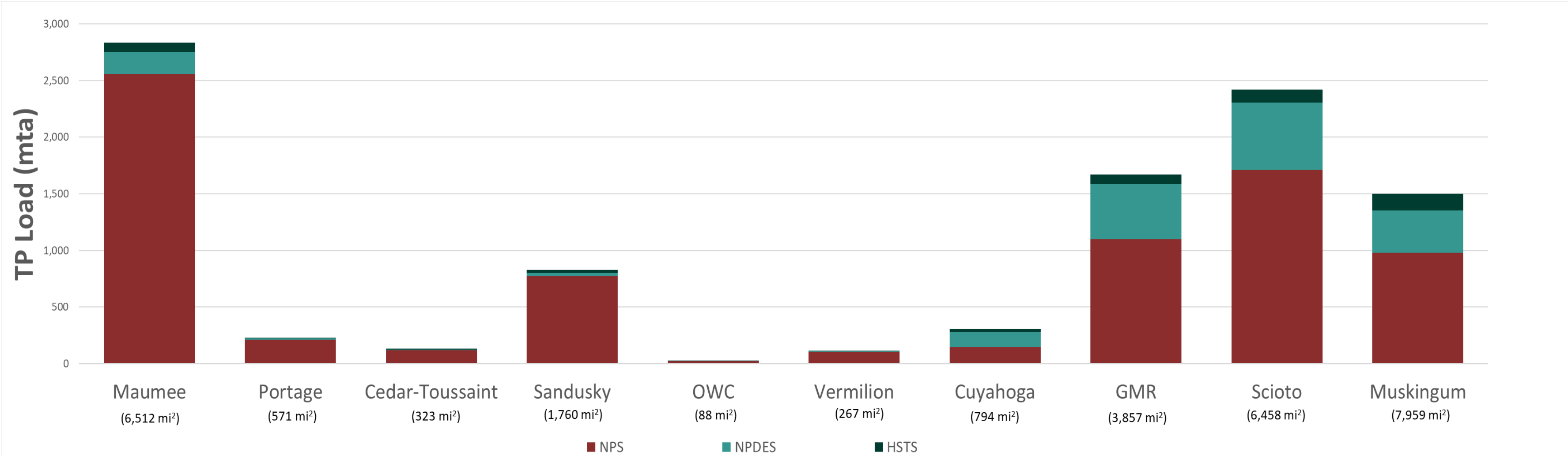


Figure 2 — Total phosphorus loading using nutrient balance methods as the average of the loads calculated from water year 2017 - 2021. "GMR" denotes Great Miami River and "OWC" Old Woman Creek.

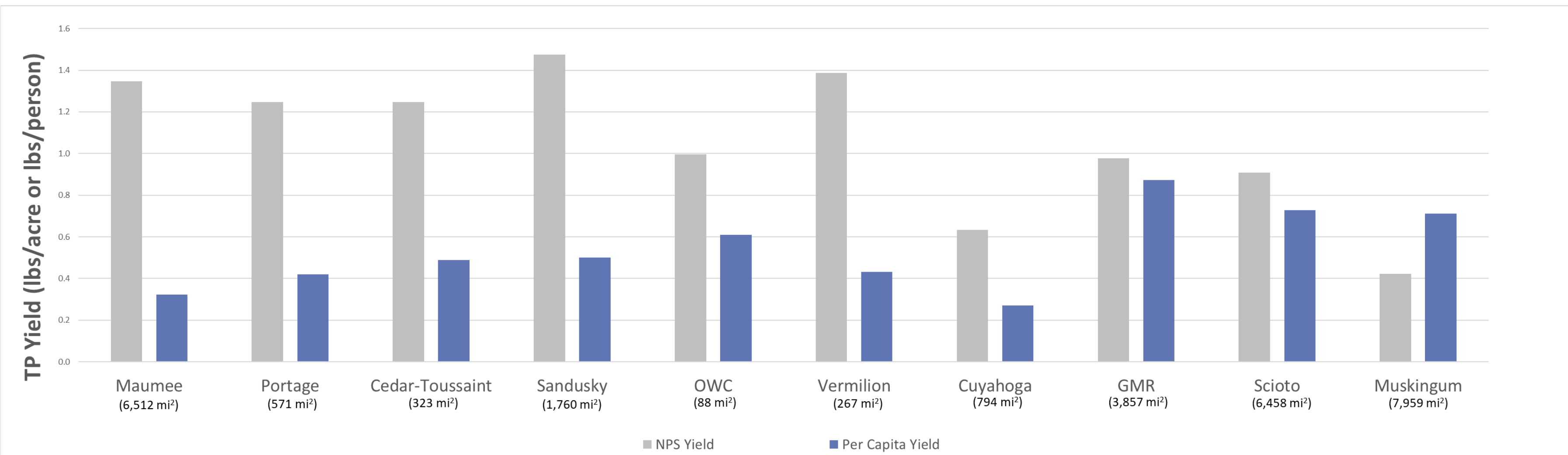


Figure 3 — Total phosphorus yields as the average of the loads calculated from water year 2017-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

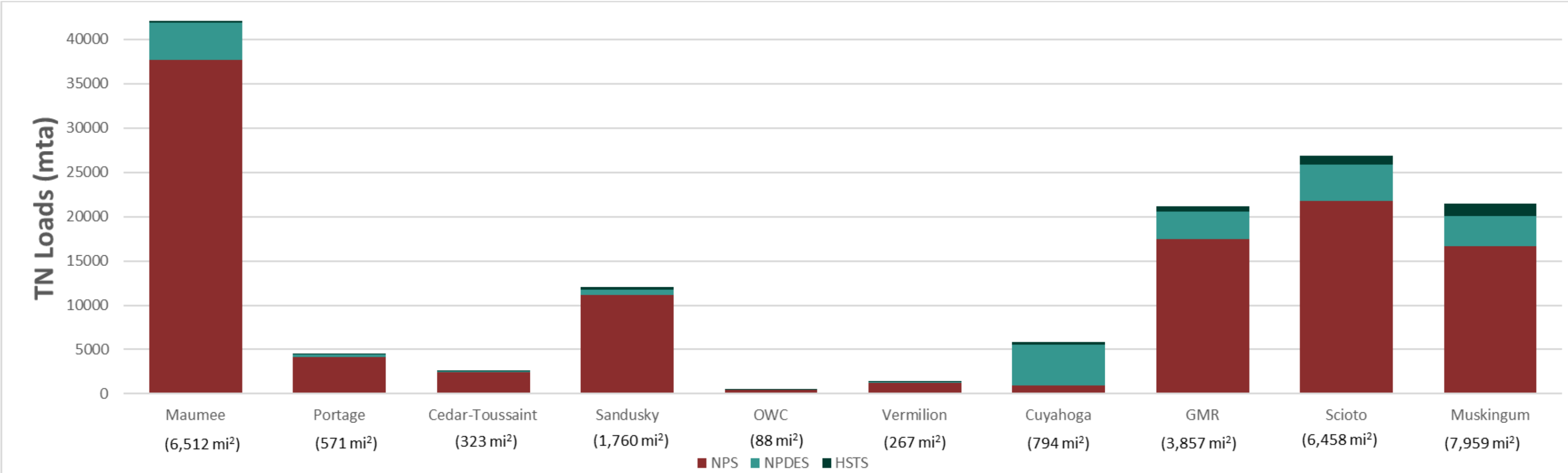


Figure 4 — Total nitrogen loading using nutrient balance methods as the average of the loads calculated from water year 2017-2021. "GMR" denotes Great Miami River and "OWC" Old Woman Creek.

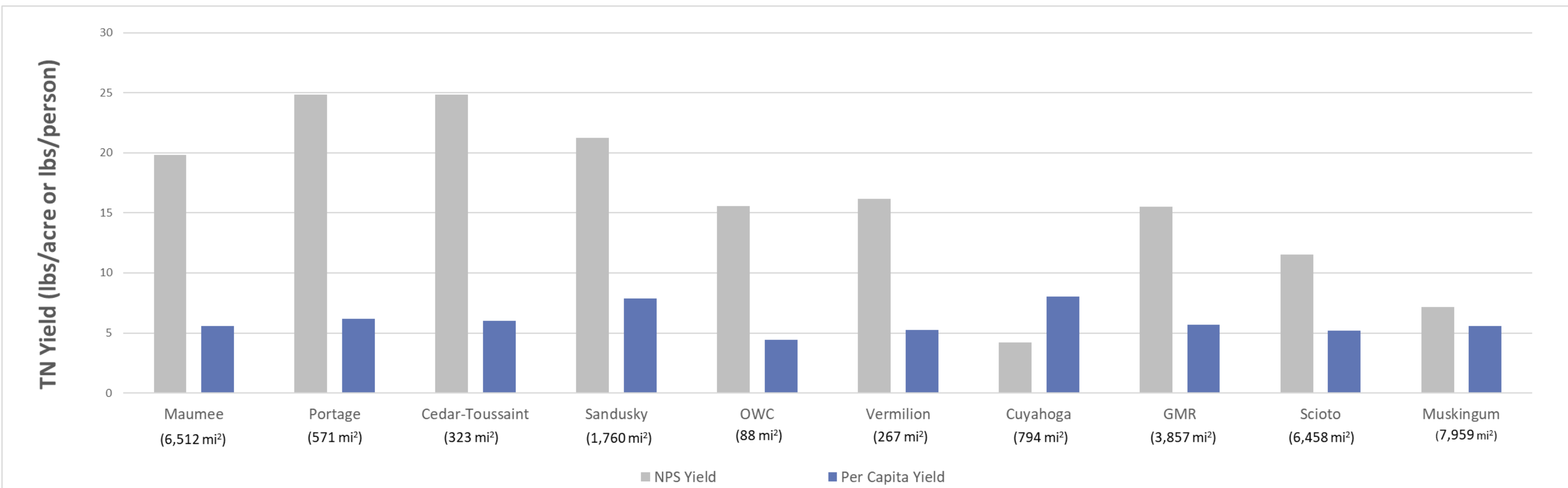


Figure 5 — Total nitrogen loading as the average of the loads calculated from water year 2017-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 3 — Annual water yield (in) and median long-term water yield (in/yr), for the watersheds calculated at the pour point (PP) of each.

Watershed	Drainage Area at PP (sq. mi.)	Water Yield (in)									
		Median (2000-2021)	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Maumee	6,330	14.1	12.1	14.0	16.0	9.5	16.5	14.0	21.5	13.8	9.6
Portage	428	13.9	13.3	15.6	15.6	10.6	14.0	15.6	24.0	13.3	11.2
Cedar Toussaint	No gage	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sandusky	1,251	15.1	18.1	17.2	12.8	10.5	14.3	16.0	21.9	11.7	11.18
Huron	371	15.3	18.1	17.8	11.4	11.7	12.7	16.4	18.1	13.1	15
Old Woman Ck	22	15.4	16.5	16.6	14.3	11.4	13.0	17.6	23.6	11.5	11.7
Vermilion	262	16.2[a]	16.9	18.3	11.3	10.8	13.7	16.2	21.1	12.8	15.2
Cuyahoga	707	22.7	21.3	22.4	20.9	16.1	23.9	23.2	29.0	12.6	19.2
Great Miami	2,685	18.0	13.6	18.2	15.7	13.2	15.2	19.9	27.9	14.8	13.2
Scioto	3,854	16.5	14.0	17.7	15.1	13.2	15.4	21.9	27.9	16.6	12.5
Muskingum	7,420	15.4[a]	14.9	18.7	15.0	11.6	14.5	20.9	26.5	18.4	12.6
LMR/EFLMR	1,679	15.9	13.2	17.9	16.5	16.8	17.8	23.3	31.3	16.4	15.5
Hocking	934	15.0	12.1	15.0	12.3	11.3	15.4	23.3	28.0	19.3	10.6

a: median computed from 2002-2021.

Table 4 — Annual total phosphorus load in metric tons per year (by water year and average of five years) for the watersheds examined in this study.

Watershed	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21	Average
Maumee	2,288	2,102	2,346	1,268	3,054	2,668	3,897	2,980	1,575	2,835
Portage	163	226	170	143	185	254	364	199	149	230
Cedar-Toussaint	96	133	101	86	108	150	213	115	87	135
Sandusky	951	833	533	449	801	844	1,226	706	563	828
Huron	NA	NA	NA	NA	NA	202	217	159	118	174[a]
Old Woman Creek	NA	NA	NA	21	27	27	38	26	24	29
Vermilion	141	146	84	68	87	125	156	80	123	114
Cuyahoga	313	354	298	206	325	321	398	243	266	311
Great Miami	1,218	1,762	1,722	878	1,397	1,803	2,455	1,464	1,189	1,670
Scioto	2,015	2,402	1,969	1,486	2,117	2,797	3,783	2,103	1,320	2,424
Muskingum	1,330	1,632	1,545	885	1,316	1,799	2,209	1,237	936	1,499
LMR/EFLMR	NA	NA	NA	NA	NA	NA	NA	NA	685	-
Hocking	NA	NA	NA	NA	NA	NA	NA	NA	133	-

a: 4-year average from 2018-2021 computed

Table 5 — Annual total nitrogen load in metric tons per year (by water year and average of five years) for the watersheds examined in this study.

Watershed	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21	Average
Maumee	43,630	37,609	44,962	30,953	49,551	40,327	49,461	35,471	37,495	42,461
Portage	3,915	3,116	4,032	3,226	5,358	4,357	5,415	3,256	4,180	4,514
Cedar-Toussaint	2,195	1,718	2,247	1,818	3,109	2,502	3,126	1,837	2,362	2,587
Sandusky	15,165	10,853	9,474	8,678	13,092	12,008	14,759	9,553	10,642	12,011
Huron	NA	NA	NA	NA	NA	2,046	2,679	1,856	2,416	2,249[a]
Old Woman Creek	NA	NA	NA	313	465	368	627	292	352	421
Vermilion	1,510	1,571	899	917	1,199	1,425	2,065	792	1,188	1,334
Cuyahoga	5,952	5,750	4,921	4,738	5,612	6,062	6,561	5,605	5,148	5,789
Great Miami	18,083	20,458	21,111	14,550	21,791	20,203	28,114	17,904	16,289	20,983
Scioto	22,729	27,711	23,949	17,819	28,077	27,961	36,707	24,578	16,778	26,820
Muskingum	18,706	22,159	18,067	12,587	18,767	23,432	29,414	21,736	14,172	21,426
LMR/EFLMR	NA	NA	NA	NA	NA	NA	NA	NA	4,836	-
Hocking	NA	NA	NA	NA	NA	NA	NA	NA	1,282	-

a: 4-year average from 2018-2021 computed

Nonpoint Source Nutrient Yield

The Muskingum and Cuyahoga watersheds show the lowest nonpoint source nutrient yields (see grey bars in Figure 3 and Figure 5) – for the total P and N averages over five years (2017 - 2021). The highest nonpoint source yields are found in the Lake Erie watersheds (excluding Cuyahoga). 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 can trap nonpoint source sediment with associated nutrients and prevent their movement downstream to the pour point. The Huron River, LMR/EFLMR, and Hocking River are absent from these statewide figures due to not having five years of data available.

Natural land cover (comprising wetlands, forest, shrub, and herbaceous land) comprised more than 47 percent of the Muskingum total watershed area (Figure 6). These types of land covers are not large generators of nonpoint nutrient loads. As noted above, the Cuyahoga watershed was a low generator of nonpoint source N yield (Figure 5) and to some extent showed a low P yield (Figure 3). Natural land cover was also high for both the Cuyahoga and Vermilion watersheds and comprised more than 36 and 26 percent of their total area, respectively. Yet the Vermilion watershed nonpoint P yield was among the highest among the watersheds (Figure 3). While Vermilion approaches the Cuyahoga in terms of natural land cover, it is also similar to the Cuyahoga in that it receives more annual precipitation than other Lake Erie watersheds (Table 3). The higher precipitation combines with its higher percentage of agricultural land than the Cuyahoga (Figure 6) to produce a higher P yield for the Vermilion.

The Sandusky, Portage, and Maumee watersheds, where agricultural land comprises the majority of the watershed area, exhibited high nonpoint source yields averaged over the five water years, for both total P and total N (Figure 3 and Figure 5).

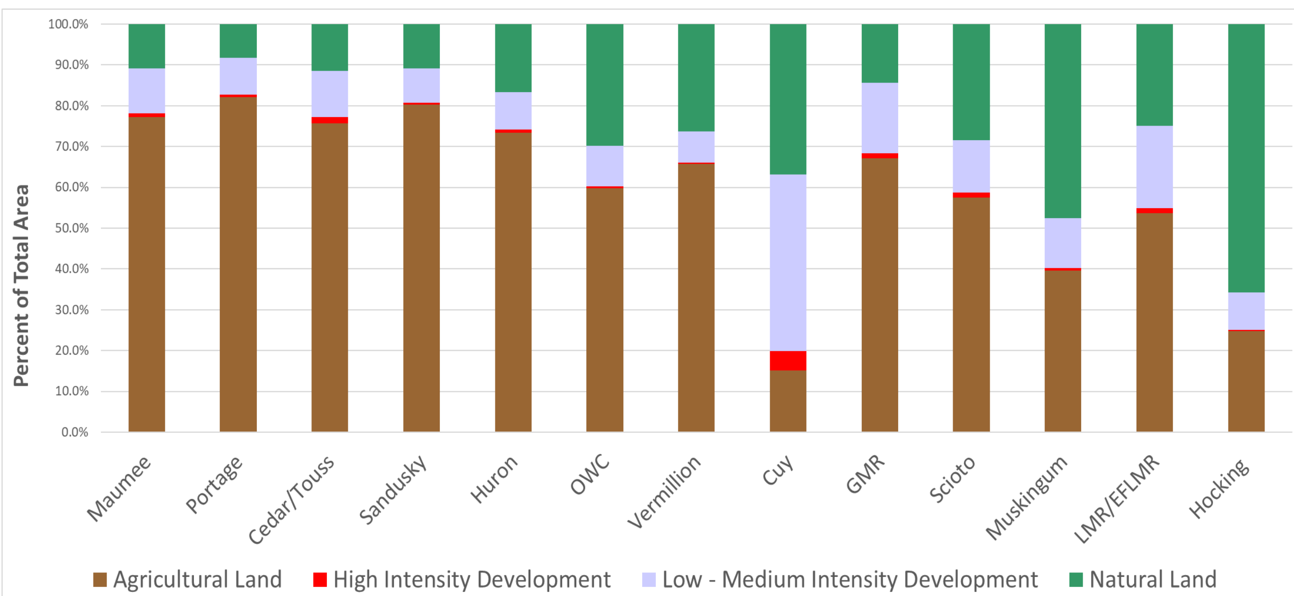


Figure 6 — Distribution of major land use and land cover categories by major watershed (shown as percent of total watershed area). Land use/cover data taken from National Land Cover Dataset for year 2019 (NLCD 2019).

Per Capita Nutrient Yield

As mentioned above, the per capita yield is the sum of NPDES and HSTS loads divided by the total human population contributing waste in the watershed. The per capita yield thus represents the *human sewage-sourced* nutrient load.

For total P, per capita yield is by far the highest for the GMR, Scioto, and Muskingum watersheds at greater than 0.7 lbs./person (see blue bars in Figure 3). 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. This watershed is a primarily urban watershed. It has a low percentage of the population served by HSTS, but high proportion served by major NPDES WWTPs with total P concentration limits. Therefore, almost all human sewage receives a high degree of treatment.

The remaining Lake Erie watersheds have moderate per capita total P yields (Figure 3). These watersheds have rural and small-town populations containing HSTS and non-major WWTPs without total P concentration limits and thus less treatment prior to discharge. Differences in total N per capita yield (see blue bars in Figure 5) are less apparent among the study watersheds.

Population Density

Estimates of population density were made using the contributing population and the total watershed area (Table 6). The Cuyahoga watershed exhibits the highest population density and is more than twice as dense as the next highest watershed. The Great Miami and Scioto watersheds exhibit the next highest population density and are similar in magnitude.

When exploring the highest relative contribution of total NPDES and HSTS load to total watershed load, the Cuyahoga watershed has the highest total N load (greater than 80 percent of total load). No other watershed is close to this percent contribution of NPDES and HSTS to total N load. For total P, the Cuyahoga watershed also has the highest load, greater than half the total load, contributed by NPDES and HSTS. The Ohio River watersheds also had higher combined NPDES and HSTS total P loads. The Muskingum's relatively higher NPDES proportion is more of a reflection of its reduced NPS load due to all the natural area versus elevated population density.

Differences between the 2022 updated contributing populations and the previous iteration contributing populations (calculated in 2016, based on 2010 census data) are two-fold. One major contributor being the methodology update (as noted in Section 2.6) as well as actual fluctuations to population across the state. In the City of Columbus alone, and observable within the Scioto watershed, the population from 2010 to 2020 increased by roughly 119,000 people (U.S. Census, 2021). Across the state, population increased by roughly 2.3 percent between 2010 and 2020 (U.S. Census, 2021. For comparisons of values used prior to wy20, Table 6 includes the previous contributing population and population densities for each watershed.

Table 2 — Population density calculated as the contributing watershed population divided by watershed area.

Watershed	Previous Iterations Contributing Population (# persons)	Previous Iterations Population Density (persons/sq. mi.)	2022 Updates Contributing Population (# persons)	2022 Updates Population Density (persons/sq. mi)
Maumee	1,391,251	212	1,380,434	212
Portage	94,674	162	101,550	178
Cedar-Toussaint	52,793	153	59,846	185
Sandusky	204,408	112	269,014	153
Huron	67,847	167	55,811	139
Old Woman Creek	11,915	135	10,563	120
Vermilion	31,126	116	33,500	126
Cuyahoga	1,126,170	1,394	1,143,142	1,440
Great Miami	1,302,134	320	1,517,842	394
Scioto	1,937,401	298	2,462,684	381
Muskingum	1,473,708	183	1,477,592	186
Hocking	NA	NA	216,503	182
LMR	NA	NA	406,308	309
EFLMR	NA	NA	147,503	314

3.2 Maumee River

The Maumee River drains 6,512 sq. mi in northwestern Ohio, southeastern Michigan and northeastern Indiana (Figure 7). The NCWQR maintains a water quality sampling station at a USGS gaging station near Waterville, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 6,250 sq. mi. and 262 sq. mi. downstream of the pour point.

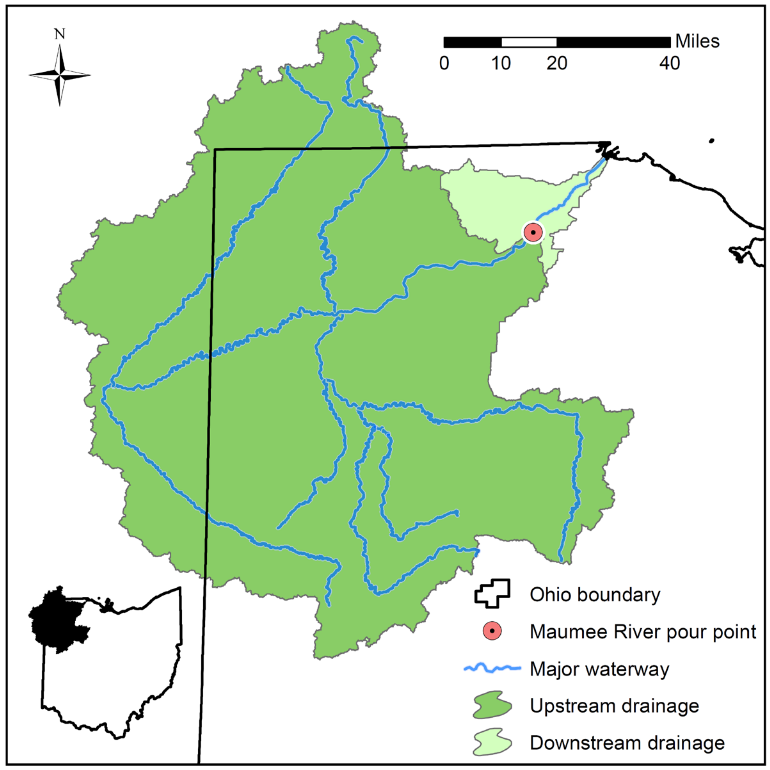


Figure 7 — Project area represented in Maumee River mass balance. The pour point along with up and downstream drainage areas are shown.

Agricultural production dominates the landscape in the watershed occurring on 77 percent of the land. This includes the fertile drained lands of the historic 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. However, downstream of the pour point is a small proportion of the entire watershed. Downstream of the pour point, the proportion of agricultural production reduces from 77 percent to 47 percent whereas both high/low intensity development and natural lands increase in proportion (11-percent in both natural lands and development to 19-percent and 34-percent, respectively).

Total P loads from the Maumee River were a maximum of 3,897 metric tons per year (mta) in wy19 and a minimum of 1,268 mta for wy16 (Figure 8 and Table 77). Total N loads from the Maumee River were a maximum of 49,551 mta in wy17 and a minimum of 30,953 mta for wy16 (Figure 10 and Table 7). Total P and total N yields are presented on Figures 9 and 11, respectively.

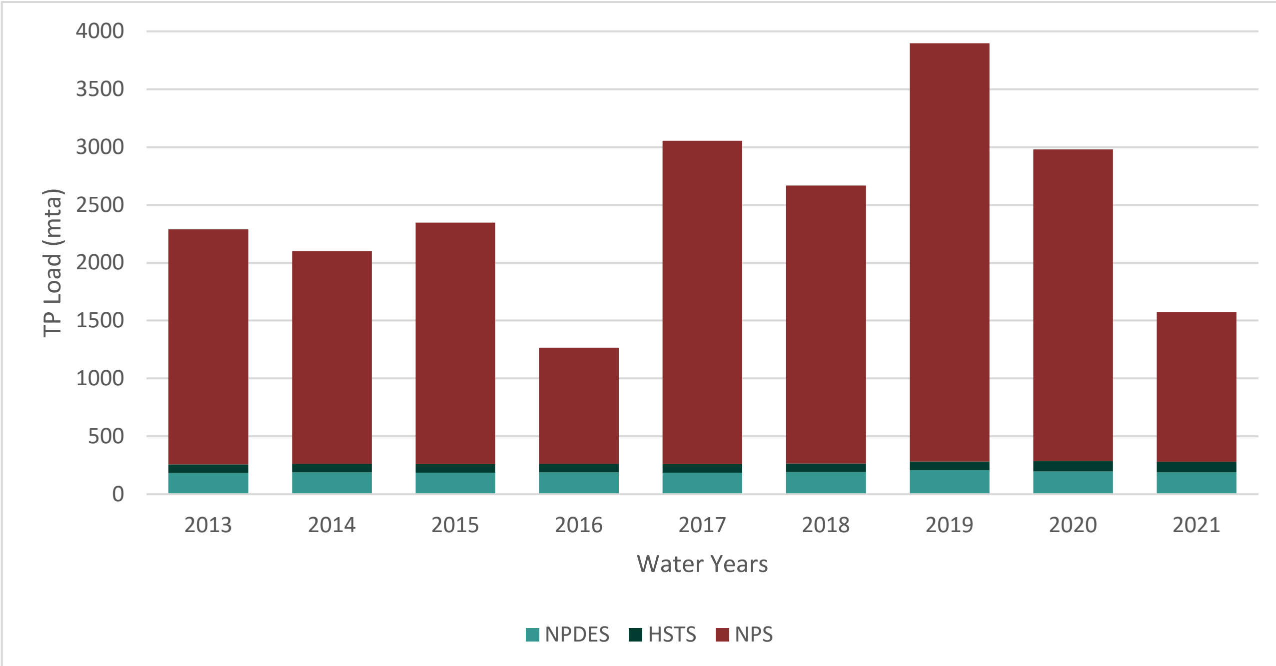


Figure 8 — Total phosphorus loads for the Maumee River for water year 2013-2021.

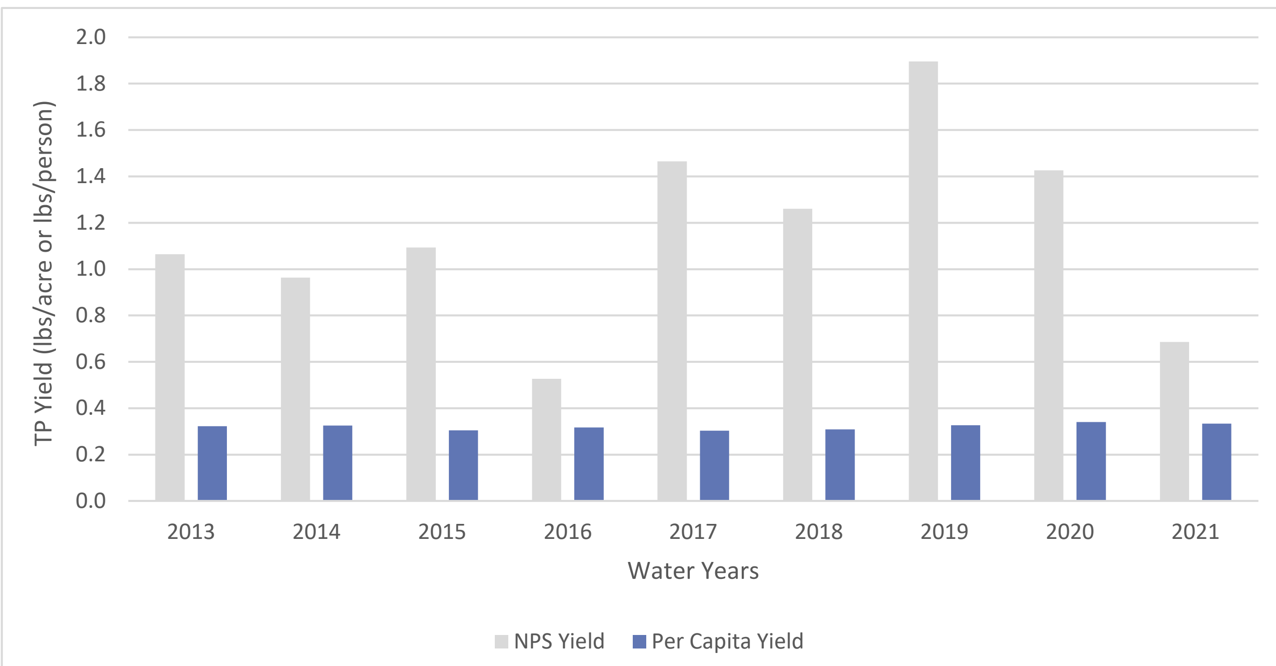


Figure 9 — Total phosphorus yields for the Maumee River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

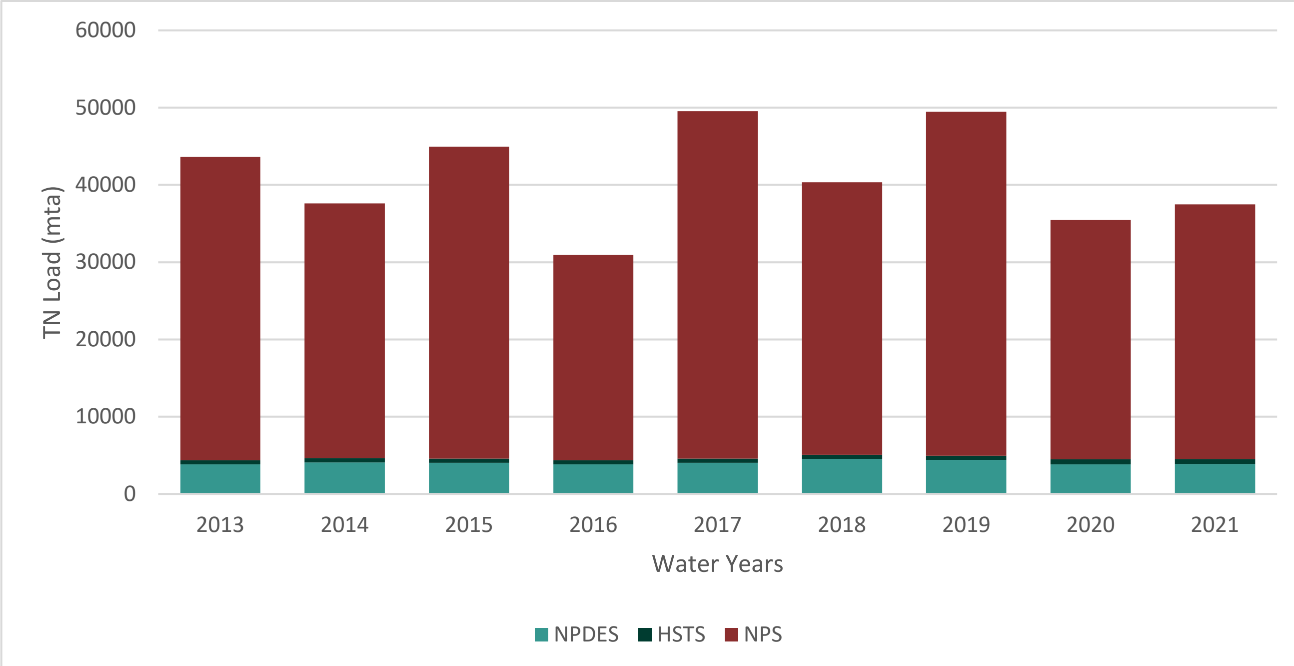


Figure 10 — Total nitrogen loads for the Maumee River for water year 2013-2021.

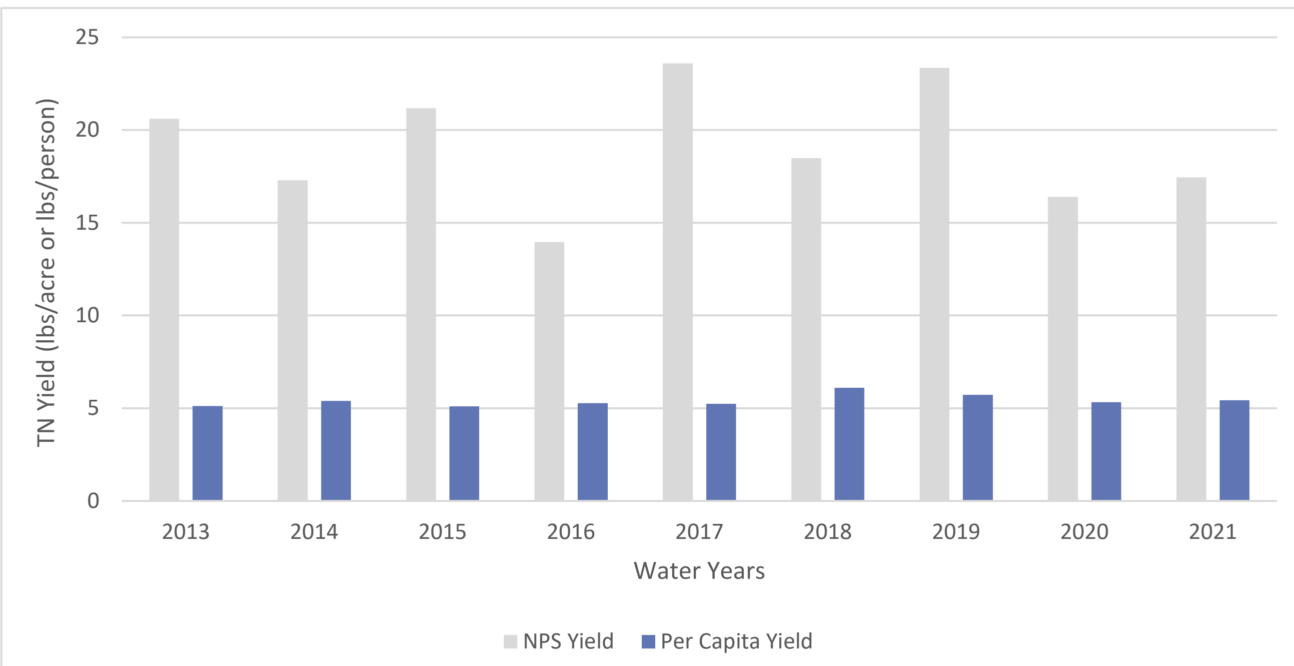


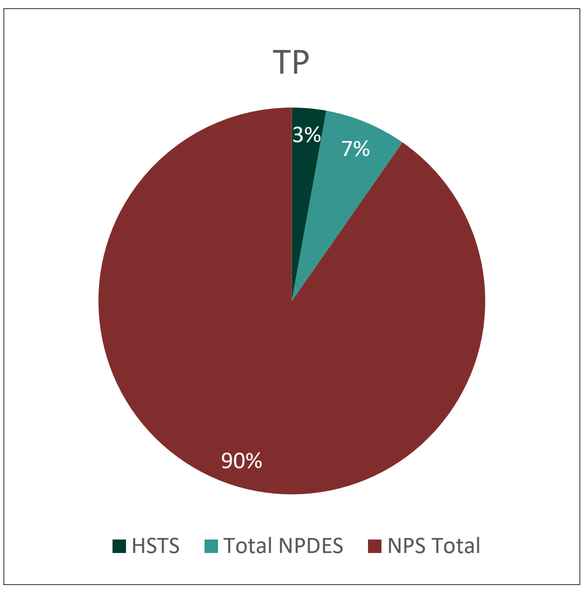
Figure 11 — Total nitrogen yields for the Maumee River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

The importance of total discharge is highlighted in the observed data where the two highest loading years, wy17 and wy19, are also the highest discharging years. The wy19 loads are larger than seen in previous years due to very high precipitation. Wy20 and wy21 were comparatively drier years (as observed in by the water yield on Table 7 below), and experienced lower total loads for both P and N.

Table 7 — Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy21. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	12.1	14.0	16.0	9.50	16.5	14.1	21.5	13.8	9.60
20-yr Median Water Yield (in) – 13.97									
Total P									
FWMC (mg/L)	0.42	0.34	0.33	0.29	0.42	0.39	0.41	0.47	0.34
Annual Load (mta)	2,288	2,102	2,346	1,268	3,054	2,668	3,897	2,980	1,575
Total N									
FWMC (mg/L)	8.05	5.89	6.05	6.93	7.38	6.26	5.11	5.50	8.40
Annual Load (mta)	43,630	37,609	44,962	30,953	49,551	40,327	49,461	35,470	37,495

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N averaged of the most recent five years are presented in Figure 12. As was readily observed in Figure 8 and Figure 10, the nonpoint source is the largest proportion of the load in the Maumee River at 90 and 89 percent, respectively, for total P and total N. The NPDES sources comprised seven percent of the total P and ten percent of the total N load. Finally, the HSTS community contributed three percent of the annual total P and one percent of the total N loads.



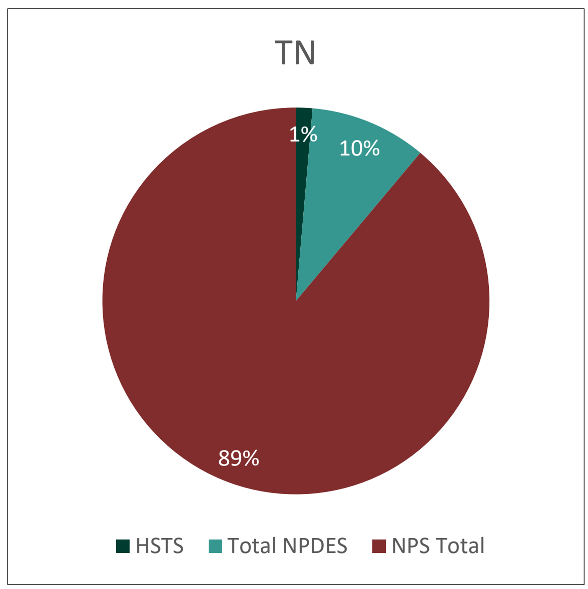


Figure 12 — Proportion of total phosphorus and nitrogen load from different sources for the Maumee watershed, average of five years (wy17-wy21).

The Maumee watershed 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). Though the Maumee contributes around four percent of the water to the Western Basin of Lake Erie, for the average of water years 2003 - 2013, it was found to deliver nearly half of the phosphorous (Maccoux, et al. 2016).

3.3 Portage River

The Portage River drains 571 sq. mi. in northwest Ohio (Figure 13). The 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 419 sq. mi. and 152 sq. mi. downstream of the pour point.

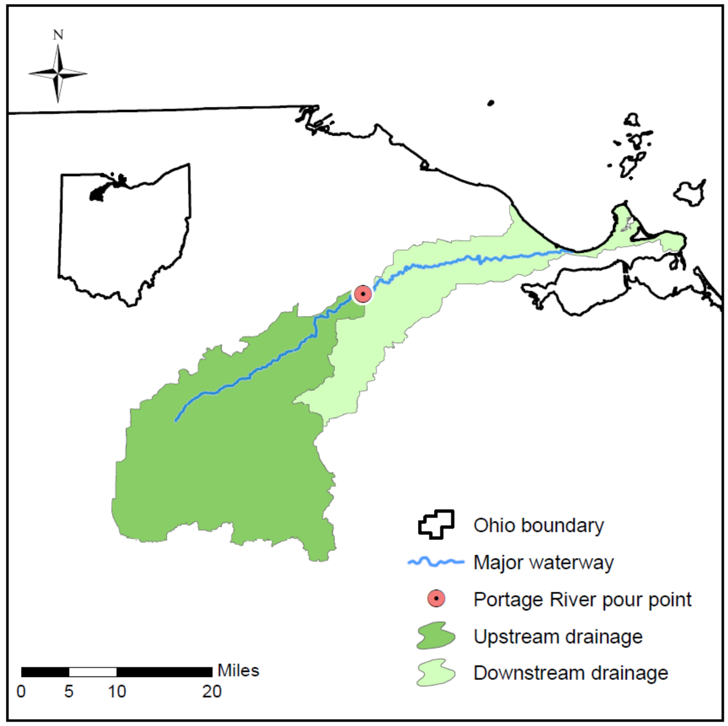


Figure 13 — Project area represented in the Portage River mass balance. The pour point along with up and downstream drainage areas are shown.

Agricultural production dominates the landscape, with 82 percent of the total land area being dedicated to agricultural production. Natural areas and development were similar at 8 percent and 10 percent, respectively. The area downstream of the pour point had similar land use with the largest change being a reduction in agricultural lands of 10 percent as compared to the upstream usage. Natural land use upstream (six percent) compared to downstream (14 percent) more than doubled, whereas development usage fluctuated from nine to 11 percent.

Total P loads from the Portage River were a maximum of 364 metric tons per year (mta) in wy19 and a minimum of 143 mta for wy16 (Figure 14 and Table 8). Total N loads from the Portage River were a maximum of 5,415 mta in wy19 and a minimum of 3,116 mta for wy14 (Figure 16 and Table 8). Total P and total N yields are presented on Figures 15 and 17, respectively.

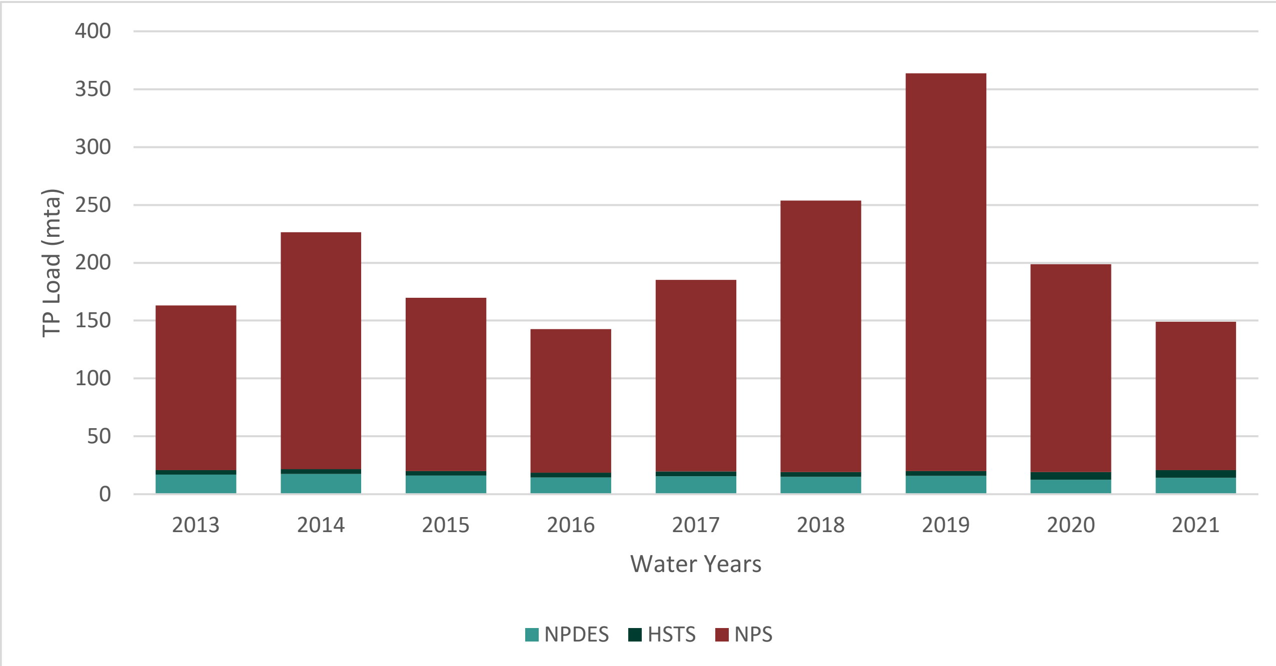


Figure 14— Total phosphorus loads for the Portage River for water year 2013-2021.

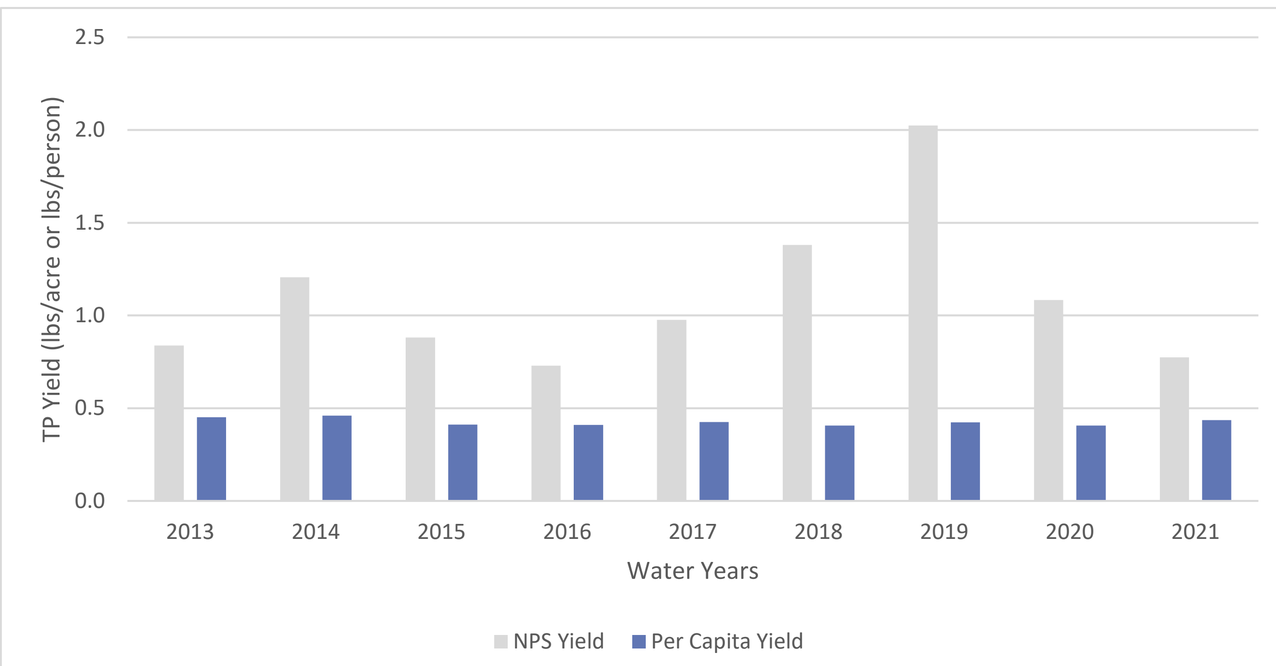


Figure 15 — Total phosphorus yields for the Portage River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

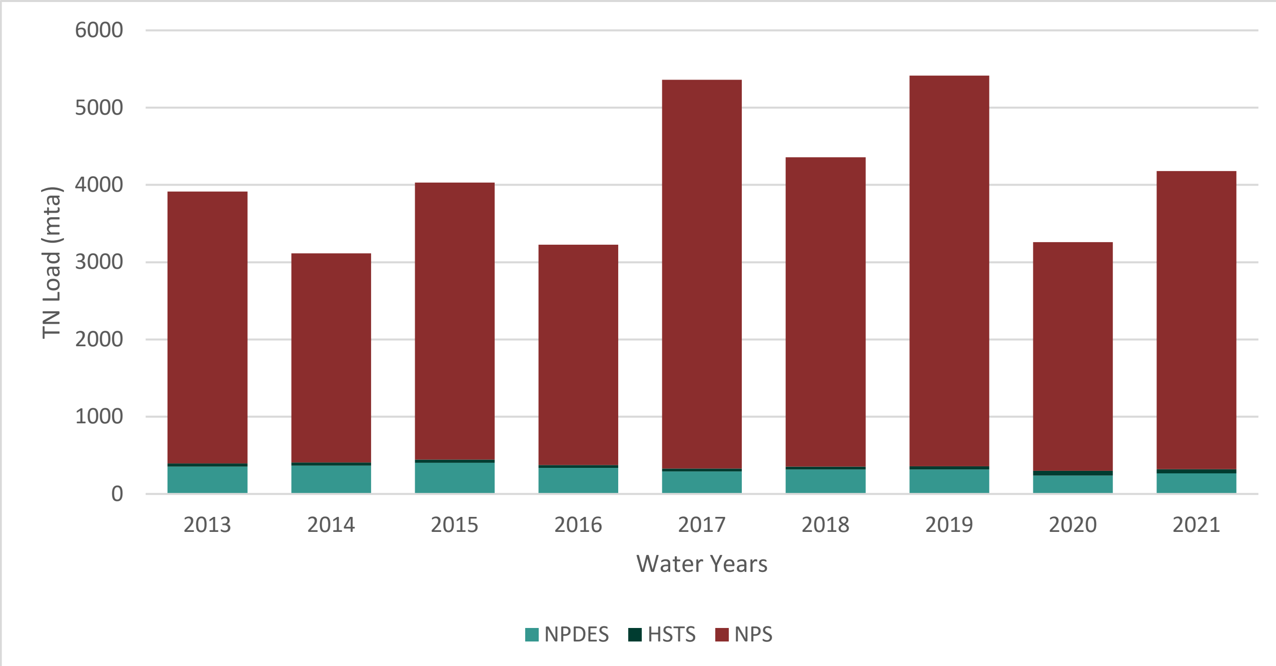


Figure 16 — Total nitrogen loads for the Portage River for water year 2013-2021.

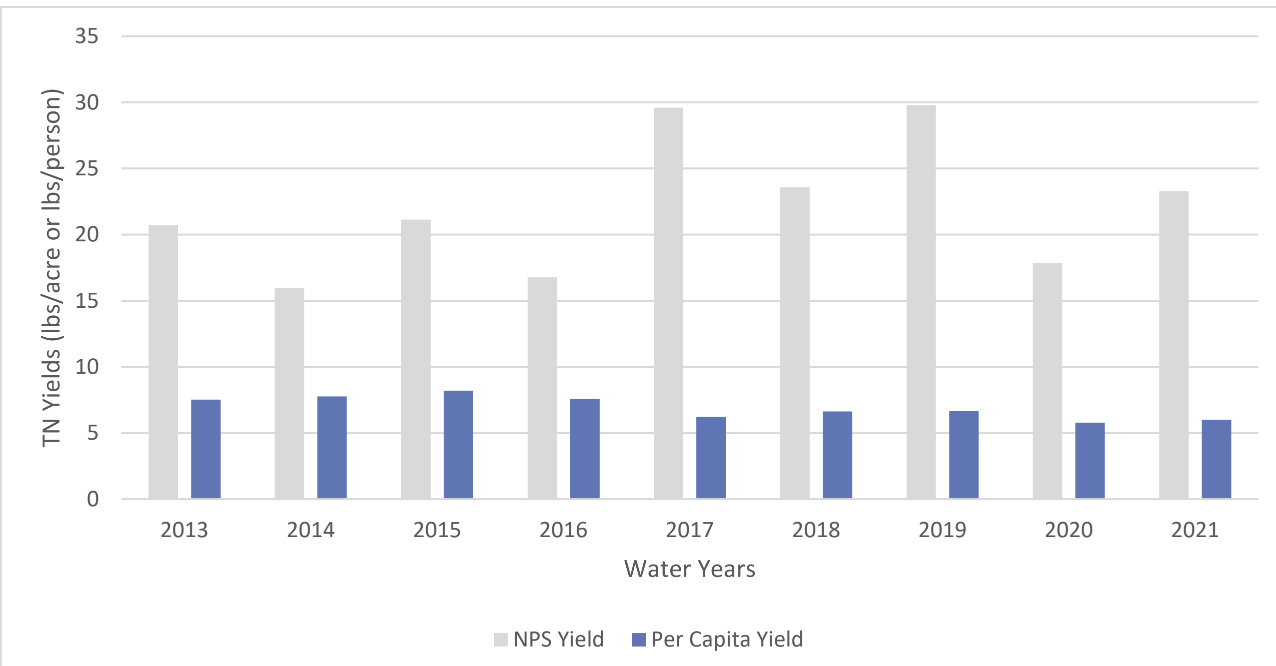


Figure 17 — Total nitrogen yields for the Portage River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 8 — Annual flow-weighted mean concentration (FWMC), total load and water yield Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy21 for the Portage Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	13.3	15.6	15.6	10.6	14	15.6	24	13.3	11.20
20-yr Median Water Yield (in) – 14.84									
Total P									
FWMC (mg/L)	0.31	0.37	0.28	0.34	0.34	0.41	0.39	0.38	0.34
Annual Load (mta)	163	226	170	143	185	254	364	199	149
Total N									
FWMC (mg/L)	7.79	5.22	6.82	7.97	9.45	7.17	5.82	6.30	9.63
Annual Load (mta)	3,915	3,116	4,032	3,226	5,358	4,357	5,415	2,358	4,180

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of five years of data are presented in Figure 18. The figure shows the nonpoint source is the largest proportion of the load in the Portage River at 92 percent for total annual P and 93 percent for total annual N. The NPDES sources comprised six percent of both total P and total N loads. Finally, the HSTS community contributed two and one percent of the total P and total N loads, respectively.

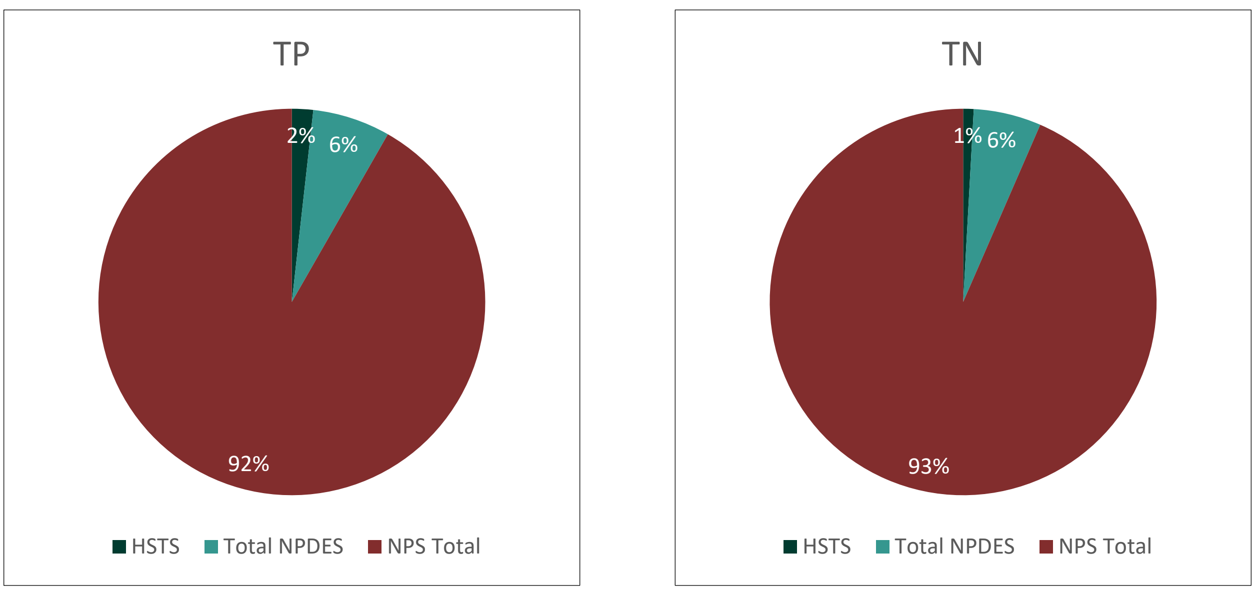


Figure 18 — Proportion of total phosphorus and nitrogen load from different sources for the Portage watershed, average of five years (wy17-wy21).

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. The results of the 2020 iteration of this study show that the Portage watershed had loads similar to the Maumee River when normalized for watershed area (see Figures 15 and 17). The 2022 iteration of this report follows this trend. Therefore, the Portage River is highlighted as an important part of nutrient reductions to the western basin of Lake Erie.

3.4 Cedar Toussaint

Cedar-Toussaint drains 323 sq. mi. in northwestern Ohio (Figure 19). The NCWQR maintains a water quality station at a USGS gaging station in Woodville, Ohio which was used as a pour point for the Portage watershed. The yields from this pour point were used to estimate the load for this specific subsect of that area. Because of this, all of the 344 sq. mi. area of this watershed can be considered downstream of the pour point.

Agricultural land dominates the land use of the Cedar-Toussaint watershed at 76 percent. Development and natural land cover are similar at 11 and 13 percent, respectively. Very little of the Cedar-Toussaint watershed contains areas of high-intensity development (1.42 percent of the total watershed).

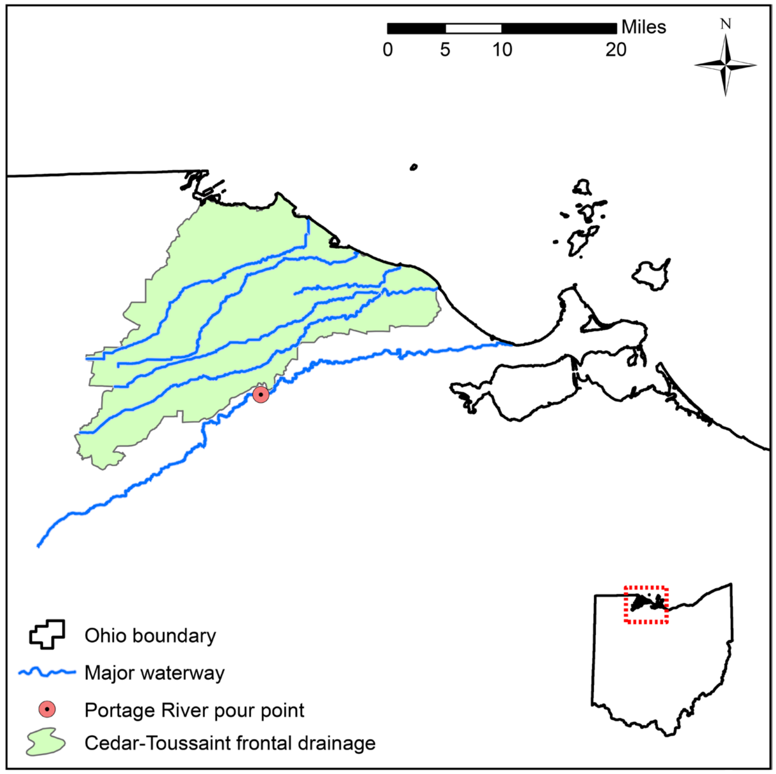


Figure 19 — Project area represented in the Cedar-Toussaint Lake Erie tributaries mass balance. The Portage River pour point being used for this watersheds' calculations is shown.

Total P loads from the Cedar-Toussaint were a maximum of 213 metric tons per year (mta) in wy19 and a minimum of 86 mta in wy16 (Figure 20 and Table 9). Total nitrogen loads from Cedar-Toussaint were a maximum 3,126 mta in wy19 and a minimum of 1,718 mta in wy14 (Figure 22 and Table 9). Total P and total N yields are presented on Figures 21 and 23, respectively. This watershed drains areas that are serviced by Toledo and Bowling Green WWTPs, however those plants discharge to other watersheds. Adjustments were made to this watershed's population to remove the watershed population serviced by those treatment plants for more accurate per capita yield calculations.

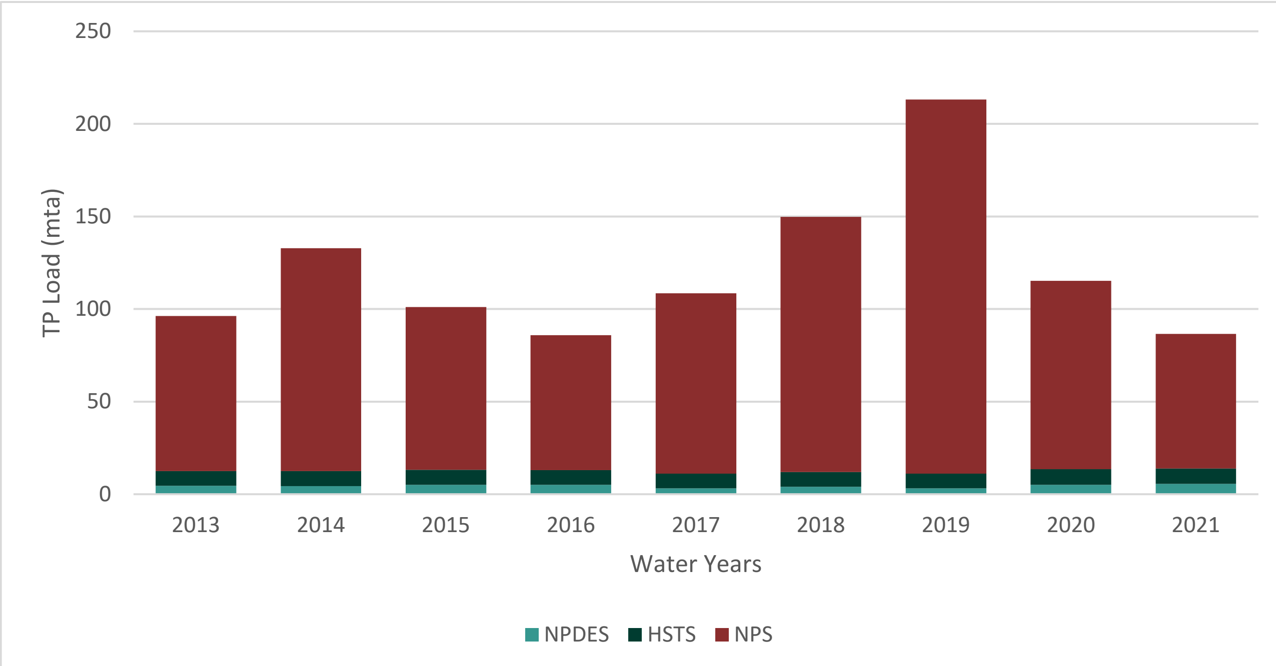


Figure 20 — Total phosphorus load for Cedar-Toussaint for water year 2013-2021.

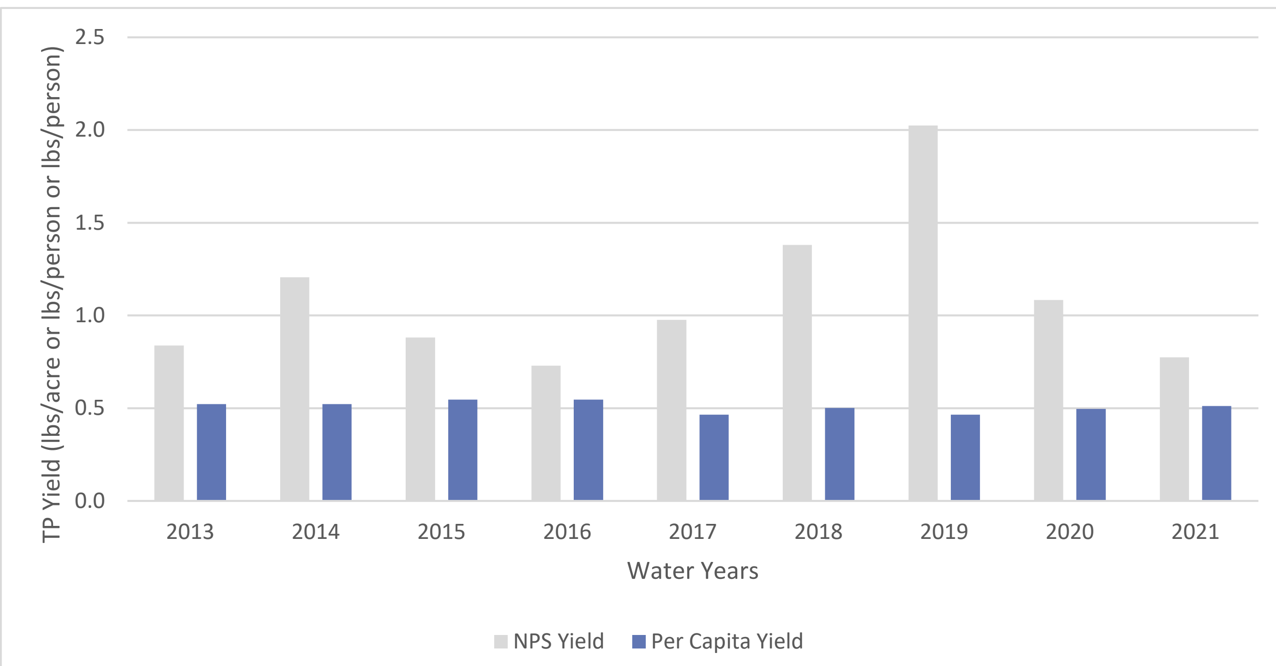


Figure 21 — Total phosphorus yields for Cedar-Toussaint for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

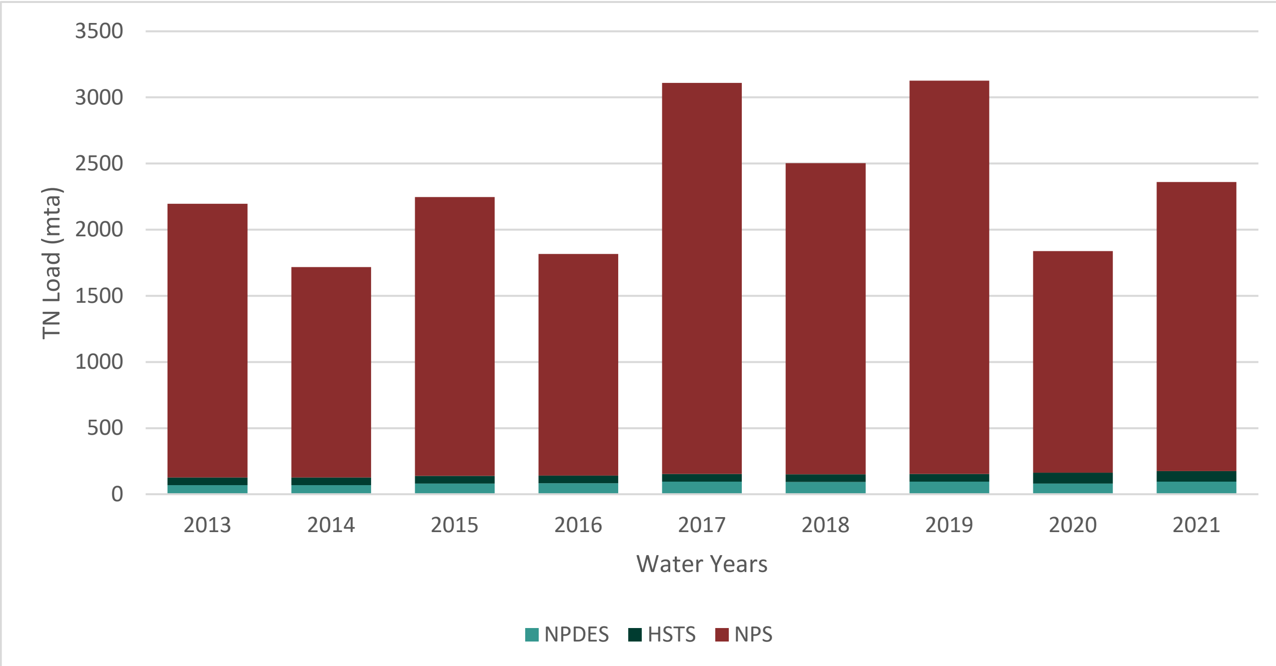


Figure 22 — Total nitrogen loads for Cedar-Toussaint for water year 2013-2021.

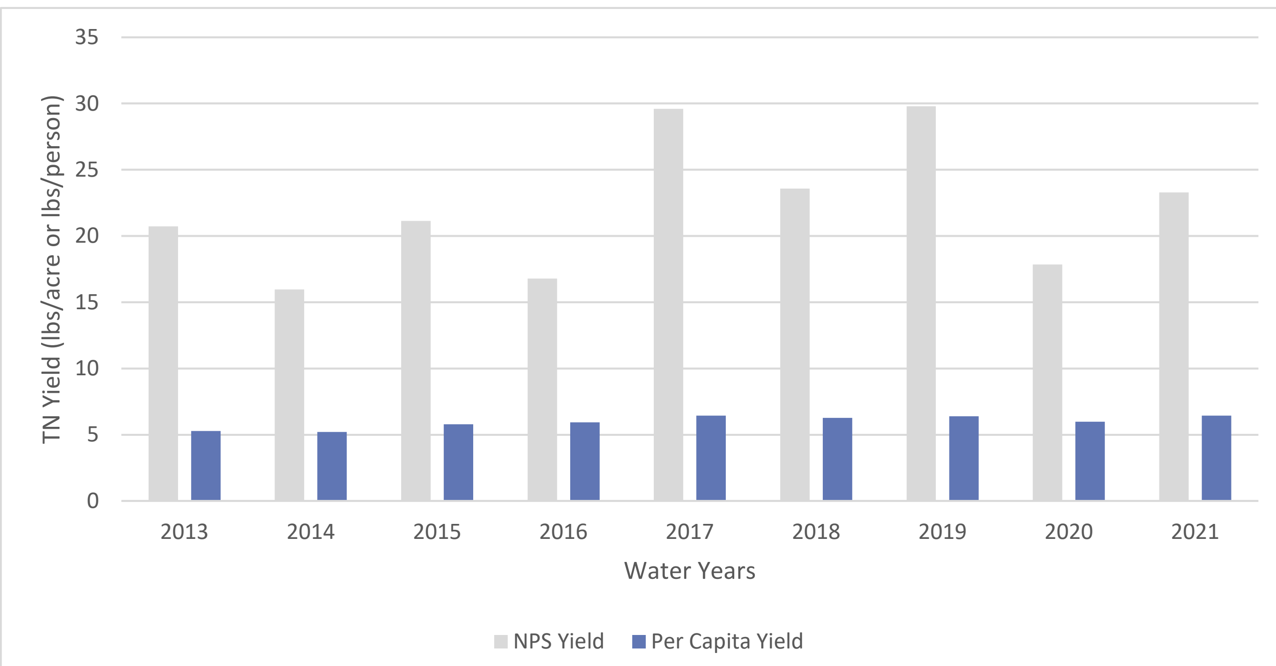


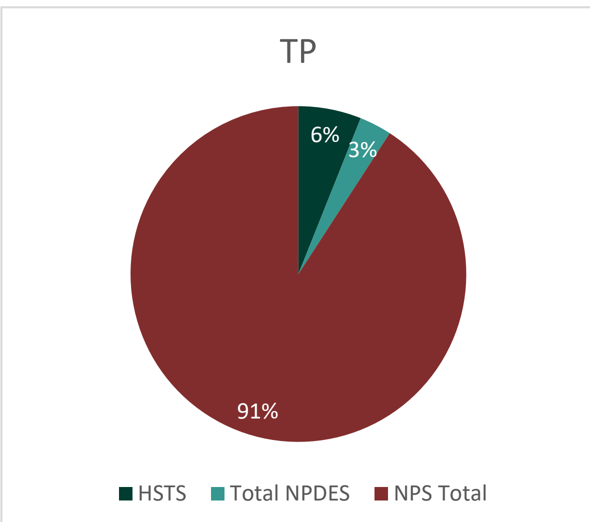
Figure 23 — Total nitrogen yields for Cedar-Toussaint for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Since loading is estimated by the loads in the Portage River there is no additional trend analysis that can be done for this watershed. Loading trends will mimic those in the Portage River.

Table 9 —Annual total loads for wy13 through wy19 for the Cedar-Toussaint Watershed. Since this watershed uses the Portage River monitoring point, no water yields and FWMCs are available.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Total P									
Annual Load (mta)	96	133	101	86	108	150	213	115	87
Total N									
Annual Load (mta)	2,195	1,718	2,247	1,818	3,109	2,502	3,126	1,837	2,362

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of the most recent five years 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 Cedar-Toussaint watershed at 91 percent for annual total P and 94 percent for annual total N. The NPDES sources contributed three percent of the annual total P and total N. Finally, the HSTS community contributed six percent of the annual total P load and three percent of total N.



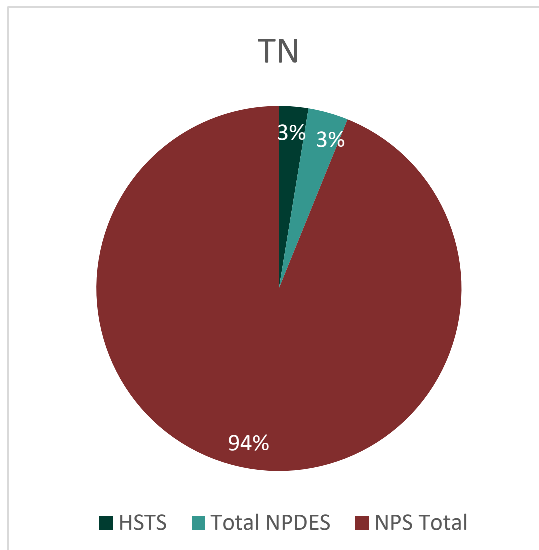


Figure 24 — Proportion of total phosphorus and nitrogen load from different sources for the Cedar-Toussaint watershed, average of five years (wy17-wy21).

3.5 Sandusky River and Sandusky Bay Tributaries Watershed

The Sandusky River and Sandusky Bay tributaries drains 1,760 sq. mi. in north-central Ohio (Figure 25). The 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 1,244 sq. mi. and 516 sq. mi. downstream of the pour point. The area draining to the Sandusky Bay is included in the area downstream of the pour point for this watershed in this report.

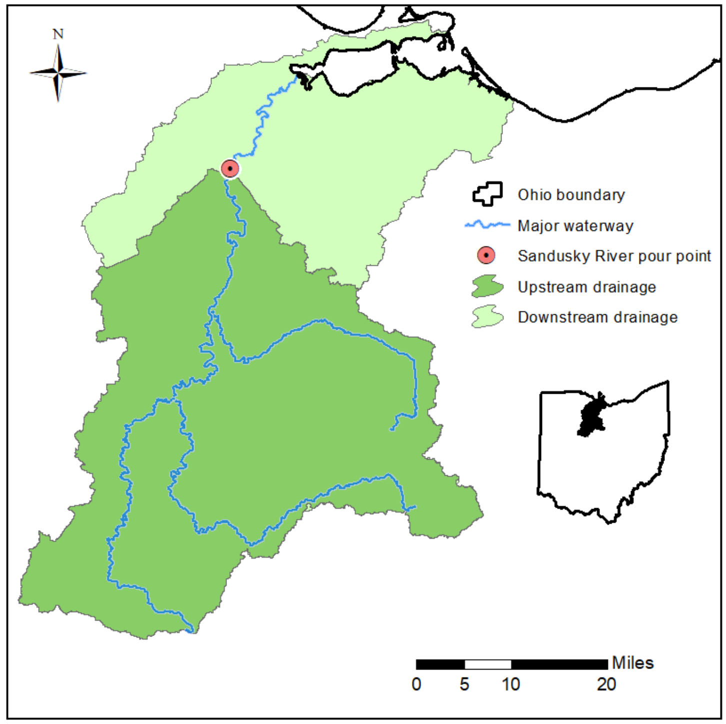


Figure 25 — Project area represented in the Sandusky River mass balance. The pour point along with up and downstream drainage areas are shown.

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.

Total P loads from this watershed were a maximum of 1,226 metric tons per year (mta) in wy19 and a minimum of 449 mta in wy16 (Figure 26 and Table 10). Total N loads from this watershed were a maximum of 15,165 mta in wy13 and a minimum of 8,678 mta in wy16 (Figure 28 and Table 10). Total P and total N yields are presented on Figures 27 and 29, respectively.

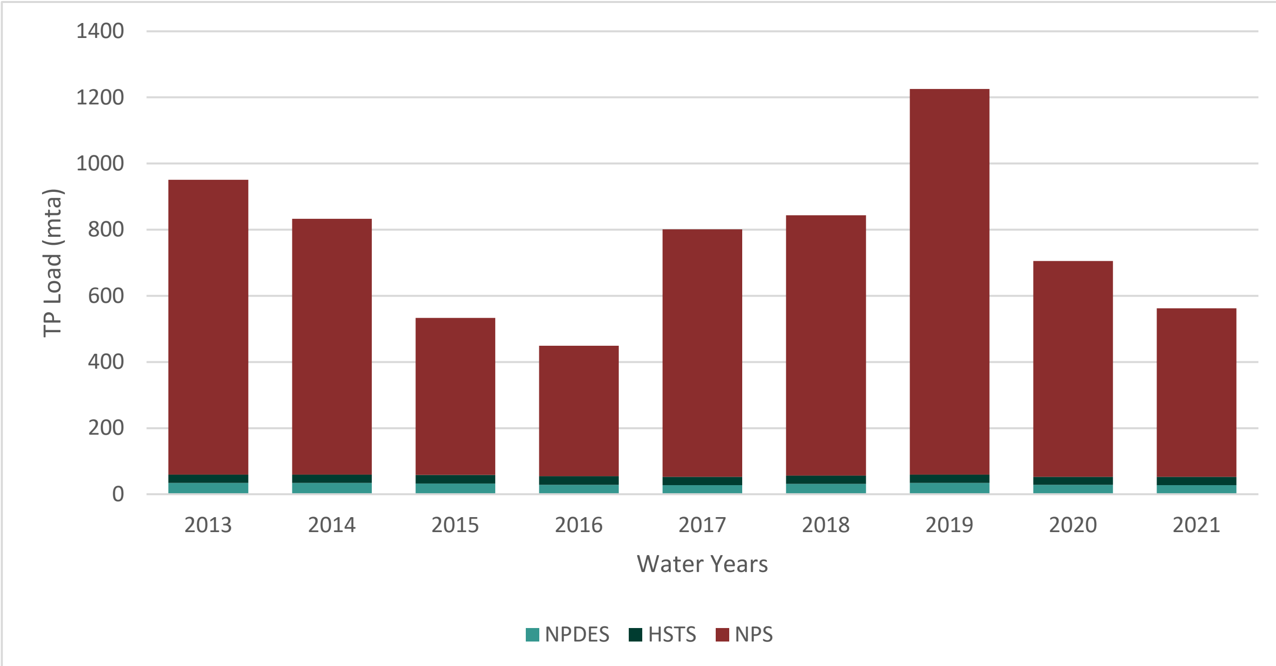


Figure 26 — Total phosphorus loads for the Sandusky River and Sandusky Bay tributaries for water year 2013-2021.

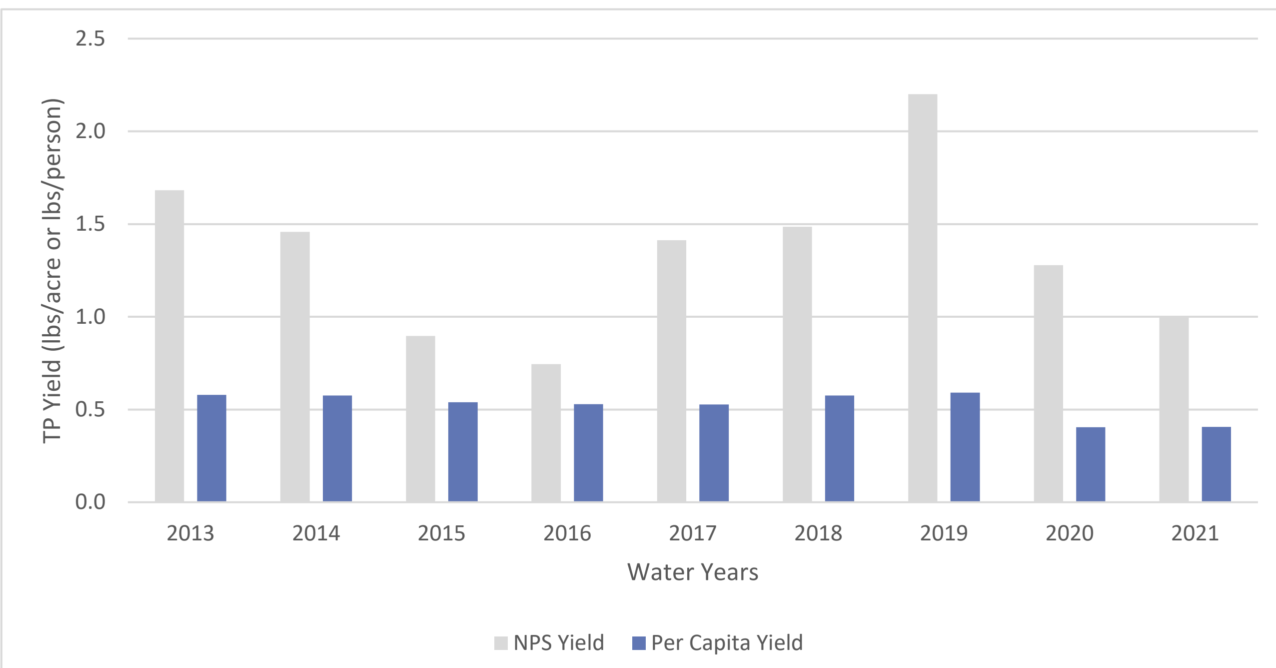


Figure 27 — Total phosphorus yields for the Sandusky River and Sandusky Bay tributaries for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

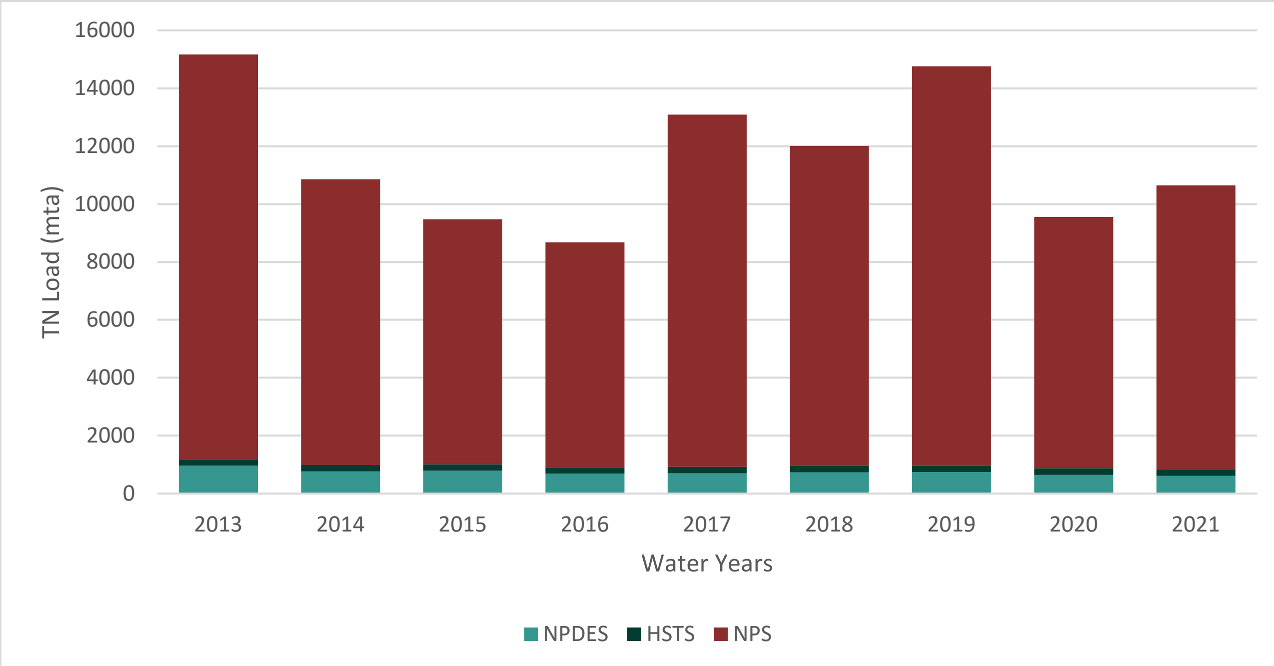


Figure 28 — Total nitrogen loads for the Sandusky River and Sandusky Bay tributaries for water year 2013-2021.

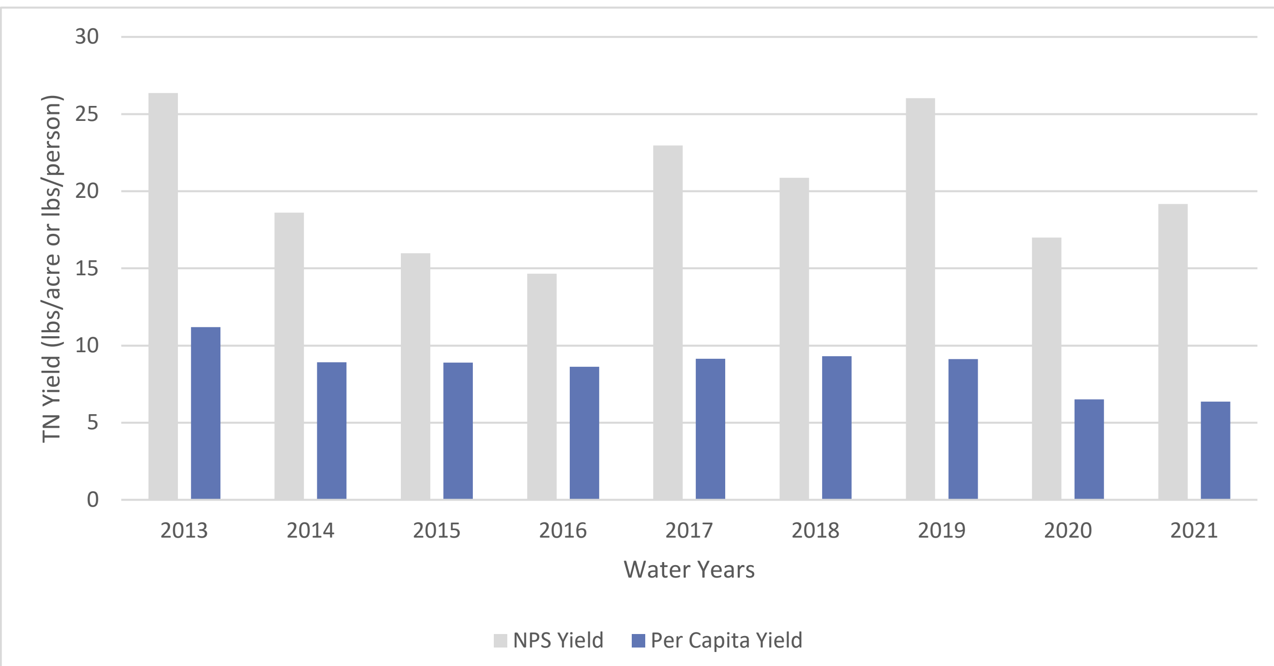


Figure 29 — Total nitrogen yields for the Sandusky River and Sandusky Bay tributaries for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 10 — Annual flow-weighted mean concentration (FWMC), total load and water yield Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy21 for the Sandusky Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	18.1	17.2	12.8	10.5	14.3	16.0	21.9	11.7	11.2
20-yr Median Water Yield (in) – 15.39									
Total P									
FWMC (mg/L)	0.43	0.39	0.33	0.34	0.46	0.44	0.39	0.51	0.42
Annual Load (mta)	951	833	533	449	801	844	1,226	706	563
Total N									
FWMC (mg/L)	6.73	5.12	6.53	6.59	7.75	6.02	5.44	6.73	7.85
Annual Load (mta)	15,165	10,853	9,474	8,678	13,092	12,008	14,759	9,553	10,642

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of the five years analyzed are presented in Figure 30. This figure shows that the nonpoint source is the largest proportion of the load in the Sandusky River at 93 and 92 percent, respectively, for total P and total N. The NPDES sources comprised four and six percent for the total P and total N loads, respectively. Finally, the HSTS community contributed three and two percent for total P and total N, respectively.

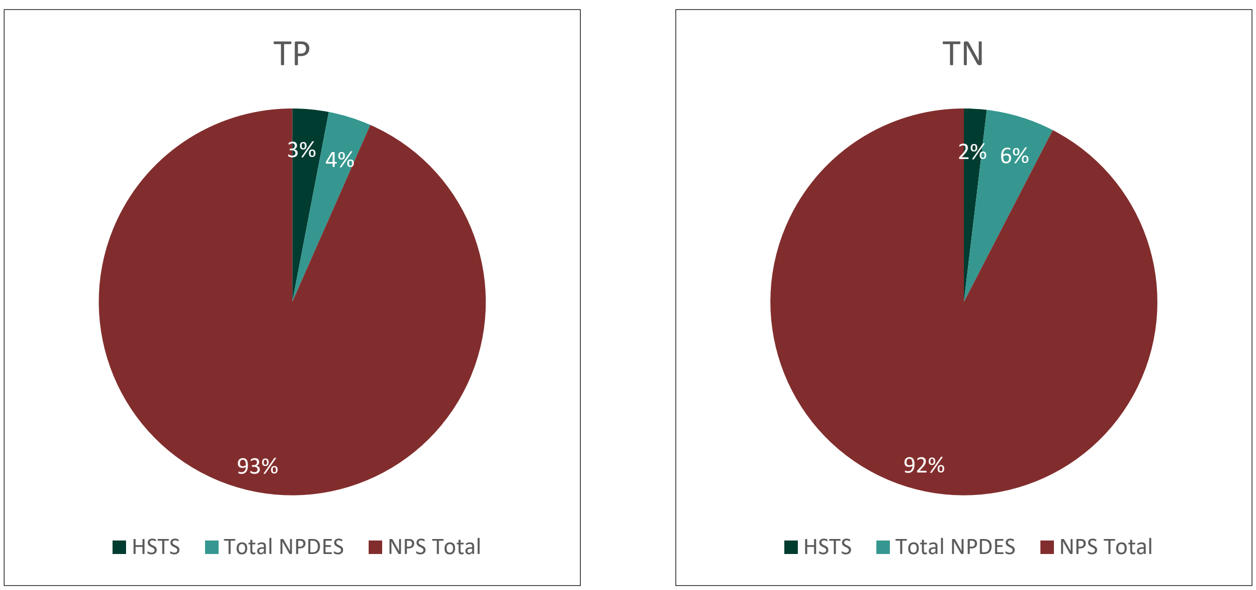


Figure 30 — Proportion of total phosphorus and nitrogen load from different sources for the Sandusky River and Sandusky Bay tributaries watershed, average of five years (wy17-wy21).

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 four 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. Further, the Sandusky River has the highest relative loadings of total P and total N attributed to nonpoint sources in this study (based on the five-year average of the 10 watersheds with available data). 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.

3.6 Huron River

The Huron River drains 403 sq. mi. in northwestern Ohio (Figure 31). The USGS maintains a water quality station at a gaging station which Heidelberg used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 368 sq. mi. and 34 sq. mi. downstream of the pour point. The downstream area has one of the higher percentages of natural land with 26 percent cover, 15 percent development, and 59 percent agricultural land).

Agricultural land dominates the land use of the Huron watershed at 73 percent.

Total P loads from the Huron River were 159 metric tons per year (mta) in wy20 and 118 mta in wy21(Figure 32 and Table 11). Total nitrogen loads from Huron River were 1,856 mta in wy20 and 2,416 mta in wy21 (Figure 34 and Table 11). Total P and total N yields are presented on Figures 33 and 35, respectively.

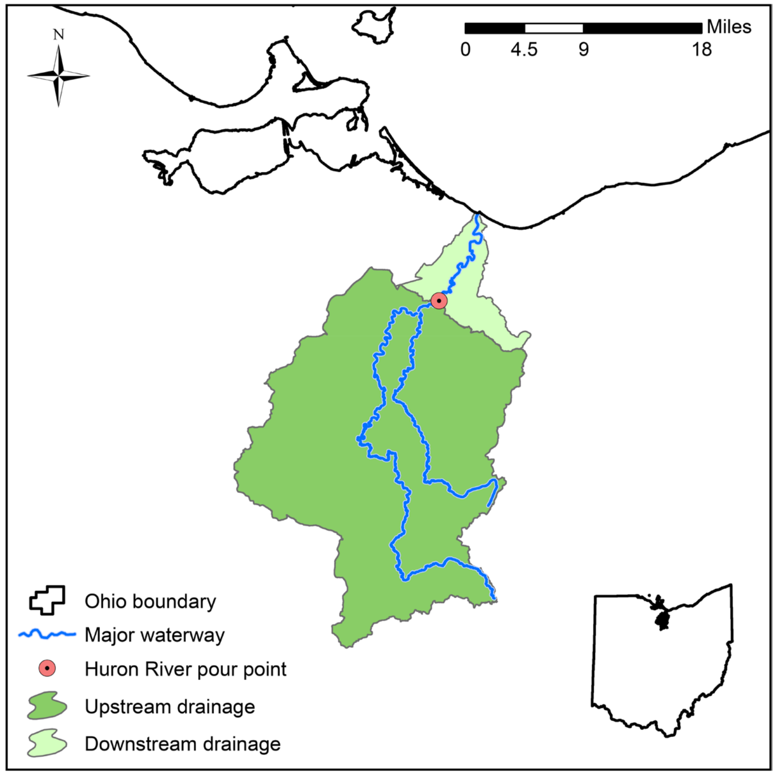


Figure 31 — Project area represented in the Huron River mass balance. A pour point is identified in one of the watersheds and yield calculations were used in the other two watershed areas.

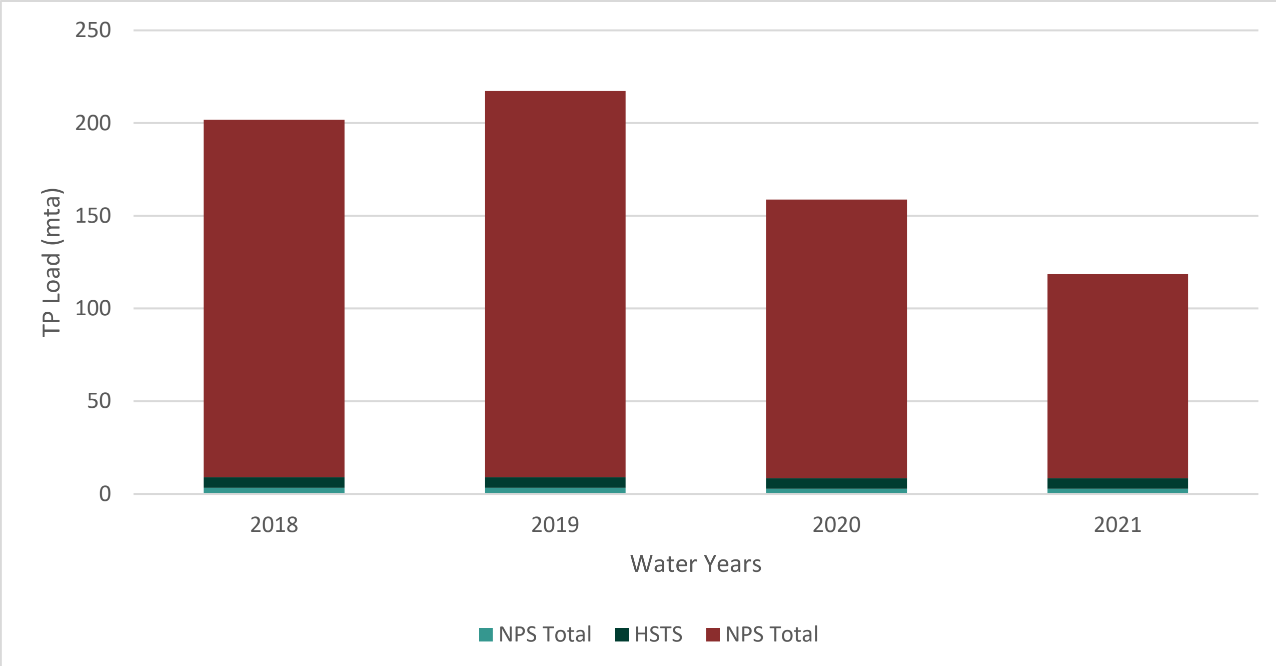


Figure 32 — Total phosphorus loads for Huron River for water year 2018-2021.

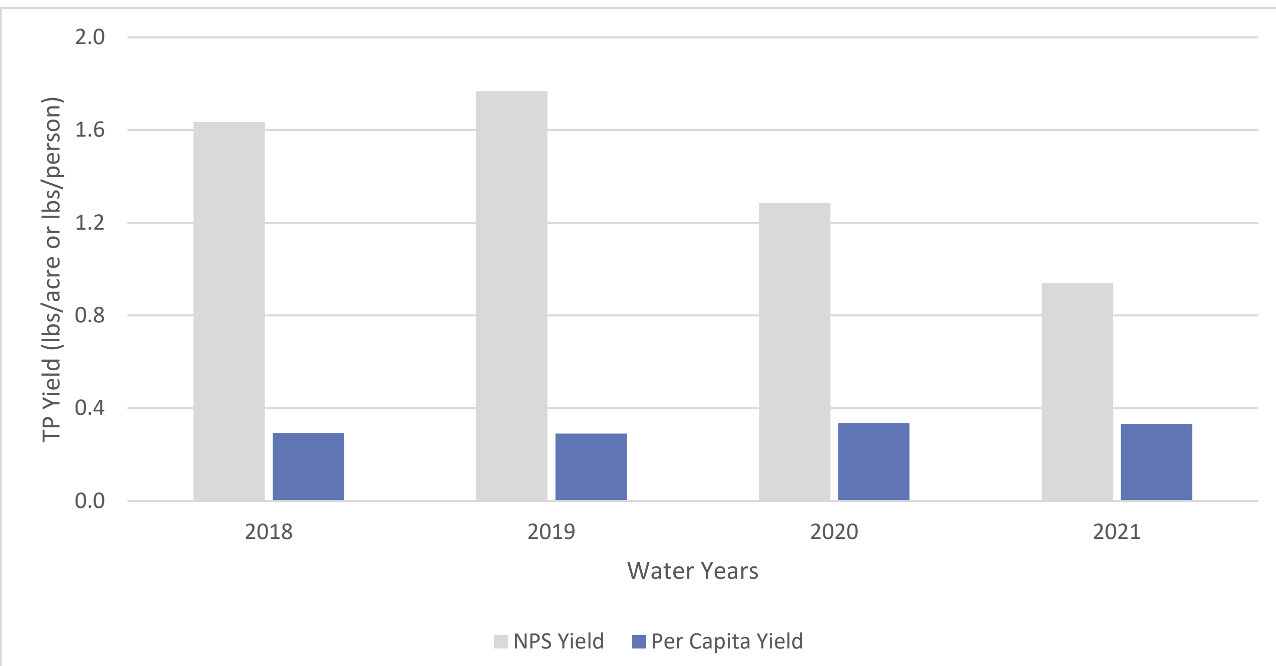


Figure 33 — Total phosphorus yields for Huron River for water year 2018-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

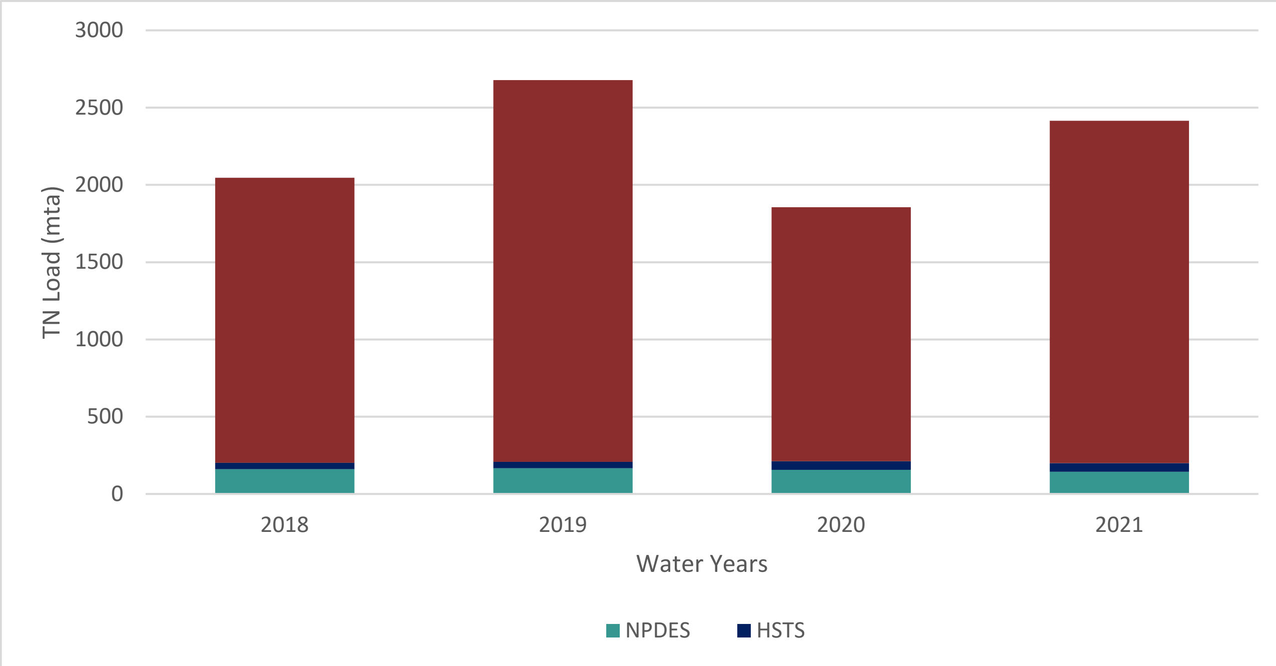


Figure 34 — Total nitrogen loads for Huron River for water year 2018-2021.

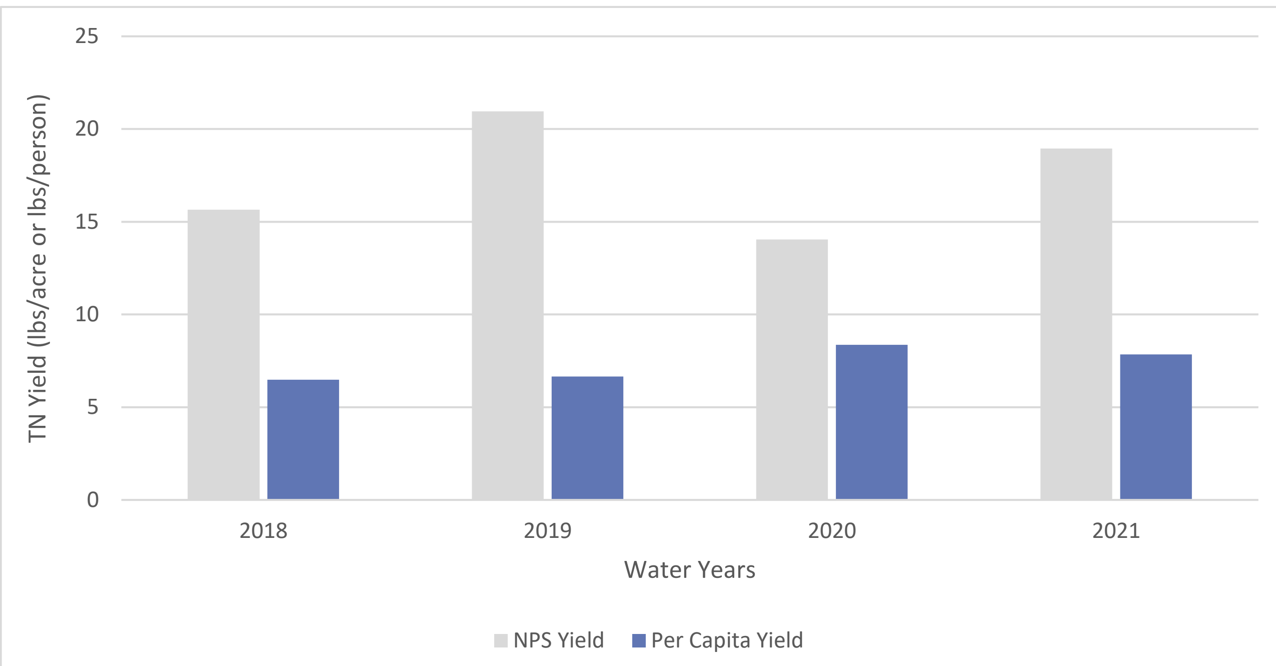


Figure 35 — Total nitrogen yields for Huron River for water year 2018-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 11 —Annual flow-weighted mean concentration (FWMC), total load and water yield for wy18 through wy21 for the Huron River. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy18	wy19	wy20	wy21
Water Yield (in/yr)	16.4	21	13.11	15
4-yr Median Water Yield (in) – 16.38				
Total P				
FWMC (mg/L)	0.44	0.39	0.45	0.29
Annual Load (mta)	202	217	159	118
Total N				
FWMC (mg/L)	4.58	4.70	5.10	5.90
Annual Load (mta)	2,046	2,679	1,856	2,416

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of the four years included in this study are presented in Figure 36. The figure shows the nonpoint source is the largest proportion of the total P and total N load in the Huron River at 95 percent for total P and 91 percent for total N. The NPDES sources contributed two percent for the total P load and seven percent of the total N load. Finally, the HSTS community contributed three percent of the total P load and two percent of the total N load.

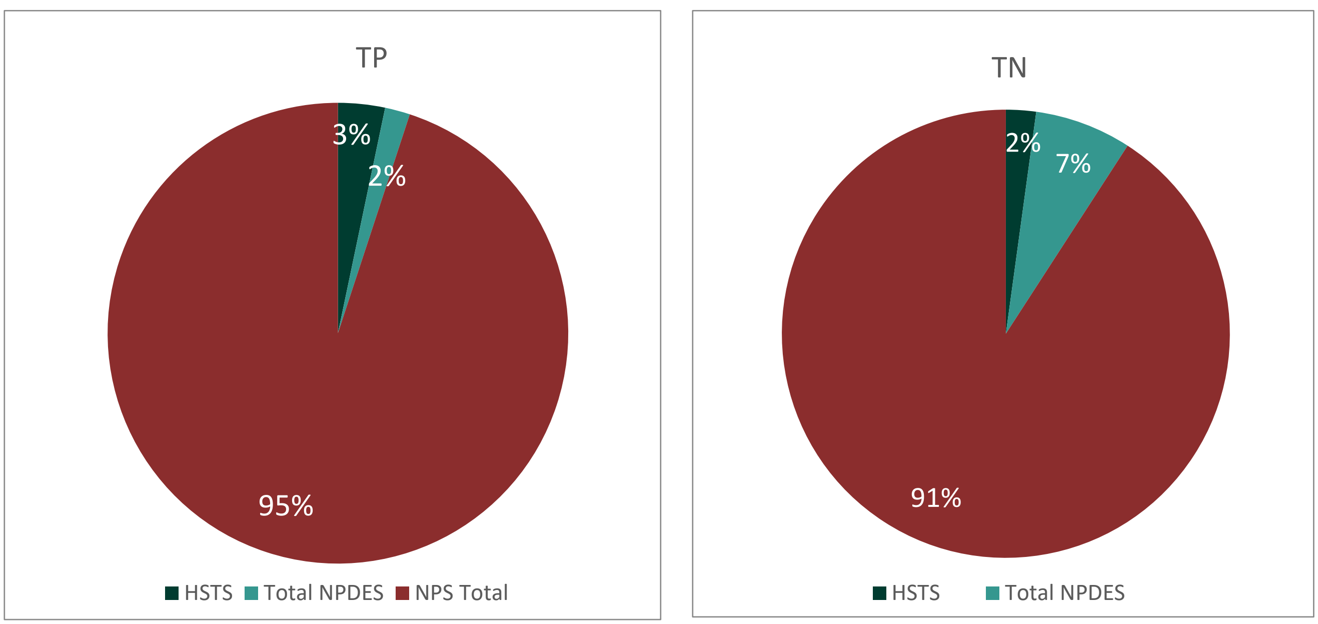


Figure 36 — Proportion of total phosphorus and nitrogen load from different sources for the Huron River watershed, average of two years (wy18-wy21).

3.7 Old Woman Creek

Old Woman Creek area included in this study drains 79 sq. mi. in northwestern Ohio (Figure 37). The USGS maintains a water quality station at a gaging station near Huron, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 22 sq. mi. and 57 sq. mi. downstream of the pour point. As evident on Figure 37, some of the area downstream of the pour point is a part of an adjacent frontal Lake Erie small watershed.

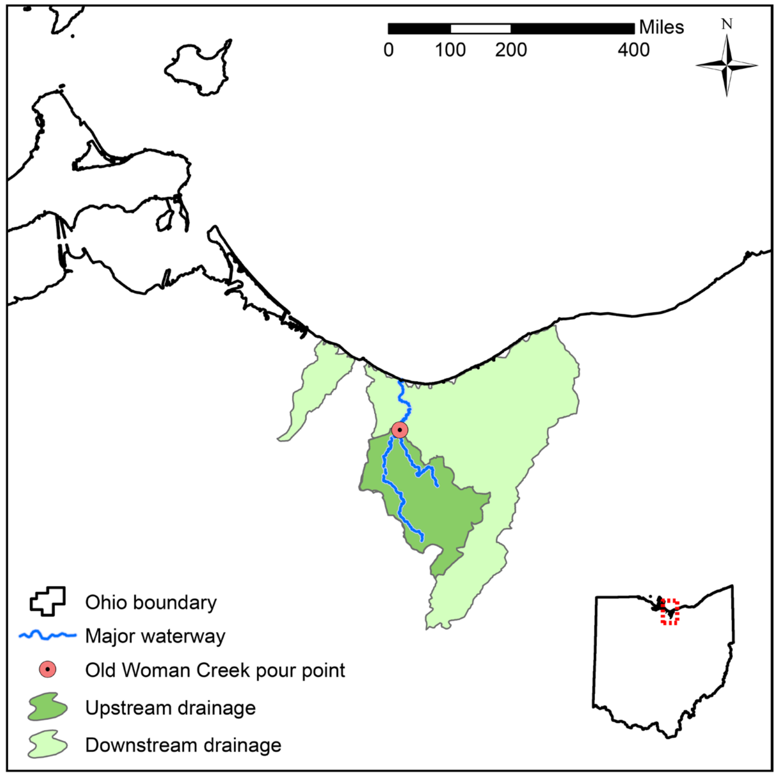


Figure 37 — Project area represented in the Old Woman Creek area mass balance. A pour point is identified in one of the watersheds and yield calculations were used in the other two watershed areas.

Agricultural land dominates the land use of the Old Woman Creek area watershed at 60 percent. Downstream of the pour point, a relatively high percentage of natural land exists (34 percent) – a 15 percent increase when compared to the upstream usage (19 percent).

Total P loads from Old Woman Creek were a maximum of 38 metric tons per year (mta) in wy19 and a minimum of 21 mta in wy16 (Figure 38 and Table 12). Total nitrogen loads from Old Woman Creek were a maximum of 627 mta in wy19 and a minimum of 292 mta in wy20 (Figure 40 and Table 12). Total P and total N yields are presented on Figures 39 and 41, respectively.

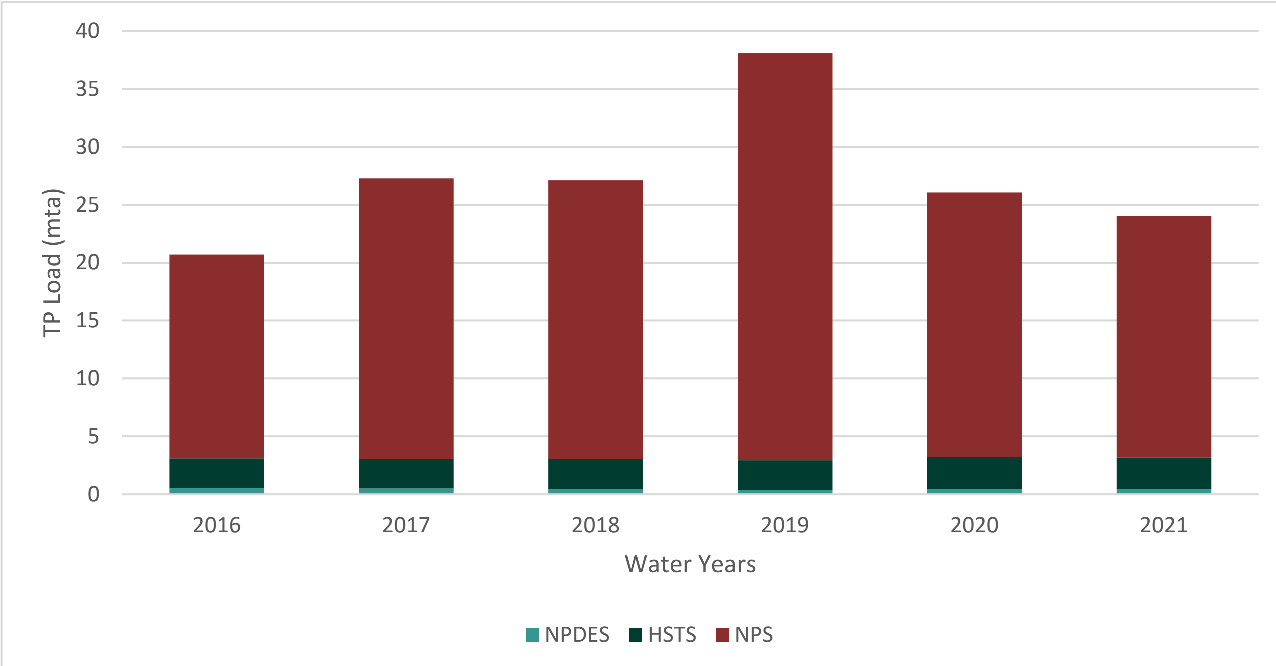


Figure 38 — Total phosphorus loads for Old Woman Creek for water year 2016-2021.

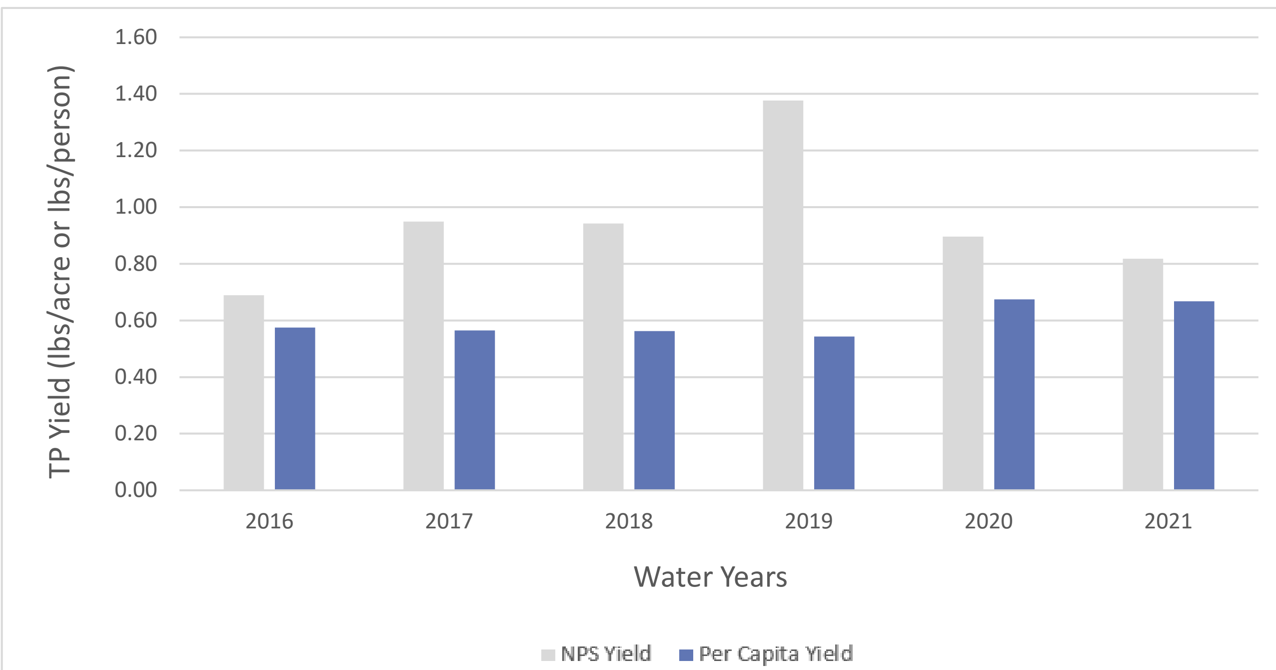


Figure 39 — Total phosphorus yields for Old Woman Creek for water year 2016-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

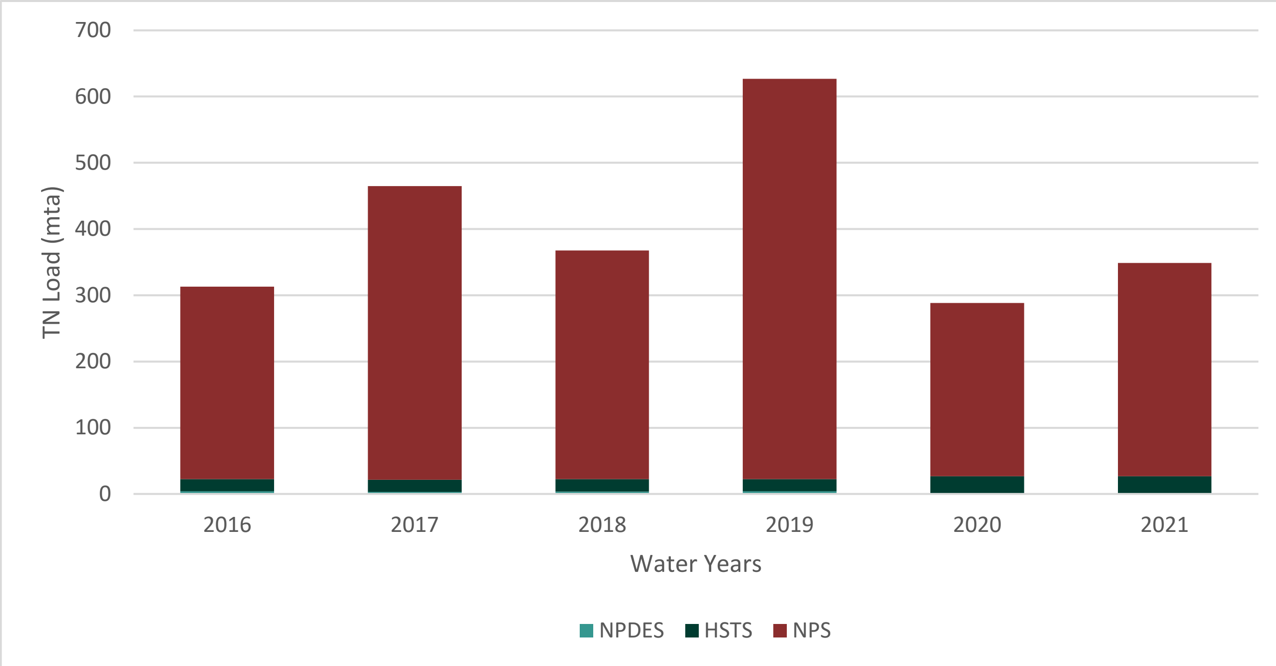


Figure 40 — Total nitrogen loads for Old Woman Creek for water year 2016-2021.

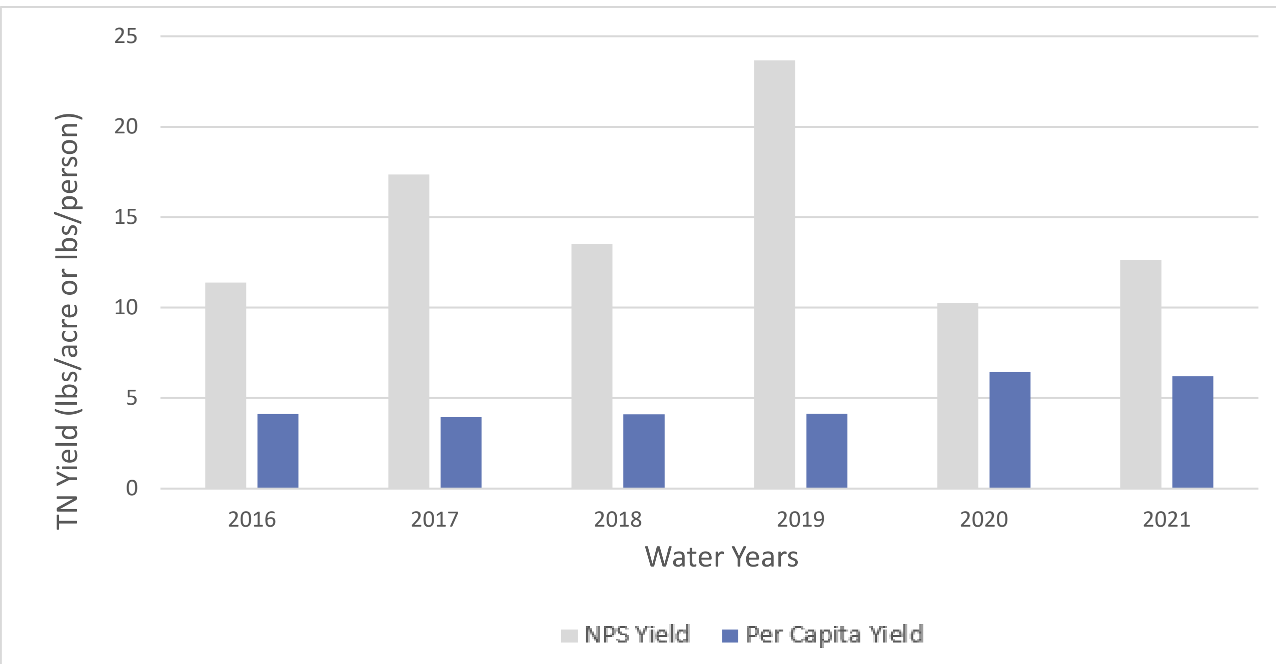
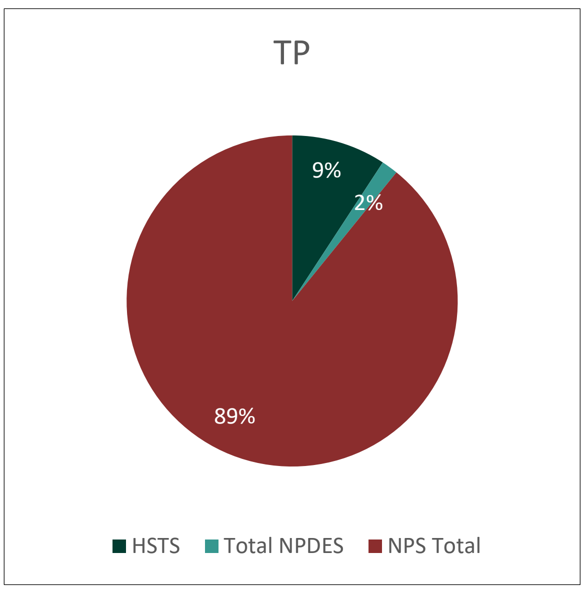


Figure 41 — Total nitrogen yields for Old Woman Creek for water year 2016-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 12 —Annual flow-weighted mean concentration (FWMC), total load and water yield for wy15 through wy21 for Old Woman Creek. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	16.5	16.6	14.3	11.4	13	17.6	23.7	11.5	11.7
20-yr Median Water Yield (in) – 15.6									
Total P									
FWMC (mg/L)	NA	NA	NA	0.30	0.36	0.26	0.28	0.36	0.34
Annual Load (mta)	NA	NA	NA	21	27	27	38	26	24
Total N									
FWMC (mg/L)	NA	NA	NA	4.67	6.13	3.57	4.55	4.11	5.11
Annual Load (mta)	NA	NA	NA	313	465	368	627	292	351

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of the six years included in this study are presented in Figure 42. The figure shows the nonpoint source is the largest proportion of the total P and total N load in Old Woman Creek at 89 percent for total P and 94 percent for total N. The NPDES sources contributed two percent total P and one percent for total N load. Finally, the HSTS community contributed nine percent of the total P load and five percent of the total N load. There additionally was a significant increase in per capita N yield, due to the correction in load allocation for the HSTS equation.



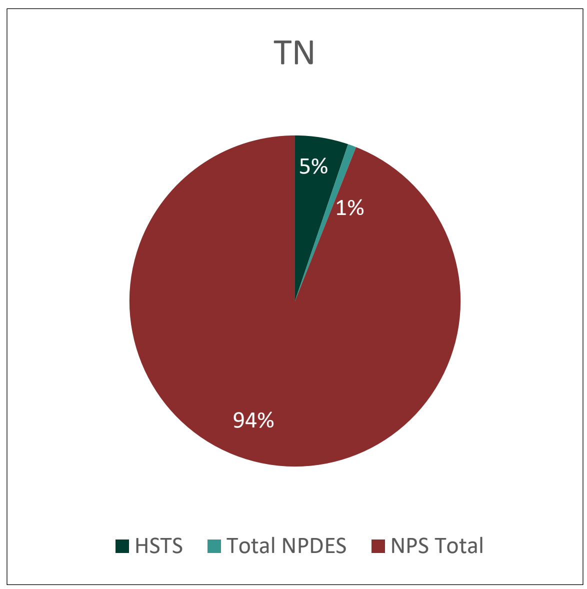


Figure 42 — Proportion of total phosphorus and nitrogen load from different sources for Old Woman Creek, average of five years (wy17-wy21).

3.8 Vermilion River

The Vermilion River drains 267 sq. mi. in north-central Ohio (Figure 43). The USGS maintains a water quality station at a gaging station in Vermilion, Ohio which was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 260 sq. mi. and seven sq. mi. downstream of the pour point.

Agricultural land dominates the land use of the Vermilion watershed at 66 percent. There is also a notable uptick in natural areas when the Vermilion is compared to the watersheds lying to its west (i.e., 42 percent natural land downstream of pour point, 26 percent upstream of pour point, total use of 26 percent). The area downstream of the pour point is three percent of the land area in the watershed so loading assumptions have little impact on the total loading calculations.

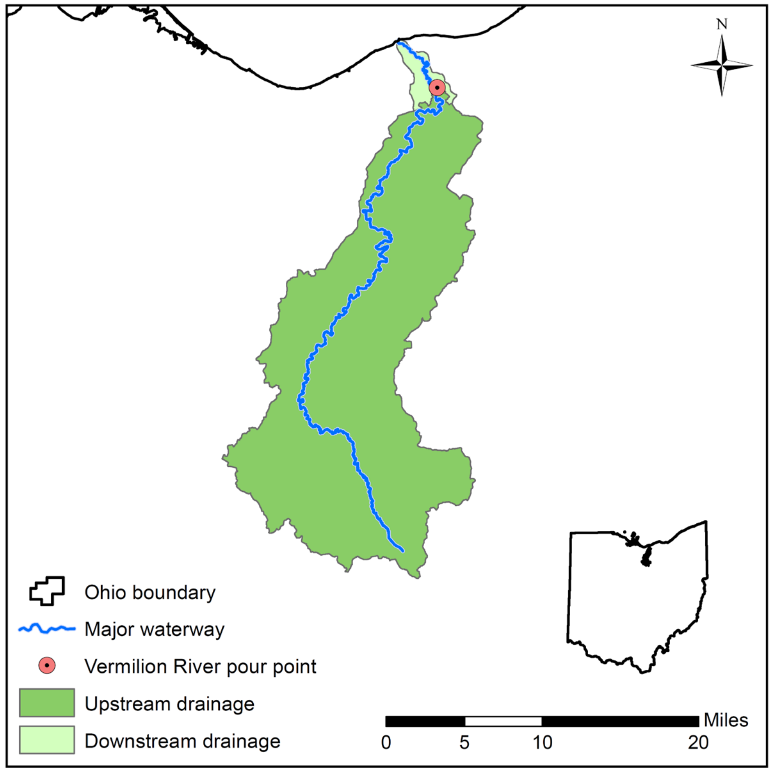


Figure 43 — Project area represented in the Vermilion River mass balance. The pour point along with up and downstream drainage areas are shown.

Total P loads from the Vermilion River were a maximum of 156 metric tons per year (mta) in wy19 and a minimum of 68 mta in wy16 (Figure 44 and Table 13). Total nitrogen loads from the Vermilion River were a maximum 2,065 mta in wy19 and a minimum of 792 mta in wy20 (Figure 46 and Table 13). Total P and total N yields are presented on Figures 45 and 47, respectively.

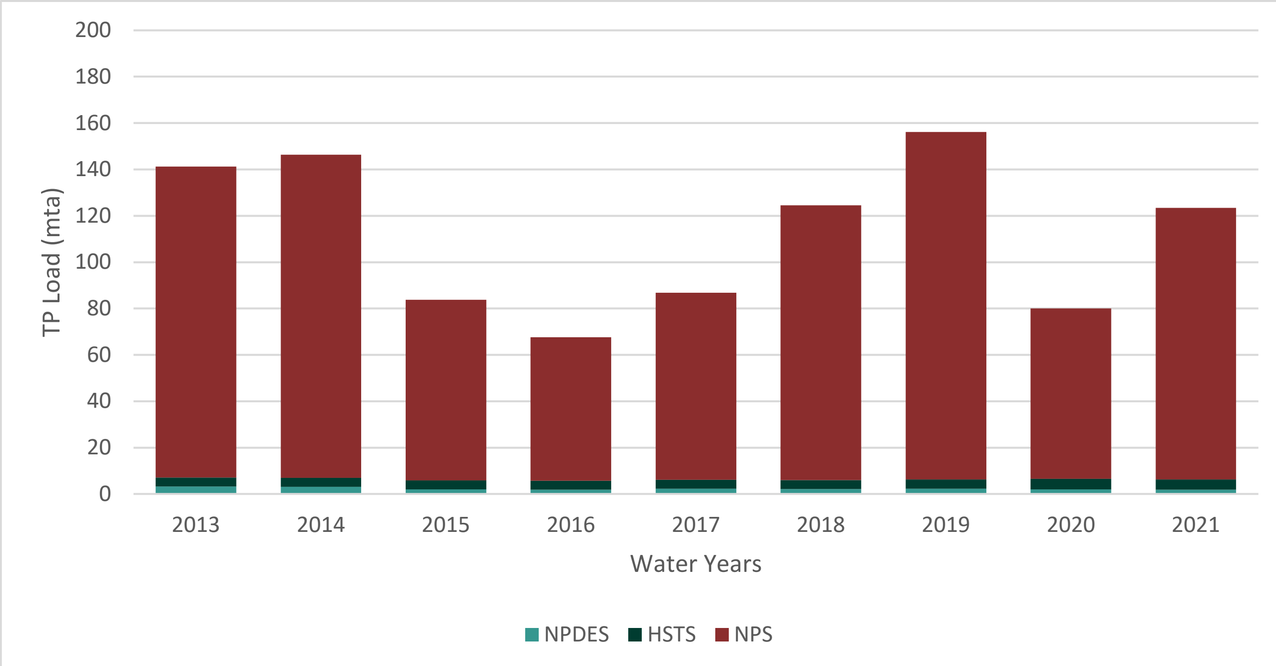


Figure 44 — Total phosphorus loads for the Vermilion River for water year 2013-2021.

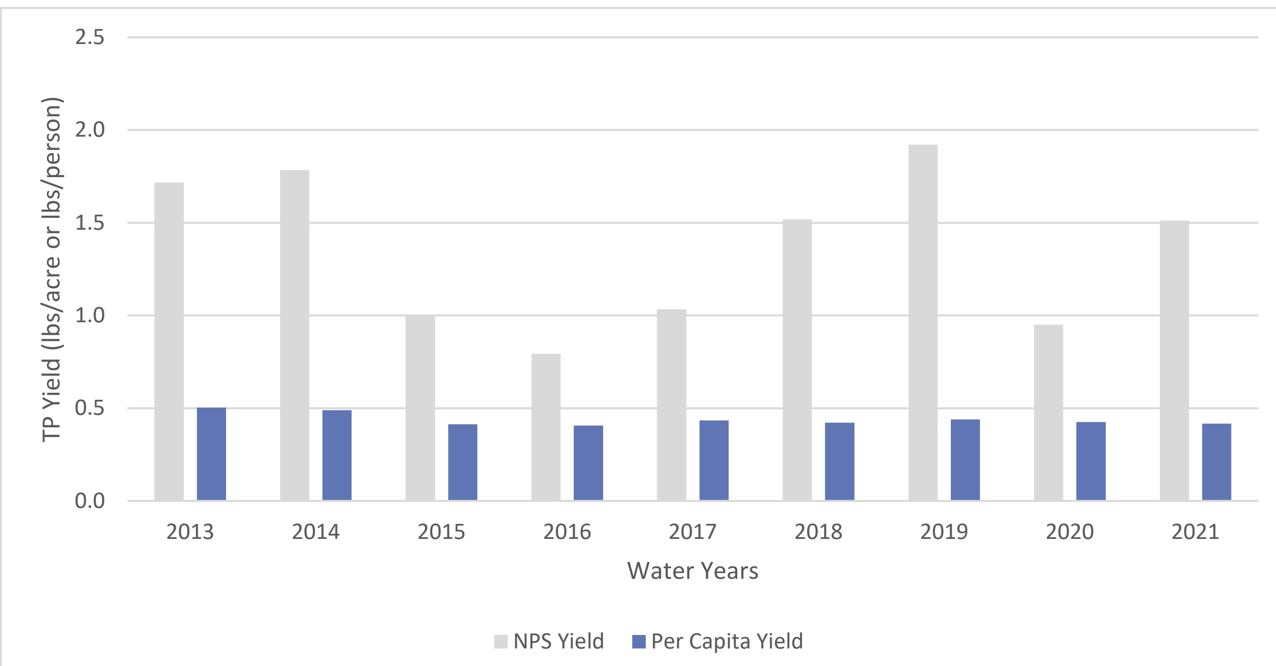


Figure 45 — Total phosphorus yields for the Vermilion River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

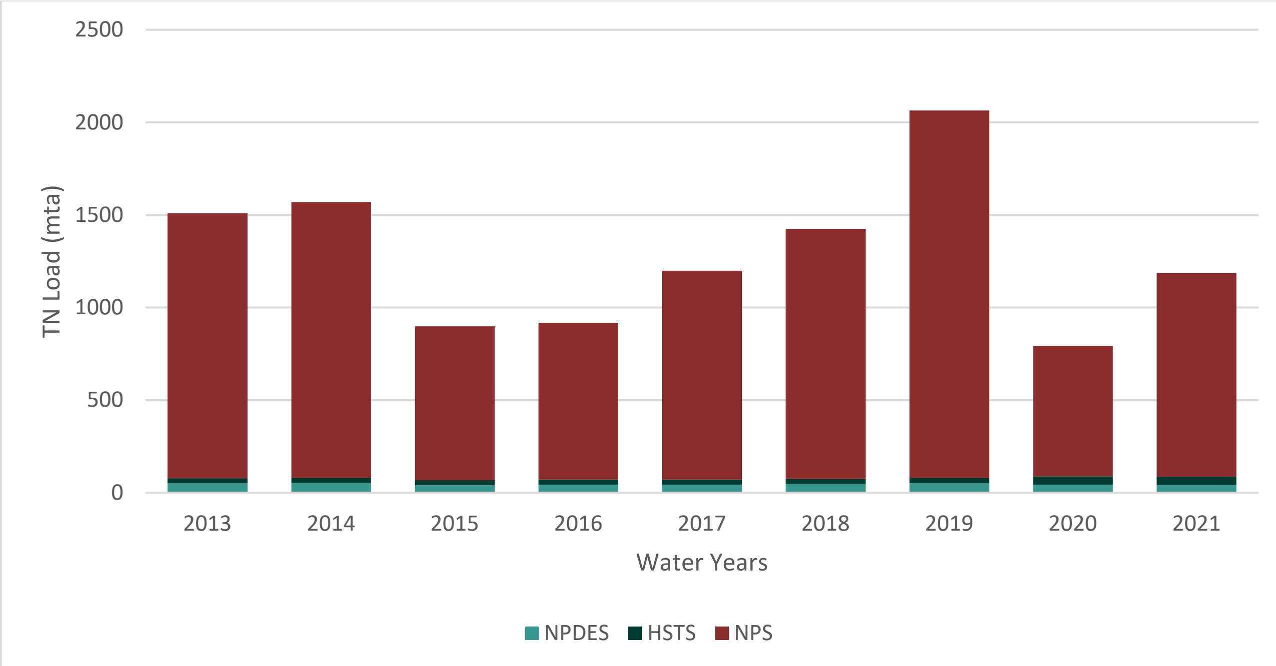


Figure 46 — Total nitrogen loads for the Vermilion River for water year 2013-2021.

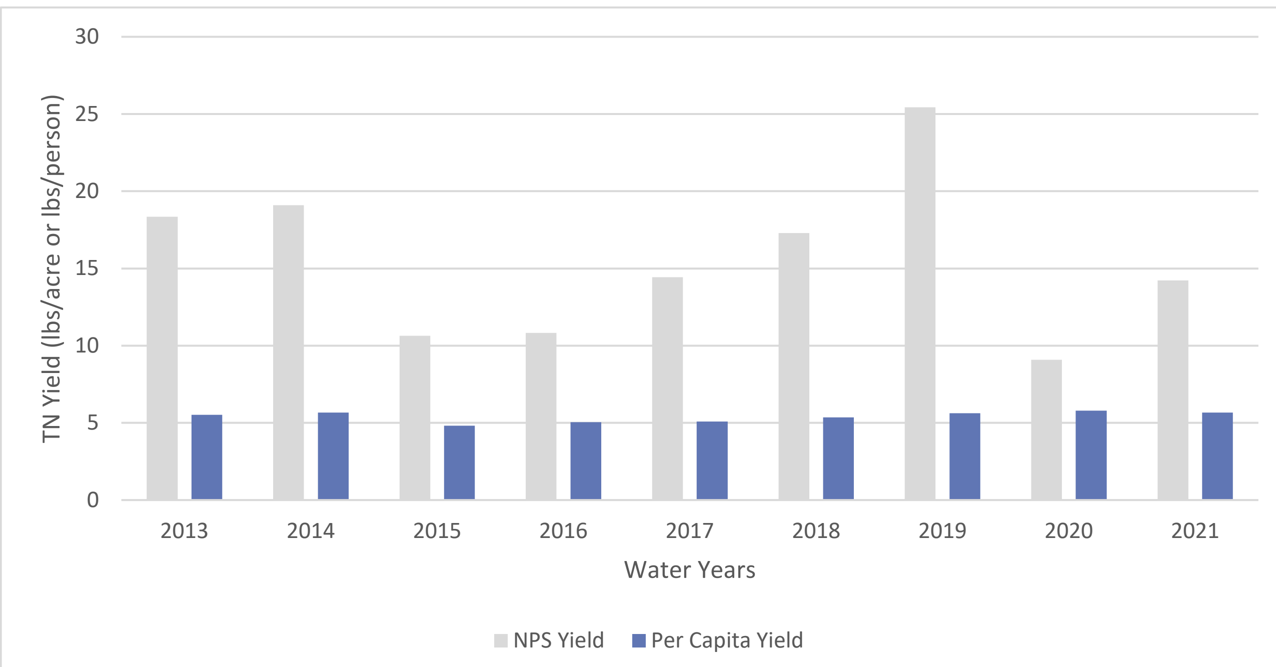


Figure 47 — Total nitrogen load yields for the Vermilion River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 13 —Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy21 for the Vermilion Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	16.9	18.3	11.3	10.8	13.7	16.2	21.1	12.8	15.2
18-yr Median Water Yield (in) – 16.20									
Total P									
FWMC (mg/L)	0.47	0.45	0.42	0.35	0.35	NA	NA	NA	NA
Annual Load (mta)	141	146	84	68	87	125	156	80	123
Total N									
FWMC (mg/L)	4.95	4.75	4.38	4.69	4.85	NA	NA	NA	NA
Annual Load (mta)	1,510	1,571	899	917	1,199	1,425	2,065	792	1,188

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of the most recent five years are presented in Figure 48. The figure shows the nonpoint source is the largest proportion of the total P and total N load in the Vermilion River at 94 percent for both. The NPDES sources contributed two percent of the annual total P and three percent of the annual total N. Finally, the HSTS community contributed three percent of the annual total P load and two percent of total N.

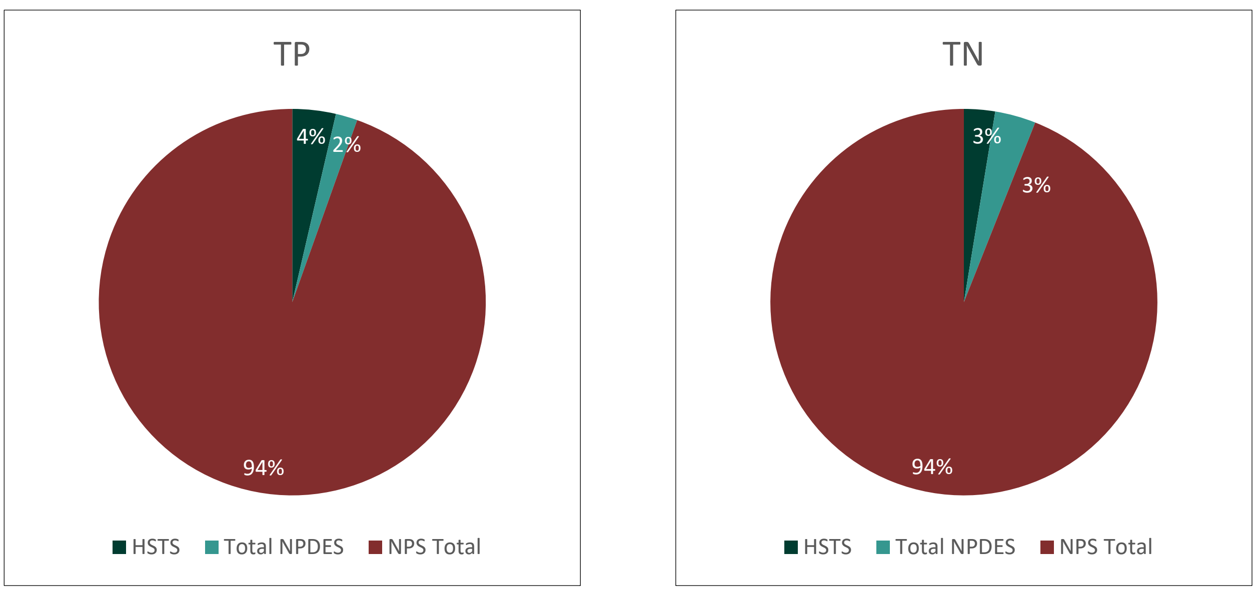


Figure 48 — Proportion of total phosphorus and nitrogen load from different sources for the Vermilion watershed, average of five years (wy17-wy21).

The data collected by the USGS was robust enough to allow for a load estimate to be derived, however, in part due to its size it has not been widely studied outside of the USGS's current effort. The Vermilion River is a central Lake Erie basin tributary and is targeted for a 40 percent reduction in annual loads to curb central basin hypoxia (Annex 4 of the 2012 Great Lakes Water Quality Agreement).

3.9 Cuyahoga River

The Cuyahoga River drains 794 sq. mi. in northeast Ohio (Figure 49). The 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.

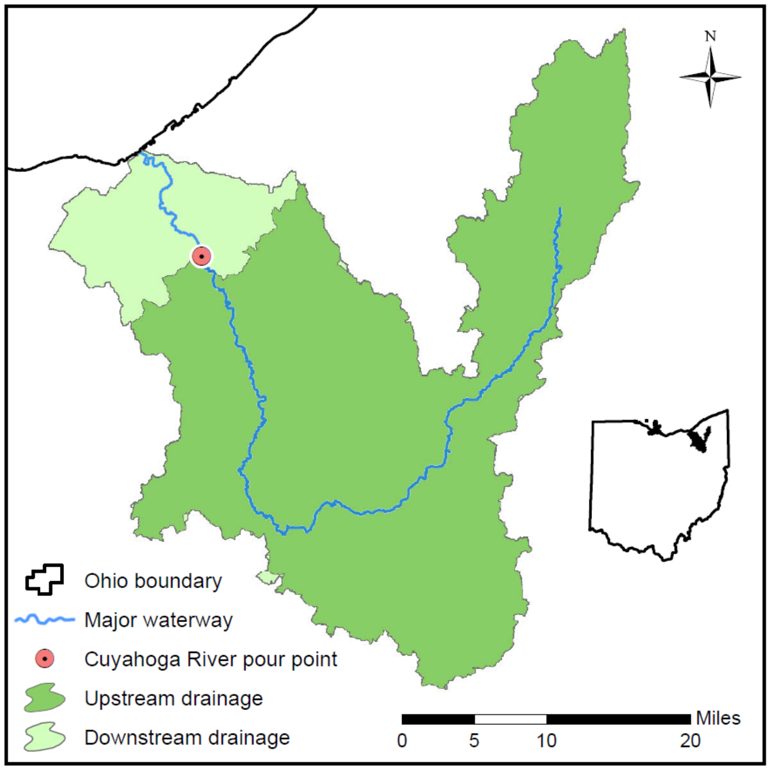


Figure 49 — Project area represented in the Cuyahoga River mass balance. The pour point along with up and downstream drainage areas are shown.

Natural areas and development dominate the land use of the Cuyahoga watershed at 37 percent and 48 percent, respectively. Downstream of the pour point there was a notable shift in land use with a reduction of natural and agricultural areas to a large increase in development (42 percent development upstream to 90 percent development downstream) Of this developed land 45 percent can be classified as low intensity, 37 percent medium intensity and 17 percent high intensity.

Total P loads from the Cuyahoga River were a maximum of 398 metric tons per year (mta) in wy19 and a minimum of 206 mta in wy16 (Figure 50 and Table 14). Total nitrogen loads from the Cuyahoga River were a maximum of 6,561 mta in wy19 and 4,738 mta in wy16 (Figure 52 and Table 14). Total P and total N yields are presented on Figures 51 and 53, respectively.

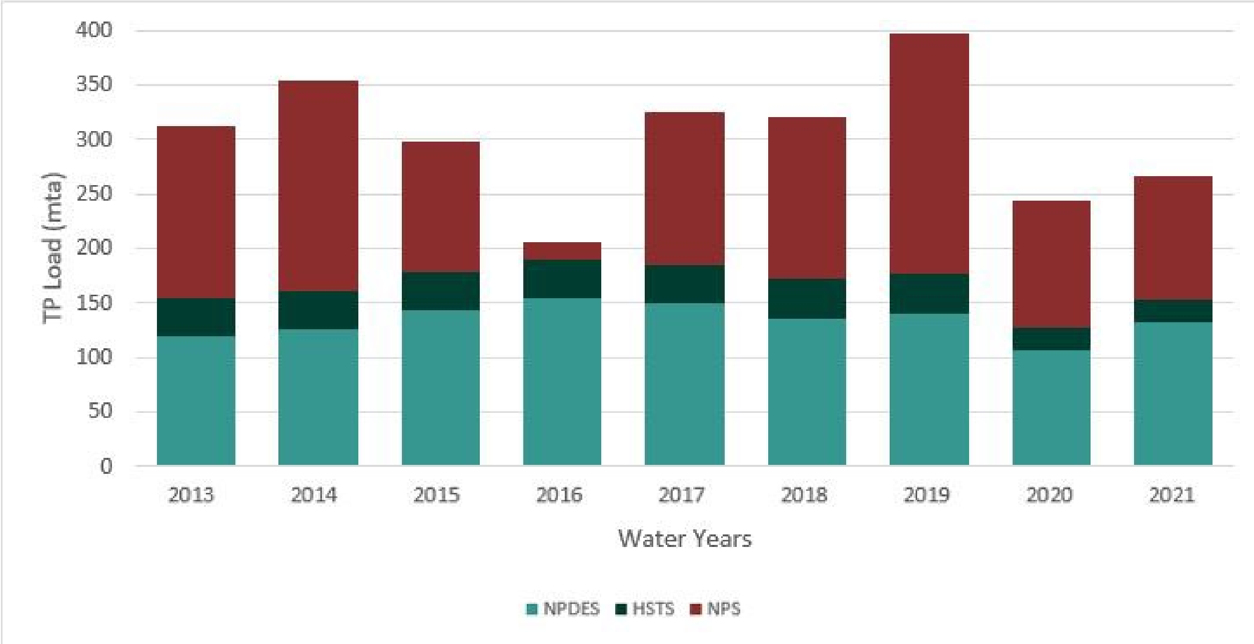


Figure 50 — Total phosphorus loads for the Cuyahoga River for water year 2013-2021.

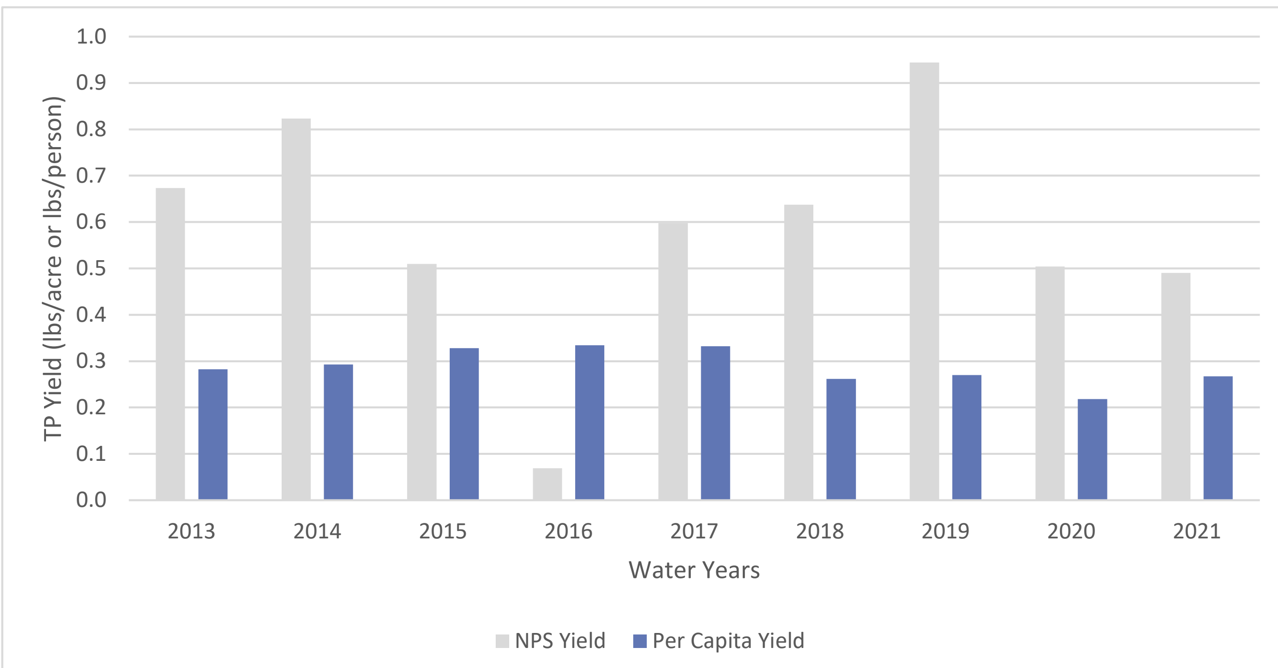


Figure 51 — Total phosphorus yields for the Cuyahoga River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

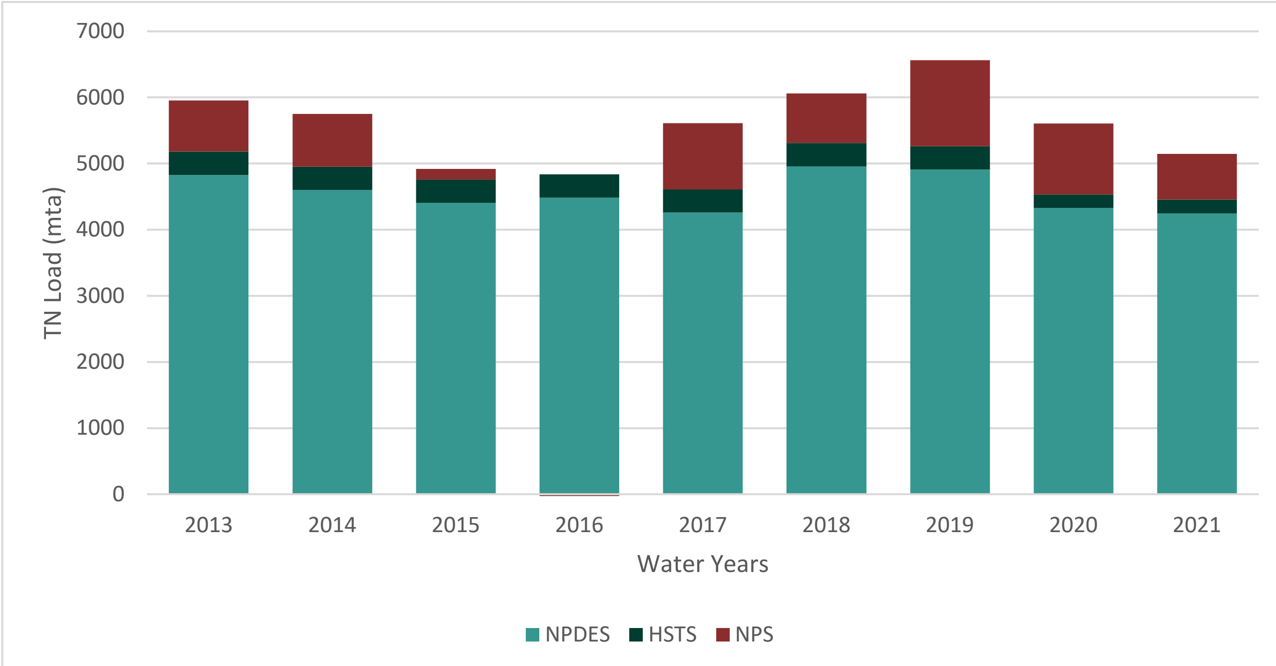


Figure 52 — Total nitrogen loads for the Cuyahoga River for water year 2013-2021.

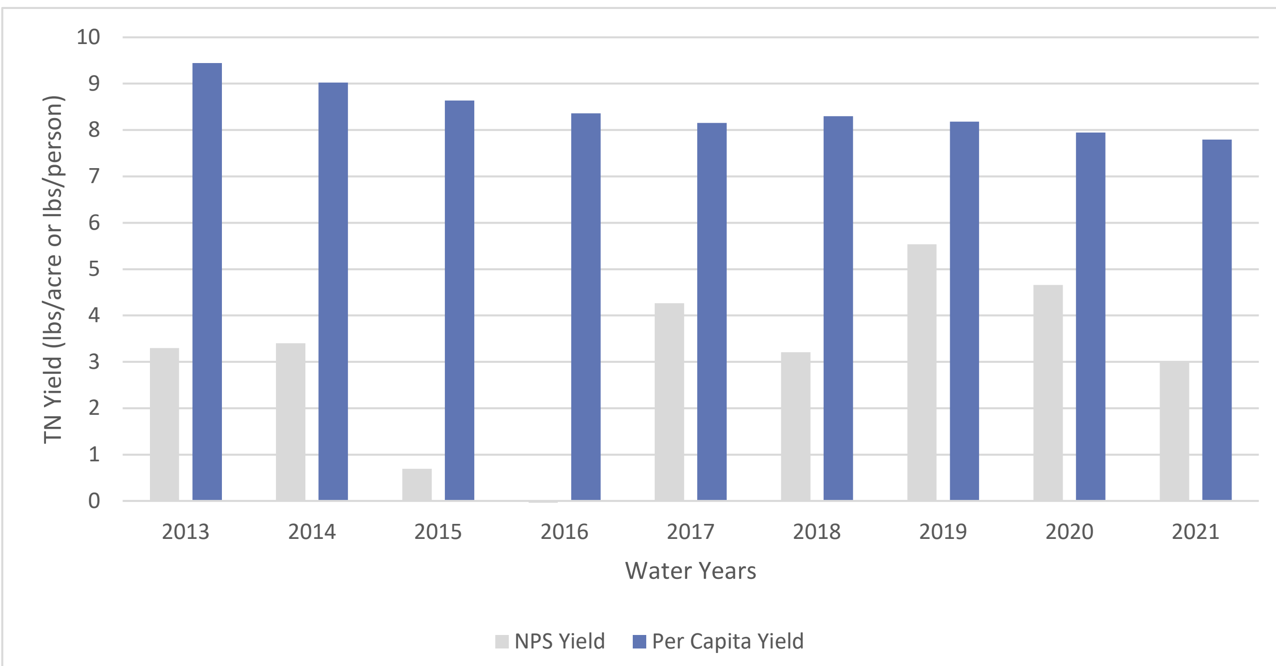


Figure 53 — Total nitrogen yields for the Cuyahoga River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

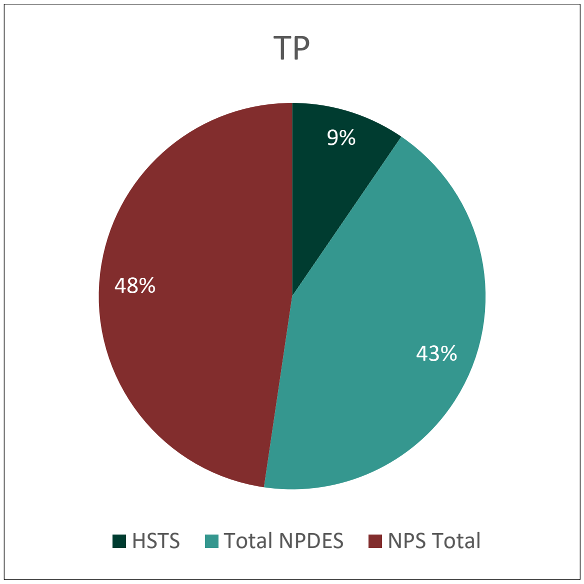
There were no apparent trends in the loadings observed for total P or total N in the Cuyahoga River watershed. The importance of total discharge is muted to some extent in this watershed due to the high proportion of point sources, especially for total N. The driest year did still yield the lowest loads. The wy19 loads are expected to be larger than seen in previous years due to very high precipitation. This was true for both total P and total N. Wy20 and wy21 were comparatively drier years (as observed in Table 14 below, Water Yield in inches per year), and experienced lower total loads for both P and N.

Table 14 — Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy21 for the Cuyahoga Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	21.3	22.4	20.9	16.1	23.9	23.2	29	21.57	19.21
20-yr Median Water Yield (in) – 21.81									
Total P									
FWMC (mg/L)	0.24	0.25	0.20	0.15	0.19	0.20	0.20	0.16	0.19
Annual Load (mta)	313	354	298	206	325	321	398	243	266
Total N									
FWMC (mg/L)	2.73	2.81	2.43	2.69	2.63	2.41	2.29	2.90	2.80
Annual Load (mta)	5,952	5,750	4,921	4,738	5,612	6,062	6,561	5,605	5,148

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of five years are presented in Figure 54. The figure shows the nonpoint source is 48 percent of the total P load and 17 percent of the total N load. The NPDES sources were 43 and 78 percent of the total P and total N loads, respectively. This was the highest proportion of the total load for in all the watersheds examined in this report for both total P and total N. Finally, the HSTS community contributed nine and five percent of the total P and N loads, respectively.

The mass balance methods attribute assimilative capacity to the nonpoint source recognizing that some parts of the landscape serve as sources of total P and total N and others as sinks. In wy16, for total N, this assumption led to a net negative yield for the nonpoint source. This was the only watershed and water year where the mass balance resulted in a negative nonpoint source yield.



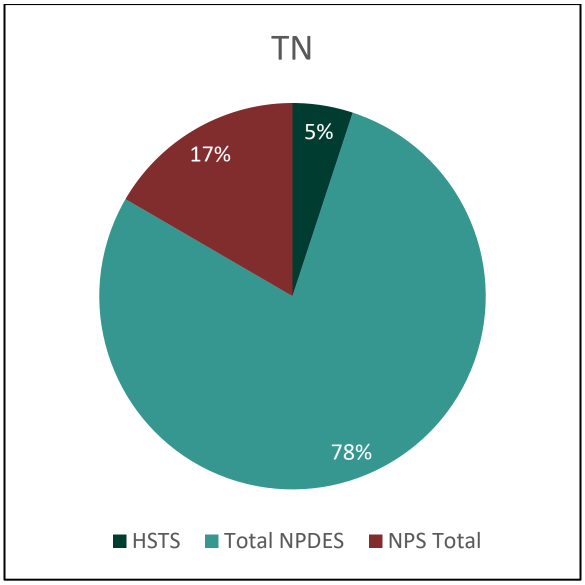


Figure 54 — Proportion of total phosphorus and nitrogen load from different sources for the Cuyahoga watershed, average of five years (wy17-wy21).

The Cuyahoga River is one of the most urbanized watersheds in Ohio with more than 1,440 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 control limits at the WWTPs discharging greater than 1.0 mgd. Even with the higher flow contribution of point sources relative to watershed size, 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).

3.10 Great Miami River

The Great Miami River drains 3,857 sq. mi., excluding drainage area of the Whitewater River, in southwest Ohio and southeast Indiana (Figure 55). The 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 2,684 sq. mi. and 1,172 sq. mi. downstream of the pour point.

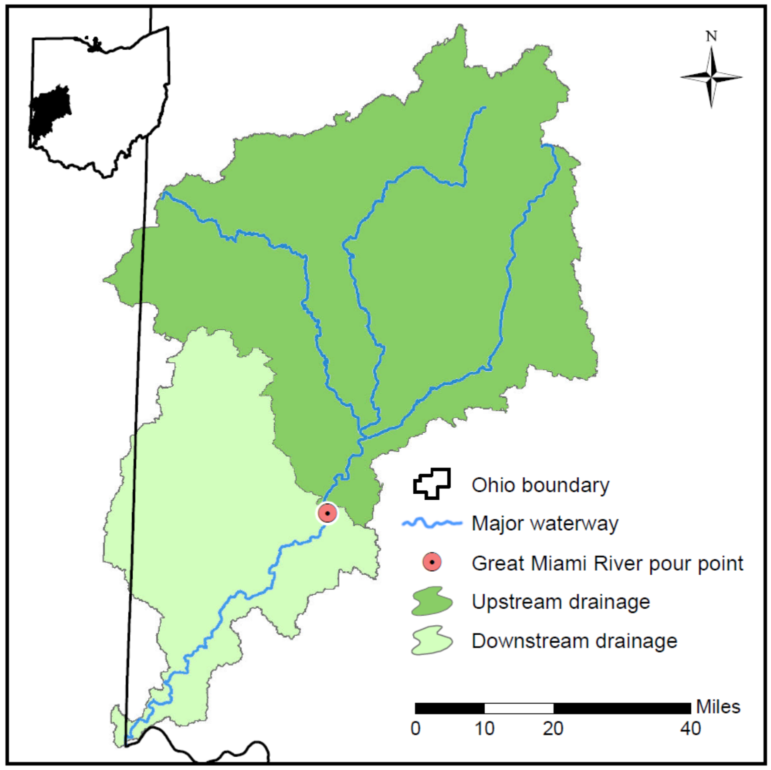


Figure 55 — Project area represented in the Great Miami River mass balance. The pour point along with up and downstream drainage areas are shown.

Agricultural land use dominates the Great Miami River watershed, with 67 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 a maximum of 2,475 metric tons per year (mta) in wy19 and a minimum of 883 mta in wy16 (Figure 56 and Table 15). Total N loads from the Great Miami River were a maximum of 28,367 mta in wy19 and a minimum of 14,669 mta in wy16 (Figure 58 and Table 15). Total P and total N yields are presented on Figures 57 and 59, respectively.

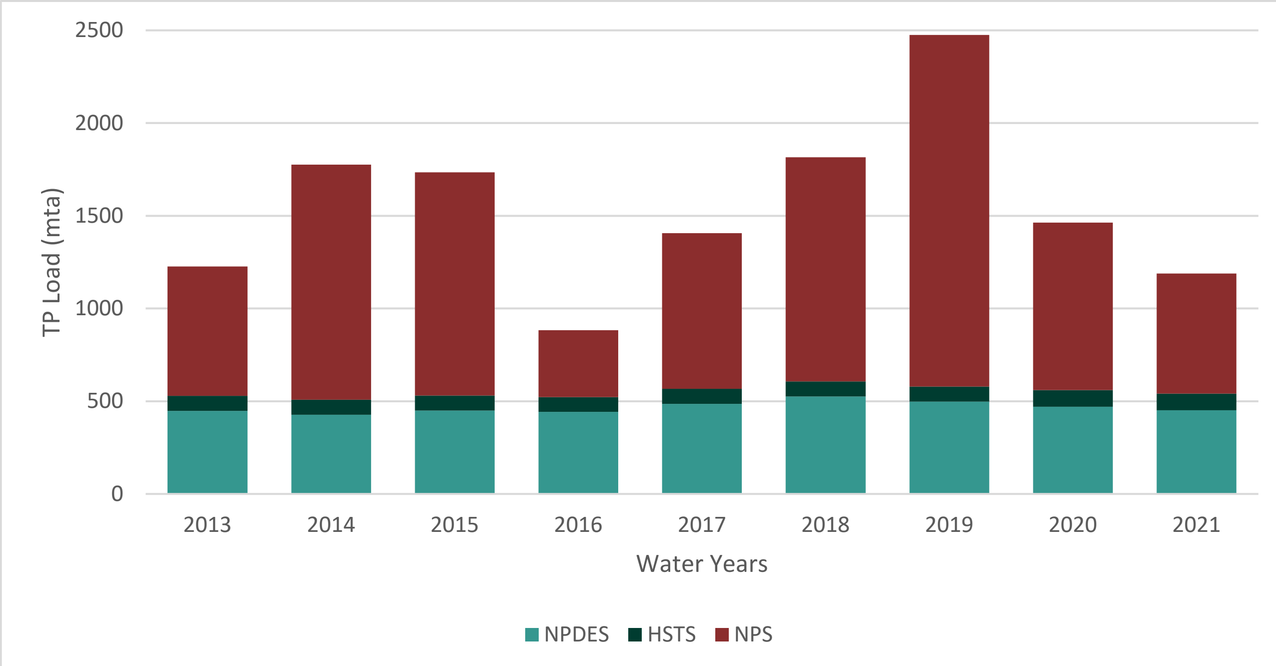


Figure 56 — Total phosphorus loads for the Great Miami River for water year 2013-2021.

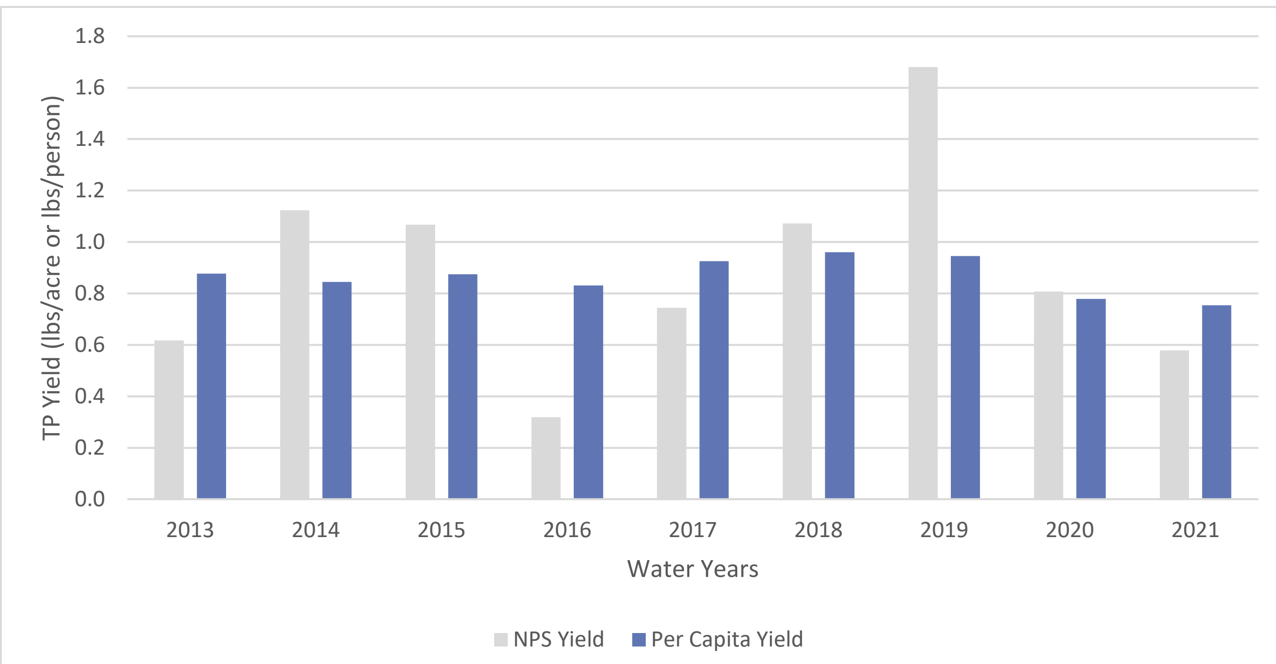


Figure 57 — Total phosphorus yields for the Great Miami River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

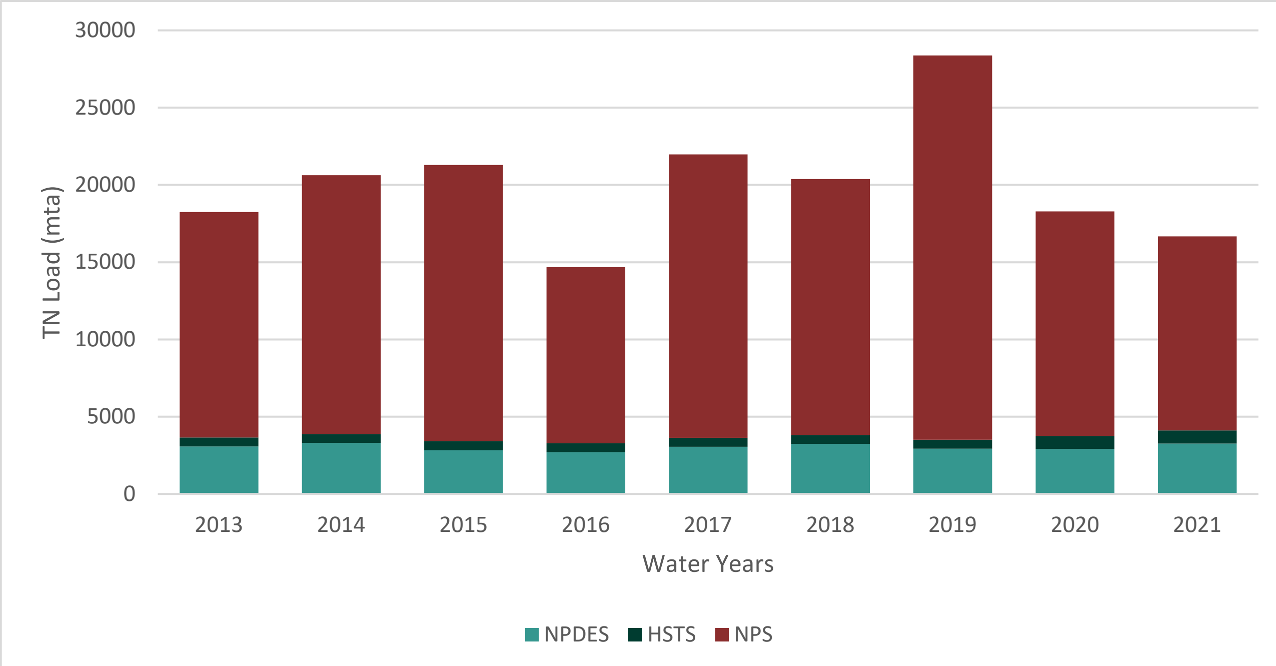


Figure 58 — Total nitrogen loads for the Great Miami River for water year 2013-2021.

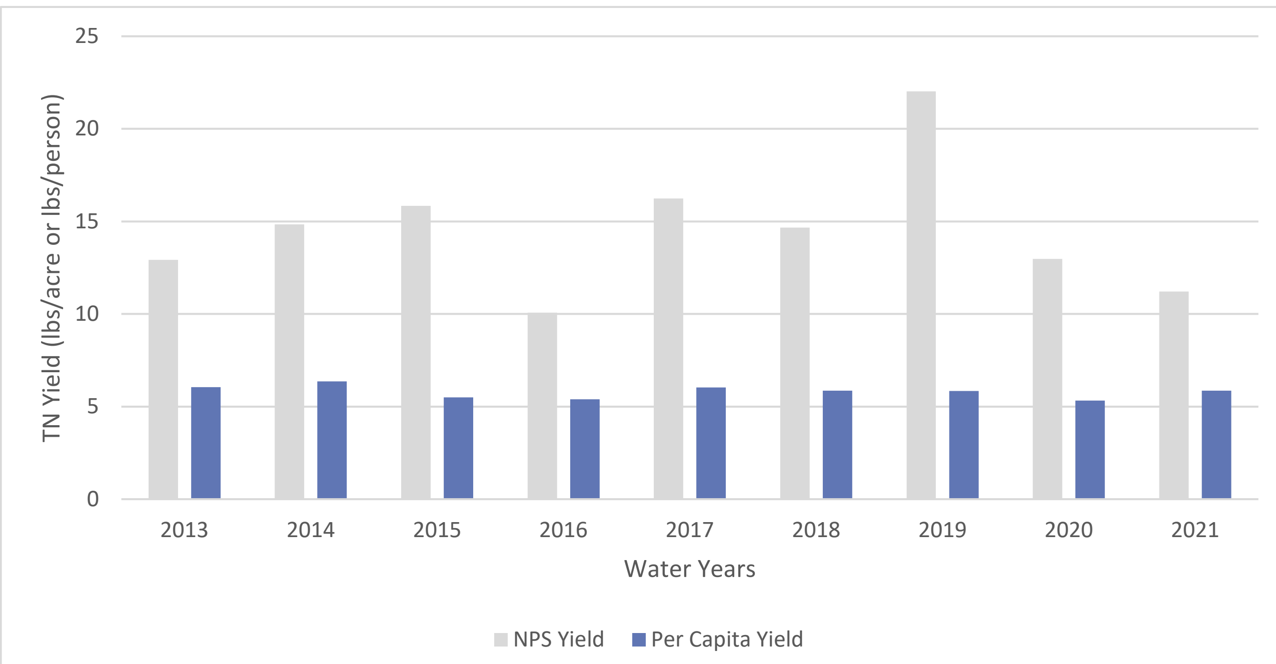


Figure 59 — Total nitrogen yields for the Great Miami River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 15 — Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy21 for the Great Miami Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	13.6	18.2	15.7	13.2	15.2	19.9	27.3	14.8	13.2
20-yr Median Water Yield (in) – 17.44									
Total P									
FWMC (mg/L)	0.37	0.39	0.64	0.25	0.37	0.37	0.36	0.39	0.36
Annual Load (mta)	1,226	1,775	1,734	883	1,407	1,816	2,475	1,464	1,889
Total N									
FWMC (mg/L)	5.33	4.68	5.29	4.02	6.20	4.04	4.05	4.80	5.00
Annual Load (mta)	18,234	20,631	21,295	14,669	21,980	20,373	28,367	17,904	16,289

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as the average for the most recent five years are presented in Figure 60. The figure shows the nonpoint source is the largest proportion of the total P and total N load in the Great Miami River at 66 and 82 percent, respectively. The NPDES sources comprised 29 percent of the total P load and 15 percent of the total N load. Finally, the HSTS community contributed five percent of the total P load and three percent of the total N load.

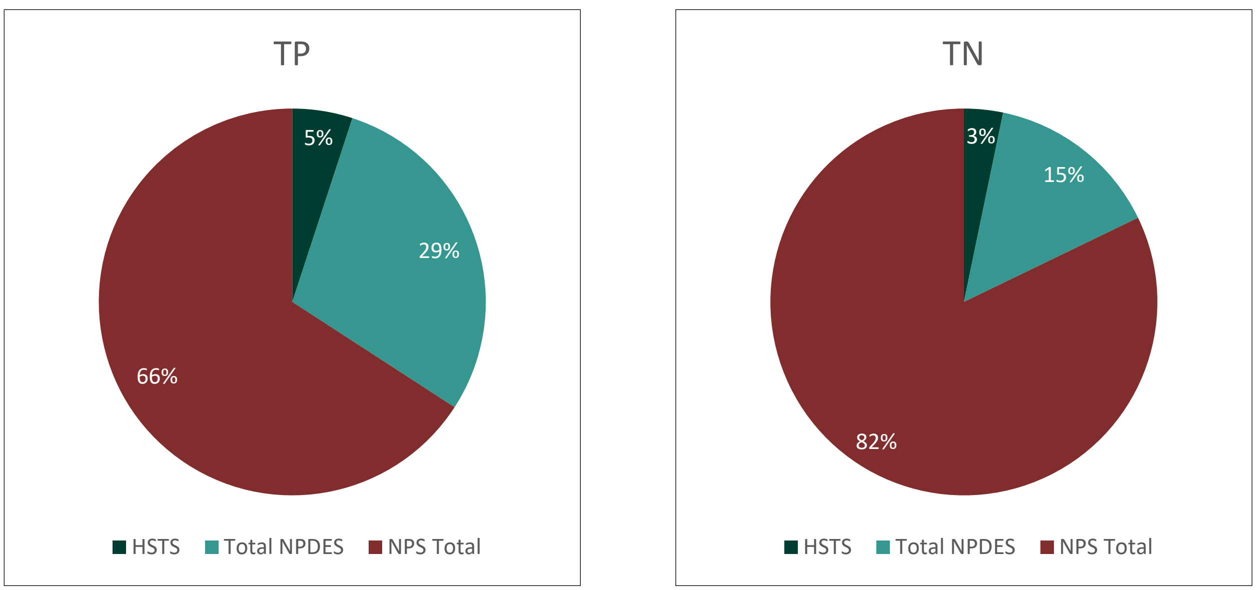


Figure 60 — Proportion of total phosphorus and nitrogen load from different sources for the Great Miami watershed, average of five years (wy17-wy21).

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 five 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.

3.11 Scioto River

The Scioto River drains 6,458 sq. mi. in central and south-central Ohio (Figure 61). The 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 3,812 sq. mi. and 2,645 sq. mi. downstream of the pour point.

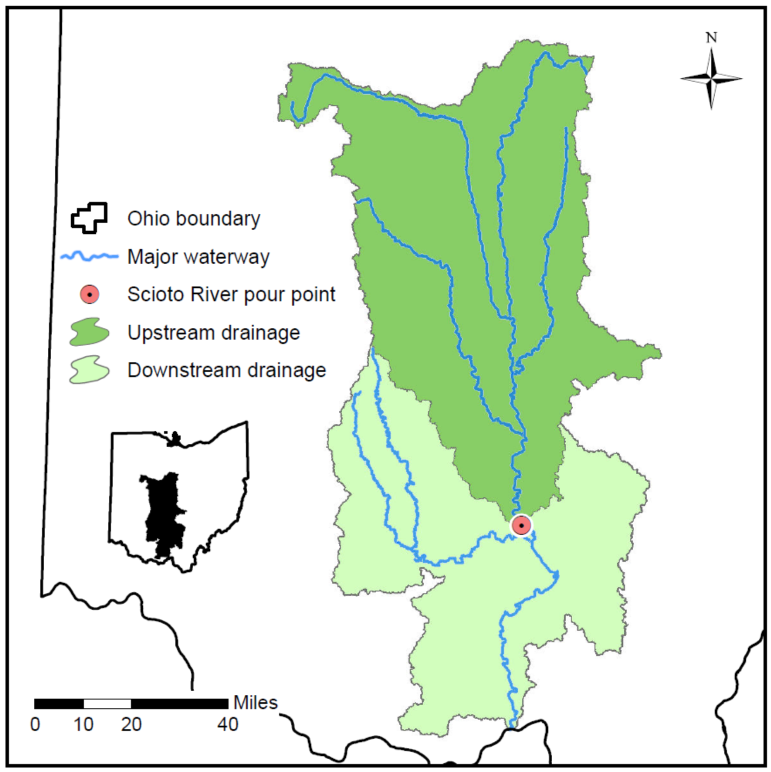


Figure 61 — Project area represented in the Scioto River mass balance. The pour point along with up and downstream drainage areas are shown.

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 (12 percent natural area upstream of pour point to 52 percent natural area downstream pour point).

Total P loads from the Scioto River were a maximum of 3,783 metric tons per year (mta) in wy19 and a minimum of 1,320 mta in wy21 (Figure 62 and Table 16). Total nitrogen loads from the Scioto River were a maximum of 36,707 mta in wy19 and a minimum of 16,778 mta in wy21 (Figure 64 and Table 16). Total P and total N yields are presented on Figures 63 and 65, respectively.

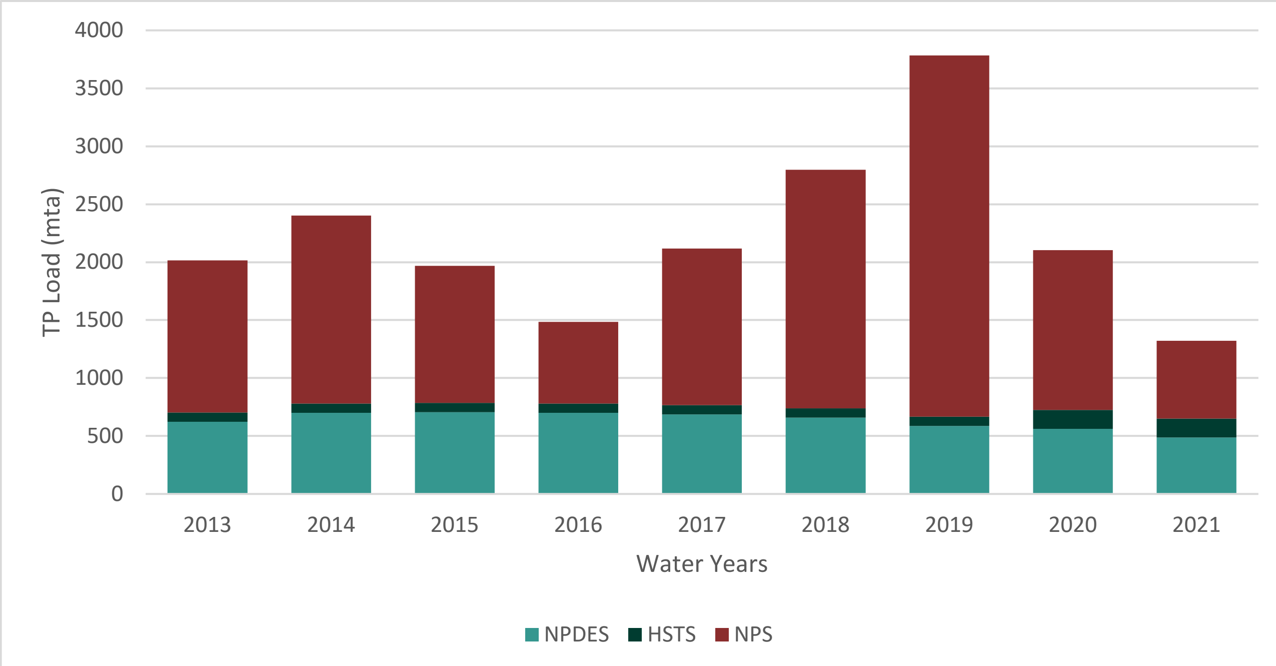


Figure 62 — Total phosphorus loads for the Scioto River for water year 2013-2021.

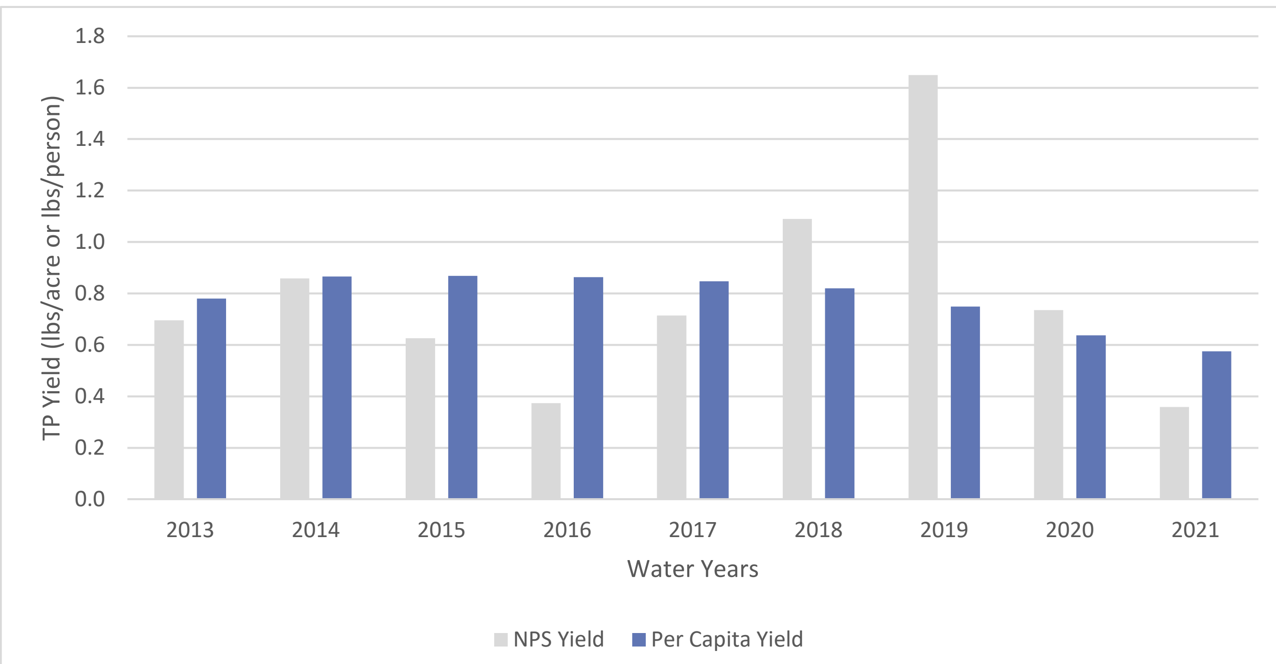


Figure 63 — Total phosphorus yields for the Scioto River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

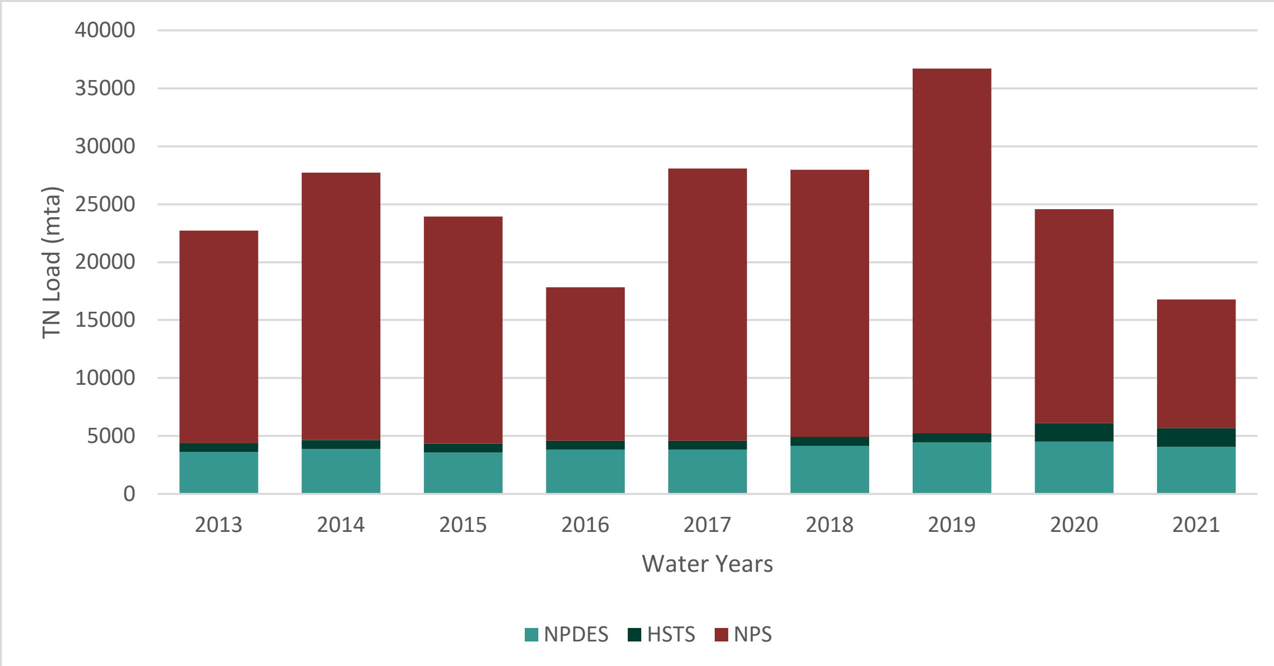


Figure 64 — Total nitrogen loads for the Scioto River for water year 2013-2021.

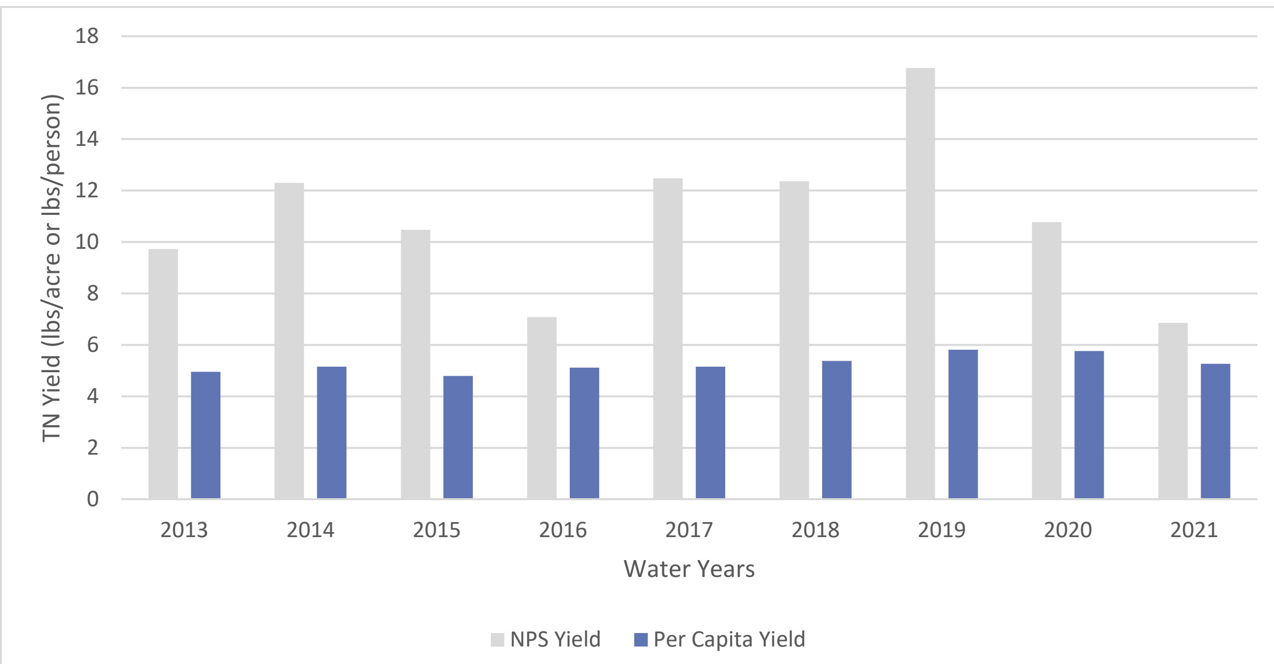
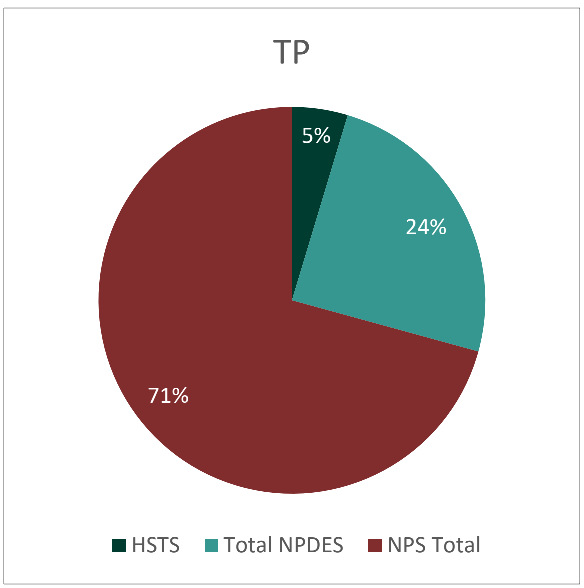


Figure 65 — Total nitrogen yields for the Scioto River for water year 2013-2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 16 — Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy21 for the Scioto Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	14.0	17.7	15.1	13.2	15.4	21.9	27.9	16.6	12.5
20-yr Median Water Yield (in) – 15.83									
Total P									
FWMC (mg/L)	0.38	0.37	0.36	0.33	0.37	0.34	0.34	0.35	0.30
Annual Load (mta)	2,015	2,402	1,969	1,486	2,117	2,798	3,783	2,103	1,320
Total N									
FWMC (mg/L)	4.08	3.85	4.00	3.98	4.72	3.23	3.29	3.90	3.70
Annual Load (mta)	22,729	27,711	23,949	17,819	28,077	27,961	36,707	24,578	16,778

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N averaged of the most recent five years are presented in Figure 66. The nonpoint source contributed 71 percent of the annual total P load and 80 percent of the annual total N load. The figure shows the NPDES sources contributed 24 percent of the total P and 16 percent of the total N loads. Finally, the HSTS community contributed five percent for total P and four percent for total N loads.



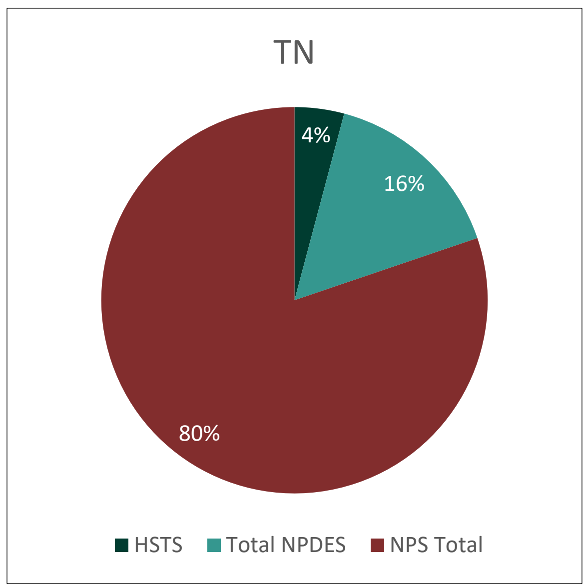


Figure 66 — Proportion of total phosphorus and nitrogen load from different sources for the Scioto watershed, average of five years (wy17-wy21).

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.

3.12 Muskingum River

The Muskingum River drains 7,959 sq. mi. primarily in northeast and southeast Ohio (Figure 67). The 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 7,336 sq. mi. and 623 sq. mi. downstream of the pour point.

Figure 67 — Project area represented in the Muskingum River mass balance. The pour point along with up and downstream drainage areas are shown.

Natural and agricultural land use dominates the Muskingum River watershed, with 47 percent and 40 percent respectively. Downstream of the pour point, the largest shift in land use was from agricultural production to natural areas (agriculture land use decreasing from 41 percent to 25 percent, and natural land use increasing from 46 percent to 67 percent)

Total phosphorus loads from the Muskingum River were a maximum of 2,209 metric tons per year (mta) in wy19 and a minimum of 885 mta in wy16 (Figure 68 and Table 17). Total N loads from the Muskingum River were a maximum of 29,414 mta in wy19 and a minimum of 12,587 mta in wy16 (Figure 70 and Table 17). Total P and total N yields are presented on Figures 69 and 71, respectively.

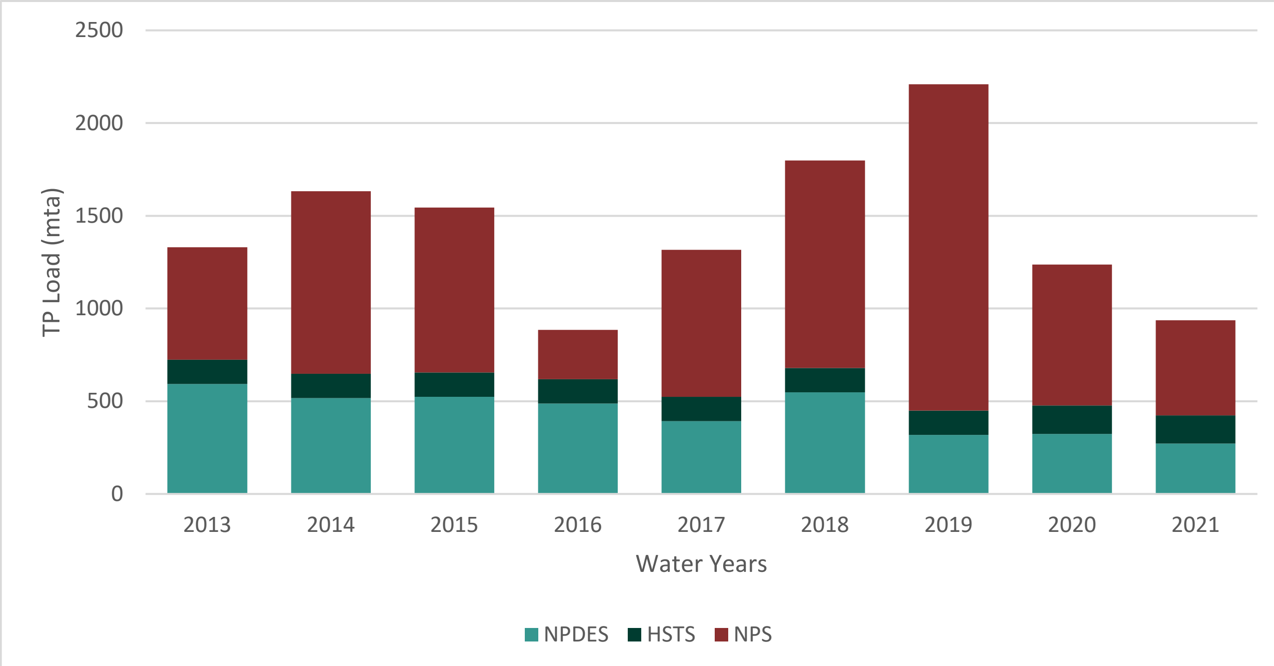


Figure 68 — Total phosphorus loads for the Muskingum River for water year 2013-2019.

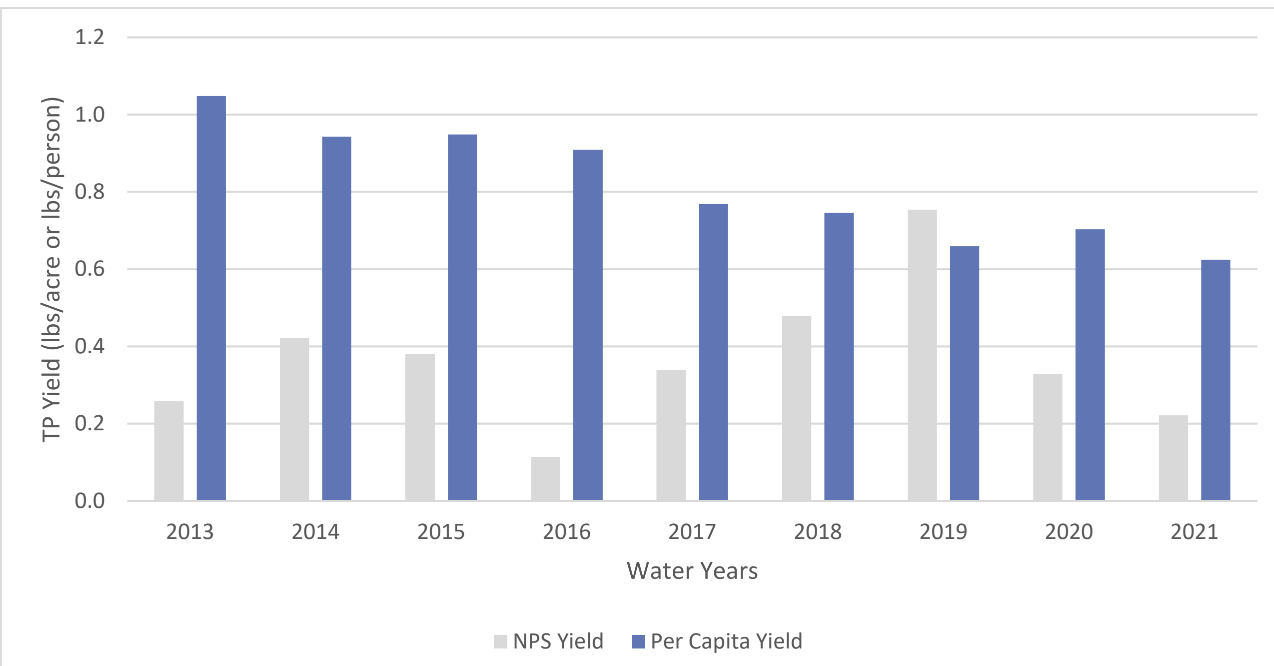


Figure 69 — Total phosphorus yields for the Muskingum River for water year 2013-2019. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

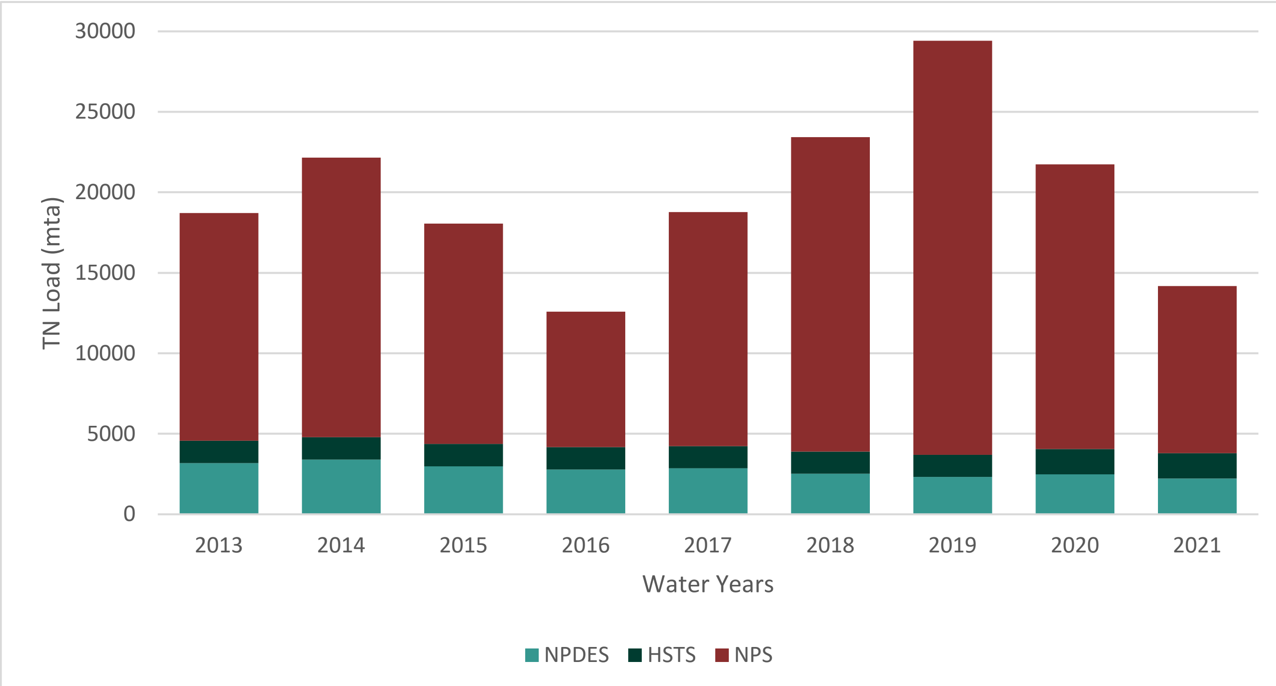


Figure 70 — Total nitrogen loads for the Muskingum River for water year 2013-2019.

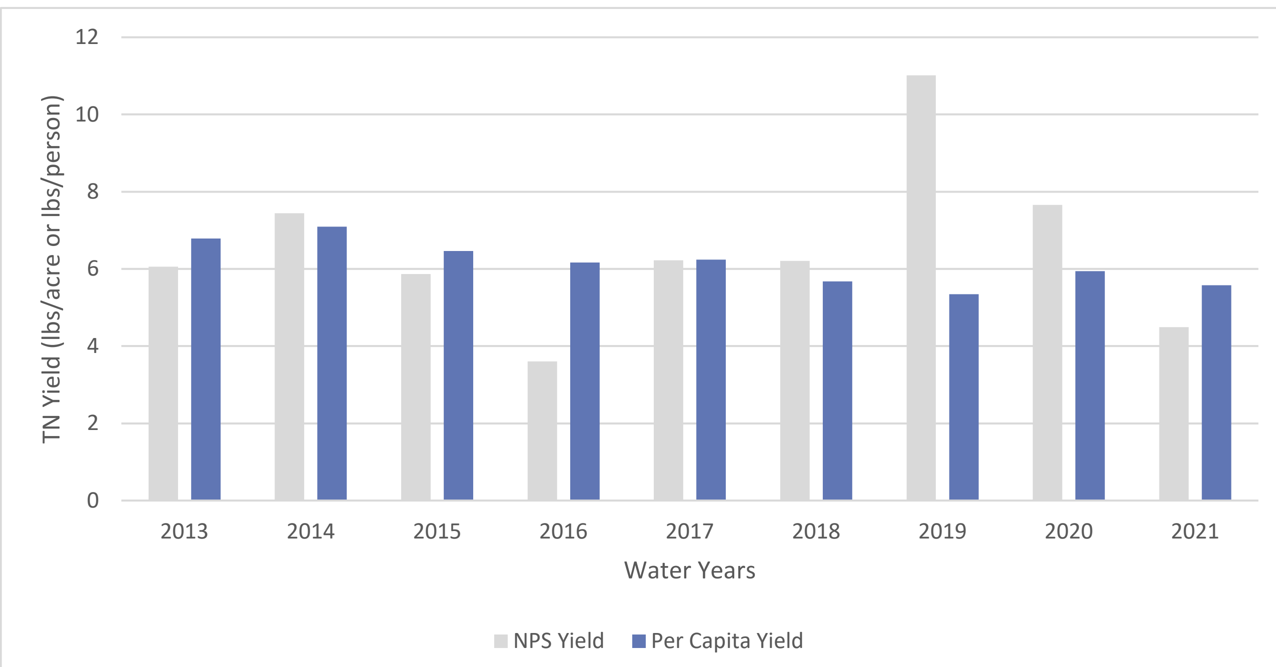


Figure 71 — Total nitrogen yields for the Muskingum River for water year 2013-2019. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

An error was corrected in the total N loading analysis for wy18 in this report. The 2020 report contained a large discrepancy in wet weather loading for that year. This report includes the corrected values.

The importance of total discharge is highlighted in the observed data for total P, where the ranking of years by flow and both total P are the same. The relationship was not as clear for total N and annual flow, highlighting the different mechanics in total P and total N loading. The wy19 loads are expected to be larger than seen in previous years due to very high precipitation. This was true for both total P and total N. Wy20 and wy21 were comparatively drier years (as observed in Table 17 below, Water Yield in inches per year), and experienced lower total loads for both P and N.

It is important to note the significance of point source yield declines since the first iteration of this report. As noted in figure 68, total P loading from point sources has declined significantly, and is nearly half of the original loading contribution.

Table 17 — Annual flow-weighted mean concentration (FWMC), total load and water yield for wy13 through wy17 for the Muskingum Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Water Yield (in/yr)	14.9	18.7	15.0	11.6	14.5	20.9	26.5	18.4	12.6
20-yr Median Water Yield (in) – 15.4									
Total P									
FWMC (mg/L)	0.17	0.17	0.2	0.15	0.18	0.17	0.16	0.13	0.15
Annual Load (mta)	1,330	1,632	1,545	885	1,316	1,799	2,209	1237	936
Total N									
FWMC (mg/L)	2.42	2.26	2.3	2.09	2.54	2.14	2.11	2.3	2.2
Annual Load (mta)	18,706	22,159	18,067	12,587	18,767	23,041	29,414	21,736	13,172

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N as an average of the five-year total in this study are presented in Figure 72. The nonpoint source contributed 66 percent of the annual total P load and 77 percent of the annual total N load. The figure shows the NPDES sources contributed 25 percent of the total P and 16 percent of the total N loads. Finally, the HSTS community contributed nine percent of the total P and seven percent of the total N load.

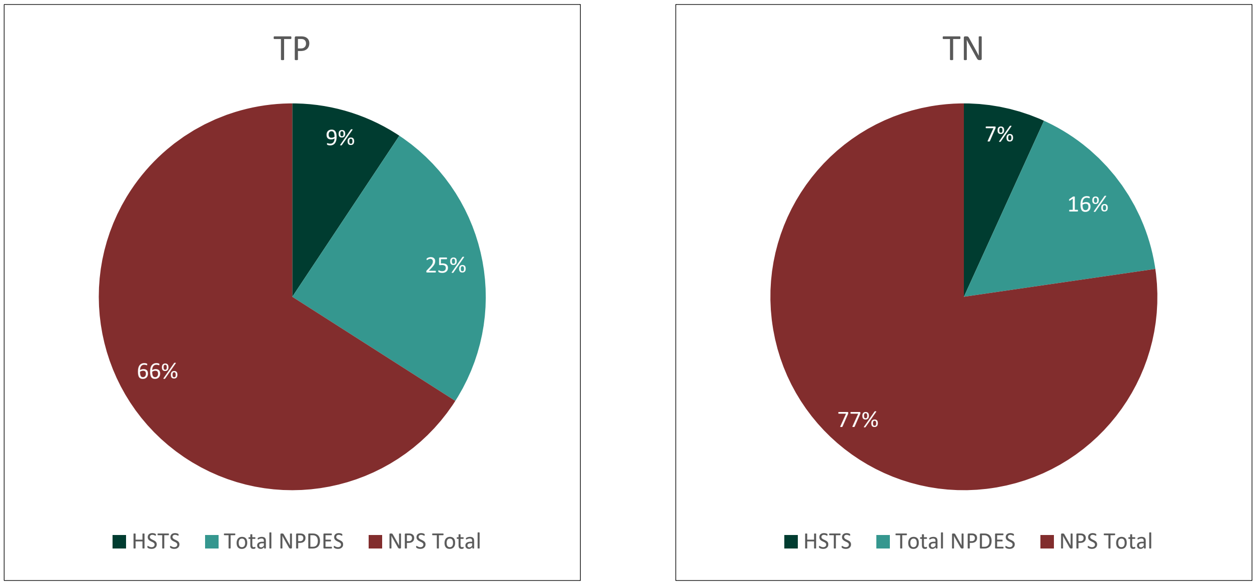


Figure 72 — Proportion of total phosphorus and nitrogen load from different sources for the Muskingum watershed, average of five years (wy17-wy19).

The Muskingum River watershed has a high proportion of natural areas. Of the watersheds with several years period of record, it has the lowest nonpoint source yield for both total P and total N for each of the last five years. This was reflected in the lowest FWMC for both total P and total N in the study.

3.13 Hocking River

The Hocking River drains 1,189 sq. mi. in southeast Ohio (Figure 73). The Hocking River gage (0315900 – Hocking River at Athens) was used as a pour point for nutrient mass balance calculations. The watershed area upstream of the pour point is 936 sq. mi. and 253 sq. mi. downstream of the pour point.

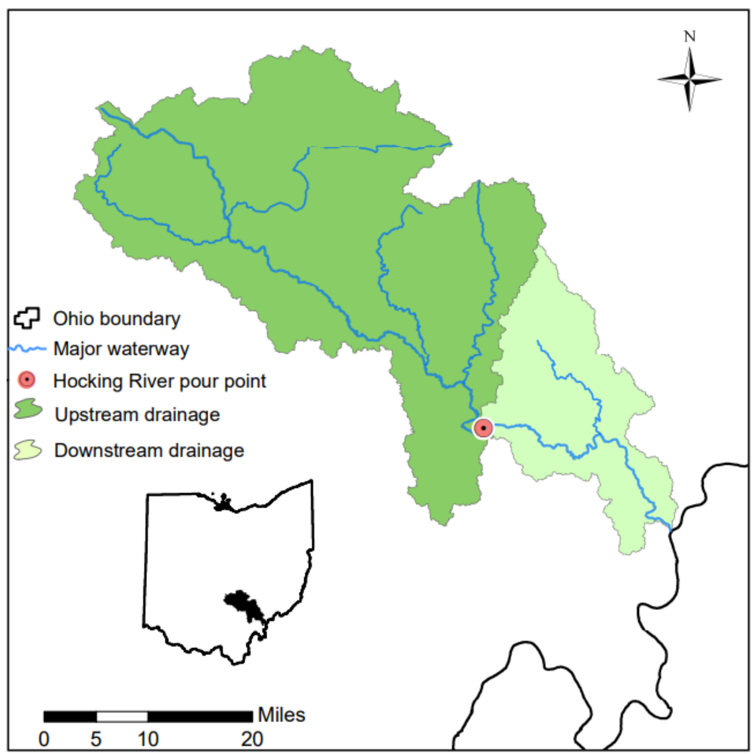


Figure 73 — Project area represented in the Hocking River mass balance. The pour point along with up and downstream drainage areas are shown.

Natural and agricultural land use dominates the Hocking River watershed, with 66 and 25 percent respectively. Downstream of the pour point, natural land accounts for 80 percent of all land use, a significant shift from the 62 percent of natural land use coverage upstream of the pour point.

The Hocking River gage is new to the nutrient mass balance study. Monitoring at this gage location began on March 1, 2020 (meaning 2020 values are not valid, as they are not inclusive of the entire wy20). 2021 is therefore the first full water year available at this location.

The total phosphorus load from the Hocking River was 133 metric tons per year (mta) in wy21 (Figure 74 and Table 18). The total N load from the Hocking River was 1,282 mta in (Figure 76 and Table 18). Total P and total N yields are presented on Figures 75 and 77, respectively.

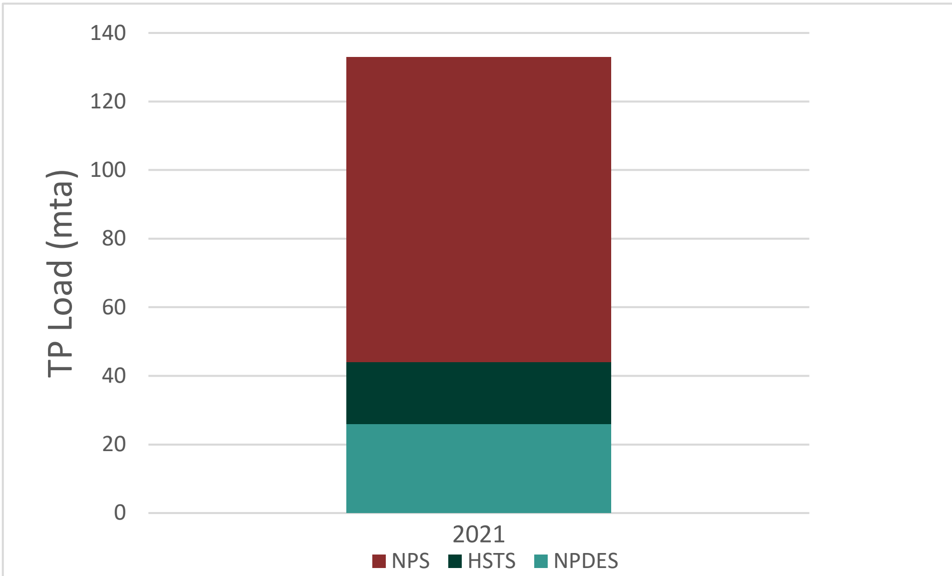


Figure 74 — Total phosphorus loads for the Hocking River for water year 2021.

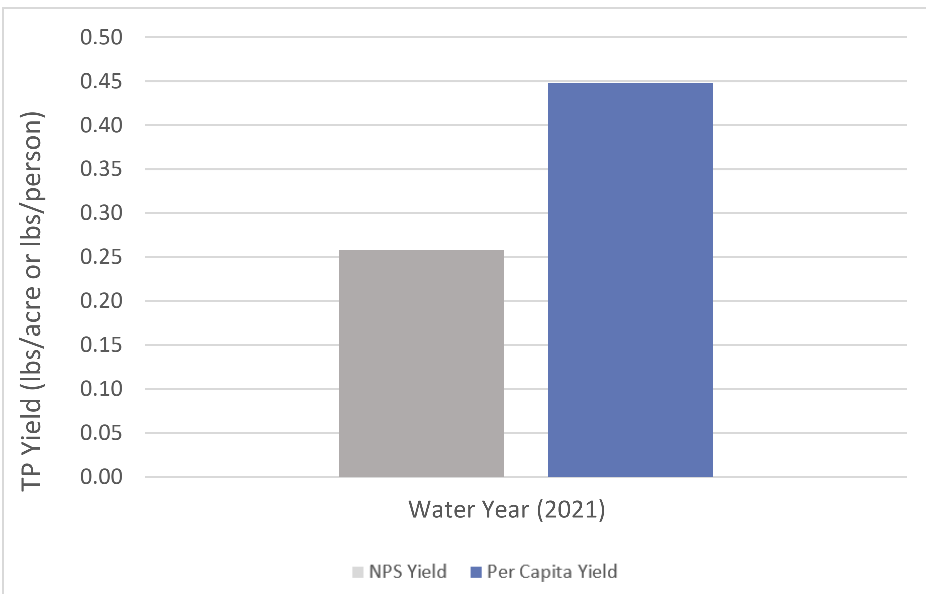


Figure 75 — Total phosphorus yields for the Hocking River for water year 2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

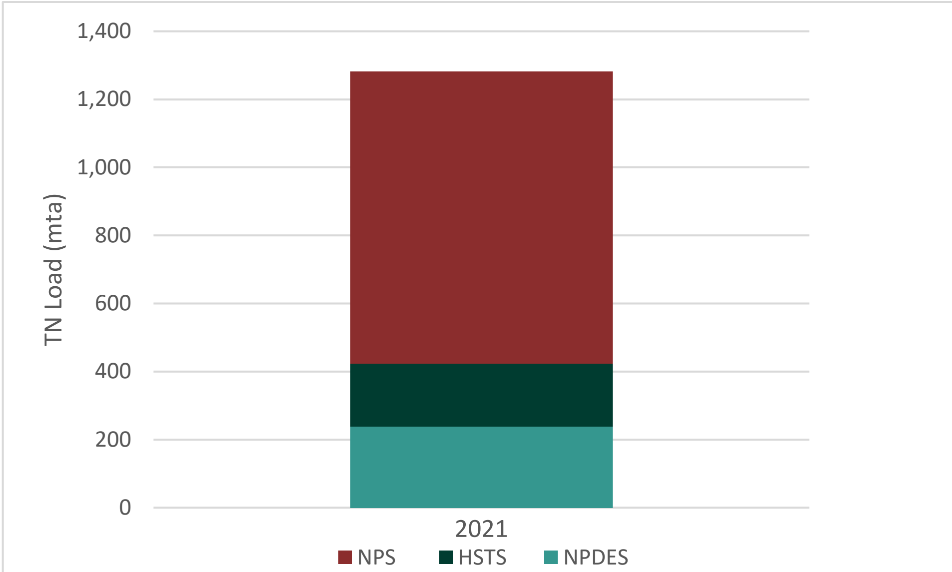


Figure 76 — Total nitrogen loads for the Hocking River for water year 2021.

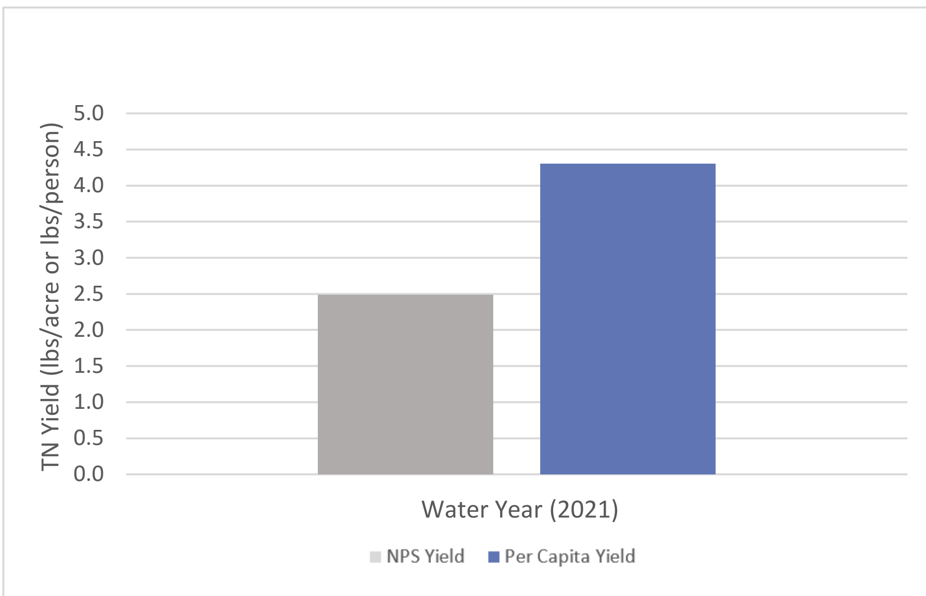


Figure 77 — Total nitrogen yields for the Hocking River for water year 2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 18— Annual flow-weighted mean concentration (FWMC), total load and water yield for wy21 for the Hocking Watershed. Water yield is annual discharge normalized by watershed area (in units of inches/yr). FWMC and water yield are calculated at the pour point and do not include downstream drainage area.

Parameter	wy21
Total P	
FWMC (mg/L)	0.16
Annual Load (mta)	134
Total N	
FWMC (mg/L)	1.56
Annual Load (mta)	1,282

The relative proportion of nonpoint source, total NPDES and HSTS loads for both total P and total N for wy21 are presented in Figure 78. The nonpoint source contributed 67 percent of the annual total P and total N load. The figure shows the NPDES sources contributed 19 percent of the total P and total N loads. Finally, the HSTS community contributed 14 percent of the total P and total N load. This is likely due to the fact that the Hocking watershed has a large percentage of contributing population being served by HSTS compared to central sewage systems. As noted in Table 3, wy21 was a 9-year low for average water yield. As such, the proportion of HSTS and NPDES is expected to be lower in more normal/future years.

Also observed in the Hocking watershed are several wastewater treatment facilities with very low phosphorus levels. Many of these facilities are operating without P limits but are considered to be within very good operational standards.

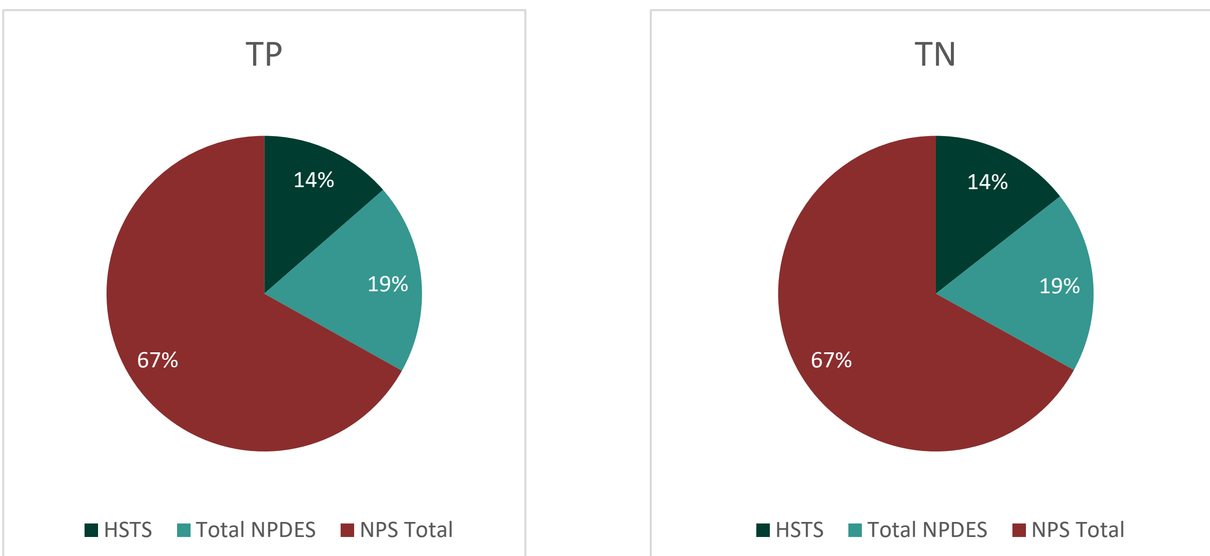


Figure 78 — Proportion of total phosphorus and nitrogen load from different sources for the Hocking watershed (wy21).

3.14 Little Miami River

The Little Miami River drains 1,317 sq. mi. in southwest Ohio (Figure 79). This watershed also includes the East Fork Little Miami River subwatershed. Since there is a monitoring station on the East Fork, the part of the watershed upstream of the station was analyzed separately. The watershed area upstream of the Little Miami River pour point is 1,190 sq. mi., and the area upstream of the East Fork Little Miami River pour point is 470 sq. mi. The area downstream of the pour points is 126 square miles.

The Little Miami River watershed is mostly dominated by agricultural land, with 55 percent of the total land use being attributed to agriculture, and 57 percent upstream of the pour point belonging to agriculture. Downstream of the pour point, a significant portion of the watershed belongs to the developed land classification (58 percent).

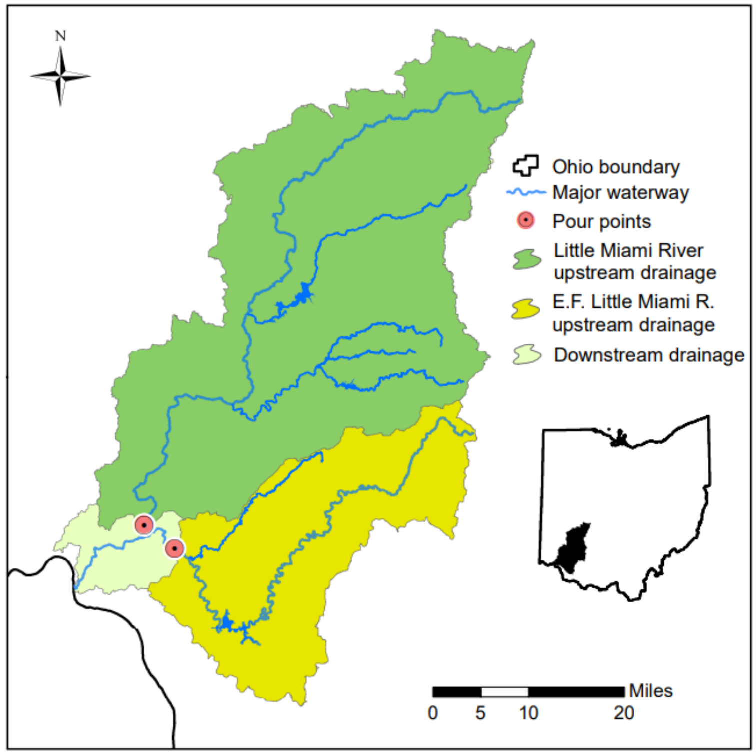


Figure 79 — Project area represented in the Little Miami River mass balance. The pour point along with up and downstream drainage areas are shown.

The Little Miami and East Fork Little Miami rivers' gages are new to the nutrient mass balance study as of the 2022 iteration. Monitoring at these gage locations began on March 1, 2020 (meaning 2020 values are not valid, as they are not inclusive of the entire wy20). 2021 is therefore the first full water year available for these pour point locations.

The total phosphorus load from the combined LMR system was 685 metric tons per year (mta) in wy21 (Figure 80 and Table 19). The total N load was 4,836 mta in (Figure 82 and Table 19). Total P and total N yields are presented on Figures 81 and 83, respectively.

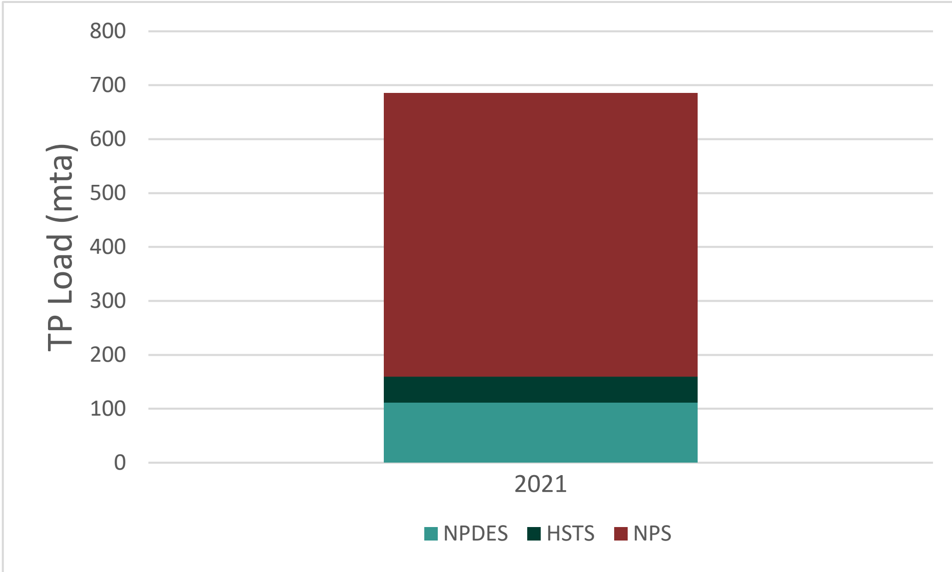


Figure 80 — Total phosphorus loads for the Little Miami River for water year 2021.

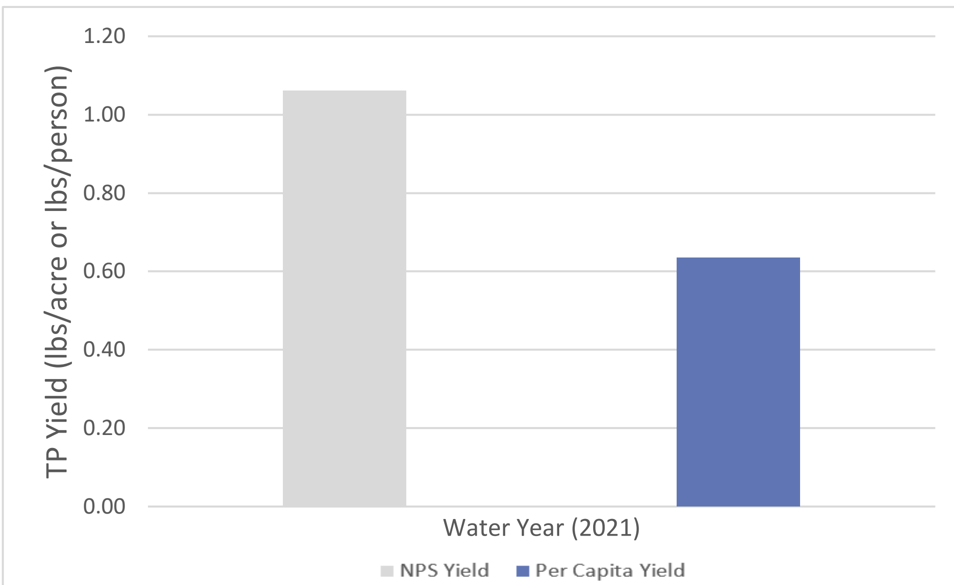


Figure 81 — Total phosphorus yields for the Little Miami River for water year 2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

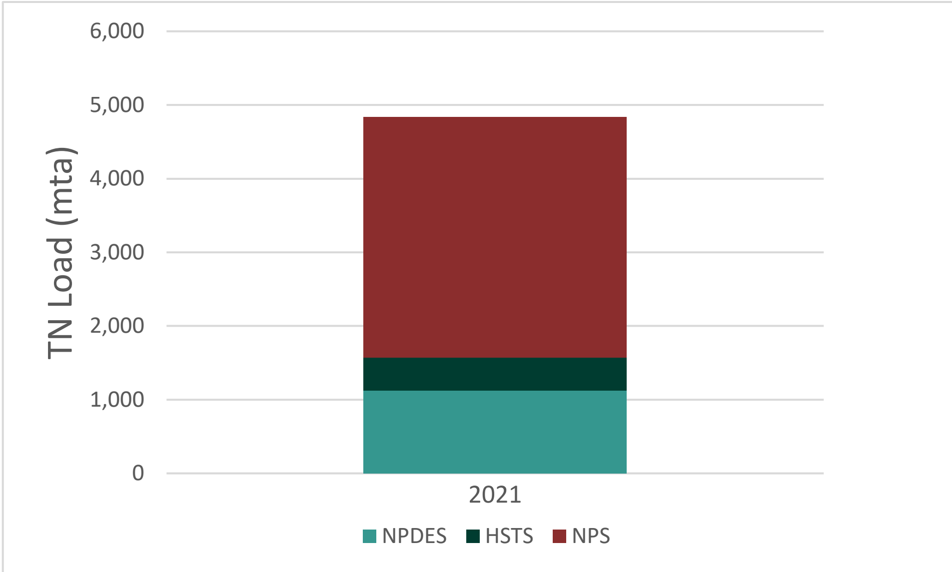


Figure 82 — Total nitrogen loads for the Little Miami River for water year 2021.

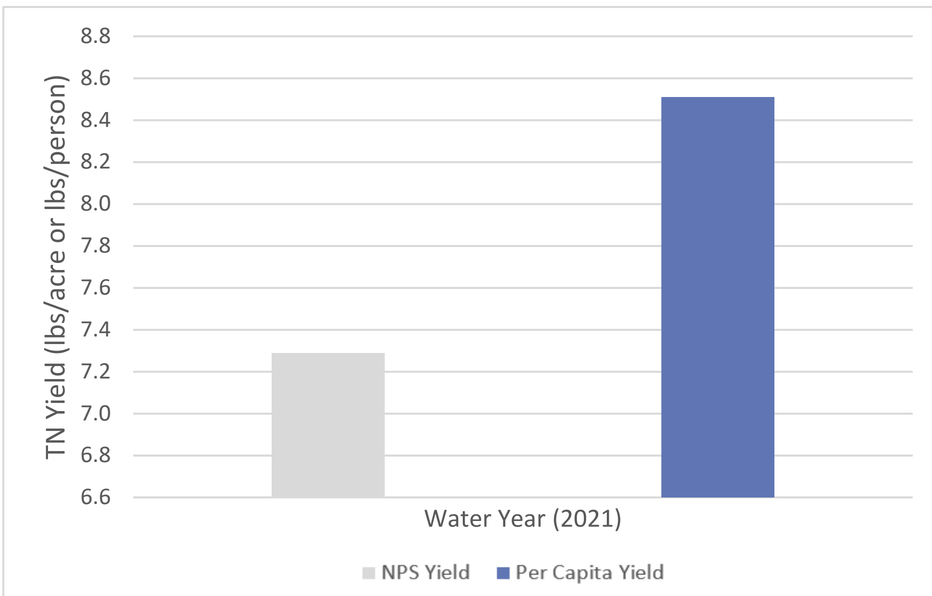


Figure 83 — Total nitrogen yields for the Little Miami River for water year 2021. Nonpoint source yields are calculated using the total measured load at the pour point and the upstream area. Per capita yields are calculated as the sum of the NPDES load and HSTS load divided by the contributing population.

Table 19 — Annual flow-weighted mean concentration (FWMC) and total load wy2021 for the Little Miami Watershed. FWMC is calculated at the pour point and does not include downstream drainage area.

Parameter	wy21
Total P	
FWMC (mg/L)	0.39
Annual Load (mta)	685
Total N	
FWMC (mg/L)	2.9
Annual Load (mta)	4,836

The relative proportion of nonpoint source, total NPDES, and HSTS loads for both total P and total N for wy21 are presented in Figure 84. The nonpoint source contributed 77 percent of the annual total P load and 68 percent of the annual total N load. The figure shows the NPDES sources contributed 16 percent of the total P and 23 percent of the total N loads. Finally, the HSTS community contributed seven percent of the total P and nine percent of the total N load.

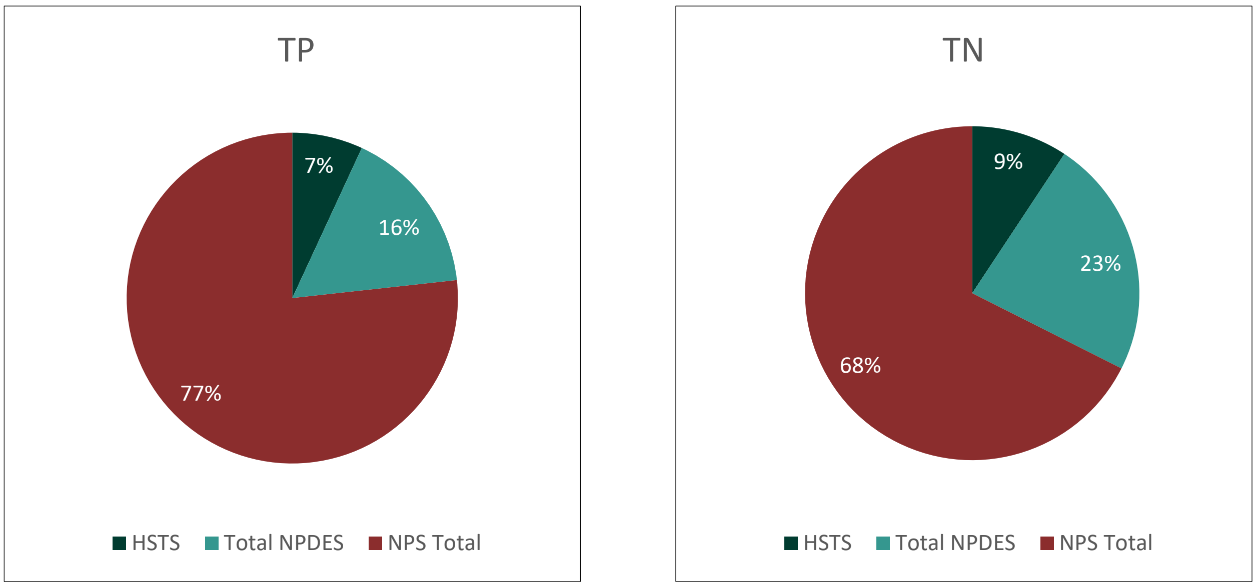


Figure 84 — Proportion of total phosphorus and nitrogen load from different sources for the Little Miami watershed (wy21).

4. Trends Discussion

Throughout this report some observations on changes in nutrient concentrations, loadings, and yields are made. Most of these observations have been focused on point source, i.e., NPDES, related changes. However, Ohio EPA has not carried out a full suite of trends analysis on total loads for Ohio's major rivers included in this report.

Hydrology, precipitation, and streamflow largely dictate changes in nonpoint source loadings. This is evident by noting the annual variation of the nonpoint source load in every river chapter of this report. While long-term changes in hydrology have been documented, there is a natural fluctuation expected year-to-year. Because of this, simple trends analysis on nonpoint source and total nutrient loads is not acceptable. More sophisticated statistical processes are required.

In lieu of robust in-house analysis, this section summarizes nutrient trends work carried out by academic researchers. The work summarized here focuses on rivers that drain to Lake Erie. Efforts to include any Ohio River drainage pollutant trends research will be made for the next version of this report.

The United States Geological Survey (USGS) has developed an R-package suite of statistical tools called EGRET (Hirsch & De Cicco, 2015). Included in EGRET is the algorithm called Weighted Regressions on Time, Discharge, and Season (WRTDS). This is a statistical method that provides flow-normalization techniques to evaluate pollutant trends in streams over time that smooths out the noise from natural hydrology fluctuations (Hirsch, 2010). WRTDS provides the user many options to control the trends' smoothing and other variables.

A recent paper (Rowland et al., 2021) used WRTDS to examine two Lake Erie tributaries in Ohio, the Maumee and Cuyahoga rivers, utilizes the same NCWQR data that is employed in this report. From this paper, Figures 85 and 86 show the TP and TN, respectively, concentration (both time and flow-weighted) and load annual results over the last several decades for both rivers. The WRTDS derived flow-normalized concentration and loads are also shown on each panel of these figures. Note that trends are much more evident in the annual WRTDS results.

The NCWQR at Heidelberg University continues to explore various trends analysis using the USGS EGRET analysis package. Figures 87 and 88 show discharge versus day of year, concentration trends for the Cuyahoga River's nitrate + nitrite and TKN, respectively. These figures show the change in concentration from 1980 to 2019 based on different times of year (the X-axis) and stream discharge conditions (the y-axis). Figures 89 and 90 show the smoothed concentrations of nitrate + nitrite over time for the Maumee and Cuyahoga rivers, respectively. Each of these plots shows concentrations fixed at three different specific streamflow discharges. These, yet to be published, figures are from active research on nitrogen trends by Dr. Nate Manning of NCWQR (Manning, 2022).

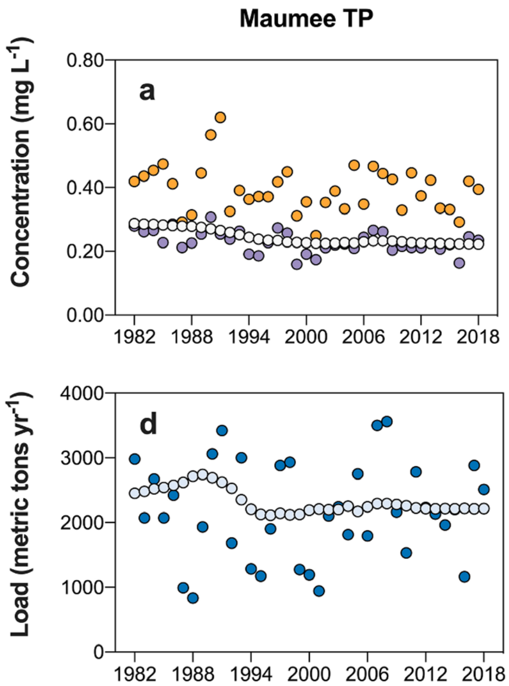


Figure 85: Total phosphorous water year annual concentrations (upper) and loads (lower) observed in the Maumee River (left) and Cuyahoga River (right). In concentration figures, the orange filled circles are flow-weighted mean and purple filled are time-weighted. In load figures, the blue filled circles are actual observed loads. The circles with lighter colored fill in all figures are flow-normalized concentration or loads. Adapted from Rowland et al., 2021.

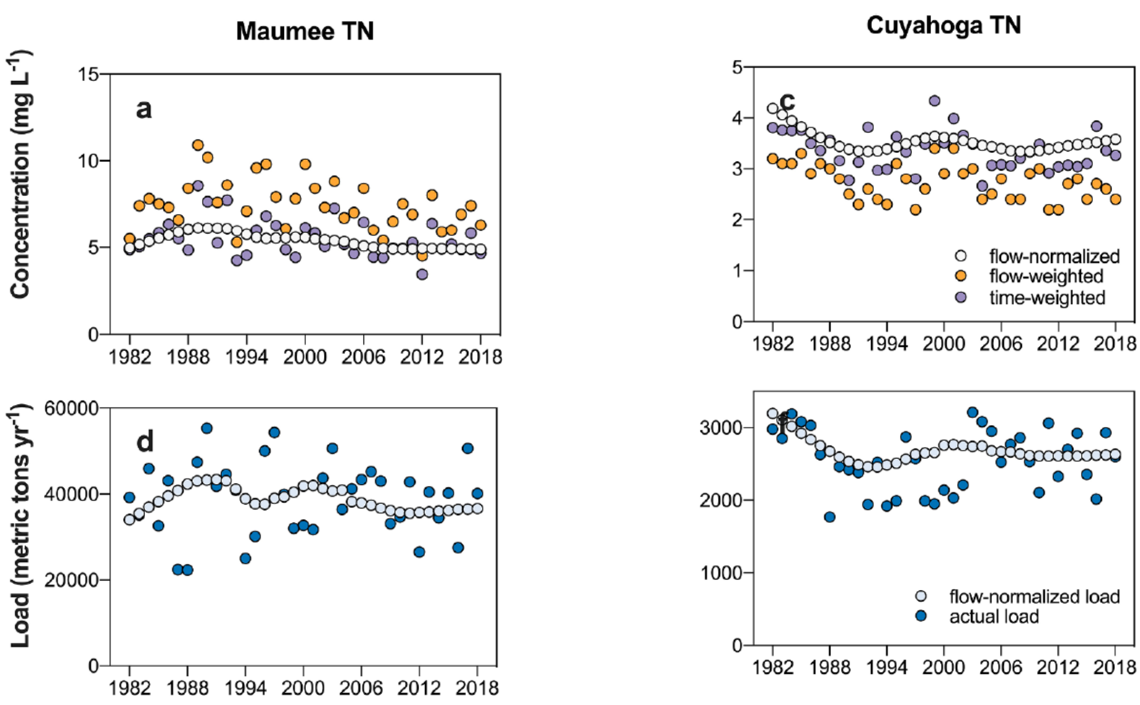


Figure 86: Total nitrogen water year annual concentrations (upper) and loads (lower) observed in the Maumee River (left) and Cuyahoga River (right). In concentration figures, the orange filled circles are flow-weighted mean and purple filled are time-weighted. In load figures, the blue filled circles are actual observed loads. The circles with lighter colored fill in all figures are flow-normalized concentration or loads. Adapted from Rowland et al., 2021.

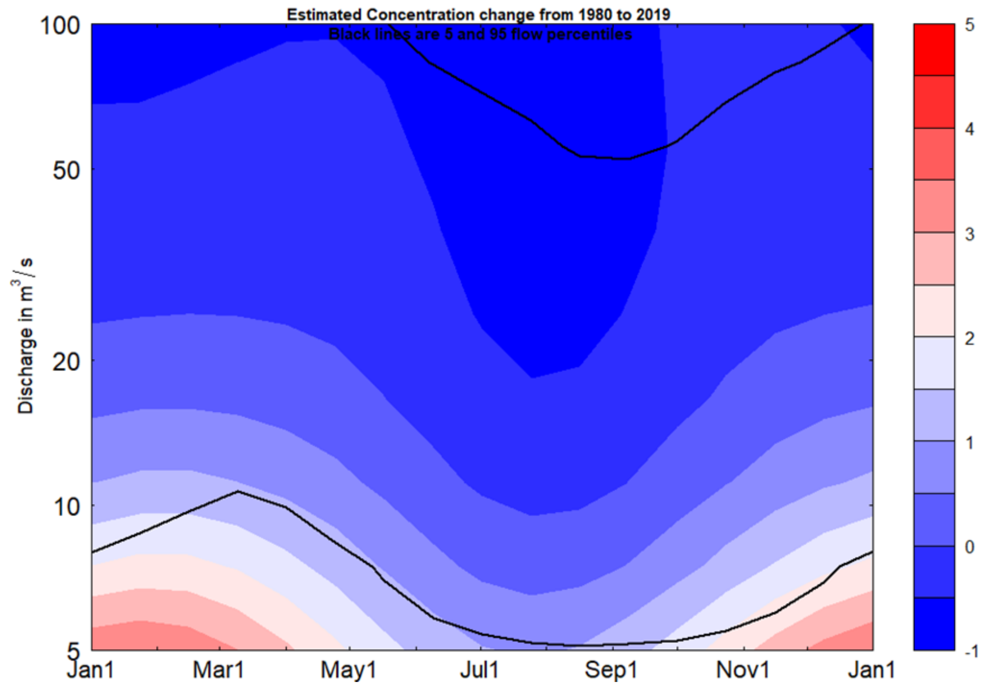


Figure 87: Changes in nitrate + nitrite concentrations from 1980 to 2019 on the Cuyahoga River. Concentration changes are based on color, note scale bar on the right. They are plotted based on stream discharge (the y-axis) and day of year (the x-axis). Upper and lower black lines show the 95th and 5th, receptively, stream flow percentiles. From Manning, 2022.

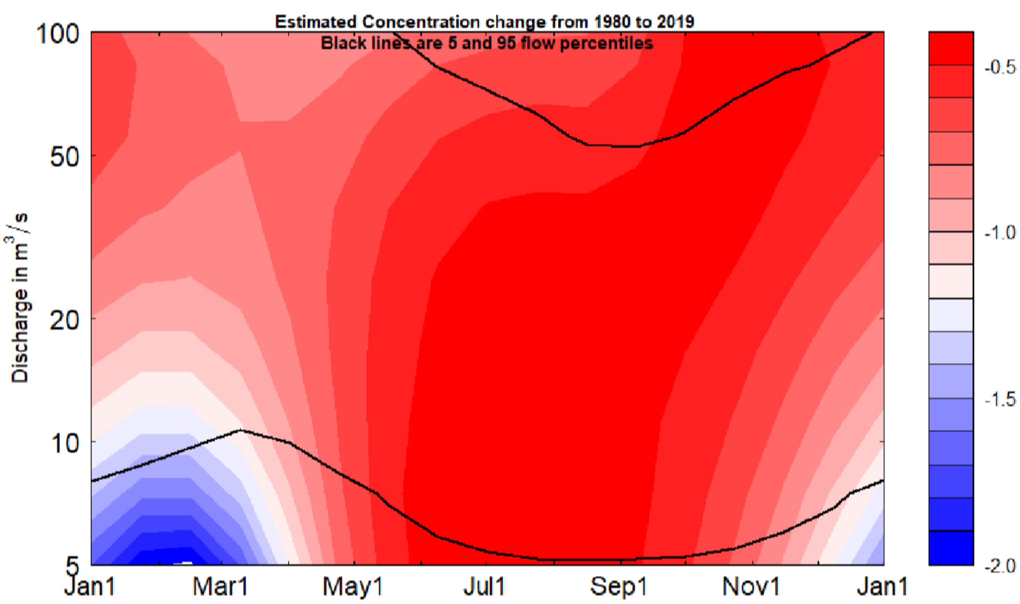


Figure 88: Changes in TKN concentrations from 1980 to 2019 on the Cuyahoga River. Concentration changes are based on color, note scale bar on the right. They are plotted based on stream discharge (the y-axis) and day of year (the x-axis). Upper and lower black lines show the 95th and 5th, receptively, stream flow percentiles. From Manning, 2022.

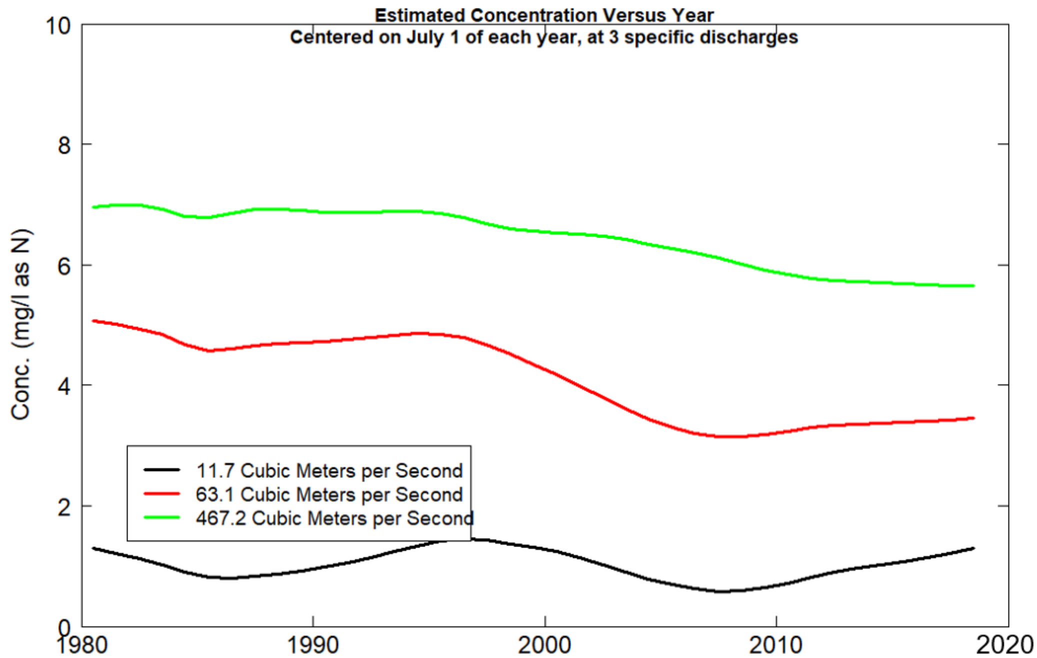


Figure 89: Maumee River nitrate + nitrite concentrations over time at three different specific streamflow discharges. From Manning, 2022.

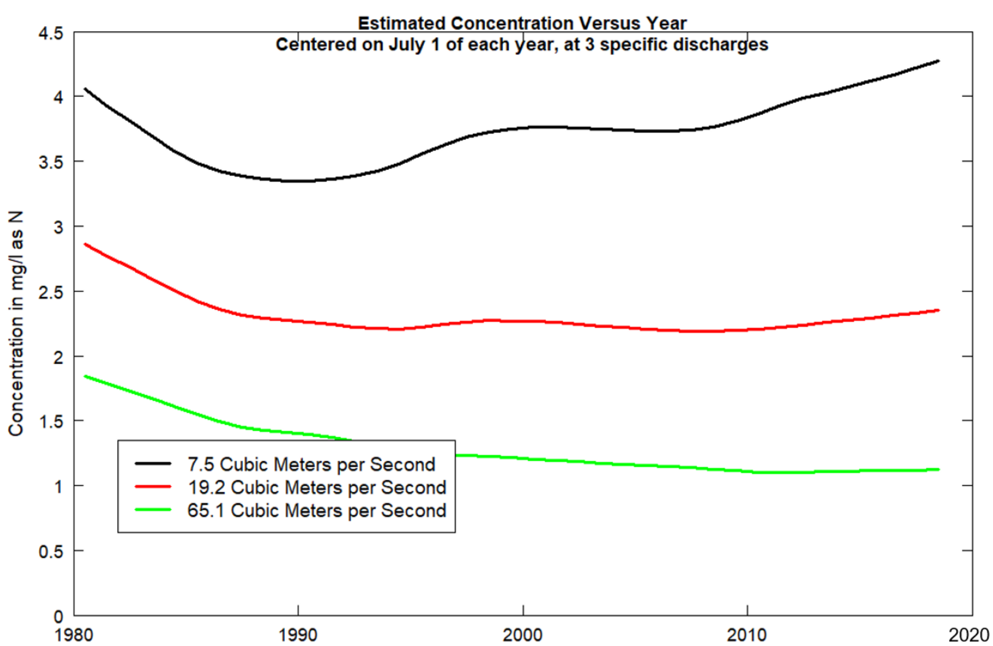


Figure 90: Cuyahoga River nitrate + nitrite concentrations over time at three different specific streamflow discharges. From Manning, 2022.

There is a general understanding that greater precipitation and streamflow is occurring due to climate change. A study by Williams and King (2020) examined changing hydrology in the Maumee watershed. Twenty-three daily rainfall and twelve streamflow gages in and near the watershed were examined from 1975 through 2017. An overall increase in rainfall between 11 and 13 percent and streamflow between 19 and 32 percent were documented for the Maumee watershed. Heavy and very heavy rainfall events brought the majority of these increases, more often in the spring. The study noted that the greatest increases of rainfall were observed in the southern half of the Maumee watershed. A different statistical analysis approach of the Maumee River found highly likely increasing streamflow trends in the days with the greatest 20 percent of streamflow (Choquette et al., 2019).

Large declines of total phosphorus loads from the 1970s through the 1980s have been documented throughout the state of Ohio. For the Maumee and Cuyahoga rivers, this decline is clear in the Rowland et al., 2021 paper and on Figure 85. These declines have been attributed to wastewater treatment upgrades due to public works programs instigated by the Clean Water Act and decades of agricultural soil conservation efforts (NRCS, 2017). Reduced phosphorus loads led to the resolution of the previous eutrophication problems in western Lake Erie (Michalak et al., 2013; Baker et al., 2014; Kane et al., 2014).

In recent years, flow normalized total phosphorus concentrations have shown slight declines. However, increases in streamflow discharges result in greater load delivery. Choquette et al., 2019 explains that this results in little net change of overall total phosphorus load delivered in Lake Erie tributaries. Like total phosphorus, Choquette et al., 2019 shows that total nitrogen loads to Lake Erie tributaries have been relatively stable due to slightly declining concentrations offset by increasing stream flows.

In Figures 87 and 88, trends of concentrations of the components that make up total nitrogen are presented for the Cuyahoga River. Figure 87 shows the nitrate + nitrite concentration declines from 1980 to 2019 are greatest in higher flows. This is a dramatic reduction compared to the watersheds with higher percentages of agricultural land draining to the western basin of Lake Erie (not shown). Increased streamflow provides more dilution of nitrogen inputs that tend to be point source driven in the Cuyahoga versus the agricultural watersheds dominated by nonpoint sources of nitrogen. Figure 88 shows TKN reductions in all conditions.

Note the most elevated nitrate + nitrite concentrations in the Maumee over time occur during the higher flow conditions examined on Figure 89. High flow concentrations are normally dictated by nonpoint sources of pollutants. That situation is flipped on Figure 90 which shows the highest flow condition in the Cuyahoga to contribute the lowest nitrate + nitrite concentrations. The Cuyahoga River is more dominated by wastewater treatment discharges which explains elevated low flow concentrations in that river. While elevated low flow concentrations may impact near-field stream conditions, they have little influence on the overall load delivery.

Readers interested in understanding more details on nutrient trends are encouraged to refer to the literature cited in this section.

5. Summary and Future Work

Nutrient loads (total P and total N) were estimated and divided into major contributing sources for thirteen watersheds in Ohio, covering 72.59 percent of the land area of Ohio. This study noted several factors that influence watershed nutrient loads, 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 the breakdown of sources contributing to those loads. The thirteen 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 reducing nutrient load impacts on the Gulf of Mexico and Lake Erie.

Pursuant to the requirements of ORC 6111.03 (U), Ohio EPA is required to update this work biennially and coinciding with the release of the *Integrated Report*[2]. External feedback on this approach and results produced valuable suggestions for future editions of the biennial nutrient balance report. Table 20 outlines objectives and potential partners for future additions and modifications to this work. 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 thirteen watersheds in the current version. This may require new means to estimate loads that require an expanded work effort.

Future editions will consider any new information that becomes available for attributing loads to appropriate sources. 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, so if these data were 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 data and modeling effort that quantifies the loading from the different sources. If data become available for any of the defined needs, Ohio EPA will consider it in future developments of the nutrient mass balance effort.

Table 3 — Proposed additions and modifications to the biennial nutrient balance approach.

Objective	Potential Partners
Spatial Extent	
Initiate use of further downstream pour point on Scioto River (OR)	Mass balance effort – Ohio EPA Pour-point monitoring – NCWQR
Expand OR watersheds – Mahoning R, Captina C	Ohio EPA, USGS
Expand OR watersheds – Wabash R (Ohio portion), Mill Ck (Cincinnati)	Ohio EPA, other
Expand LE watersheds – Grand R, Black R, Rocky R, Chagrin R	Ohio EPA, USGS and NCWQR monitoring, other
Methodology / Approach	
Evaluate data reported to Ohio EPA at upstream monitoring stations from NPDES permitted sources for use in load estimation tools.	Ohio EPA
Data Input / Parameterization	
Further improve estimate of CSO total P and total N concentrations	Ohio municipalities, AOMWA
Continue to encourage accurate NPDES reporting of population served for WWTP	Ohio municipalities, Ohio EPA
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=U.S. Geological Survey, NCWQR=National Center for Water Quality Research, ODA=Ohio Department of Agriculture, SWCD=soil and water conservation district	

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[2] *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.

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Appendix A – Summary Tables for Mass Balance Calculations

Table B1 — Summary of total P loading components for calculating the nutrient mass balance in the Maumee River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	32.7	39.5	36.3	34.2	35.0	36.1	34.0	35.5	34.6
NPDES 2 – Municipal 0.1-1.0 mgd	17.3	19.7	17.1	20.8	17.9	19.3	20.5	19.2	15.7
NDPES 3 – Municipal <0.1 mgd	8.2	8.9	8.2	7.4	8.5	9.4	12.6	7.4	7.8
NPDES – Industrial	11.9	11.8	11.8	12.7	13.0	10.8	12.7	11.7	13.4
Wet Weather UPST Pour Point	1.7	1.7	3.0	1.6	2.6	2.6	2.9	1.8	1.7
OOS Point Source	33.0	34.9	42.7	44.1	46.8	50.4	55.4	52.0	50.0
OOS Wet Weather	7.8	9.3	10.0	3.9	7.2	5.9	5.1	6.1	6.4
Total NPDES UPST Pour Point	112.5	125.8	129.1	124.8	131.0	134.5	143.2	133.7	126.9
HSTS UPST Pour Point	72.2	72.2	72.2	72.2	72.2	72.2	72.2	0.0[a]	0.0[a]
Load @ Pour Point	2,130.0	1,960.0	2,200.0	1,160.0	2,880.0	2,510.0	3,680.0	2,720.0	1,370.0
NPS UPST Pour Point	1,945.3	1,762.1	1,998.7	963.1	2,676.9	2,303.3	3,464.7	2,586.3	1,243.1
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	68.4	60.3	54.3	61.7	54.2	53.8	63.4	60.9	60.6
NPDES 2 – Municipal 0.1-1.0 mgd	1.7	1.6	0.7	0.6	0.4	0.3	0.5	0.6	0.4
NDPES 3 – Municipal <0.1 mgd	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.4
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	1.1	1.1	1.5	0.4	0.6	1.4	0.6	0.3	1.7
Total NPDES DST Pour Point	71.4	63.2	56.8	63.0	55.5	55.8	64.8	62.1	63.1
HSTS DST Pour Point	3.1	3.1	3.1	3.1	3.1	3.1	3.1	0.0[a]	0.0[a]
NPS DST Pour Point	83.7	75.8	86.0	41.4	115.2	99.1	149.1	108.4	52.1
Totals	a: Methods used for this watershed did not divide HSTS loads upstream and downstream of the pour point								
HSTS	75.3	75.3	75.3	75.3	75.3	75.3	75.3	89.4	89.4
Total NPDES	183.9	189.0	185.9	187.8	186.4	190.3	207.9	195.8	189.9
NPS Total	2,029.0	1,837.9	2,084.7	1,004.5	2,792.1	2,402.5	3,613.8	2,694.7	1,295.3
Total Load	2,288.2	2,102.1	2,345.9	1,267.6	3,053.8	2,668.0	3,897.0	2,979.9	1,574.5
% HSTS	3%	4%	3%	6%	2%	3%	2%	3%	6%
% NPDES	8%	9%	8%	15%	6%	7%	5%	7%	12%
% of NPDES – Municipal ≥ 1.0 mgd	55.0%	52.8%	48.7%	51.1%	47.8%	47.2%	46.8%	49.2%	50.1%
% of NPDES – Municipal 0.1-1.0 mgd	10.3%	11.2%	9.6%	11.4%	9.8%	10.3%	10.1%	10.1%	8.4%
% of NPDES – Municipal <0.1 mgd	4.5%	4.9%	4.5%	4.1%	4.7%	5.1%	6.2%	4.0%	4.3%
% of NPDES – Industrial	6.5%	6.3%	6.3%	6.8%	7.0%	5.7%	6.1%	6.0%	7.0%
% of NPDES – Wet Weather	1.5%	1.5%	2.5%	1.1%	1.7%	2.1%	1.7%	1.1%	1.8%
% NPS	89%	87%	89%	79%	91%	90%	93%	90%	82%
Yield UPST Pour Point (lb/acre)	1.06	0.96	1.09	0.53	1.46	1.26	1.90	1.43	0.69
Per Capita Yield (lb/person)	0.32	0.33	0.30	0.32	0.30	0.31	0.33	0.34	0.33

Table B2 — Summary of total N loading components for calculating the nutrient mass balance in the Maumee River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	794.2	797.9	776.5	803.0	889.2	984.3	943.4	805.4	800.5
NPDES 2 – Municipal 0.1-1.0 mgd	141.9	132.0	137.1	146.1	124.2	138.6	146.1	149.4	121.3
NDPES 3 – Municipal <0.1 mgd	67.7	54.2	52.4	53.8	53.8	57.8	98.0	42.7	42.4
NPDES – Industrial	54.0	52.5	57.6	58.4	56.9	48.1	39.6	31.3	31.3
Wet Weather UPST Pour Point	47.3	45.9	83.1	43.8	71.1	70.0	79.6	49.9	46.9
OOS Point Source	793.3	864.5	912.9	811.6	928.7	919.9	1,051.5	896.2	844.1
OOS Wet Weather	206.8	246.9	267.7	104.1	192.5	157.5	136.9	162.3	147.7
Total NPDES UPST Pour Point	2,105.2	2,193.9	2,287.3	2,020.8	2,316.3	2,376.1	2,495.2	2137.1	2034.4
HSTS UPST Pour Point	520.6	520.6	520.6	520.6	520.6	520.6	520.6	0.0[a]	0.0[a]
Load @ Pour Point	40,275.8	34,323.6	41,520.8	28,042.2	45,958.5	36,690.0	45,700.0	31,874.0	33,690.0
NPS UPST Pour Point	37,649.9	31,609.1	38,712.9	25,500.8	43,121.5	33,793.3	42,684.2	29,736.9	31,655.6
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	1,667.3	1,860.0	1,698.4	1,765.4	1,683.2	2,107.1	1,869.8	1684.0	1773.3
NPDES 2 – Municipal 0.1-1.0 mgd	12.9	11.6	9.7	12.4	12.1	13.6	14.6	12.0	12.1
NDPES 3 – Municipal <0.1 mgd	1.3	1.4	2.0	2.1	2.2	2.4	1.4	1.3	1.5
NPDES – Industrial	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2
Wet Weather DST Pour Point	29.5	29.7	42.3	11.5	16.5	37.2	15.8	8.0	46.2
Total NPDES DST Pour Point	1,711.1	1,902.7	1,752.5	1,791.4	1,714.1	2,160.3	1,901.7	1,705.2	1,833.3
HSTS DST Pour Point	22.4	22.4	22.4	22.4	22.4	22.4	22.4	0.0[a]	0.0[a]
NPS DST Pour Point	1,620.3	1,360.3	1,666.1	1,097.5	1,855.8	1,454.3	1,837.0	1,246.9	1,327.4
Totals	a: Methods used for this watershed did not divide HSTS loads upstream and downstream of the pour point								
HSTS	543.0	543.0	543.0	543.0	543.0	543.0	543.0	644.5	644.5
Total NPDES	3,816.3	4,096.6	4,039.7	3,812.2	4,030.5	4,536.4	4,396.9	3842.3	3867.6
NPS Total	39,270.3	32,969.5	40,379.0	26,598.3	44,977.3	35,247.6	44,521.2	30,983.8	32,983.0
Total Load	43,629.6	37,609.1	44,961.7	30,953.5	49,550.8	40,327.1	49,461.1	35,470.7	37,495.2
% HSTS	1%	1%	1%	2%	1%	1%	1%	2%	2%
% NPDES	9%	11%	9%	12%	8%	11%	9%	11%	10%
% of NPDES – Municipal ≥ 1.0 mgd	64.5%	64.9%	61.3%	67.4%	63.8%	68.1%	64.0%	64.8%	66.5%
% of NPDES – Municipal 0.1-1.0 mgd	4.1%	3.5%	3.6%	4.2%	3.4%	3.4%	3.7%	4.2%	3.4%
% of NPDES – Municipal <0.1 mgd	1.8%	1.4%	1.3%	1.5%	1.4%	1.3%	2.3%	1.1%	1.1%
% of NPDES – Industrial	1.4%	1.3%	1.4%	1.5%	1.4%	1.1%	0.9%	0.8%	0.8%
% of NPDES – Wet Weather	2.0%	1.8%	3.1%	1.4%	2.2%	2.4%	2.2%	1.5%	2.4%
% NPS	90%	88%	90%	86%	91%	87%	90%	87%	88%
Yield UPST Pour Point (lb/acre)	20.60	17.29	21.18	13.95	23.59	18.49	23.35	16.39	17.45
Per Capita Yield (lb/person)	5.12	5.39	5.10	5.27	5.24	6.10	5.73	5.33	5.42

Table B3 — Summary of total P loading components for calculating the nutrient mass balance in the Portage River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	6.0	6.3	6.8	6.6	6.9	5.7	5.1	4.6	5.2
NPDES 2 – Municipal 0.1-1.0 mgd	1.8	1.8	1.4	1.1	2.0	1.8	1.8	1.3	0.9
NDPES 3 – Municipal <0.1 mgd	0.8	0.7	0.7	0.7	0.7	0.8	1.3	0.6	0.7
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	1.4	1.3	1.6	0.9	1.2	1.1	1.3	0.4	0.6
Total NPDES UPST Pour Point	9.9	10.1	10.5	9.3	10.8	9.4	9.5	6.9	7.5
HSTS UPST Pour Point	3.0	3.0	3.0	3.0	3.0	3.0	3.0	4.4	4.4
Load @ Pour Point	117.0	163.0	123.0	103.0	135.0	184.0	264.0	143.0	106.0
NPS UPST Pour Point	104.1	149.9	109.6	90.7	121.2	171.6	251.6	131.7	94.2
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	0.5	0.4	0.3	0.4	0.3	0.4	0.4	0.4	0.2
NPDES 2 – Municipal 0.1-1.0 mgd	3.1	3.4	3.2	3.5	3.3	3.6	4.3	3.0	3.4
NDPES 3 – Municipal <0.1 mgd	3.2	3.1	1.3	1.2	1.1	1.1	1.3	2.1	2.8
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.2	0.5	0.8	0.2	0.1	0.5	0.4	0.1	0.1
Total NPDES DST Pour Point	7.0	7.3	5.6	5.2	4.8	5.7	6.4	5.6	6.6
HSTS DST Pour Point	1.1	1.1	1.1	1.1	1.1	1.1	1.1	2.4	2.4
NPS DST Pour Point	38.2	55.0	40.2	33.3	44.5	62.9	92.3	47.8	34.1
Totals									
HSTS	4.1	4.1	4.1	4.1	4.1	4.1	4.1	6.8	6.8
Total NPDES	16.8	17.5	16.0	14.5	15.6	15.1	15.8	12.5	14.1
NPS Total	142.3	204.9	149.7	124.0	165.7	234.5	343.8	179.5	128.3
Total Load	163.2	226.4	169.8	142.6	185.3	253.7	363.7	198.8	149.1
% HSTS	2%	2%	2%	3%	2%	2%	1%	3%	5%
% NPDES	10%	8%	9%	10%	8%	6%	4%	6%	9%
% of NPDES – Municipal ≥ 1.0 mgd	38.5%	38.4%	44.3%	48.1%	46.1%	40.3%	34.9%	39.8%	38.8%
% of NPDES – Municipal 0.1-1.0 mgd	28.8%	29.6%	28.5%	31.2%	33.7%	35.8%	38.1%	34.2%	30.8%
% of NPDES – Municipal <0.1 mgd	23.5%	22.0%	12.1%	13.5%	11.4%	12.7%	16.2%	21.6%	25.1%
% of NPDES – Industrial	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
% of NPDES – Wet Weather	9.1%	10.0%	14.9%	7.1%	8.7%	11.1%	10.7%	4.3%	5.3%
% NPS	87%	90%	88%	87%	89%	92%	95%	90%	86%
Yield UPST Pour Point (lb/acre)	0.84	1.21	0.88	0.73	0.98	1.38	2.02	1.08	0.77
Per Capita Yield (lb/person)	0.45	0.46	0.41	0.41	0.43	0.41	0.42	0.41	0.44

Table B4 — Summary of total N loading components for calculating the nutrient mass balance in the Portage River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	192.4	206.1	225.8	202.4	142.7	152.7	140.5	117.8	135.7
NPDES 2 – Municipal 0.1-1.0 mgd	20.5	21.1	16.7	16.4	16.6	18.4	19.7	14.7	13.7
NDPES 3 – Municipal <0.1 mgd	6.6	6.0	5.8	3.4	3.4	3.6	3.8	2.4	2.7
NPDES – Industrial	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Wet Weather UPST Pour Point	37.3	35.2	45.0	23.8	33.4	31.4	36.3	11.2	17.4
Total NPDES UPST Pour Point	256.8	268.5	293.2	246.2	196.2	206.2	200.4	146.1	169.5
HSTS UPST Pour Point	28.9	28.9	28.9	28.9	28.9	28.9	28.9	42.2	31.5
Load @ Pour Point	2,861.4	2,279.4	2,947.1	2,360.9	3,903.4	3,163.0	3,930.0	2,358.0	3,033.0
NPS UPST Pour Point	2,575.8	1,982.1	2,625.1	2,085.9	3,678.4	2,927.9	3,700.7	2,169.7	2,832.0
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	37.0	34.2	39.8	38.4	35.7	37.5	47.9	38.0	38.6
NPDES 2 – Municipal 0.1-1.0 mgd	17.1	16.9	17.1	17.2	21.1	24.3	23.2	16.3	20.1
NDPES 3 – Municipal <0.1 mgd	10.7	9.9	7.7	7.5	8.3	9.4	11.5	11.6	11.5
NPDES – Industrial	28.2	25.3	26.2	21.4	26.2	24.0	24.8	20.9	24.2
Wet Weather DST Pour Point	4.9	12.5	20.6	4.6	3.7	14.6	9.9	3.7	3.1
Total NPDES DST Pour Point	97.9	98.8	111.4	89.2	95.1	109.7	117.3	90.5	97.5
HSTS DST Pour Point	10.6	10.6	10.6	10.6	10.6	10.6	10.6	23.1	23.1
NPS DST Pour Point	944.8	727.1	962.9	765.1	1,349.3	1,074.0	1,357.5	786.4	1,026.4
Totals									
HSTS	39.5	39.5	39.5	39.5	39.5	39.5	39.5	65.3	54.6
Total NPDES	354.6	367.3	404.6	335.3	291.3	315.9	317.7	236.6	266.9
NPS Total	3,520.6	2,709.1	3,588.0	2,851.0	5,027.7	4,002.0	5,058.2	2,956.1	3,858.5
Total Load	3,914.7	3,115.9	4,032.0	3,225.8	5,358.4	4,357.4	5,415.4	3,258.0	4,180.0
% HSTS	1%	1%	1%	1%	1%	1%	1%	2%	1%
% NPDES	9%	12%	10%	10%	5%	7%	6%	7%	6%
% of NPDES – Municipal ≥ 1.0 mgd	64.7%	65.4%	65.6%	71.8%	61.3%	60.2%	59.3%	65.9%	65.3%
% of NPDES – Municipal 0.1-1.0 mgd	10.6%	10.3%	8.4%	10.0%	12.9%	13.5%	13.5%	13.1%	12.7%
% of NPDES – Municipal <0.1 mgd	4.9%	4.3%	3.3%	3.3%	4.0%	4.1%	4.8%	5.9%	5.3%
% of NPDES – Industrial	8.0%	6.9%	6.5%	6.4%	9.0%	7.6%	7.8%	8.8%	9.1%
% of NPDES – Wet Weather	11.9%	13.0%	16.2%	8.5%	12.7%	14.6%	14.5%	6.3%	7.7%
% NPS	90%	87%	89%	88%	94%	92%	93%	91%	92%
Yield UPST Pour Point (lb/acre)	20.73	15.96	21.13	16.79	29.61	23.57	29.79	17.84	23.29
Per Capita Yield (lb/person)	7.54	7.77	8.20	7.56	6.22	6.64	6.66	5.78	6.01

Table B5 — Summary of total P loading components for calculating the nutrient mass balance in the Cedar-Toussaint watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
NOTE: as no monitoring station exists in this watershed, all area loads are estimated using yields from adjacent watershed (Portage)									
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	2.3	1.7	2.5	2.5	0.9	1.9	1.1	3.5	3.6
NPDES 2 – Municipal 0.1-1.0 mgd	1.3	1.7	1.6	1.5	1.2	1.1	1.2	0.8	0.9
NDPES 3 – Municipal <0.1 mgd	0.9	1.1	0.9	1.1	0.9	0.9	0.9	0.9	1.0
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	4.5	4.5	5.1	5.0	3.1	4.0	3.1	5.1	5.6
HSTS DST Pour Point	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.3	8.3
NPS DST Pour Point	83.6	120.4	88.0	72.9	97.4	137.8	202.1	101.7	72.7
Totals									
HSTS	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.3	8.3
Total NPDES	4.5	4.5	5.1	5.0	3.1	4.0	3.1	5.1	5.6
NPS Total	83.6	120.4	88.0	72.9	97.4	137.8	202.1	101.7	72.7
Total Load	96.2	132.9	101.1	86.0	108.5	149.8	213.2	115.2	86.6
% HSTS	8%	6%	8%	9%	7%	5%	4%	7%	10%
% NPDES	5%	3%	5%	6%	3%	3%	1%	4%	6%
% of NPDES – Municipal ≥ 1.0 mgd	50.6%	37.3%	50.0%	48.9%	30.3%	48.1%	34.0%	67.9%	64.9%
% of NPDES – Municipal 0.1-1.0 mgd	29.3%	38.6%	32.1%	29.8%	39.7%	28.3%	37.9%	15.3%	16.9%
% of NPDES – Municipal <0.1 mgd	20.1%	24.1%	17.9%	21.3%	29.9%	23.5%	28.0%	16.8%	18.2%
% of NPDES – Industrial	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%
% of NPDES – Wet Weather	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% NPS	87%	91%	87%	85%	90%	92%	95%	88%	84%
Yield UPST Pour Point (lb/acre)	0.84	1.21	0.88	0.73	0.98	1.38	2.02	1.08	0.77
Per Capita Yield (lb/person)	0.52	0.52	0.55	0.55	0.46	0.50	0.47	0.50	0.51

Table B6 — Summary of total N loading components for calculating the nutrient mass balance in the Cedar-Toussaint watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
NOTE: as no monitoring station exists in this watershed, all area loads are estimated using yields from adjacent watershed (Portage)									
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	57.4	55.9	71.6	74.1	85.6	80.7	85.4	72.7	85.7
NPDES 2 – Municipal 0.1-1.0 mgd	4.0	5.3	3.6	3.5	4.7	4.3	4.5	3.2	3.2
NDPES 3 – Municipal <0.1 mgd	7.0	5.3	5.5	6.3	5.7	6.9	5.0	5.9	5.6
NPDES – Industrial	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	68.4	67.5	80.6	83.9	96.0	91.9	94.9	81.8	94.5
HSTS DST Pour Point	58.0	58.0	58.0	58.0	58.0	58.0	58.0	80.4	80.4
NPS DST Pour Point	2,069.1	1,592.2	2,108.7	1,675.6	2,954.9	2,352.0	2,972.8	1,675.2	2,186.6
Totals									
HSTS	58.0	58.0	58.0	58.0	58.0	58.0	58.0	80.4	80.4
Total NPDES	68.4	67.5	80.6	83.9	96.0	91.9	94.9	81.8	94.5
NPS Total	2,069.1	1,592.2	2,108.7	1,675.6	2,954.9	2,352.0	2,972.8	1,675.2	2,186.6
Total Load	2,195.5	1,717.7	2,247.4	1,817.5	3,108.9	2,502.0	3,125.7	1,837.4	2,361.5
% HSTS	3%	3%	3%	3%	2%	2%	2%	4%	3%
% NPDES	3%	4%	4%	5%	3%	4%	3%	4%	4%
% of NPDES – Municipal ≥ 1.0 mgd	83.9%	82.7%	88.7%	88.3%	89.1%	87.8%	90.0%	88.9%	90.6%
% of NPDES – Municipal 0.1-1.0 mgd	5.9%	7.9%	4.4%	4.2%	4.9%	4.7%	4.7%	4.0%	3.4%
% of NPDES – Municipal <0.1 mgd	10.2%	7.9%	6.8%	7.5%	6.0%	7.5%	5.3%	7.2%	6.0%
% of NPDES – Industrial	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% of NPDES – Wet Weather	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% NPS	94%	93%	94%	92%	95%	94%	95%	91%	93%
Yield UPST Pour Point (lb/acre)	20.73	15.96	21.13	16.79	29.61	23.57	29.79	17.84	23.29
Per Capita Yield (lb/person)	5.28	5.20	5.79	5.93	6.43	6.26	6.38	5.97	6.44

Table B7 — Summary of total P loading components for calculating the nutrient mass balance in the Sandusky River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	12.8	9.9	8.1	6.7	8.2	9.3	9.7	8.2	7.9
NPDES 2 – Municipal 0.1-1.0 mgd	2.0	2.4	2.5	2.3	2.1	2.2	2.0	1.4	1.2
NDPES 3 – Municipal <0.1 mgd	1.0	1.0	1.0	0.9	1.0	1.1	1.0	1.1	1.4
NPDES – Industrial	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1
Wet Weather UPST Pour Point	1.8	1.9	1.8	1.6	1.6	2.0	3.0	2.0	1.9
Total NPDES UPST Pour Point	17.7	15.3	13.5	11.6	13.0	14.7	15.9	12.7	12.5
HSTS UPST Pour Point	13.2	13.2	13.2	13.2	13.2	13.2	13.2	12.8	12.8
Load @ Pour Point	642.0	558.0	352.0	295.0	539.0	567.0	828.0	486.0	385.0
NPS UPST Pour Point	611.0	529.5	325.3	270.2	512.7	539.0	798.9	460.5	359.7
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	10.9	12.9	11.6	12.3	10.5	13.4	14.6	12.5	12.9
NPDES 2 – Municipal 0.1-1.0 mgd	0.4	0.4	0.3	0.4	0.4	0.4	0.7	0.3	0.4
NDPES 3 – Municipal <0.1 mgd	1.2	1.4	1.1	1.1	1.3	1.6	1.5	1.5	1.5
NPDES – Industrial	0.1	0.4	1.2	0.9	0.6	0.2	0.1	0.1	0.1
Wet Weather DST Pour Point	3.7	4.0	5.0	2.5	1.1	1.2	1.3	0.9	0.5
Total NPDES DST Pour Point	16.3	19.1	19.2	17.2	13.9	16.8	18.2	15.2	15.4
HSTS DST Pour Point	12.1	12.1	12.1	12.1	12.1	12.1	12.1	11.7	11.7
NPS DST Pour Point	281.0	243.5	149.6	124.3	235.8	247.9	367.4	192.7	150.5
Totals									
HSTS	25.4	25.4	25.4	25.4	25.4	25.4	25.4	24.4	24.4
Total NPDES	34.0	34.4	32.7	28.8	27.0	31.5	34.0	28.0	27.9
NPS Total	892.0	773.0	474.8	394.5	748.5	786.9	1,166.3	653.2	510.2
Total Load	951.4	832.7	532.9	448.6	800.9	843.8	1,225.7	705.6	562.5
% HSTS	3%	3%	5%	6%	3%	3%	2%	3%	4%
% NPDES	4%	4%	6%	6%	3%	4%	3%	4%	5%
% of NPDES – Municipal ≥ 1.0 mgd	69.7%	66.5%	60.1%	66.1%	69.3%	72.0%	71.3%	74.1%	74.6%
% of NPDES – Municipal 0.1-1.0 mgd	7.1%	8.2%	8.7%	9.3%	9.1%	8.2%	7.8%	5.8%	5.7%
% of NPDES – Municipal <0.1 mgd	6.5%	6.9%	6.7%	6.8%	8.6%	8.6%	7.4%	9.1%	10.2%
% of NPDES – Industrial	0.5%	1.2%	3.8%	3.5%	3.0%	1.3%	0.7%	0.5%	0.7%
% of NPDES – Wet Weather	16.3%	17.3%	20.6%	14.4%	10.0%	10.1%	12.8%	10.6%	8.7%
% NPS	94%	93%	89%	88%	93%	93%	95%	93%	91%
Yield UPST Pour Point (lb/acre)	1.68	1.46	0.90	0.74	1.41	1.48	2.20	1.28	1.00
Per Capita Yield (lb/person)	0.58	0.58	0.54	0.53	0.53	0.58	0.59	0.40	0.41

Table B8 — Summary of total N loading components for calculating the nutrient mass balance in the Sandusky River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	165.6	152.7	138.2	124.7	138.3	124.4	115.6	128.9	102.6
NPDES 2 – Municipal 0.1-1.0 mgd	19.1	19.0	20.7	23.6	15.4	19.2	16.1	15.4	16.1
NDPES 3 – Municipal <0.1 mgd	7.4	7.5	7.7	6.8	7.9	10.0	8.6	8.5	7.6
NPDES – Industrial	0.2	0.2	0.2	0.2	0.4	0.5	0.5	0.7	0.7
Wet Weather UPST Pour Point	49.6	53.0	48.4	44.2	44.7	53.5	83.5	55.8	52.2
Total NPDES UPST Pour Point	241.9	232.4	215.2	199.6	206.7	207.5	224.4	209.3	179.1
HSTS UPST Pour Point	128.1	128.1	128.1	128.1	128.1	128.1	128.1	123.7	123.7
Load @ Pour Point	9,943.2	7,116.2	6,141.6	5,646.8	8,670.6	7,910.0	9,800.0	6,450.0	7,210.0
NPS UPST Pour Point	9,573.1	6,755.7	5,798.2	5,319.0	8,335.7	7,574.3	9,447.5	6,117.1	6,907.2
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	591.6	401.6	405.5	386.4	425.0	442.9	434.4	362.2	366.5
NPDES 2 – Municipal 0.1-1.0 mgd	13.3	7.4	13.5	14.7	12.9	15.2	23.0	16.3	20.7
NDPES 3 – Municipal <0.1 mgd	21.1	19.0	18.8	23.0	28.9	31.3	28.4	26.4	26.2
NPDES – Industrial	0.2	0.1	0.2	0.1	0.1	0.4	0.2	0.2	0.7
Wet Weather DST Pour Point	101.8	109.4	136.4	69.0	29.4	33.3	36.3	25.5	14.3
Total NPDES DST Pour Point	728.0	537.6	574.5	493.2	496.3	523.1	522.2	430.7	428.4
HSTS DST Pour Point	92.0	92.0	92.0	92.0	92.0	92.0	92.0	112.8	112.8
NPS DST Pour Point	4,402.3	3,106.7	2,666.4	2,446.0	3,833.3	3,483.1	4,344.5	2,559.8	2,890.5
Totals									
HSTS	220.1	220.1	220.1	220.1	220.1	220.1	220.1	236.4	236.4
Total NPDES	969.9	770.0	789.7	692.8	703.1	730.7	746.6	639.9	607.6
NPS Total	13,975.4	9,862.4	8,464.5	7,765.1	12,168.9	1,1057.4	13,792.0	8,676.9	9,797.6
Total Load	15,165.4	10,852.5	9,474.3	8,678.0	13,092.1	12,008.2	14,758.7	9,553.3	10,641.6
% HSTS	1%	2%	2%	3%	2%	2%	1%	2%	2%
% NPDES	6%	7%	8%	8%	5%	6%	5%	7%	6%
% of NPDES – Municipal ≥ 1.0 mgd	78.1%	72.0%	68.9%	73.8%	80.1%	77.6%	73.7%	76.7%	77.2%
% of NPDES – Municipal 0.1-1.0 mgd	3.3%	3.4%	4.3%	5.5%	4.0%	4.7%	5.2%	5.0%	6.0%
% of NPDES – Municipal <0.1 mgd	2.9%	3.4%	3.4%	4.3%	5.2%	5.7%	5.0%	5.4%	5.6%
% of NPDES – Industrial	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%
% of NPDES – Wet Weather	15.6%	21.1%	23.4%	16.4%	10.5%	11.9%	16.0%	12.7%	10.9%
% NPS	92%	91%	89%	89%	93%	92%	93%	91%	92%
Yield UPST Pour Point (lb/acre)	26.37	18.61	15.97	14.65	22.96	20.86	26.02	16.99	19.18
Per Capita Yield (lb/person)	11.20	8.92	8.89	8.62	9.15	9.31	9.13	6.51	6.36

Table B9 — Summary of total P loading components for calculating the nutrient mass balance in the Huron watershed.

	TP Load (mta)			
Source	wy18	wy19	wy20	wy21
Upstream of Pour Point				
NPDES 1 – Municipal ≥1.0 mgd	1.8	1.9	1.3	1.2
NPDES 2 – Municipal 0.1-1.0 mgd	0.8	0.5	0.5	0.4
NDPES 3 – Municipal <0.1 mgd	0.2	0.1	0.2	0.1
NPDES – Industrial	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	0.1	0.1	0.0	0.1
OOS Point Source	121.2	125.2	125.2	125.2
Total NPDES UPST Pour Point	2.8	2.6	2.0	1.8
HSTS UPST Pour Point	5.3	5.3	4.6	4.6
Load @ Pour Point	184.0	198.0	144.0	107.0
NPS UPST Pour Point	175.9	190.1	137.4	100.6
Downstream of Pour Point				
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	0.5	0.7	0.7	0.8
NDPES 3 – Municipal <0.1 mgd	0.0	0.0	0.1	0.1
NPDES – Industrial	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	0.5	0.7	0.8	0.9
HSTS DST Pour Point	0.5	0.5	1.1	1.1
NPS DST Pour Point	16.8	18.2	12.9	9.4
Totals				
HSTS	5.8	5.8	5.7	5.7
Total NPDES	3.3	3.3	2.9	2.8
NPS Total	192.7	208.3	150.2	110.0
Total Load	201.8	217.4	158.8	118.5
% HSTS	3%	3%	4%	5%
% NPDES	2%	2%	2%	2%
% of NPDES – Municipal ≥ 1.0 mgd	53.4%	57.1%	46.8%	44.8%
% of NPDES – Municipal 0.1-1.0 mgd	39.1%	34.6%	43.7%	45.3%
% of NPDES – Municipal <0.1 mgd	5.5%	4.2%	8.0%	8.1%
% of NPDES – Industrial	0.0%	0.0%	0.0%	0.0%
% of NPDES – Wet Weather	1.9%	4.1%	1.5%	1.8%
% NPS	95%	96%	95%	93%
Yield UPST Pour Point (lb/acre)	1.64	1.77	1.29	0.94
Per Capita Yield (lb/person)	0.29	0.29	0.34	0.33

Table B10 — Summary of total N loading components for calculating the nutrient mass balance in the Huron watershed.

Source	TN Load (mta) wy18	wy19	wy20	wy21
Upstream of Pour Point				
NPDES 1 – Municipal ≥1.0 mgd	100.9	97.7	86.5	77.2
NPDES 2 – Municipal 0.1-1.0 mgd	10.3	9.8	8.2	7.4
NDPES 3 – Municipal <0.1 mgd	1.7	1.0	0.9	1.1
NPDES – Industrial	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	1.8	3.7	1.2	1.4
Total NPDES UPST Pour Point	114.6	112.3	96.8	87.1
HSTS UPST Pour Point	38.0	38.0	45.0	45.0
Load @ Pour Point	1,836.0	2,405.0	1,644.0	2,158.0
NPS UPST Pour Point	1,683.4	2,254.7	1,502.3	2,025.9
Downstream of Pour Point				
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	44.9	54.2	59.6	56.3
NDPES 3 – Municipal <0.1 mgd	0.3	0.3	0.4	0.8
NPDES – Industrial	0.1	0.1	0.1	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	45.2	54.6	60.2	57.1
HSTS DST Pour Point	3.6	3.6	10.9	10.9
NPS DST Pour Point	160.8	215.4	140.6	189.6
Totals				
HSTS	41.6	41.6	55.9	55.9
Total NPDES	159.8	166.9	156.9	144.3
NPS Total	1,844.2	2,470.1	1,642.9	2,215.5
Total Load	2,045.7	2,678.6	1,855.7	2,415.7
% HSTS	2%	2%	3%	2%
% NPDES	8%	6%	8%	6%
% of NPDES – Municipal ≥ 1.0 mgd	63.1%	58.6%	55.2%	53.5%
% of NPDES – Municipal 0.1-1.0 mgd	34.5%	38.4%	43.2%	44.2%
% of NPDES – Municipal <0.1 mgd	1.2%	0.8%	0.8%	1.4%
% of NPDES – Industrial	0.0%	0.0%	0.1%	0.0%
% of NPDES – Wet Weather	1.1%	2.2%	0.7%	1.0%
% NPS	90%	92%	89%	92%
Yield UPST Pour Point (lb/acre)	15.65	20.96	14.05	18.95
Per Capita Yield (lb/person)	6.49	6.65	8.36	7.85

Table B11 — Summary of total P loading components for calculating the nutrient mass balance in the Old Woman Creek watershed.

	TP Load (mta)					
Source	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point						
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0
NDPES 3 – Municipal <0.1 mgd	0.0	0.0	0.0	0.0	0.0	0.0
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0
HSTS UPST Pour Point	0.6	0.6	0.6	0.6	0.5	0.5
Load @ Pour Point	5.1	6.7	6.7	9.5	6.2	5.7
NPS UPST Pour Point	4.4	6.0	6.0	8.8	5.7	5.2
Downstream of Pour Point						
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	0.3	0.3	0.3	0.2	0.3	0.3
NDPES 3 – Municipal <0.1 mgd	0.2	0.2	0.2	0.2	0.2	0.1
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	0.6	0.5	0.5	0.4	0.5	0.4
HSTS DST Pour Point	1.9	1.9	1.9	1.9	2.2	2.2
NPS DST Pour Point	13.2	18.2	18.0	26.3	17.2	15.7
Totals						
HSTS	2.6	2.6	2.6	2.6	2.7	2.7
Total NPDES	0.6	0.5	0.5	0.4	0.5	0.5
NPS Total	17.6	24.2	24.1	35.2	22.8	20.8
Total Load	20.7	27.3	27.1	38.1	26.1	24.0
% HSTS	12%	9%	9%	7%	11%	11%
% NPDES	3%	2%	2%	1%	2%	2%
% of NPDES – Municipal ≥ 1.0 mgd	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% of NPDES – Municipal 0.1-1.0 mgd	58.7%	55.7%	60.8%	55.0%	63.3%	75.7%
% of NPDES – Municipal <0.1 mgd	41.3%	44.3%	39.2%	45.0%	36.7%	24.3%
% of NPDES – Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% of NPDES – Wet Weather	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% NPS	85%	89%	89%	92%	88%	87%
Yield UPST Pour Point (lb/acre)	0.69	0.95	0.94	1.38	0.90	0.82
Per Capita Yield (lb/person)	0.57	0.57	0.56	0.54	0.67	0.67

Table B12 — Summary of total N loading components for calculating the nutrient mass balance in the Old Woman Creek watershed.

	TN Load (mta)					
Source	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point						
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0
NDPES 3 – Municipal <0.1 mgd	0.0	0.0	0.0	0.1	0.1	0.0
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	0.0	0.0	0.0	0.1	0.1	0.0
HSTS UPST Pour Point	4.6	4.6	4.6	4.6	5.4	5.4
Load @ Pour Point	77.6	116.0	91.4	156.5	70.1	85.1
NPS UPST Pour Point	73.0	111.4	86.8	151.8	64.7	79.7
Downstream of Pour Point						
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	1.6	1.5	2.0	2.2	2.5	1.8
NDPES 3 – Municipal <0.1 mgd	2.2	1.4	1.8	1.7	1.3	0.9
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	3.8	2.9	3.8	3.9	3.8	2.7
HSTS DST Pour Point	13.8	13.8	13.8	13.8	21.6	21.6
NPS DST Pour Point	217.6	332.1	258.7	452.6	196.5	242.2
Totals						
HSTS	18.4	18.4	18.4	18.4	27.0	27.0
Total NPDES	3.8	2.9	3.8	4.0	3.8	2.7
NPS Total	290.6	443.4	345.5	604.4	261.2	321.9
Total Load	312.8	464.7	367.6	626.8	292.0	351.6
% HSTS	6%	4%	5%	3%	9%	8%
% NPDES	1%	1%	1%	1%	1%	1%
% of NPDES – Municipal ≥ 1.0 mgd	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% of NPDES – Municipal 0.1-1.0 mgd	40.9%	50.6%	52.8%	54.7%	64.1%	65.9%
% of NPDES – Municipal <0.1 mgd	59.1%	49.4%	47.2%	45.3%	35.9%	34.1%
% of NPDES – Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% of NPDES – Wet Weather	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% NPS	93%	95%	94%	96%	89%	92%
Yield UPST Pour Point (lb/acre)	11.38	17.36	13.53	23.66	10.25	12.64
Per Capita Yield (lb/person)	4.12	3.94	4.10	4.14	6.44	6.21

Table B13 — Summary of total P loading components for calculating the nutrient mass balance in the Vermilion River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	2.1	2.0	0.9	0.8	0.9	1.1	1.2	0.9	0.7
NDPES 3 – Municipal <0.1 mgd	0.6	0.6	0.7	0.5	0.5	0.6	0.7	0.6	0.7
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	2.7	2.5	1.6	1.3	1.4	1.7	1.9	1.5	1.4
HSTS UPST Pour Point	3.8	3.8	3.8	3.8	3.8	3.8	3.8	4.3	4.3
Load @ Pour Point	137.1	142.1	81.2	65.4	83.8	121.0	151.7	77.7	119.9
NPS UPST Pour Point	130.6	135.8	75.9	60.3	78.6	115.5	146.1	71.8	114.3
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	0.5	0.5	0.4	0.6	0.8	0.4	0.5	0.4	0.5
NPDES 2 – Municipal 0.1-1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NDPES 3 – Municipal <0.1 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	0.5	0.5	0.4	0.6	0.8	0.4	0.5	0.4	0.5
HSTS DST Pour Point	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
NPS DST Pour Point	3.5	3.6	2.0	1.6	2.1	3.1	3.9	1.8	2.8
Totals									
HSTS	3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.5	4.5
Total NPDES	3.2	3.0	1.9	1.9	2.2	2.1	2.3	2.0	1.8
NPS Total	134.1	139.4	77.9	61.9	80.7	118.6	150.0	73.6	117.1
Total Load	141.2	146.3	83.7	67.7	86.8	124.6	156.2	80.1	123.4
% HSTS	3%	3%	5%	6%	4%	3%	2%	6%	4%
% NPDES	2%	2%	2%	3%	3%	2%	1%	2%	1%
% of NPDES – Municipal ≥ 1.0 mgd	15.1%	16.6%	19.6%	30.6%	36.3%	19.9%	20.1%	21.9%	25.0%
% of NPDES – Municipal 0.1-1.0 mgd	64.7%	64.6%	45.8%	42.4%	42.6%	52.0%	50.6%	48.5%	38.2%
% of NPDES – Municipal <0.1 mgd	20.2%	18.8%	34.6%	27.0%	21.1%	28.1%	29.3%	29.6%	36.8%
% of NPDES – Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% of NPDES – Wet Weather	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% NPS	95%	95%	93%	92%	93%	95%	96%	92%	95%
Yield UPST Pour Point (lb/acre)	1.72	1.79	1.00	0.79	1.03	1.52	1.92	0.95	1.51
Per Capita Yield (lb/person)	0.50	0.49	0.41	0.41	0.43	0.42	0.44	0.43	0.42

Table B14 — Summary of total N loading components for calculating the nutrient mass balance in the Vermilion River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	13.7	15.2	12.6	14.0	15.0	15.3	15.3	14.7	12.3
NDPES 3 – Municipal <0.1 mgd	5.3	5.7	5.3	5.9	4.7	5.5	4.5	3.7	5.1
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OOS Point Source	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OOS Wet Weather	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	19.0	20.9	18.0	19.9	19.7	20.8	19.8	18.3	17.4
HSTS UPST Pour Point	27.3	27.3	27.3	27.3	27.3	27.3	27.3	42.2	42.2
Load @ Pour Point	1,441.6	1,500.0	854.8	871.1	1,144.9	1,362.6	1,980.9	747.6	1,134.5
NPS UPST Pour Point	1,395.2	1,451.7	809.4	823.9	1,097.9	1,314.5	1,933.7	687.1	1,074.9
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	30.9	31.0	21.9	23.3	23.9	26.7	31.5	25.4	24.3
NPDES 2 – Municipal 0.1-1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NDPES 3 – Municipal <0.1 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	30.9	31.0	21.9	23.3	23.9	26.7	31.5	25.4	24.3
HSTS DST Pour Point	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2.2	2.2
NPS DST Pour Point	37.3	38.8	21.6	22.0	29.3	35.1	51.7	17.0	26.6
Totals									
HSTS	28.1	28.1	28.1	28.1	28.1	28.1	28.1	44.4	44.4
Total NPDES	49.9	51.9	39.9	43.2	43.6	47.5	51.2	43.7	41.7
NPS Total	1,432.5	1,490.5	831.1	845.9	1,127.2	1,349.6	1,985.4	704.1	1101.6
Total Load	1,510.5	1,570.5	899.0	917.2	1,198.9	1,425.2	2,064.7	792.0	1,187.7
% HSTS	2%	2%	3%	3%	2%	2%	1%	6%	4%
% NPDES	3%	3%	4%	5%	4%	3%	2%	6%	4%
% of NPDES – Municipal ≥ 1.0 mgd	61.9%	59.7%	54.9%	54.0%	54.8%	56.2%	61.4%	58.1%	58.4%
% of NPDES – Municipal 0.1-1.0 mgd	27.4%	29.2%	31.7%	32.3%	34.3%	32.2%	29.8%	33.5%	29.4%
% of NPDES – Municipal <0.1 mgd	10.7%	11.1%	13.4%	13.7%	10.8%	11.7%	8.8%	8.4%	12.2%
% of NPDES – Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% of NPDES – Wet Weather	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% NPS	95%	95%	92%	92%	94%	95%	96%	89%	93%
Yield UPST Pour Point (lb/acre)	18.35	19.09	10.64	10.83	14.44	17.29	25.43	9.09	14.22
Per Capita Yield (lb/person)	5.52	5.67	4.81	5.05	5.08	5.36	5.62	5.80	5.67

Table B15 — Summary of total P loading components for calculating the nutrient mass balance in the Cuyahoga River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	64.7	58.8	53.6	59.4	57.2	53.0	37.0	30.0	45.4
NPDES 2 – Municipal 0.1-1.0 mgd	1.1	1.1	1.1	1.2	1.4	0.9	1.2	1.2	1.1
NDPES 3 – Municipal <0.1 mgd	1.8	1.2	1.4	1.4	1.4	1.5	1.5	1.6	1.2
NPDES – Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet Weather UPST Pour Point	3.1	2.9	2.2	1.8	2.2	2.6	2.4	0.8	0.6
OOS Point Source	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OOS Wet Weather	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	70.8	64.0	58.3	63.7	62.1	58.1	42.2	33.7	48.4
HSTS UPST Pour Point	31.1	31.1	31.1	31.1	31.1	31.1	31.1	20.5	20.5
Load @ Pour Point	240.0	264.0	194.0	109.0	216.0	220.0	267.0	155.0	167.0
NPS UPST Pour Point	138.2	168.9	104.6	14.2	122.8	130.9	193.7	100.8	98.1
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	41.1	53.0	75.8	73.2	74.3	42.8	62.7	59.5	70.0
NPDES 2 – Municipal 0.1-1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NDPES 3 – Municipal <0.1 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES – Industrial	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Wet Weather DST Pour Point	8.0	8.2	8.7	17.5	12.9	35.2	35.7	13.0	13.4
Total NPDES DST Pour Point	49.1	61.2	84.5	90.7	87.3	78.1	98.6	72.6	83.6
HSTS DST Pour Point	4.4	4.4	4.4	4.4	4.4	4.4	4.4	0.3	0.3
NPS DST Pour Point	19.7	24.1	14.9	2.0	17.5	18.7	27.7	15.3	14.9
Totals									
HSTS	35.5	35.5	35.5	35.5	35.5	35.5	35.5	20.9	20.9
Total NPDES	119.8	125.2	142.8	154.4	149.4	136.2	140.7	106.3	131.9
NPS Total	157.9	193.0	119.6	16.2	140.3	149.5	221.4	116.1	112.9
Total Load	313.3	353.8	297.9	206.1	325.2	321.2	397.7	243.2	265.7
% HSTS	11%	10%	12%	17%	11%	11%	9%	9%	8%
% NPDES	38%	35%	48%	75%	46%	42%	35%	44%	50%
% of NPDES – Municipal ≥ 1.0 mgd	88.3%	89.3%	90.6%	85.8%	88.0%	70.4%	70.9%	84.2%	87.4%
% of NPDES – Municipal 0.1-1.0 mgd	0.9%	0.9%	0.8%	0.8%	0.9%	0.7%	0.9%	1.1%	0.9%
% of NPDES – Municipal <0.1 mgd	1.5%	1.0%	1.0%	0.9%	0.9%	1.1%	1.1%	1.5%	0.9%
% of NPDES – Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
% of NPDES – Wet Weather	9.2%	8.9%	7.6%	12.5%	10.1%	27.8%	27.1%	13.1%	10.7%
% NPS	50%	55%	40%	8%	43%	47%	56%	48%	43%
Yield UPST Pour Point (lb/acre)	0.67	0.82	0.51	0.07	0.60	0.64	0.94	0.50	0.49
Per Capita Yield (lb/person)	0.28	0.29	0.33	0.33	0.33	0.26	0.27	0.22	0.27

Table B16 — Summary of total N loading components for calculating the nutrient mass balance in the Cuyahoga River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	1,604.6	1,796.9	1,754.0	1,641.7	1,395.3	1,488.1	1,499.4	1707.1	1653.1
NPDES 2 – Municipal 0.1-1.0 mgd	52.0	51.6	56.0	50.4	50.0	46.1	46.2	43.7	43.1
NDPES 3 – Municipal <0.1 mgd	26.2	25.1	28.6	28.6	28.2	29.7	28.8	27.9	17.5
NPDES – Industrial	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3
Wet Weather UPST Pour Point	84.6	78.5	60.9	48.6	59.5	70.8	67.0	23.2	17.2
OOS Point Source	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OOS Wet Weather	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	1,767.7	1,952.2	1,899.7	1,769.6	1,533.2	1,635.0	1,641.8	1,802.2	1,731.3
HSTS UPST Pour Point	307.3	307.3	307.3	307.3	307.3	307.3	307.3	202.0	202.0
Load @ Pour Point	2,751.3	2,957.3	2,349.8	1,991.2	2,715.7	2,600.0	3,085.0	2,936.0	2,536.0
NPS UPST Pour Point	676.4	697.9	142.9	-85.6	875.3	657.8	1,136.0	931.8	602.7
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	2,790.7	2,384.6	2,222.6	2,198.8	2,342.0	2,325.2	2,253.9	2,136.1	2,121.0
NPDES 2 – Municipal 0.1-1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NDPES 3 – Municipal <0.1 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES – Industrial	51.3	38.8	46.4	38.2	31.4	34.5	36.6	31.7	28.3
Wet Weather DST Pour Point	217.9	225.3	237.8	478.3	353.4	964.7	979.2	357.0	368.4
Total NPDES DST Pour Point	3,060.0	2,648.7	2,506.9	2,715.3	2,726.9	3,324.5	3,269.7	2,524.7	2,517.6
HSTS DST Pour Point	43.9	43.9	43.9	43.9	43.9	43.9	43.9	3.1	3.1
NPS DST Pour Point	96.6	99.7	20.4	-12.2	125.0	94.0	162.3	141.3	91.4
Totals									
HSTS	351.2	351.2	351.2	351.2	351.2	351.2	351.2	205.1	205.1
Total NPDES	4,827.7	4,600.9	4,406.5	4,484.8	4,260.1	4,959.4	4,911.4	4,326.9	4,249.0
NPS Total	773.0	797.6	163.3	-97.8	1,000.3	751.7	1,298.3	1,073.1	694.1
Total Load	5,951.8	5,749.6	4,921.0	4,738.1	5,611.6	6,062.3	6,560.9	5,605.1	5,148.2
% HSTS	6%	6%	7%	7%	6%	6%	5%	4%	4%
% NPDES	81%	80%	90%	95%	76%	82%	75%	77%	83%
% of NPDES – Municipal ≥ 1.0 mgd	91.0%	90.9%	90.2%	85.6%	87.7%	76.9%	76.4%	88.8%	88.8%
% of NPDES – Municipal 0.1-1.0 mgd	1.1%	1.1%	1.3%	1.1%	1.2%	0.9%	0.9%	1.0%	1.0%
% of NPDES – Municipal <0.1 mgd	0.5%	0.5%	0.6%	0.6%	0.7%	0.6%	0.6%	0.6%	0.4%
% of NPDES – Industrial	1.1%	0.8%	1.1%	0.9%	0.7%	0.7%	0.8%	0.7%	0.7%
% of NPDES – Wet Weather	6.3%	6.6%	6.8%	11.7%	9.7%	20.9%	21.3%	8.8%	9.1%
% NPS	13%	14%	3%	-2%	18%	12%	20%	19%	13%
Yield UPST Pour Point (lb/acre)	3.30	3.40	0.70	-0.42	4.27	3.21	5.54	4.66	3.01
Per Capita Yield (lb/person)	9.44	9.02	8.64	8.36	8.16	8.30	8.18	7.95	7.79

Table B12 — Summary of total P loading components for calculating the nutrient mass balance in the Great Miami River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	313.8	291.2	323.2	297.0	357.3	377.7	361.7	335.8	324.9
NPDES 2 – Municipal 0.1-1.0 mgd	17.8	16.9	15.5	17.0	17.1	16.2	22.3	18.7	17.3
NDPES 3 – Municipal <0.1 mgd	2.8	2.5	2.5	2.9	2.7	2.8	2.3	2.3	2.7
NPDES – Industrial	1.6	1.4	2.8	3.3	3.6	2.2	4.7	2.1	1.6
Wet Weather UPST Pour Point	1.4	3.1	2.4	2.2	1.2	11.5	0.9	0.8	0.4
Total NPDES UPST Pour Point	337.5	315.0	346.4	322.4	381.9	410.3	391.9	359.7	346.8
HSTS UPST Pour Point	56.8	56.8	56.8	56.8	56.8	56.8	56.8	51.3	51.3
Load @ Pour Point	879.5	1,254.7	1,242.2	629.5	1,023.8	1,310.0	1,770.0	1,040.0	849.0
NPS UPST Pour Point	485.2	882.9	839.0	250.3	585.1	842.9	1,321.3	629.1	450.9
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	84.4	89.8	79.0	79.4	75.4	76.9	77.1	75.5	72.3
NPDES 2 – Municipal 0.1-1.0 mgd	15.4	14.2	12.3	10.5	9.9	9.2	10.4	11.1	9.1
NDPES 3 – Municipal <0.1 mgd	3.4	3.6	3.6	3.4	3.3	3.9	3.6	3.4	3.6
NPDES – Industrial	7.4	4.0	5.4	25.6	14.6	24.5	14.3	19.9	18.6
Wet Weather DST Pour Point	0.3	0.5	2.6	0.6	0.7	0.7	0.7	1.6	1.5
Total NPDES DST Pour Point	110.8	112.1	102.9	119.5	103.9	115.2	106.1	111.4	105.1
HSTS DST Pour Point	24.4	24.4	24.4	24.4	24.4	24.4	24.4	37.8	37.8
NPS DST Pour Point	211.1	383.9	364.8	109.0	254.5	366.5	574.4	274.7	196.9
Totals									
HSTS	80.7	80.7	80.7	80.7	80.7	80.7	80.7	89.1	89.1
Total NPDES	448.3	427.2	449.2	441.9	485.8	525.6	498.0	471.0	452.0
NPS Total	696.9	1,267.3	1,204.4	359.9	840.2	1,209.9	1,896.3	903.8	647.8
Total Load	1,225.9	1,775.2	1,734.4	882.5	1,406.6	1,816.2	2,475.0	1,463.9	1,188.8
% HSTS	7%	5%	5%	9%	6%	4%	3%	6%	7%
% NPDES	37%	24%	26%	50%	35%	29%	20%	32%	38%
% of NPDES – Municipal ≥ 1.0 mgd	88.8%	89.2%	89.5%	85.2%	89.1%	86.5%	88.1%	87.3%	87.9%
% of NPDES – Municipal 0.1-1.0 mgd	7.4%	7.3%	6.2%	6.2%	5.5%	4.8%	6.6%	6.3%	5.8%
% of NPDES – Municipal <0.1 mgd	1.4%	1.4%	1.3%	1.4%	1.2%	1.3%	1.2%	1.2%	1.4%
% of NPDES – Industrial	2.0%	1.2%	1.8%	6.5%	3.8%	5.1%	3.8%	4.7%	4.5%
% of NPDES – Wet Weather	0.4%	0.9%	1.1%	0.6%	0.4%	2.3%	0.3%	0.5%	0.4%
% NPS	57%	71%	69%	40%	59%	66%	76%	62%	54%
Yield UPST Pour Point (lb/acre)	0.62	1.12	1.07	0.32	0.74	1.07	1.68	0.81	0.58
Per Capita Yield (lb/person)	0.88	0.84	0.87	0.83	0.92	0.96	0.95	0.78	0.75

Table B18 — Summary of total N loading components for calculating the nutrient mass balance in the Great Miami River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	2,121.5	2,001.5	1,731.0	1,569.2	2,090.0	1,874.1	1,932.7	1911.2	2338.9
NPDES 2 – Municipal 0.1-1.0 mgd	106.7	114.7	136.0	144.9	133.3	150.6	161.0	163.7	149.4
NDPES 3 – Municipal <0.1 mgd	17.7	17.0	17.7	20.4	18.8	18.0	17.8	15.2	16.4
NPDES – Industrial	0.7	1.1	3.2	3.9	5.3	4.1	3.9	4.8	4.4
Wet Weather UPST Pour Point	37.9	84.9	65.8	60.2	33.0	315.0	24.9	21.5	10.1
Total NPDES UPST Pour Point	2,284.5	2,219.1	1,953.7	1,798.7	2,280.3	2,361.8	2,140.2	2116.4	2519.2
HSTS UPST Pour Point	409.8	409.8	409.8	409.8	409.8	409.8	409.8	488.0	488.0
Load @ Pour Point	12,858.5	14,297.9	14,822.0	10,136.7	15,468.3	14,310.0	19,870.0	12,710.0	11,750.0
NPS UPST Pour Point	10,164.2	11,669.0	12,458.5	7,928.2	12,778.2	11,538.4	17,320.0	10,105.6	8,742.8
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	646.1	923.1	677.6	789.6	643.5	722.5	656.5	606.4	585.4
NPDES 2 – Municipal 0.1-1.0 mgd	78.6	92.2	75.2	59.3	76.7	92.4	76.4	84.3	67.2
NDPES 3 – Municipal <0.1 mgd	25.8	26.6	24.5	19.5	16.5	20.1	22.7	39.8	26.9
NPDES – Industrial	23.0	27.3	32.4	23.7	25.5	17.4	19.8	26.1	19.7
Wet Weather DST Pour Point	7.3	15.0	72.0	16.7	18.7	19.2	17.9	42.6	40.2
Total NPDES DST Pour Point	780.7	1084.2	881.7	908.9	780.9	871.7	793.2	799.2	739.4
HSTS DST Pour Point	176.3	176.3	176.3	176.3	176.3	176.3	176.3	359.4	359.4
NPS DST Pour Point	4,418.4	5,072.2	5,415.3	3,446.8	5,554.2	5,015.5	7,527.8	4,413.6	3,818.4
Totals									
HSTS	582.0	582.0	582.0	582.0	582.0	582.0	582.0	847.4	847.4
Total NPDES	3,065.2	3,303.3	2,835.4	2,707.5	3,061.2	3,233.4	2,933.5	2,915.6	3,258.6
NPS Total	14,586.7	16,745.3	17,877.8	11,379.1	18,336.5	16,558.1	24,851.8	14,519.2	12,561.2
Total Load	18,233.9	20,630.6	21,295.3	14,668.6	21,979.8	20,373.5	28,367.3	18,282.2	16,667.2
% HSTS	3%	3%	3%	4%	3%	3%	2%	5%	5%
% NPDES	17%	16%	13%	18%	14%	16%	10%	16%	20%
% of NPDES – Municipal ≥ 1.0 mgd	90.3%	88.5%	84.9%	87.1%	89.3%	80.3%	88.3%	86.4%	89.7%
% of NPDES – Municipal 0.1-1.0 mgd	6.0%	6.3%	7.4%	7.5%	6.9%	7.5%	8.1%	8.5%	6.6%
% of NPDES – Municipal <0.1 mgd	1.4%	1.3%	1.5%	1.5%	1.2%	1.2%	1.4%	1.9%	1.3%
% of NPDES – Industrial	0.8%	0.9%	1.3%	1.0%	1.0%	0.7%	0.8%	1.1%	0.7%
% of NPDES – Wet Weather	1.5%	3.0%	4.9%	2.8%	1.7%	10.3%	1.5%	2.2%	1.5%
% NPS	80%	81%	84%	78%	83%	81%	88%	79%	75%
Yield UPST Pour Point (lb/acre)	12.92	14.83	15.84	10.08	16.24	14.67	22.02	12.97	11.22
Per Capita Yield (lb/person)	6.06	6.36	5.49	5.39	6.03	5.86	5.84	5.33	5.86

Table B19 — Summary of total P loading components for calculating the nutrient mass balance in the Scioto River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	528.4	599.1	604.1	604.6	584.8	566.2	493.4	454.2	386.0
NPDES 2 – Municipal 0.1-1.0 mgd	26.1	27.0	24.9	26.1	29.5	27.2	27.6	34.2	35.8
NDPES 3 – Municipal <0.1 mgd	13.1	15.0	13.2	13.0	12.9	12.9	12.6	12.9	11.1
NPDES – Industrial	0.2	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.3
Wet Weather UPST Pour Point	1.7	3.9	4.2	3.6	2.3	7.0	4.4	5.8	1.4
Total NPDES UPST Pour Point	569.5	645.2	646.6	647.5	629.6	613.4	538.2	507.3	434.6
HSTS UPST Pour Point	47.4	47.4	47.4	47.4	47.4	47.4	47.4	129.2	129.2
Load @ Pour Point	1,394.8	1,652.4	1,393.9	1,112.2	1,476.0	1,880.0	2,430.0	1,450.0	960.0
NPS UPST Pour Point	777.9	959.7	699.9	417.3	799.0	1,219.2	1,844.4	813.5	396.2
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	25.9	27.6	28.8	22.3	25.5	21.2	29.5	32.3	31.5
NPDES 2 – Municipal 0.1-1.0 mgd	6.3	6.5	6.1	6.6	6.1	6.3	7.6	6.9	7.6
NDPES 3 – Municipal <0.1 mgd	5.8	5.9	5.4	5.9	5.6	6.9	7.0	8.3	7.5
NPDES – Industrial	13.9	15.5	19.9	18.7	20.2	9.9	5.5	7.3	5.8
Wet Weather DST Pour Point	0.2	0.2	0.0	0.0	0.0	0.0	0.1	0.3	0.0
Total NPDES DST Pour Point	52.0	55.6	60.3	53.4	57.5	44.2	49.7	55.2	52.4
HSTS DST Pour Point	32.7	32.7	32.7	32.7	32.7	32.7	32.7	33.1	33.1
NPS DST Pour Point	535.9	661.1	482.2	287.5	550.4	839.9	1270.6	564.6	275.0
Totals									
HSTS	80.1	80.1	80.1	80.1	80.1	80.1	80.1	162.3	162.3
Total NPDES	621.5	700.9	706.8	700.9	687.1	657.6	587.9	562.5	487.0
NPS Total	1,313.8	1,620.9	1,182.1	704.8	1,349.4	2,059.0	3,115.0	1,378.1	671.1
Total Load	2,015.4	2,401.8	1,969.0	1,485.8	2,116.6	2,796.8	3,783.0	2,102.9	1,320.5
% HSTS	4%	3%	4%	5%	4%	3%	2%	8%	12%
% NPDES	31%	29%	36%	47%	32%	24%	16%	27%	37%
% of NPDES – Municipal ≥ 1.0 mgd	89.2%	89.4%	89.5%	89.4%	88.8%	89.3%	89.0%	86.5%	85.7%
% of NPDES – Municipal 0.1-1.0 mgd	5.2%	4.8%	4.4%	4.7%	5.2%	5.1%	6.0%	7.3%	8.9%
% of NPDES – Municipal <0.1 mgd	3.0%	3.0%	2.6%	2.7%	2.7%	3.0%	3.3%	3.8%	3.8%
% of NPDES – Industrial	2.3%	2.2%	2.8%	2.7%	3.0%	1.5%	1.0%	1.3%	1.2%
% of NPDES – Wet Weather	0.3%	0.6%	0.6%	0.5%	0.3%	1.1%	0.8%	1.1%	0.3%
% NPS	65%	67%	60%	47%	64%	74%	82%	66%	51%
Yield UPST Pour Point (lb/acre)	0.70	0.86	0.63	0.37	0.71	1.09	1.65	0.74	0.36
Per Capita Yield (lb/person)	0.78	0.87	0.87	0.86	0.85	0.82	0.75	0.64	0.57

Table B20 — Summary of total N loading components for calculating the nutrient mass balance in the Scioto River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	2,870.3	2,978.0	2,710.8	2,984.3	3,011.0	3,176.1	3,598.8	3,586.9	3,382.4
NPDES 2 – Municipal 0.1-1.0 mgd	272.5	298.1	263.8	279.3	305.0	327.2	319.9	335.2	287.9
NDPES 3 – Municipal <0.1 mgd	113.7	121.7	116.6	120.1	121.7	129.6	114.6	107.3	92.4
NPDES – Industrial	0.3	0.6	1.0	1.2	0.5	0.4	0.3	1.7	1.3
Wet Weather UPST Pour Point	45.8	106.0	115.3	98.1	64.2	192.5	120.5	157.6	37.1
Total NPDES UPST Pour Point	3,302.6	3,504.3	3,207.4	3,482.9	3,502.4	3,825.8	4,154.1	4,188.6	3,801.1
HSTS UPST Pour Point	463.3	463.3	463.3	463.3	463.3	463.3	463.3	1,277.5	1,277.5
Load @ Pour Point	14,609.1	17,621.0	15,273.1	11,769.5	17,864.5	17,930.0	23,250.0	16,370.0	11,640.0
NPS UPST Pour Point	10,843.3	13,653.4	11,602.4	7,823.4	13,898.8	13,640.9	18,632.6	10,903.8	6,561.4
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	216.0	253.0	242.7	221.2	196.4	186.0	184.0	175.5	141.9
NPDES 2 – Municipal 0.1-1.0 mgd	43.3	47.9	43.6	50.1	48.0	62.6	56.0	66.8	61.4
NDPES 3 – Municipal <0.1 mgd	57.9	50.0	47.8	56.1	59.4	60.7	52.1	58.3	48.0
NPDES – Industrial	9.5	8.4	29.1	13.2	14.6	5.8	6.0	5.6	4.8
Wet Weather DST Pour Point	4.2	5.4	1.1	0.5	0.0	0.1	3.7	7.1	0.6
Total NPDES DST Pour Point	330.8	364.7	364.3	341.0	318.3	315.2	301.8	313.2	256.7
HSTS DST Pour Point	319.2	319.2	319.2	319.2	319.2	319.2	319.2	327.0	327.0
NPS DST Pour Point	7,469.9	9,405.8	7,992.8	5,389.5	9,574.8	9,397.2	12,835.9	7,568.1	4,554.1
Totals									
HSTS	782.5	782.5	782.5	782.5	782.5	782.5	782.5	1,604.6	1,604.6
Total NPDES	3,633.4	3,869.0	3,571.8	3,823.9	3,820.7	4,140.9	4,456.0	4,501.8	4,057.8
NPS Total	18,313.1	23,059.2	19,595.2	13,212.8	23,473.5	23,038.1	31,468.5	18,472.0	11,115.5
Total Load	22,729.0	27,710.7	23,949.5	17,819.2	28,076.7	27,961.5	36,706.9	24,578.4	16,777.9
% HSTS	3%	3%	3%	4%	3%	3%	2%	7%	10%
% NPDES	16%	14%	15%	21%	14%	15%	12%	18%	24%
% of NPDES – Municipal ≥ 1.0 mgd	84.9%	83.5%	82.7%	83.8%	83.9%	81.2%	84.9%	83.6%	86.9%
% of NPDES – Municipal 0.1-1.0 mgd	8.7%	8.9%	8.6%	8.6%	9.2%	9.4%	8.4%	8.9%	8.6%
% of NPDES – Municipal <0.1 mgd	4.7%	4.4%	4.6%	4.6%	4.7%	4.6%	3.7%	3.7%	3.5%
% of NPDES – Industrial	0.3%	0.2%	0.8%	0.4%	0.4%	0.2%	0.1%	0.2%	0.1%
% of NPDES – Wet Weather	1.4%	2.9%	3.3%	2.6%	1.7%	4.7%	2.8%	3.7%	0.9%
% NPS	81%	83%	82%	74%	84%	82%	86%	75%	66%
Yield UPST Pour Point (lb/acre)	9.69	12.21	10.37	6.99	12.42	12.19	16.66	9.85	5.93
Per Capita Yield (lb/person)	4.96	5.16	4.79	5.11	5.15	5.38	5.81	5.31	5.03

Table B21 — Summary of total P loading components for calculating the nutrient mass balance in the Muskingum River watershed.

	TP Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	504.6	433.5	440.4	416.8	315.5	296.9	245.0	259.3	200.4
NPDES 2 – Municipal 0.1-1.0 mgd	53.3	53.0	50.5	50.8	56.3	59.0	52.5	48.6	52.9
NDPES 3 – Municipal <0.1 mgd	9.6	10.3	10.4	7.5	9.4	9.8	9.4	8.2	10.0
NPDES – Industrial	23.5	17.6	20.7	10.6	9.0	7.4	5.2	4.2	5.0
Wet Weather UPST Pour Point	0.5	0.8	1.0	0.8	1.1	172.6	3.6	1.4	0.6
OOS Point Source	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OOS Wet Weather	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	591.6	515.2	523.0	486.5	391.3	545.6	315.6	321.6	268.8
HSTS UPST Pour Point	121.0	121.0	121.0	121.0	121.0	121.0	121.0	148.0	148.0
Load @ Pour Point	1,270.8	1,543.4	1,464.4	852.7	1,243.2	1,700.0	2,060.0	1,170.0	889.0
NPS UPST Pour Point	558.2	907.1	820.4	245.2	730.9	1,033.3	1,623.4	700.4	472.2
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	1.5	1.7	1.2	1.1	1.3	1.4	2.3	2.0	2.1
NDPES 3 – Municipal <0.1 mgd	0.2	0.5	0.3	0.2	0.1	0.2	0.2	0.1	0.1
NPDES – Industrial	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	1.8	2.3	1.5	1.5	1.6	1.7	2.5	2.1	2.2
HSTS DST Pour Point	10.2	10.2	10.2	10.2	10.2	10.2	10.2	5.0	5.0
NPS DST Pour Point	46.9	76.3	69.0	20.6	61.5	86.9	136.5	59.4	40.1
Totals									
HSTS	131.2	131.2	131.2	131.2	131.2	131.2	131.2	153.1	153.1
Total NPDES	593.4	517.5	524.5	488.0	392.9	547.3	318.1	323.6	271.0
NPS Total	605.1	983.4	889.4	265.8	792.3	1120.2	1759.9	759.8	512.2
Total Load	1,329.7	1,632.1	1,545.1	885.0	1,316.4	1,798.8	2,209.2	1,236.5	936.3
% HSTS	10%	8%	8%	15%	10%	7%	6%	12%	16%
% NPDES	45%	32%	34%	55%	30%	30%	14%	26%	29%
% of NPDES – Municipal ≥ 1.0 mgd	85.0%	83.8%	84.0%	85.4%	80.3%	54.3%	77.0%	80.1%	73.9%
% of NPDES – Municipal 0.1-1.0 mgd	9.2%	10.6%	9.8%	10.6%	14.7%	11.0%	17.2%	15.6%	20.3%
% of NPDES – Municipal <0.1 mgd	1.6%	2.1%	2.0%	1.6%	2.4%	1.8%	3.0%	2.6%	3.7%
% of NPDES – Industrial	4.0%	3.4%	4.0%	2.2%	2.3%	1.3%	1.7%	1.3%	1.8%
% of NPDES – Wet Weather	0.1%	0.2%	0.2%	0.2%	0.3%	31.5%	1.1%	0.4%	0.2%
% NPS	46%	60%	58%	30%	60%	62%	80%	61%	55%
Yield UPST Pour Point (lb/acre)	0.26	0.42	0.38	0.11	0.34	0.48	0.75	0.33	0.22
Per Capita Yield (lb/person)	1.05	0.94	0.95	0.91	0.77	0.75	0.66	0.70	0.62

Table B22 — Summary of total N loading components for calculating the nutrient mass balance in the Muskingum River watershed.

	TN Load (mta)								
Source	wy13	wy14	wy15	wy16	wy17	wy18	wy19	wy20	wy21
Upstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	2,684.6	2,848.2	2,470.7	2,321.3	2,306.0	1,893.6	1,709.4	1,971.9	1,732.3
NPDES 2 – Municipal 0.1-1.0 mgd	364.9	405.0	356.5	361.5	385.0	410.8	395.0	361.4	351.1
NDPES 3 – Municipal <0.1 mgd	91.2	93.3	94.7	45.0	85.2	90.1	77.3	72.9	72.9
NPDES – Industrial	17.9	18.6	20.1	23.9	29.9	26.1	24.4	28.1	29.8
Wet Weather UPST Pour Point	14.9	21.7	26.5	22.3	29.4	78.7	98.6	37.0	15.6
OOS Point Source	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OOS Wet Weather	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total NPDES UPST Pour Point	3,173.4	3,386.7	2,968.5	2,774.0	2,835.4	2,499.7	2,304.8	2,471.2	2,201.6
HSTS UPST Pour Point	1,273.6	1,273.6	1,273.6	1,273.6	1,273.6	1,273.6	1,273.6	1,516.1	1,516.1
Load @ Pour Point	17,488.0	20,687.1	16,877.0	11,812.0	17,515.3	21,790.0	27,300.0	20,290.0	13,290.0
NPS UPST Pour Point	13,041.0	16,026.9	12,634.9	7,764.5	13,406.3	18,016.7	23,721.6	16,302.7	9,572.3
Downstream of Pour Point									
NPDES 1 – Municipal ≥1.0 mgd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NPDES 2 – Municipal 0.1-1.0 mgd	12.2	14.8	15.4	11.9	13.7	16.2	9.4	8.9	14.3
NDPES 3 – Municipal <0.1 mgd	1.5	0.9	1.8	1.1	1.7	1.8	1.3	1.0	1.6
NPDES – Industrial	0.1	1.6	2.9	1.8	1.7	1.9	1.4	1.5	1.7
Wet Weather DST Pour Point	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Total NPDES DST Pour Point	13.8	17.2	20.1	14.8	17.2	19.9	12.1	11.4	17.6
HSTS DST Pour Point	107.1	107.1	107.1	107.1	107.1	107.1	107.1	51.7	51.7
NPS DST Pour Point	1,096.7	1,347.8	1,062.6	653.0	1,127.4	1,515.2	1,994.9	1,383.4	812.3
Totals									
HSTS	1,380.7	1,380.7	1,380.7	1,380.7	1,380.7	1,380.7	1,380.7	1567.8	1567.8
Total NPDES	3,187.2	3,403.9	2,988.6	2,788.7	2,852.6	2,519.6	2,316.9	2482.6	2219.3
NPS Total	14,137.7	17,374.7	13,697.4	8,417.4	14,533.8	19,531.9	25,716.6	17,686.0	10,384.5
Total Load	18,705.6	22,159.3	18,066.7	12,586.9	18,767.1	23,432.1	29,414.2	21,736.5	14,171.6
% HSTS	7%	6%	8%	11%	7%	6%	5%	7%	11%
% NPDES	17%	15%	17%	22%	15%	11%	8%	11%	16%
% of NPDES – Municipal ≥ 1.0 mgd	84.2%	83.7%	82.7%	83.2%	80.8%	75.2%	73.8%	79.4%	78.1%
% of NPDES – Municipal 0.1-1.0 mgd	11.8%	12.3%	12.4%	13.4%	14.0%	17.0%	17.5%	14.9%	16.5%
% of NPDES – Municipal <0.1 mgd	2.9%	2.8%	3.2%	1.7%	3.0%	3.6%	3.4%	3.0%	3.4%
% of NPDES – Industrial	0.6%	0.6%	0.8%	0.9%	1.1%	1.1%	1.1%	1.2%	1.4%
% of NPDES – Wet Weather	0.5%	0.6%	0.9%	0.8%	1.0%	3.1%	4.3%	1.5%	0.7%
% NPS	76%	78%	76%	67%	77%	83%	87%	81%	73%
Yield UPST Pour Point (lb/acre)	6.06	7.44	5.87	3.61	6.22	8.37	11.01	7.66	4.50
Per Capita Yield (lb/person)	6.78	7.10	6.46	6.17	6.24	5.68	5.35	5.94	5.58

Table B23 — Summary of total P and N loading components for calculating the nutrient mass balance in the Hocking River watershed.

Source	TP (mta) wy21
Upstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	11.6
NPDES 2 – Municipal 0.1-1.0 mgd	3.9
NDPES 3 – Municipal <0.1 mgd	2.8
NPDES – Industrial	0.0
Wet Weather UPST Pour Point	0.0
OOS Point Source	0.0
OOS Wet Weather	0.0
Total NPDES UPST Pour Point	18.3
HSTS UPST Pour Point	16.2
Load @ Pour Point	104.5
NPS UPST Pour Point	70.0
Downstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	7.6
NPDES 2 – Municipal 0.1-1.0 mgd	0.0
NDPES 3 – Municipal <0.1 mgd	0.1
NPDES – Industrial	0.0
Wet Weather DST Pour Point	0.0
Total NPDES DST Pour Point	7.7
HSTS DST Pour Point	1.8
NPS DST Pour Point	18.9
Totals	
HSTS	18.1
Total NPDES	26.0
NPS Total	88.9
Total Load	133.0
% HSTS	14%
% NPDES	20%
% NPS	67%
Yield UPST Pour Point (lb/acre)	0.26
Per Capita Yield (lb/person)	0.45

Source	TN (mta) wy21
Upstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	132.6
NPDES 2 – Municipal 0.1-1.0 mgd	39.5
NDPES 3 – Municipal <0.1 mgd	18.3
NPDES – Industrial	0.2
Wet Weather UPST Pour Point	0.8
OOS Point Source	0.0
OOS Wet Weather	0.0
Total NPDES UPST Pour Point	191.4
HSTS UPST Pour Point	166.2
Load @ Pour Point	1033.4
NPS UPST Pour Point	675.8
Downstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	46.1
NPDES 2 – Municipal 0.1-1.0 mgd	0.0
NDPES 3 – Municipal <0.1 mgd	1.0
NPDES – Industrial	0.0
Wet Weather DST Pour Point	0.0
Total NPDES DST Pour Point	47.1
HSTS DST Pour Point	18.8
NPS DST Pour Point	182.6
Totals	
HSTS	185.0
Total NPDES	238.5
NPS Total	858.5
Total Load	1,282.0
% HSTS	14%
% NPDES	19%
% NPS	67%
Yield UPST Pour Point (lb/acre)	2.49
Per Capita Yield (lb/person)	4.31

Table B24 — Summary of total P loading components for calculating the nutrient mass balance in the LMR and EFLMR watershed.

Source	TP (mta) wy21
Upstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	63.1
NPDES 2 – Municipal 0.1-1.0 mgd	20.5
NDPES 3 – Municipal <0.1 mgd	2.8
NPDES – Industrial	0.0
Wet Weather UPST Pour Point	0.0
OOS Point Source	0.0
OOS Wet Weather	0.0
Total NPDES UPST Pour Point	86.4
HSTS UPST Pour Point	42.2
Load @ Pour Point	615.8
NPS UPST Pour Point	487.1
Downstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	23.6
NPDES 2 – Municipal 0.1-1.0 mgd	1.9
NDPES 3 – Municipal <0.1 mgd	0.3
NPDES – Industrial	0.0
Wet Weather DST Pour Point	0.0
Total NPDES DST Pour Point	25.7
HSTS DST Pour Point	5.0
NPS DST Pour Point	38.8
Totals	
HSTS	47.3
Total NPDES	112.2
NPS Total	525.9
Total Load	685.4
% HSTS	7%
% NPDES	16%
% NPS	77%
Yield UPST Pour Point (lb/acre)	1.06
Per Capita Yield (lb/person)	0.63

Source	TN (mta) wy21
Upstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	774.9
NPDES 2 – Municipal 0.1-1.0 mgd	167.6
NDPES 3 – Municipal <0.1 mgd	19.4
NPDES – Industrial	0.0
Wet Weather UPST Pour Point	0.0
OOS Point Source	0.0
OOS Wet Weather	0.0
Total NPDES UPST Pour Point	962.0
HSTS UPST Pour Point	401.9
Load @ Pour Point	4364.8
NPS UPST Pour Point	3000.9
Downstream of Pour Point	
NPDES 1 – Municipal ≥1.0 mgd	148.6
NPDES 2 – Municipal 0.1-1.0 mgd	5.1
NDPES 3 – Municipal <0.1 mgd	2.9
NPDES – Industrial	0.5
Wet Weather DST Pour Point	0.0
Total NPDES DST Pour Point	157.2
HSTS DST Pour Point	47.7
NPS DST Pour Point	266.6
Totals	
HSTS	449.6
Total NPDES	1,119.1
NPS Total	3,267.4
Total Load	4,836.2
% HSTS	9%
% NPDES	23%
% NPS	68%
Yield UPST Pour Point (lb/acre)	7.29
Per Capita Yield (lb/person)	6.24

Appendix B – Overview of Estimation Methods for Land Cover and Population

B1. General Methods

This appendix outlines the methods to update the land cover and human population data for the nutrient mass balance effort.

Section B2 explains the following calculation steps:

1. Delineated upstream and downstream watershed from relevant pour points.
2. The area of each land cover class in each watershed, upstream and downstream was calculated.
3. A dasymetric density raster of population was created to estimate the watershed and sewered area populations. The raster was based on U.S. Census block data for 2020.
4. An overlay of potentially sewered areas for Ohio was created. It is based on sewered areas provided by areawide agencies, and census place boundaries of municipalities and incorporated areas with sewer services in areas not covered by areawide or regional agencies. Census place and municipal boundaries were adjusted to best match known sewered areas.
5. Estimation of the population in unsewered areas was calculated by subtracting the estimate of sewered area population from the estimate of total population in each watershed.

Section B3 explains the sources of data used for this effort.

B2. Process Steps

B2.1 Watershed Delineation

1. USGS Stream Stats delineation tool was used to set the pour points location in the Stream Stats stream layer.
    a. If the provided coordinates did not match stream cells, the nearest valid stream cell was used as the delineation point.
2. *USGS Streamer* was used to traverse downstream to river mouth to identify delineation points for the watershed downstream of the pour point.
    a. ***https://txpub.usgs.gov/DSS/streamer/web/***
3. The derived basin or watershed was downloaded as shapefile or geodatabase.
4. Basins and watersheds exported from Stream Stats were simplified to smooth boundaries and reduce the generation of sliver polygons along boundaries.
    a. ArcGIS Pro – Simplify Polygon tool

B2.2 Land Cover Estimations

1. The simplified watersheds were projected to Albers Conic Equal Area to match the NLCD.
2. Tabulate Areas Spatial Analysis tool in ArcGIS Pro was used to calculate area of each land cover class for each watershed.

B2.3 Sewered Area Determinations

1. Sewered Area maps provided by areawide planning agencies were combined with sewered area delineations of municipalities served by public wastewater treatment plants.
2. Sewered Areas as determined by maps created by *Ohio areawide planning agencies*.
    a. Delineated areas from regional planning agencies are categorized by the service level for sewers, for example the categories include, but are not limited to Areas currently served with sanitary sewers, Areas expected to be served in the next twenty years, Areas expected to remain on individual on-lot systems or semi-public systems, and Areas for which no wastewater management options have been declared.

    b. For the purposes of this analysis areas with existing sewers were used to delineate "Sewered Areas" for this analysis.
    c. Each areawide agency used its own method to determine service levels, and those best corresponding to areas serviced with sewers were included in Sewered Areas polygon dataset.
    d. The agencies include:
        i. Toledo Metropolitan Area Council of Governments (TMACOG)
        ii. Northeast Ohio Areawide Coordinating Agency (NOACA)
            1. Northeast Ohio Regional Sewer District
        iii. Eastgate Regional Council of Governments
        iv. Miami Valley Regional Planning Commission
        v. Ohio-Kentucky-Indiana Regional Council of Governments (OKI)
3. Delineation of Sewered Areas not covered by an areawide planning agency.
    a. Census place polygons were identified for municipalities and areas served by public wastewater treatment plants. The polygon boundaries were edited to match known areas that were sewered, or to remove areas known not to sewered as determined by Ohio EPA staff.
        i. In instances where a census place polygon was adjacent or near to a wastewater treatment plant, and had the same or similar name, it was assigned as sewered. The sewered area polygons were then reviewed by DSW staff and adjustments were made to either include or exclude areas known to staff to be sewered or unsewered.
    b. Assignment of Watershed Identification to each sewered area polygon.
        i. The identity tool in ArcGIS Pro was used to assign a watershed ID value to each sewered area polygon, or part of a polygon.
            1. The East Fork of the Little Miami Watershed sewered area was calculated separately to avoid assigning both East Fork and the Little Miami River identification numbers to the sewered area polygons that would fall inside both watersheds.)

B2.4 Dasymetric Population Density Raster

1. The U.S. EPA Dasymetric Toolbox was used to calculate the population density raster for Ohio and surrounding watershed areas.
    a. https://www.epa.gov/enviroatlas/dasymetric-toolbox
        i. Used the U.S. EPA *Intelligent Dasymetric Mapping (IDM) Toolbox* for ArcGIS 10.3
        ii. ArcMap 10.8 was used to run the tools.
2. Inputs to the Toolbox:
    a. Block level population for Ohio, Indiana, and Michigan:
        i. Decennial Census 2020 (Total: P1_001N)
            1. Tl_2020_tabblock.shp block populations for Ohio, Indiana and Michigan
            2. Projected to Albers Equal Area – matching NLCD projection.
        ii. Identity tool was used to assign a watershed id to each census block or partial block. Partial block populations were calculated based on the percentage of area of the original block. The blocks and partial block populations were summed for each watershed and used as a benchmark to population estimates based on the dasymetric raster.
    b. USGS NLCD 2019

3. The dasymetric estimate of population uses land cover categories to assign population to areas within a census block that are likely to be populated. In the calculation of the dasymetric raster land cover classifications for open water (11), emergent herbaceuous wetlands (95) and unclassified (0) were set at zero to prevent population values from being assigned to those cells.

B2.2 Population in Sewered and Unsewered Areas

1. Population in the sewered areas of each subject watershed was determined by overlaying the dasymetric population raster with the sewered area polygons having watershed identification numbers. The sewered area population is the sum of each grid cell value falling inside the sewered area within each watershed.
    a. Tabulate Area tools was used to calculate watershed sewered area population.
2. Unsewered population for each watershed was determined by subtracting sewered area population from the population of the watershed.

B3. Data Sourcing

B3.1 Watershed Delineation

- Pour Points (Initial)
    - Excel spreadsheet provided by Division of Surface Water of pour point location (latitude and longitude coordinates)
    - Most pour points were at or near USGS gaging sites.
- Pour Points Adjusted (aligned to nearest location usable to *USGS StreamStats*)
    - ***https://streamstats.usgs.gov/ss/***
- *USGS Streams* was used to determine the river basin pour points. A downstream trace from the pour point to the mouth was used to set the pour point for the river basin delineation.
    - ***https://txpub.usgs.gov/DSS/streamer/web/***

B3.2 Land Cover in each Watershed

- USGS National Land Cover Database (NLCD) 2019 (***https://www.mrlc.gov/***)
- Simplified watershed polygons derived from Stream stats.

B3.3 U.S. Census Population by Block

- Decennial Census 2020 (Total: P1_001N)
    - Tl_2020_tabblock.shp block populations for Ohio, Indiana and Michigan

B3.4 Sewered Areas

- Areawide Planning Agencies Sewered area coverage maps (Areawide counties only).
- Estimated based on census place polygons (All Other Counties/NonAreawides).