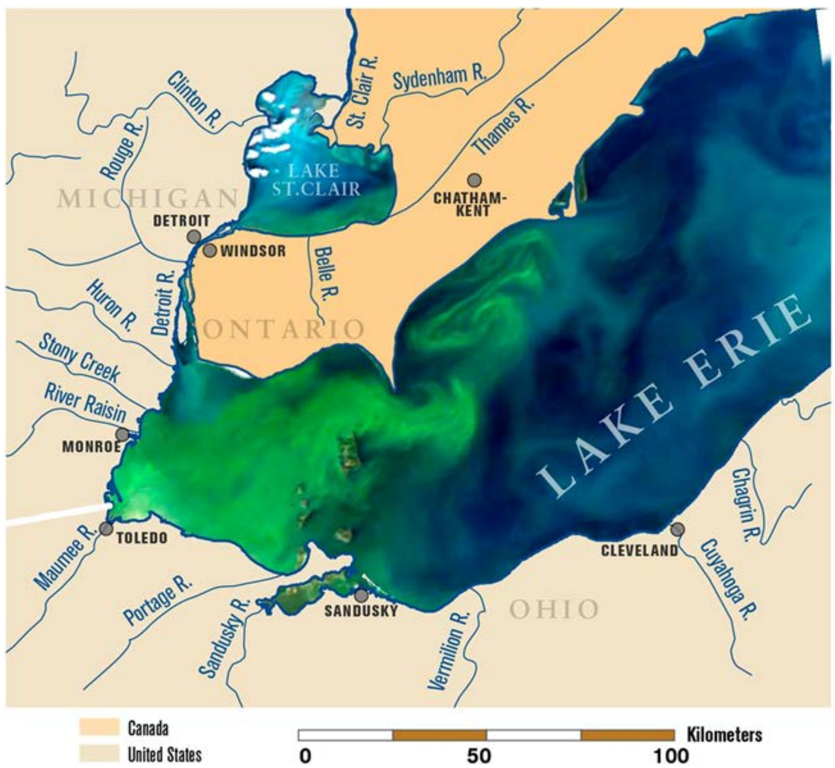
Ohio Environmental Protection Agency

Preliminary Modeling Results for the

Maumee Watershed Nutrient

Total Maximum Daily Load Development



Michalak et al., 2013

Ohio EPA Technical Report AMS/2020-MWN-4

Division of Surface Water

Assessment and Modeling Section

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TMDL Development

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List of Acronyms

AOC – Area of Concern

AFG – allowance for future growth

ARS – Agricultural Research Service

BMP – best management practice

CAFF – concentrated animal feeding facility

CAFO – concentrated animal feeding operation

CDP – census-designated places

CEAP – Conservation Effects Assessment Project

CLM – certified livestock manager

CSA – critical source areas

CSO – combined sewer overflows

DAP – Domestic Action Plan

DLEP – Division of Livestock Environmental Permitting

DRP – dissolved reactive phosphorus

DSWC – Division of Soil and Water Conservation

EWG – Environmental Working Group

FWMC – flow-weighted mean concentration

GLRI – Great Lakes Restoration Initiative

GLWQA – Great Lakes Water Quality Agreement

HAB – harmful algal bloom

HABRI – Harmful Algal Bloom Research Initiative

HSTS – home sewage treatment systems

HUC – hydrologic unit code

ICIS – Integrated Compliance Information System

IJC – International Joint Commission

LA – load allocation

LTCP – long-term control plan

MAP – monoammonium phosphate

MOS – margin of safety

MPCA – Minnesota Pollution Control Agency

MS4 – municipal separate storm sewer system

MSGP – Multi-Sector General Permit

NCWQR – National Center for Water Quality Research

NLCD – National Land Cover Database

NOAA – National Oceanic and Atmospheric Administration

NPDES – National Pollutant Discharge Elimination System

NPS – nonpoint source

NPS-IS – Nonpoint Source Pollution Implementation Strategy

NRCS – Natural Resources Conservation Service

NSE – Nash Sutcliffe Efficiency

OAC – Ohio Administrative Code

ODA – Ohio Department of Agriculture

ODH – Ohio Department of Health

ODNR – Ohio Department of Natural Resources

OLEC – Ohio Lake Erie Commission

OOS – out of state

OSU – Ohio State University

PMR – Preliminary Modeling Results

RCPP – Regional Conservation Partnership Program

SB – Senate Bill

SPARROW – SPAtially Referenced Regressions on Watershed attributes

SSO – sanitary sewer overflow

SWAT – Soil and Water Assessment Tool

SWCD – soil and water conservation district

TMACOG – Toledo Metropolitan Area Council of Governments

TMDL – total maximum daily load

USDA – United States Department of Agriculture

USGS – United States Geological Survey

WLA – wasteload allocation

WLEB – Western Lake Erie Basin

WQS – water quality standard

WWTP – wastewater treatment plant

List of Units of Measure

kg – kilogram

L – liter

lb – pound

mg – milligram

MG – million gallons

MGD – million gallons per day

mi^2 – square miles

MT – metric ton

ppm – part per million

1. Background

This document, the Preliminary Modeling Results (PMR), provides the analytical methods to develop total maximum daily loads (TMDLs) for the Maumee Watershed Nutrient project. This is the fourth step in the TMDL development process. This project addresses shoreline and open water impairments in the Western Lake Erie Basin (WLEB) caused by cyanobacteria that may produce cyanotoxins and are commonly known as harmful algal blooms (HABs). Figure 1 shows the impaired Lake Erie assessment units applicable to this TMDL project. This figure also shows the Maumee watershed. This project outlines pollutant reductions in this watershed to address the impaired Lake Erie assessment units. Table 1 outlines the 8-digit hydrologic unit code (HUC) watersheds in the Maumee watershed that are included in this project; there are seven of them.

Figure 1. Map of Ohio's WLEB assessment units and the Maumee River watershed.

Table 1. Maumee River watershed HUC 8s included in this TMDL.

HUC 8	Watershed Name	HUC 8	Watershed Name
04100003*	St. Joseph River	04100007*	Auglaize River
04100004*	St. Marys River	04100008	Blanchard River
04100005*	Upper Maumee River	04100009	Lower Maumee River
04100006*	Tiffin River		

* Only the Ohio portions of these HUC 8s will be included in this TMDL's allocations

All three Lake Erie assessment units considered in this project are impaired for their recreation use and public drinking water supply use. The WLEB and islands shoreline units are also impaired for aquatic life use due to nutrients. The recreation use impairments are due to HAB events that regularly occur in western Lake Erie. The public drinking water supply use impairments are due to cyanotoxins, which are a product of HAB events. Cyanotoxins from HABs present risks to drinking water and recreation uses, a problem recognized as increasing in Ohio and globally (Cheung et al., 2013). In 2014, cyanotoxins from that summer's HAB concentrated around the City of Toledo's drinking water intake. With treatment technology to address cyanotoxins in drinking water not yet in place, the city issued a do not drink or use advisory that lasted for three days. The 2011 record-sized bloom was surpassed in 2015 resulting in that year scoring a 10.5 on what had been a 1 through 10 scale of the Western Lake Erie Bloom Severity Index, see Figure 2 (Ohio EPA, 2020a; Wayne et al., 2015).

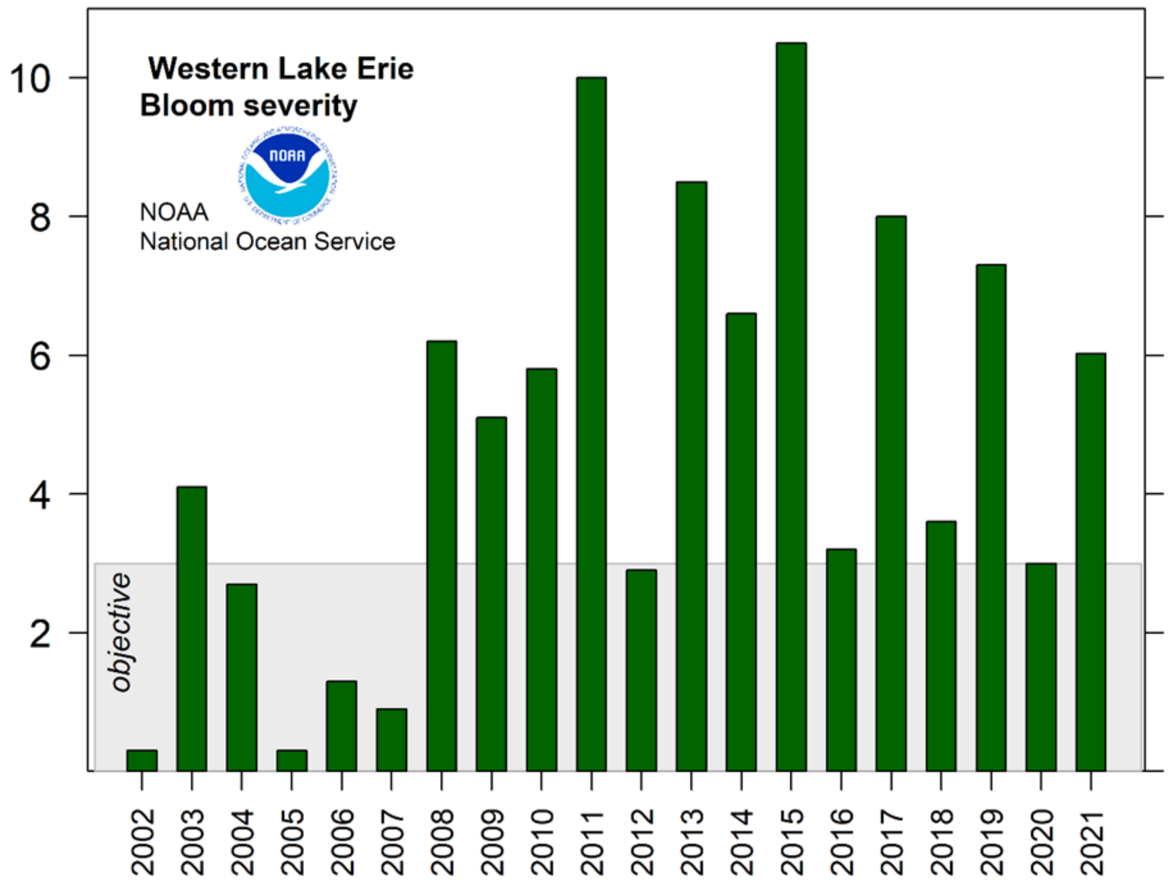


Figure 2. Western Lake Erie HAB severity observed since 2002. Adapted from figure by Dr. Rick Stumpf, NOAA National Centers for Coastal Ocean Science.

The Great Lakes Fisheries Commission-Lake Erie Committee promotes the maintenance of mesotrophic (moderately enriched) status for the WLEB to maintain the desired carrying capacity for a healthy and diverse fish community. The WLEB is currently in a eutrophic (more enriched) status.

Due to non-attainment within these Lake Erie assessment units, this project is carried out to develop TMDLs as required by Section 303(d) of the Clean Water Act and the United States Environmental Protection Agency's Water Quality Planning and Management Regulations (Title 40 of the Code of Federal Regulations [CFR], Part 130). This TMDL report, the PMR, identifies sources, pollutant targets, needed reductions, and recommends implementation strategies. Specifically, total phosphorus TMDL allocations for the Maumee watershed are developed to address all applicable Lake Erie impairments. This project focuses on reducing the most bioavailable portion of total phosphorus, characterized by the parameter dissolved reactive phosphorus (DRP). Table 2 below lists the Lake

Erie assessment units addressed by this project, showing their associated causes of impairment and the actions taken to address those impairments. Ohio EPA has assigned a high priority for TMDL development to these assessment units and impairments (Ohio EPA, 2020a).

Table 2. Summary of impairments in Lake Erie and methods used to address impairments in the Maumee Watershed Nutrient TMDL.

Lake Erie Assessment Unit	Narrative Description	Causes of Impairment (Beneficial use in parentheses)	Action Taken
041202000201	WLEB Shoreline (≤3 meters depth)	*Algae* (Recreation use)	Maumee Watershed Nutrient TMDL: Total phosphorus allocations with a focus on DRP reductions
		Algae: Cyanotoxins (Public drinking water use)	
		Nutrients (Aquatic life use)	
041202000301	WLEB Open Water (>3 meters depth)	*Algae* (Recreation use)	
		Algae: Cyanotoxins (Public drinking water use)	
041202000101	Lake Erie Islands Shoreline (≤3 meters depth)	*Algae* (Recreation use)	
		Algae: Cyanotoxins (Public drinking water use)	
		Nutrients (Aquatic life use)	

More details of the impaired assessment units and Maumee watershed area are provided in the report, Loading Analysis Plan and Supporting Data Acquisition Needed for the Maumee Watershed Nutrient Total Maximum Daily Load Development (Ohio EPA, 2022).

Several existing reports describe the overall natural and human characteristics of Lake Erie and its major tributaries, including the Maumee River. The Ohio Lake Erie Commission (OLEC) oversees the Lake Erie Quality Index that describes the ecological, economic, and perceived condition of Ohio's portion of Lake Erie (OLEC, in preparation). The U.S. and Canadian binational Lake Erie management recommendation reports also outline characteristic summaries (Lake Erie Lakewide Management Plan, 2011; Great Lakes Water Quality Agreement Nutrients Annex Subcommittee, 2019; and Environment and Climate Change Canada and U.S. EPA, 2021).

Ohio EPA plans to continue utilizing the TMDL tool to target near-field implementation in Ohio's Maumee watershed as it works to meet the far-field phosphorus targets and allocations. Ohio has six approved TMDL reports for subwatersheds in the Maumee watershed basin. Additional details on these TMDL reports can be found in Appendix 4 of this report. Ohio EPA will continue to develop near-field TMDL reports where necessary in the Maumee watershed.

2. Phosphorus in the Maumee Watershed

This section explores the overall understanding of phosphorus in the Maumee watershed. It starts with discussion that links phosphorus as a pollutant to the HABs (section 2.1). This explains why phosphorus reductions are required to address the HAB impairments in western Lake Erie. A comprehensive source assessment follows (2.2) which opens with an explanation of the overall phosphorus trends that facilitated the existing western Lake Erie seasonal HABs. The source assessment is then broken down into four components: nonpoint source (2.2.1), point source (2.2.2), household sewage treatment (2.2.3), and instream processes (2.2.4). The nonpoint and point source components are further subdivided by detailed sources to adequately cover the breadth of information. All source assessments document relevant research and available information regarding the nature of that source's phosphorus delivery mechanisms and its prevalence in the Maumee watershed. A critical source areas (2.3) discussion looks at the heterogeneity of phosphorus delivered throughout the Maumee watershed. This is organized by examining different efforts with the intent to study and/or manage phosphorus throughout the Maumee watershed. Finally, this section presents a summary of phosphorus in the Maumee watershed (2.4).

2.1. Linking phosphorus to impairment

Both the recreation and public drinking water uses of the Lake Erie assessment units addressed by this TMDL are impaired due to HAB events. The recreation impairment is driven by analyses of the size of HAB blooms with various timing considerations (Ohio EPA, 2020a).

The binational U.S. and Canadian Great Lakes Water Quality Agreement (GLWQA) includes 10-issue specific annexes, including Annex 4: Nutrients (herein referred to as Annex 4). Annex 4 convened an Objectives and Targets Task Team in 2013 to determine how to meet Lake Erie objectives impacted by nutrients as outlined in the GLWQA's 2012 amendment. This group recommended reduction of all available forms of phosphorus to meet HAB ecosystem objectives. Phosphorus targets to achieve the objective were expressed as both total phosphorus and DRP delivered to Lake Erie during the "spring loading period" of March 1 through July 31 each year (Annex 4, 2015). If target loads are achieved, the sizes of WLEB HABs are expected to be less than or equal to size of the blooms observed in 2004 or 2012. Those are considered years with mild, acceptable-sized blooms. The targets consider annual variability in streamflow and are expected to be met in nine out of 10 years.

Ohio EPA's Lake Erie HAB recreation assessment methodology was developed to adhere to the Annex 4 western Lake Erie HAB objective. When Annex 4 WLEB HAB size objectives are met, Ohio will be able to remove, or "delist," the recreation impairment status. The Annex 4 phosphorus-reduction targets are therefore directly applicable to the recreation impairment.

Public drinking water use impairments are based on the occurrence and concentration of cyanotoxins at public drinking water supply intakes and/or finished drinking water (Ohio EPA, 2020a). The Loading Analysis Plan prepared for this project identified that these impairments can be removed when Annex 4 HAB objective conditions occur (Ohio EPA, 2022). The Annex 4 phosphorus-reduction targets are therefore directly applicable to the public drinking water use impairments as well.

The WLEB and Lake Erie Islands shoreline assessment units are also listed as impaired for aquatic life use due to nutrients. The Lake Erie Western Basin Open Water assessment unit is currently not assessed for aquatic life use. The Great Lakes Fisheries Commission-Lake Erie Committee evaluated the impact of the Annex 4 phosphorus-reduction targets on the lake's trophic status (Annex 4, 2015). The Lake Erie Committee promotes the maintenance of the mesotrophic status of the WLEB to maintain the desired carrying capacity for a healthy and diverse fish community. The concentrations expected to maintain that status are in the 10-15 µg/L range. The lake models used by the Annex 4 task team that developed the targets document found the change in concentration in the WLEB at the proposed 40 percent reduction would result in reduction of the average concentration from 19 µg/L (2008 conditions) to 12-15 µg/L. These reductions move the lake from eutrophic to mesotrophic conditions and facilitate a healthy aquatic community. Because of this, the TMDLs for recreation use impairments due to algae will also directly address the aquatic life use impairments associated with nutrients.

Because the Annex 4 objectives will address all three impaired beneficial uses, the Annex 4 targets will be used to create one set of phosphorus allocations. No distinct implementation or reduction actions will be specifically recommended for any single beneficial use. When these pollutant reductions occur and targets are met, Ohio EPA expects these beneficial uses to attain Ohio's water quality standards, and the impairments will be delisted from the state's 303(d) list.

2.2. Source assessment of phosphorus – in total and dissolved reactive forms

Source assessment is used in a TMDL project to identify and characterize pollutant sources by type, magnitude, and location (U.S. EPA, 1999a). This TMDL's source assessment leverages an extensive amount of water quality observations and studies that have taken place in the Maumee watershed. It is intended to be a very robust examination that provides a strong basis for pollutant-reduction implementation recommendations.

Active research, noted throughout this section, is expected to result in refinements to this understanding. Examining phosphorus movement processes and emerging science provides input for the TMDL's adaptive management cycle to inform modifications to implementation recommendations as needed.

Tributary water quality monitoring is a key component to understanding sources of phosphorus in the Maumee watershed. It is the foundation of most of the research discussed in this detailed assessment. Monitoring of the Maumee River near Waterville, Ohio, which has occurred since 1975 by the National Center for Water Quality Research at Heidelberg University (NCWQR), provides insight into what has changed over time. This location is 23 river miles upstream of the Maumee Bay (shown on Figure 3). This point is the farthest downstream regular monitoring location before the river becomes backwatered from Lake Erie.

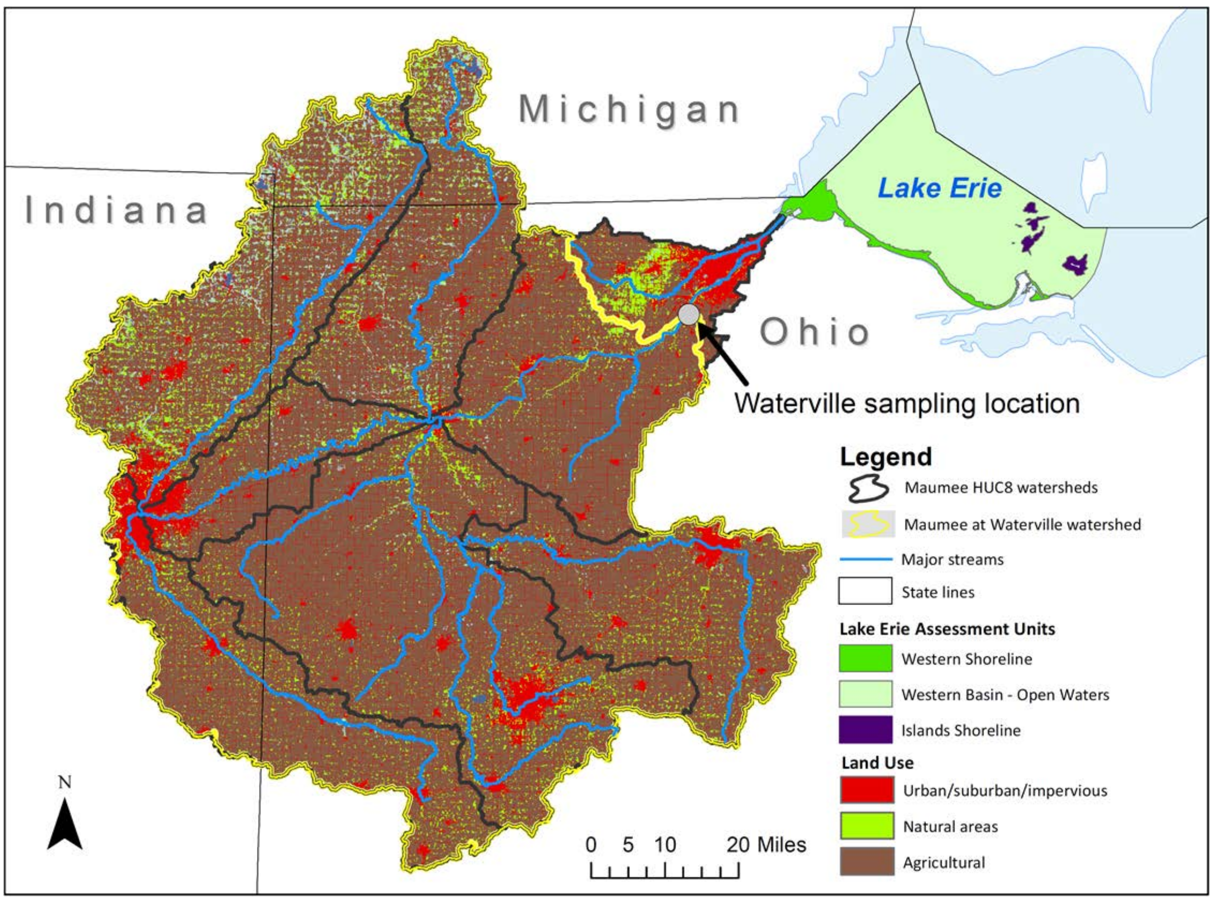


Figure 3. Maumee River watershed map showing generalized land uses. The Waterville monitoring station is located with a gray dot. The part of the watershed draining to the Waterville monitoring station is highlighted as a yellow line.

Sample collection is automated at this location with between one and three samples analyzed every day for several nutrient parameters and suspended sediments. These data are tied to the nearby United States Geological Survey (USGS) continuous streamflow gage at Waterville. With this wealth of sampling data, relatively straightforward analytical methods are carried out to calculate daily loads and flow-weighted mean concentrations (FWMCs) (NCWQR, 2022).

Of all its tributaries, the Maumee watershed contributes the greatest total phosphorus and DRP load to Lake Erie (Koltun, 2021; Maccoux et al., 2016). Figure 4 shows the Maumee watershed and its average total phosphorus load in relation to other Lake Erie watersheds. The Maumee delivers more than three and a half times as much phosphorus as the second greatest exporting watershed, the Sandusky River (Maccoux et al., 2016). Draining 6,570 square miles, the Maumee is the largest watershed to Lake Erie and is the largest river network drainage basin in all the great lakes (ODNR, 2018).

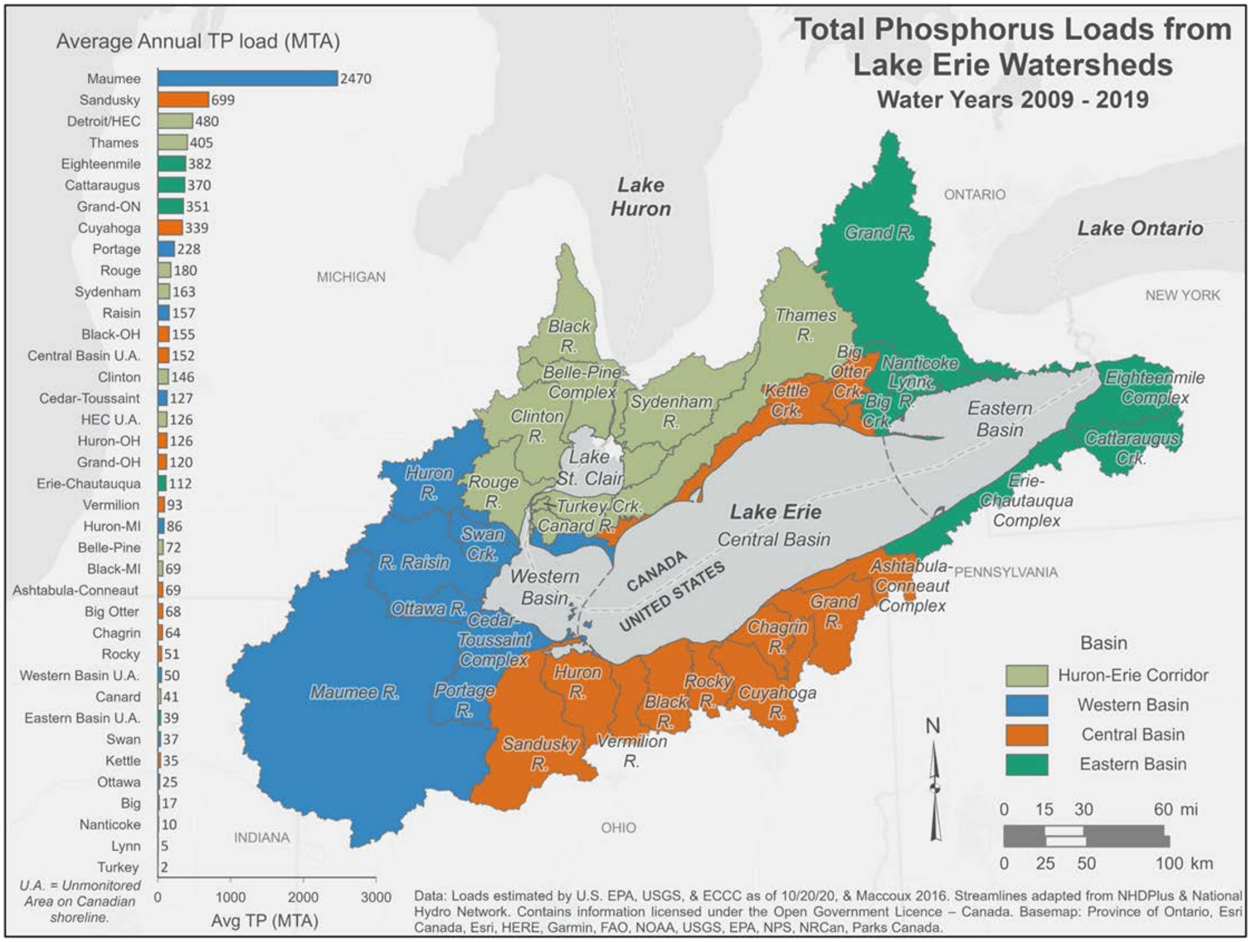


Figure 4. Lake Erie major watersheds divided into contributing basins by color. The bar chart on the left arranges watersheds by average annual total phosphorus export (2009-2019). Source: Annex 4, 2021.

While its size certainly plays a role in the amount of exported load, elevated phosphorus concentrations show that the Maumee, and other WLEB tributaries, contribute more nutrients per unit area than other watersheds. For example, OLEC's annual water monitoring fact sheet shows phosphorus FWMCs of the Maumee, Portage, and Sandusky regularly greater than the Cuyahoga and Huron (OLEC, 2020a).

Interannual variability in phosphorus loads and concentrations are strongly influenced by the amount of streamflow in the Maumee River. A recent paper used flow-normalization techniques to evaluate nutrient trends over time at the Maumee River Waterville sampling location from 1982 through 2018 (Rowland et al., 2021). Flow-normalization minimizes the effect of flow variability when interpreting trends in concentration and loads. Figure 5 shows the concentration and load annual results and trends for total phosphorus and DRP over the last several decades with the flow-normalized trend overlaying the data. Note Rowland et al. (2021) uses soluble reactive phosphorus instead of DRP; however, these parameters are essentially equivalent with only minor differences in analytical technique. The paper reports a steady and gradual decrease in total phosphorus over this time, whereas the DRP trend is more variable. The Maumee River initially shows a DRP reduction through the 1980s and then a stable, lower annual export through the early 1990s. DRP then increased for about a decade and has stabilized at an elevated level since 2006.

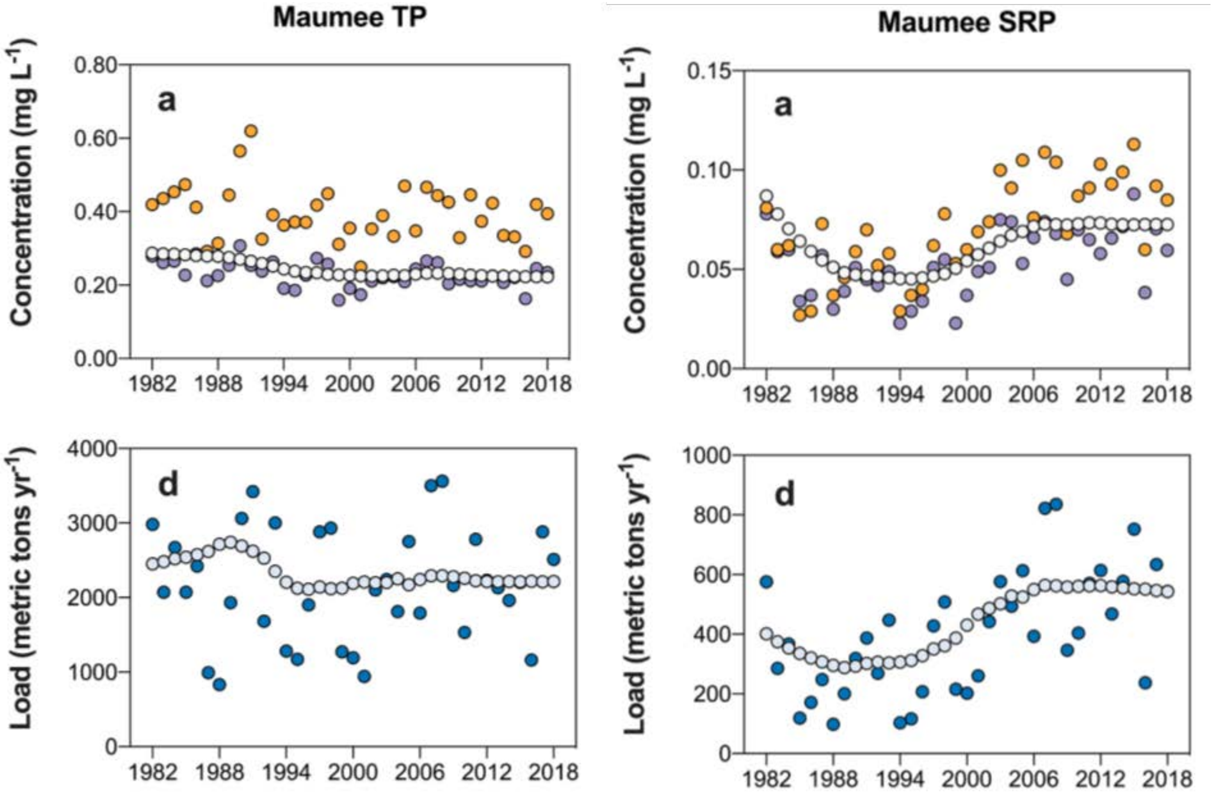


Figure 5. Total phosphorus (left) and DRP (right) water year annual concentrations (upper) and loads (lower) observed in the Maumee River at the Waterville monitoring station. In concentration figures, the orange filled circles are flow-weighted mean and purple filled are time-weighted. In load figures, 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).

The timing of this DRP increases corresponds to the increase of the WLEB HABs discussed in the previous subsection. It is this elevated DRP export that the Maumee Watershed Nutrient TMDL project intends to remediate. The remainder of this subsection will examine the sources of phosphorus within the Maumee watershed.

Ohio EPA's Nutrient Mass Balance project provides a biennial nutrient analyses of the state's major tributaries (Ohio EPA, 2020b). The monitoring results from the NCWQR are used, with the Waterville sampling station employed for the Maumee's watershed assessment. In these analyses, the monitoring station locations are called "pour points." Various methods are used to calculate the loads from the watershed that are added between the pour point and the mouth of the river so that this area can be included in the analyses.

Ohio EPA's Nutrient Mass Balance study assigns total phosphorus loads to three coarse source categories:

- National Pollutant Discharge Elimination System (NPDES) – Discharging point sources that are covered by individual NPDES permits make up the NPDES load. This source consists mostly of effluent from public wastewater treatment plants. These loads are determined based on compiling the individual plants' self-monitoring of their effluent data. Loads from combined sewer overflows are also included in the NDPES category. Note that permitted stormwater is not included in the NPDES category of Ohio EPA's Nutrient Mass Balance work; instead, it is grouped with nonpoint sources. How permitted stormwater is characterized in this TMDL is further addressed in this source assessment.
- Home sewage treatment systems (HSTS) – Loads from HSTS are calculated based on unsewered population and various levels of treatment performance.

- Nonpoint sources (NPS) – The remaining load is attributed, or balanced, to nonpoint sources.

Ohio EPA's 2020 Nutrient Mass Balance report included an analysis of the spring loading season for WLEB tributaries. Figure 6 shows the Maumee's total phosphorus spring load broken down by the major source categories for the most recent seven years (Ohio EPA, 2020b). Nonpoint source loads contribute the vast majority of total phosphorus load to the Maumee, 92 percent on average in the last five years. The NPDES and HSTS load contributed an average 6 percent and 2 percent of the spring total phosphorus load, respectively. The Nutrient Mass Balance determined that 79 percent of the land upstream of the Waterville pour point is used for agricultural production; this is evident on the map in Figure 3 above. Detailed analyses that links land uses to load contributions are presented in the next three subsections divided by the three major source categories: nonpoint source, NPDES, and HSTS.

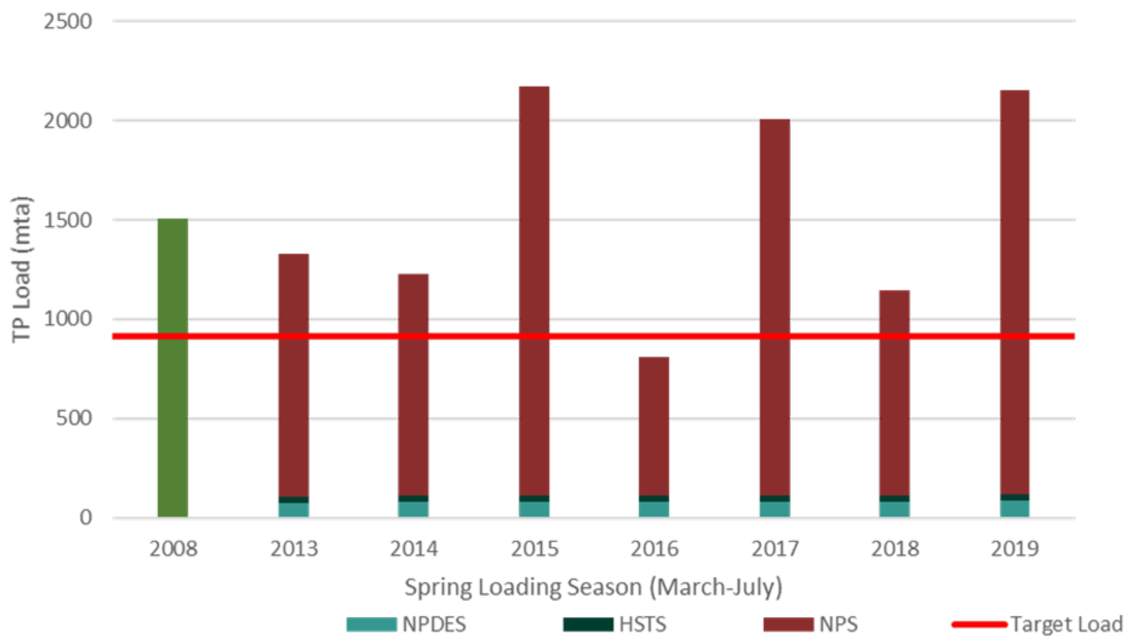


Figure 6. Maumee River total phosphorus loads for spring seasons in 2013-2019 broken out by Ohio EPA Nutrient Mass Balance major source categories. Note that the NPDES load in this work only includes the non-stormwater individual permitted load. For comparison with the Annex 4 reduction targets baseline the 2008 spring season total load is also shown. (Ohio EPA, 2020b, Appendix A)

Process models, like the Soil and Water Assessment Tool (SWAT) provide an effective means to simulate pollutant movement in a watershed. SWAT is designed to simulate agricultural watersheds, allowing the model developers to incorporate detailed agronomic and conservation practices. Nutrients applied as fertilizers and existing in soils are accounted for in detail. They are removed with crops, discharged to waterways, or remain on fields for the next season. All additional nutrient exports in a watershed, including from point sources and HSTS, are incorporated in SWAT modeling. Precipitation input data drives the movement of water and pollutants, which includes careful understanding of evapotranspiration, surface runoff, tile discharge, and ground water storage. Phosphorus is divided into inorganic and mineral pools with several subdivisions throughout SWAT's modeled processes. These two major categories of phosphorus remain discrete at stream outlets (Neitsch et al., 2011). SWAT is therefore a useful tool in understanding the magnitude of existing sources of total phosphorus and DRP in a watershed.

SWAT models have been developed for the entire Maumee River watershed with high levels of detail (Kalcic et al., 2016; Scavia et al., 2017; Apostel et al., 2021). Academic efforts in the Maumee watershed have improved the baseline spatial resolution of SWAT models, even to the field scale. This work better represents tile drainage, nutrient soil stratification, and many other factors (Apostel et al., 2021). The sources of exported nutrients including legacy soil phosphorus and manure as a fertilizer have been described using SWAT outputs (Kast et al., 2019; Kast et al., 2021). SWAT has been used in addressing uncertainties in identifying pollutant critical source areas (Evenson et al., 2021) and the time lag in legacy phosphorus reductions (Muenich, et al., 2016).

These improved models have been used to consider various best management practices (BMPs) to meet the Annex 4 targets discussed in this report. Some of these studies used multiple SWAT models (a method known as "ensemble modeling") to utilize the strength of various model parameterization choices in estimating the certainty of success for various BMP scenarios (Kalcic et al., 2016; Scavia et al., 2017; Martin et al., 2021).

The baseline, or existing conditions, results of SWAT modeling will be presented throughout this assessment evaluating existing sources of phosphorus. Content from all peer-reviewed research noted above will be included. However, the Kast et al. (2021) study is the most important to this analysis as this work specifically focuses on source contributions of phosphorus loads from the Maumee watershed. Source contribution results from this study are summarized for the same March through July "spring loading period" applicable to this TMDL project. This work used a SWAT model calibrated to the data from 2005-2015 at the Waterville sampling location. A validation was carried out using data from 2000-2004. Calibration and validation statistics summarized by both monthly and daily time periods were found to be satisfactory.

SWAT modeling advancements are ongoing, concurrent with this TMDL's development. A project in the Maumee watershed is being carried out by The Ohio State University (OSU), University of Wisconsin, and University of Toledo to directly assess the state of Ohio's H2Ohio BMP programs (HABRI/H2Ohio, 2020-2021). This project also intends to use remote sensing algorithms to improve model inputs of existing conservation practices for the baseline simulation. Additional ongoing studies are working to improve SWAT in-stream phosphorus cycling and how legacy phosphorus is modeled (HABRI, 2019; NRCS, 2021, respectively). The results of this work will be valuable to Ohio's adaptive implementation of this TMDL and help further refine this source assessment. In addition to discussions throughout this source assessment, Appendix 2 presents a detailed review of SWAT research in the Maumee.

2.2.1. Nonpoint sources of phosphorus

Recent research has evaluated why DRP increased from a low in the mid-1990s to causing the lake's current annual HABs. In 2015, researchers from the United States Department of Agriculture's (USDA's) Agricultural Research Service (ARS) outlined a list of 25 "theories" about the cause of this increase (Smith et al., 2015). These theories include a wide range of hypotheses, including changes to agricultural lands or management practices, climate change, and invasive species. They note that multiple factors and their interactions are most likely driving the changes seen in the system. Nearly all these theories involve nonpoint sources of DRP. This section explores these nonpoint sources and considers how they many have contributed to the increase in DRP in the Maumee watershed.

Figure 6 shows that nonpoint source loads vary substantially from year to year. Guo et al. (2021) analyzed the magnitude of nutrient export during the spring loading season in the Maumee watershed. Figure 7 shows this relationship by plotting loading season Maumee DRP and particulate phosphorus loads against season streamflow discharge. (Particulate phosphorus is the portion of phosphorus attached to particles in the water; the sum of DRP and particulate phosphorus is total phosphorus.) This work shows that load-streamflow relationship measured in the Maumee River has been consistent since 2002. This reflects the fact that nonpoint sources are tightly linked to precipitation and the resulting streamflow.

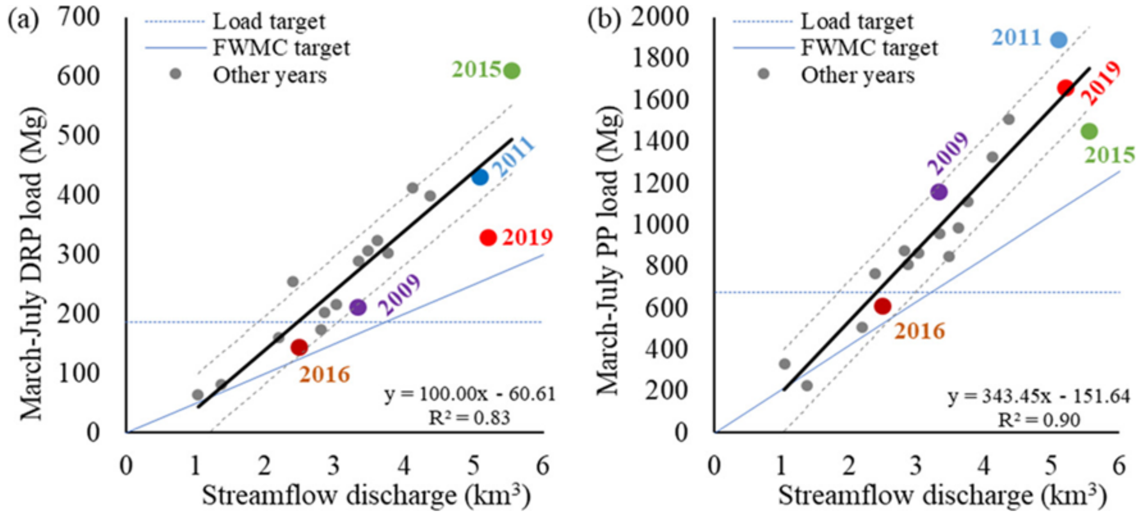


Figure 7. DRP load (a) and participate phosphorus (b) plotted against Maumee River "spring" loading season streamflow discharge showing results from 2002-2019; with several years labeled. The bold black lines show the linear relationship between load and discharge, with dashed gray lines showing 95th confidence intervals of that relationship. Other lines represent various target conditions. (Guo et al., 2021)

Figure 8 also shows the relationship between discharge and spring season DRP load illustrating how this trend differed between the 1983-1999 and 2000-2021 timeframes. The 2000-2021 timeframe shows both higher spring discharge events and higher DRP concentrations relative to the 1983-1999 timeframe.

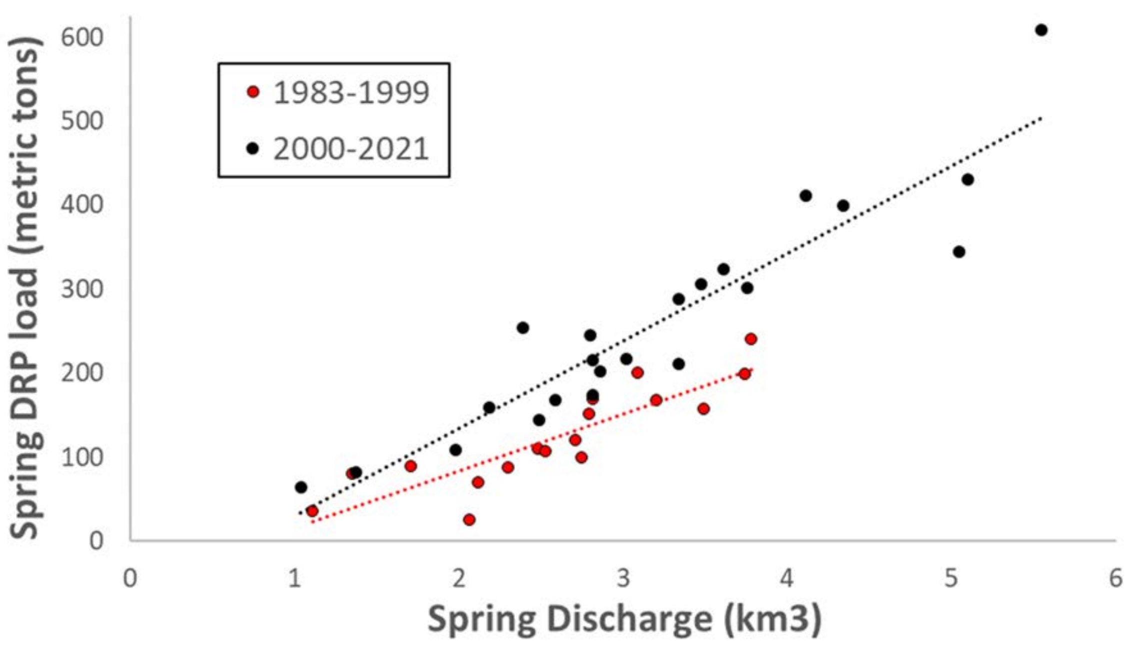


Figure 8. Spring (March-July) discharge plotted against the Maumee River spring loading season for two time periods, 1983-1999 (red dots) and 2000-2021 (black dots). Lines are a best fit of the linear relationship in the two time periods.

With the overall knowledge that the movement of water drives pollutants from nonpoint sources to the stream network, and ultimately to Lake Erie, the different types of nonpoint sources of phosphorus in the Maumee watershed are now discussed.

2.2.1.1. Row crop fertilizer sources: commercial and manure

Fertilizer use

Row crops predominate the land use in the Maumee watershed. Corn and soybean production with some rotations of wheat occurs on 70 percent of the watershed's agricultural land area (Kalcic et al., 2016). Other crops, such as alfalfa, hay, and vegetables are present but less common. Row crop agriculture requires certain concentrations of phosphorus in the soil to achieve expected crop yields. Phosphorus fertilization, along with nitrogen and potassium, is often needed to maintain adequate soil concentrations. Many agronomic factors are considered when determining fertilization farm management decisions, such as the type and amount of fertilizer used. Many environmental factors come into play dictating if phosphorus used as fertilizer ends up being exported off crop land to the Maumee watershed stream network and eventually to Lake Erie. This subsection explores these considerations and their implications for phosphorus export from fertilizer use.

There are two major categories of row crop phosphorus fertilizer: commercial (sometimes referred to as chemical or inorganic) and organic. Commercial phosphorus fertilizers are typically made by converting mineral rock phosphate to phosphoric acid and then undergoing further chemical refinement. The resulting types of commercial fertilizers have varying concentrations of phosphate (the biologically available form of phosphorus) for crop uptake. The major categories are superphosphate, monoammonium phosphate, and diammonium phosphate.

Organic fertilizers consist of manure, composts, and biosolids. The use of manure is by far the leading organic fertilizer in the Maumee watershed. Therefore, manure is the focus of organic fertilizer use in this source assessment. Chemical analyses are required to understand the available phosphorus content from different manure sources. The rate of decomposition of organic fertilizers in the field must also be understood. This allows producers to determine manure application rates that are equivalent to commercial fertilizers.

The rate of phosphorus fertilizer applied to fields in the Maumee watershed is generally determined by the Tri-State Recommendations (Culman et al., 2020). Figure 9 shows the conceptual framework for phosphorus fertilizer recommendations. These recommendations were revised in 2020 with the following updates:

- Critical levels were updated to reflect a shift to the new default Mehlich-3 extractant. Levels were practically unchanged but the Mehlich-3 extractant typically yields a 35 percent higher soil test phosphorus than the Bray P1 extractant.
- The new standard identified the build-up range is recommended, recognizing that economic or soil specific factors may influence application decisions.
- The new standard removes the recommendation to apply phosphorus while excess soil phosphorus is drawn down to the maintenance limit.
- Updated the crop removal rates to reflect a decrease in the removal rates per bushel of grain.
- The critical level for phosphorus is 20 parts per million (ppm) with the maintenance limit is 40 ppm (30 ppm and 50 ppm, respectively, if wheat is in the rotation).

The timing of application for both manure and commercial fertilizer is dependent on cropping system and field conditions. Precipitation or poor drainage can result in soil moisture levels that prevent the farmer from operating equipment in the field. Proper timing of fertilizer application is also important to minimize risk of loss due to runoff or erosion.

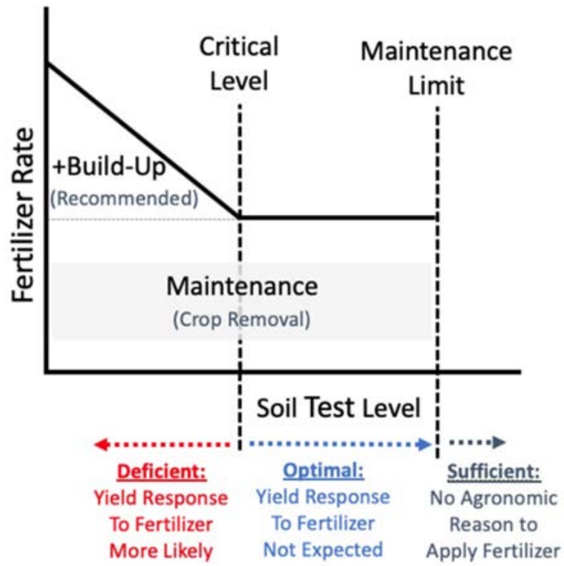


Figure 9. Figure shows the conceptual framework for fertilizer applications. (Culman et al. 2020)

Commercial phosphorus fertilizer is typically applied after harvest in the fall or in the spring before planting. It is often applied in a formulation that includes nitrogen, such as monoammonium phosphate or diammonium phosphate. Fertilizer may be applied across a field at a flat rate, or at a variable rate based on grid or zonal soil tests. Surface broadcasting fertilizer is common, but fertilizer on the soil surface is vulnerable to runoff. Incorporating the fertilizer into the soil can reduce the risk of loss. Fertilizer incorporation can be done through tillage, which works the fertilizer into the soil, or by applying the fertilizer subsurface using specialized equipment.

Manure is often applied in the late summer or fall post-harvest but may be applied in the spring if field conditions allow or if needed for a growing crop. Runoff risk can be reduced by injecting manure directly into the soil or incorporating it using tillage. Manure applications should follow the Ohio USDA Natural Resources Conservation Service (NRCS) Nutrient Management Practice Standard (Code 590) (USDA, 2020).

Oversight of manure application and commercial fertilizer is provided by ODA. This authority is divided between three ODA divisions:

- The ODA Division of Livestock Environmental Permitting (DLEP) has regulatory authority over Ohio's largest livestock and poultry operations, specifically animal feeding facilities required to have a permit under Ohio Revised Code Chapter 903.

  DLEP is charged with regulating the construction and operation of Ohio's largest livestock and poultry facilities using science-based guidelines that protect the environment while allowing the facility to be productive. DLEP rules regulate how Ohio's largest livestock and poultry farms manage manure, wastewater, and nutrients, as well as control flies, rodents, and other pests. Permitted facilities, known as Concentrated Animal Feeding Facilities (CAFFs), are designed to have zero discharge of pollutants into waters of the state from the production area.

  The Livestock Management Certification program assures that managers and manure applicators receive training and are informed about utilizing manure according to regulations and best practices.

- The ODA Division of Soil and Water Conservation (DSWC) has regulatory authority over manure application from most agricultural operations in Ohio, specifically those that do not possess a permit issued under Chapter 903 or division (J) of section 6111.03 of the Revised Code. The DSWC establishes a set of standards for management and conservation practices in farming and animal feeding operations to reduce pollution of waters of the state by soil sediment, animal manure, and residual farm products. This authority is granted through Ohio Revised Code Chapter 939.

Enforcement of DSWC regulations is typically performed through a complaint process. If the DSWC receives a complaint alleging that an agricultural operation is not in compliance with these standards, then the Division will investigate. If the DSWC determines that the agricultural operation is in violation of the law, then the Division will seek to find a cooperative solution to return the operation to compliance. ODA may require corrective actions. If these corrective actions are not completed, ODA has the authority to issue a civil penalty of up to $10,000 per violation per day.

ODA has entered into agreements with local soil and water conservation districts (SWCDs) to implement these rules. These agreements give the SWCDs authority to investigate complaints, identify violations, and require corrective actions. SWCDs also assist ODA by providing landowners and farm operators with technical assistance, advice, expertise, and information about the level of conservation necessary to comply with the rules and standards.

- The ODA Division of Plant Health (DPH) has some regulatory authority over commercial fertilizer application. This Division oversees the licensing program for the manufacture or distribute commercial fertilizer in Ohio, including collecting annual tonnage reports for fertilizer sales. DPH also runs the Agricultural Fertilizer Applicator certification program. After Sept. 30, 2017, any individual in Ohio who applies or supervises the application of a commercial fertilizer to more than 50 acres of agricultural production grown primarily for sale is required to be certified by ODA under the rules in Ohio Administrative Code (OAC) 901:5-4-02. Since 2017, more than 16,000 fertilizer applicators have received training through this program.

On Jan. 1, 2016, additional Ohio statutes came into effect restricting the application of manure and commercial fertilizer in the WLEB in Ohio. [The WLEB is defined by Ohio Revised Code 905.326 and is composed of 11 hydrologic units (HUC-8). The Maumee watershed in Ohio is completely within the Western Basin in Ohio.] These statutes, Ohio Revised Code 905.326 and 939.08, are colloquially referred to by their introduced legislation: Senate Bill 1. For applications of manure or fertilizer (defined as nitrogen or phosphorus) in the Western Basin, a person may not apply:

- On snow-covered or frozen soil;
- When the top two inches of soil are saturated from precipitation; or,
- When the local weather forecast prediction for the application area contains greater than a 50 percent chance of precipitation exceeding one inch in a 12-hour period for granular commercial fertilizer, or one-half inch in a 24-hour period for manure.

These requirements do not apply if the manure or commercial fertilizer is injected into the ground, incorporated within 24 hours of surface application, or applied to a growing crop. In the event of an emergency, manure can be applied in accordance with the Ohio USDA NRCS Nutrient Management Practice Standard (Code 590) with written consent from the director of ODA.

Commercial fertilizer sales can be used to determine the amount of commercial fertilizer applied to a given watershed. A study sponsored by the International Joint Commission (IJC) found commercial fertilizer to be responsible for 81 percent of fertilizer phosphorus applied to the United States portion of the WLEB's watersheds' croplands in 2006-2007 (IJC, 2018). That work noted commercial fertilizer use declining as more livestock operations concentrated their feeding operations. Moving livestock out of pastures results in more manure available for fertilization of cropland. This shift has brought attention to the number of livestock present in the Maumee watershed and the management of manure.

In 2021, ODA inventoried livestock in the Maumee watershed in Ohio and evaluated population trends for recent years. Details of this analysis are included in Appendix 1. Figure 10 shows an estimated 88 percent increase of animal units from 2002 to 2017 in the Maumee watershed. However, this came after a decrease that bottomed out in the early 2000s, as shown in Figure 11. The analysis estimates that 5,100 metric tons (MT) of manure phosphorus were produced in the Maumee watershed in Ohio in 2017. Combining that estimate with an estimate of crop removal shows that manure phosphorus produced supplies approximately 23 percent of the crop need in the Maumee watershed in Ohio.

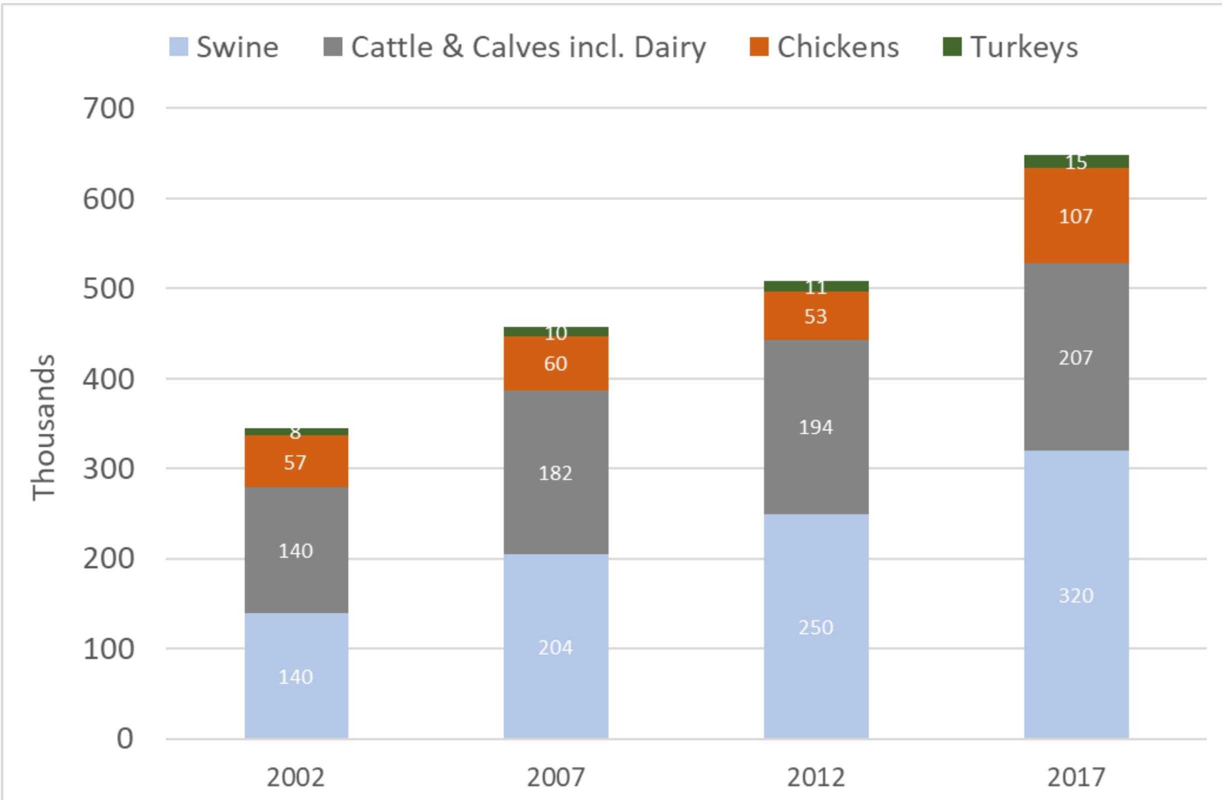


Figure 10. ODA estimate of animal unit capacity based on a combination of USDA's Census of Agriculture and ODA-DLEP numbers.

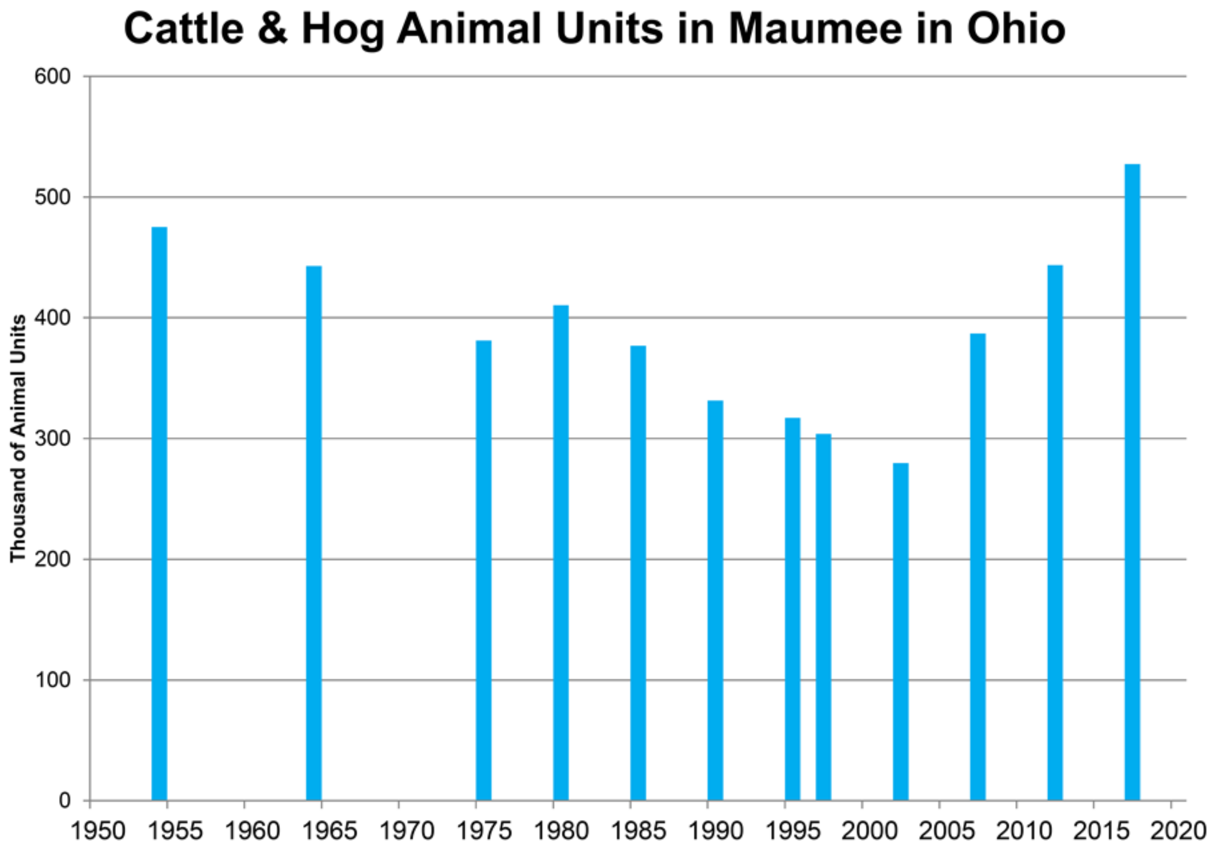


Figure 11. Capacity for cattle and hog animal units in the Maumee watershed have recently been trending upward based on ODA's analysis of the USDA Census of Agriculture.

As manure phosphorus production has increased in the watershed, the use of commercial fertilizer has decreased proportionally. This represents a shift in the relative contributions of fertilizer types rather than an increase in phosphorus application (EWG, 2019). Understanding the specific management of manure fertilizer is an important consideration for this source assessment.

Kast et al. (2019) examined concentrated animal feeding operation (CAFO)/CAFF manure management in the Maumee watershed. The authors found 79 percent of acres under control of CAFO/CAFFs that receive manure had less than 50 ppm (using Bray-P1 procedures). However, that paper described the management of about 80 percent of the Maumee's manure phosphorus still represented a "knowledge gap" due to CAFO/CAFF manure transfers and non-permitted livestock operations. Work is underway to address this knowledge gap using publicly available data.

The Environmental Working Group (EWG) recently published a report on animal feeding operations in the Western Lake Erie Basin (EWG, 2022). This work modifies NRCS' Agricultural Conservation Practice Framework toolbox to identify agricultural fields that are more likely to use manure as a nutrient source throughout the WLEB's HUC-12 watersheds. Farm-scale accounting of manure production is estimated throughout the watershed using this tool. This includes analyses of permitted CAFO/CAFF data, detailed review of aerial imagery to indicate locations and capacities of non-permitted facilities, and quality control activities such as comparisons with USDA Census of Agriculture. This work found that phosphorus from livestock manure produced in the WLEB supplies about 23 percent of that removed by crops. Thus, the EWG estimate of manure phosphorus for crop need agrees with the ODA estimate described above for the Maumee watershed. Importantly, these independent studies used different methods and had similar findings.

An objective of the EWG (2022) research is to evaluate the spatial distribution of manure production and row crop fields throughout WLEB's watersheds and then identify fields at risk for over application of manure. This involves analyzing the proximity of manure application from each livestock operation following methods of Porter and James (2020). The methods distribute manure to all available fields near livestock operations at agronomic rates. If more manure is available, the application continues to fields further away until it is completely utilized. EWG (2022) reported that some areas with the most livestock production require manure to be transported more than three miles away.

Several factors play a role in understanding manure distribution when assessing the risk of over application. These include the extent of manure being sold as a commodity, especially chicken litter, and technology and practices used in cost-effective transportation of manure. At large poultry operations, chicken litter is often managed as a solid product that results in a high nutrient density product. Thus, chicken litter competes with commercial fertilizer as a marketed product that is economical to transport greater distances compared to liquid manure. In the Maumee watershed, CAFOs/CAFF house 8.7 million egg laying hens and participate in the market-based manure utilization model. Thus, manure from these facilities compete with commercial fertilizer regionally and less directly with other nearby manure nutrients.

Fertilizer contribution to phosphorus pollution

Fertilizer, both commercial and manure, does enter stream networks and contributes to phosphorus pollution. This is generally precipitation induced and inadvertent. These phosphorus losses are typically consistent with the definition of agricultural stormwater and thus exempt from Clean Water Act regulation. A robust metanalysis of research studies on this subject with authors from USDA's ARS found that generally less than 2 percent of applied phosphorus is lost from fields (Christianson et al., 2016). This environmental externality also impacts agricultural producers economically. It is therefore beneficial for all interests to mitigate phosphorus loss. Agricultural producers aim to minimize these costs while maintaining agronomic yield expectations. Many additional agricultural BMPs exist to address the risk of fertilizer phosphorus pollution. These are outlined in the implementation framework of this report.

Fertilizer, both commercial and manure, is at times lost from farms and fields in a way that is inconsistent with the definition of agricultural stormwater. These discharges are unacceptable according to federal and state regulations (see Ohio Revised Code Section 6111.04 and OAC 901:13-1, OAC 901:5, OAC 901:10-1-10). When livestock operations are found to have a discharge of manure or other waste products, they are required to eliminate the discharge. They also may be required to pay a penalty and to obtain a permit from Ohio EPA and/or ODA to ensure that future discharges do not occur. When direct discharge events do occur, management actions are required to eliminate the source and mitigate the impact. Mitigation often results in much of the discharged material being removed from the surface waterbody. Overall, these discharges represent a small proportion of manure or commercial fertilizer applied in the watershed. For example, ODA-DLEP has responded to five or fewer substantiated spills in each of the last five years (2017-2021). The ODA-DLEP oversees manure application completed by CAFO/CAFF operations and certified livestock managers, representing a substantial amount of manure applied in the watershed.

Like all nonpoint source pollutants, fertilizer phosphorus loss from fields is driven by the movement of water. Large, infrequent precipitation events are known to drive most of phosphorus exported from the Maumee watershed. Baker et al. (2014a) calculated 76 and 86 percent of the DRP and particulate phosphorus, respectively, is exported at high stream flows (i.e., during the 20 percent of the time with the highest flows). These high precipitation, high stream flow events can overwhelm measures taken to avoid fertilizer phosphorus loss and make them less effective. Phosphorus from fertilizer is washed off fields and delivered to streams via runoff and subsurface tile drainage. Phosphorus can be attached to soil, or other particles, in the particulate form or in the dissolved form most often monitored as DRP (Christianson et al., 2016). Phosphorus stored in soils that is naturally occurring and/or from prior crop fertilization (often referred to as legacy or soil phosphorus) is discussed in Section 2.2.1.2 below.

Manure overapplication near livestock operations may lead to phosphorus accumulation in soil leading to greater export risk (see discussion on agricultural soil and legacy phosphorus sources in Section 2.2.1.2). Studies have shown manure overapplication can occur due to applications on soils with already elevated available phosphorus and by over estimating crop yield/nutrient removal (Long et al., 2018). Kast et al. (2019) did not find evidence that this was widespread in fields under control by CAFOs/CAFFs in the Maumee watershed. These samples come from fields that use 66 percent of CAFO/CAFF swine and 37 percent of CAFO/CAFF cattle manure. CAFO/CAFF operations do not report soil test phosphorus data to Ohio state agencies for fields not under their control (including manure transferred from CAFO/CAFFs through distribution and utilization and smaller facilities).

Another process affecting nutrient movement from fertilizer applications is preferential flow, where soil cracks, earthworm burrows, and other soil fissures can lead to rapid transport to tile drains. This pathway exists for all applied nutrients. Incidences of manure discharges are more prevalent with liquid waste from swine and dairy operations (Hoorman and Shipitalo, 2006). Current nutrient management standards, as well as state law and administrative codes, have incorporated requirements aimed to reduce the risk of these discharge events. These requirements include many recommendations by Hoorman and Shipitalo (2006) and other studies. Practices exist to prevent the movement of manure or commercial fertilizer to tile lines, and include tillage to disrupt macropores, blocking tile lines to prevent discharge, limiting the volume of liquid waste that can be applied, prohibitions for snow covered/frozen ground, restrictions on soil water content, and more.

Consequently, when discharges of fertilizer, manure or commercial, are not consistent with the definition of agricultural stormwater, parties are often liable for civil penalties and damages. As discussed above, these discharges do sometimes occur and certainly cause local disturbances. However, these discharges are irregular and infrequent. They result in delivering a relatively small amount of the overall load when compared to other sources.

Manure fertilizer form and application methods play a role in phosphorus loss. Surface broadcasting of liquid manure with no soil incorporation has been found to have higher total phosphorus and DRP export rates compared to other methods (Veith et al., 2011; Wang, et al., 2022). Several studies have shown that the greater amount of water-soluble phosphorus content in manure fertilizer the greater the amount of DRP export (summarized in LimnoTech, 2017 and Wang, et al., 2022).

Using monitoring data collected at “irregular intervals” and for a different purpose, Waller et al. (2021) found small surface water total phosphorus concentration increases in two out of three Wisconsin watersheds downstream of large, confined livestock operations (a companion paper to this work included an economic analysis, Raff and Meyer, 2022). The critical source analysis in Section 2.3 of this report examines phosphorus concentrations and loads from continuous monitoring throughout the Maumee watershed.

In other studies, manure as a fertilizer has been documented to increase soil organic matter promoting infiltration and thus reducing phosphorus loss (IJC, 2018). Another metanalysis of research studies on phosphorus loss from agricultural fields found no significant difference in range of total phosphorus and DRP export from commercial versus organic (manure) fertilizer applications, although the authors noted the sample size of comparable studies was not robust (Christianson et al., 2016).

A county level study examined soil test phosphorus and farm soils phosphorus balance trends throughout Ohio (Dayton et al., 2020). This work found that from 1987 to 2014, 84 percent of Ohio counties had a negative phosphorus balance which indicates that phosphorus outputs exceed inputs. All but two counties that drain to the Maumee watershed, Mercer and Lucas, were found to have a negative balance. This paper suggests that decreasing phosphorus inputs and management of soil phosphorus content sets the stage for reduced phosphorus export to streams.

A recent fertilizer study by ODA shows a decreasing trend in nitrogen and phosphorus fertilizer sales in the Maumee River watershed since 2007 (for additional details see Appendix 1). The study evaluated fertilizer sales in the Maumee River watershed, using annual statistics that are regularly tracked by ODA's Plant Health Division. Those statistics show a 15-20 percent decrease in fertilizer sales from 2007-2020 (Figure 12). The relationship between fertilizer sales and crop removal was also examined. Crop removal estimates for corn, wheat, and soybeans in the Maumee River watershed were calculated using National Agricultural Statistics Service data and crop removal rates from the Tri-State Fertilizer Recommendations. These data showed crop removal increasing, while fertilizer application has decreased (Figure 12).

To further highlight the relationship, fertilizer application was examined as a ratio to crop removal (Figure 13). This ratio was consistently below 1.0 with a decreasing trend, which shows that nutrients applied through fertilizers were less than that removed through crop harvest. If crop removal exceeds fertilizer application, over time soil phosphorus levels will decrease.

Commercial fertilizer is the largest source of crop nutrients, but manure also contributes to crop needs. The combined phosphorus from commercial fertilizers and manure were graphed for 2007, 2012, and 2017 in Figure 14. The combined phosphorus values varied but were below crop removal.

In addition to evaluating research using empirically measured data, other modeling efforts offer additional insight to the role of different fertilizers in phosphorus export.

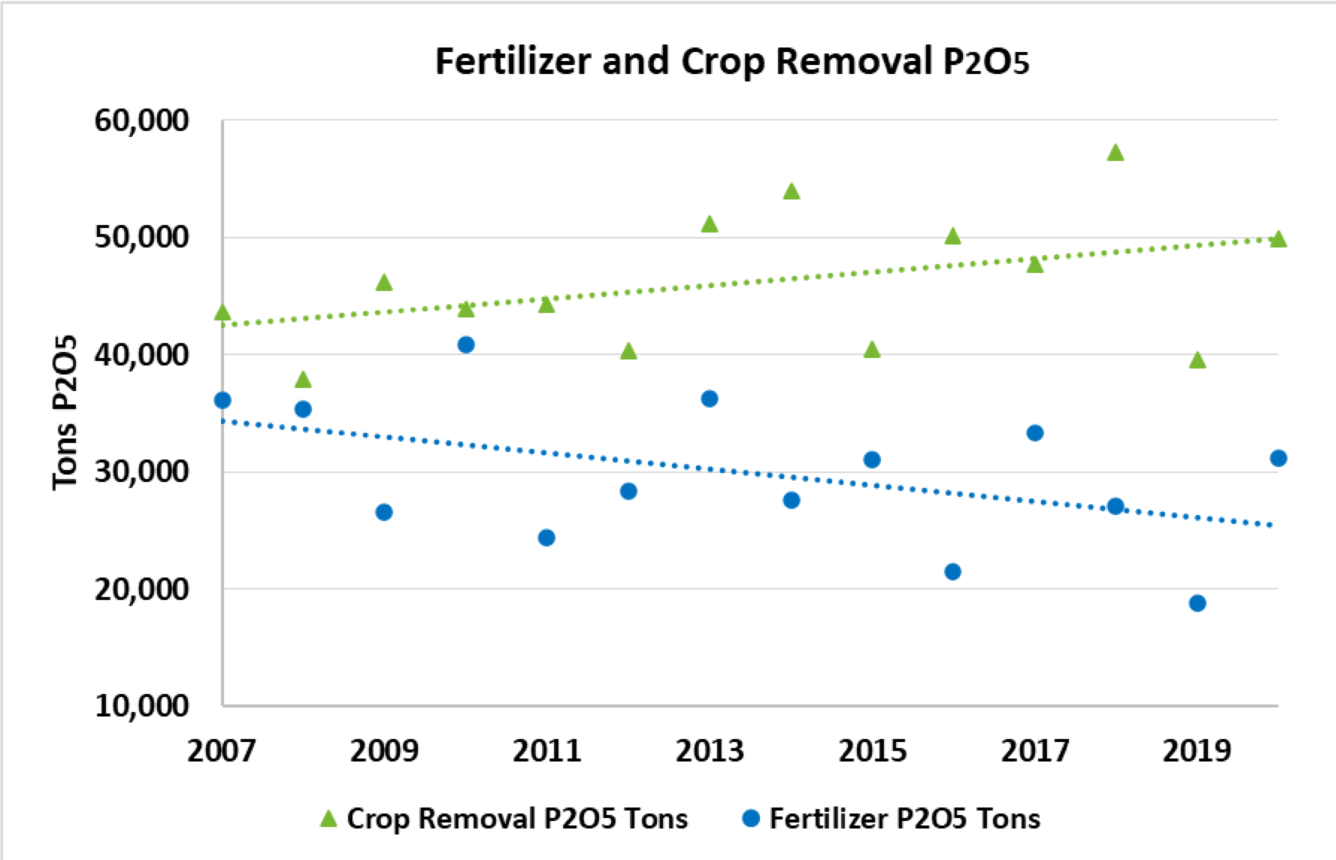


Figure 12. Tons of P_2O_5 from fertilizer sales, and corn, soybean, and wheat crop removal in the Maumee River watershed from 2007 to 2020.

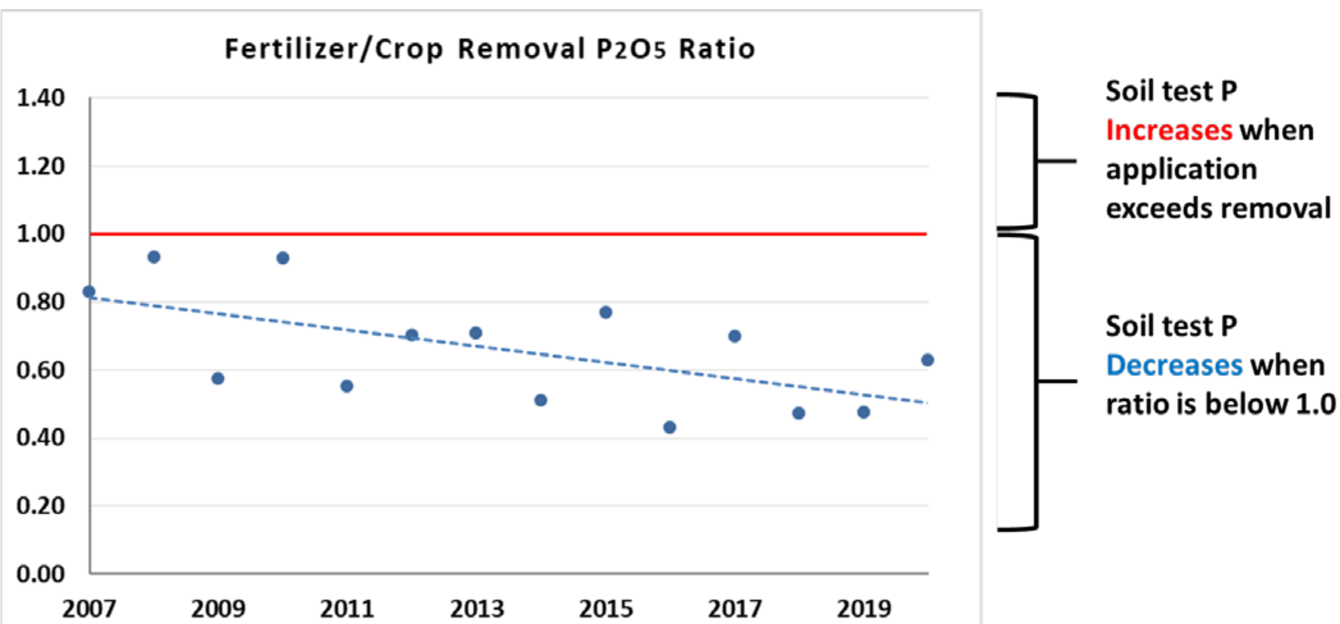


Figure 13. The ratio of P_2O_5 from fertilizer sales and crop removal from 2007 to 2020. A ratio below 1.0 indicates a net deficit of P_2O_5 in relation to crop needs.

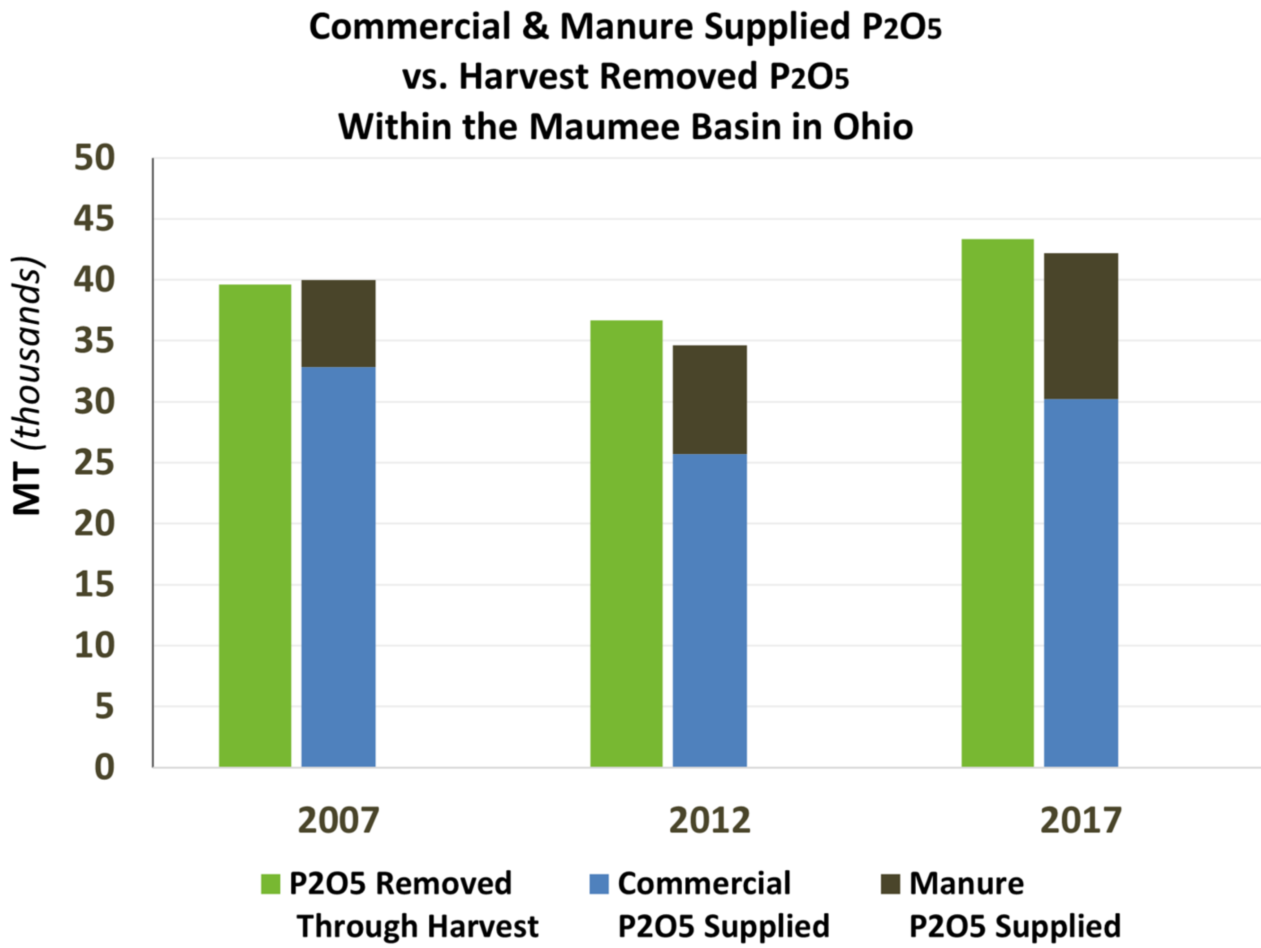


Figure 14. Harvest removed P_2O_5 compared with combined P_2O_5 from commercial fertilizers and manure, for 2007, 2012 and 2017.

SWAT modeling was used to evaluate the impact of different sources of fertilizer. Commercial fertilizer contributes an average of 58 and 42 percent of the DRP and total phosphorus load, respectively, delivered to the Maumee Bay during the spring loading months (Kast et al., 2021). That same study found manure fertilizer contributes 12 and 8 percent of DRP and total phosphorus load, respectively. Ensemble SWAT modeling presented in Martin et al. (2021) found eliminating manure resulted in 7.7 and 7.2 percent DRP and total phosphorus export reductions, respectively. Commercial fertilizer as a source contributed the greatest amount of DRP according to the Kast et al. (2021) work, and the second most total phosphorus. The largest total phosphorus source contribution was from soil sources, which are discussed in the next subsection.

Kast et al. (2021) also used SWAT to evaluate the impact of liquid content in manure. SWAT does not include manure liquid content as an input, a potential model weakness that is overcome by adding an irrigation event equivalent to the water content, a practice used in the Kast et al. (2021) model. To evaluate the impact of manure liquid content, a sensitivity analysis was performed that eliminated the irrigation event and found little change to overall export. In another example, a scenario cut the average initial soil phosphorus concentration by 75 percent, finding DRP and total phosphorus export was reduced by 29 and 24 percent, respectively. When the initial soil phosphorus concentration was doubled, DRP and total phosphorus export increased by about 35 and 23 percent, respectively.

Kast et al. (2021) calculated delivery ratios that determine how much of the fertilizer applied to row crops is exported and delivered to the mouth of the Maumee River. Delivery ratios represent the amount applied compared to the amount transported to Lake Erie. Similar average delivery ratios were found for commercial and manure fertilizers; around 3 percent for total phosphorus and 1 percent for DRP. This is in line with the Christianson et al. (2016) metanalysis that found no export difference between these sources of fertilizer. Other, statistical-based modeling in the overall Great Lakes region found no statistical difference between commercial and manure fertilizers export to streams, both around 2 percent (Robinson et al., 2019).

The assumptions used to determine the amount and location of manure application in the 2021 SWAT modeling paper are built upon work published in Kast et al. (2019), some of which is summarized above. Using assumptions similar to the EWG project outlined previously, this modeling work considered manure to be applied to about 18 percent of crop land at least once every six years (see Figure 15). The authors note that if fields receiving manure fertilizers have greater soil phosphorus than fields receiving commercial fertilizers, then the contribution of manure may be underestimated.

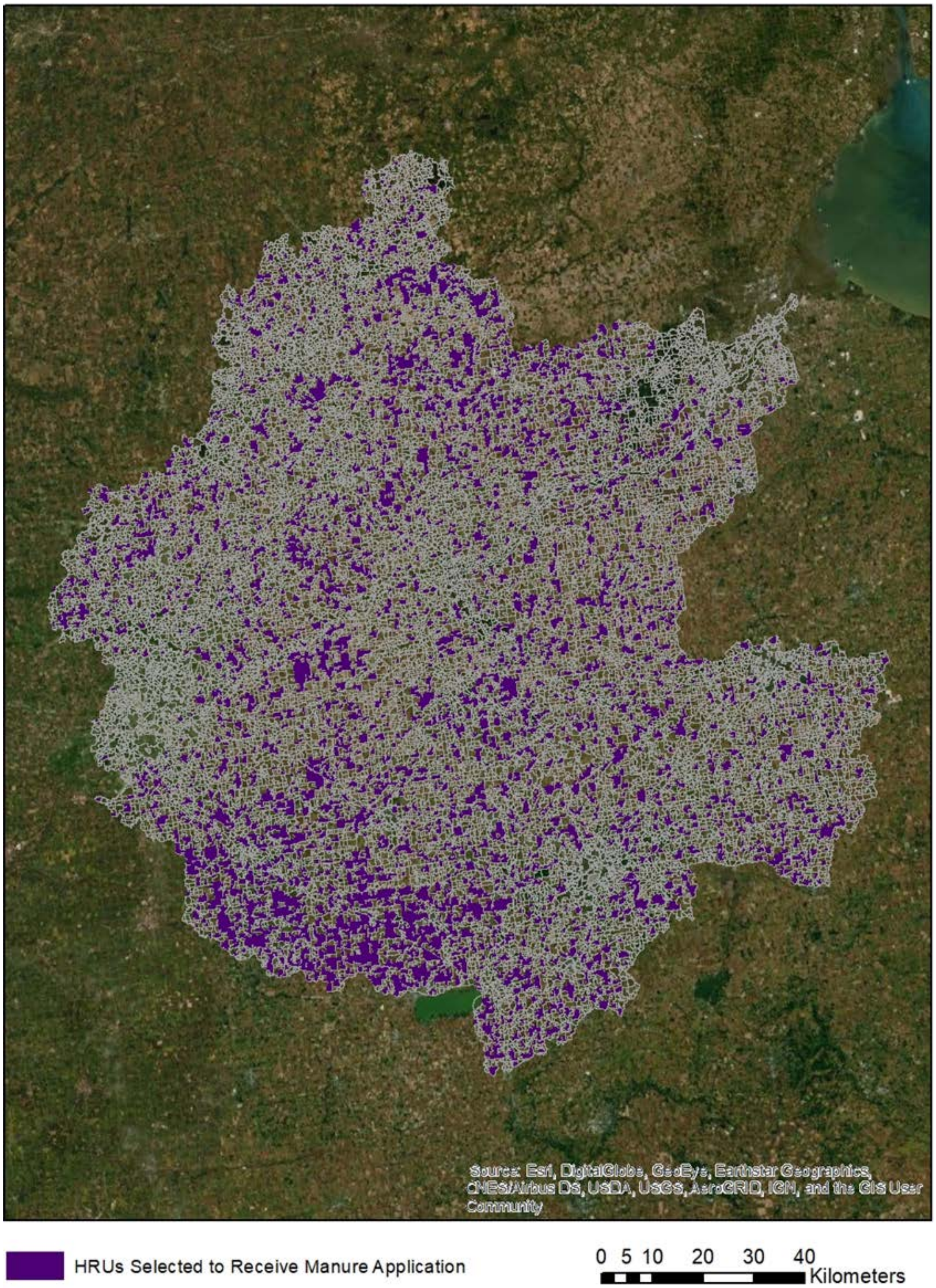


Figure 15. Locations of hydrologic response units (HRUs) chosen to receive manure applications within the watershed. Approximately 18 percent of the agricultural cropland was selected to receive manure applications at least once every six years. From Kast et al., 2021 Supplemental Material.

A current SWAT modeling project examining H2Ohio practices will continue improving model performance. The model will incorporate more detailed existing conditions including using actual soil test phosphorus concentrations as an input (most models us this as a calibration parameter), and existing BMPs (HABRI/H2Ohio, 2020-2021).

More information about SWAT modeling in the Maumee can be found in Appendix 2.

Fertilizer's role in increased DRP to Lake Erie

Examining fertilizer as a source can be used to help understand the increase of DRP the Maumee River delivers to Lake Erie that started in the early 1990s and stabilized at an elevated level around 2006 (see discussion and Figure 5 above).

As explained above, the number of livestock and amount of manure fertilizer used in the Maumee watershed has increased since the early 2000s. However, this increase occurred about a decade after DRP increases started. In fact, it coincides more closely to when DRP loads stabilized, albeit at DRP levels considered unacceptably high. Also explained above, increased production and usage of manure as a fertilizer has co-occurred with reductions in commercial fertilizers and increases in crop removal. Given this information, factors other than just the amount of fertilizer (commercial or manure) used must be explored to explain the observed DRP increases.

An IJC (2018) report on fertilizer found some type of conservation tillage has been employed in 63 percent of the WLEB watersheds' cropland, with adoption largely taking place in the early 1990s. The report notes that conservation tillage increases the accumulation of phosphorus in the uppermost layers of soil and promotes more soil macropores (worm holes). These factors make the phosphorus more available for transport overland and via subsurface tile drains. This is exacerbated by increases in tile drainage in the Maumee watershed, which has grown to cover at least 86 percent of agricultural land in the Maumee watershed (LimnoTech, 2017). These changes do coincide with the observed increase in DRP loads starting in the mid-1990s.

The DRP load in 2019 is highlighted in the Guo et al. (2021) study as it fell well below expectations given the amount of streamflow discharge that year (note the bright red dot on Figure 7 in panel A, several pages above). This load was 29 percent lower than predicted by flow alone, has been explained due to a 62 percent reduction in applied phosphorus fertilizer that year (the study considered both commercial and manure sources of fertilizer). The reduction of application occurred in 2019 because the excessively wet conditions resulted in a record number of unplanted and unfertilized row crop fields. While a 62 percent reduction in fertilization is incompatible with sustaining crop yields, the quick, easily observable response to exported DRP loads in 2019 supports the idea that changing key agricultural management practices will in fact result in changes to nutrient export. It shows that improving fertilization rate, timing, and placement of phosphorus could quickly reduce DRP loads.

Row crop fertilizer (commercial or manure) applied in a given agronomic season is clearly a source of phosphorus exported to the Maumee watershed. The changes in agriculture field management, noted above, have increased the mobility of DRP from these fertilizers. However, these changes also increase mobility and export of phosphorus "left-over" from previous fertilizations. These factors are considered next.

2.2.1.2. Agricultural soil and legacy sources

This discussion provides an overview of agricultural soil and legacy sources in the Maumee watershed. Phosphorus is naturally occurring in soils but also can accumulate in soil to higher than natural levels due to agricultural use. The term legacy phosphorus is used to describe different phenomena in soil and results in several definitions. However, they all share the concept of soil phosphorus from fertilizer or manure application in the past (legacy). Some definitions apply a threshold and discuss legacy phosphorus when available soil phosphorus exceeds a certain level (e.g., 100 ppm-P Mehlich-3). Both perspectives are important when considering the impact of past fertilization on phosphorus loss.

Erosion of agricultural soils

Various human land uses, particularly cropland tillage and land clearing for development, accelerate soil erosion. It is undesirable for cropland to have excessive soil losses. There are also several undesirable environmental impacts when soil enters stream networks. Physically, some of the soil becomes sediment that smothers stream habitat and fills pool areas. Some of it becomes suspended solids in the water column which makes the water murky looking and more difficult for some organisms to function. Chemically, phosphorus is attached to the soil particles and can become suspended in the water column as particulate phosphorus or be separated in the stream and become dissolved in the water there.

Agricultural soil conservation tillage efforts and construction stormwater standards have greatly reduced soil erosion and sediment delivered to streams over many decades. Agricultural tillage is performed to control weeds, prepare a seedbed, manage crop residue, and increase fertility (by providing a short-term stimulus to soil microbial activity). Tillage can increase the risk of erosion by breaking apart soil structure and reducing crop residue. "Conventional tillage" is soil inversion, typically with a moldboard plow, in the fall, winter, or spring, followed by a disc, harrow, or field cultivator. "Minimum tillage" replaces the moldboard plowing with chisel plowing, discing, or field cultivating. With "No-till", weed control is accomplished with herbicides and the soil is not tilled. "Conservation tillage" is an umbrella term that refers to either minimum tillage or no-till.

This discussion provides an overview of these soil sources to the Maumee watershed from agricultural land uses.

Sediment exports to Lake Erie tripled from 1935 to the early 1970s. The IJC is a binational, independent institution formed to guide U.S. and Canada on developing solutions to protecting the Great Lakes as outlined by the Boundary Waters Treaty. In 1972, the IJC facilitated the GLWQA where both countries agreed to take actions to address eutrophication issues in Lake Erie. The export of phosphorus bound to soil loss was determined the largest source from agricultural lands and soil conservation practices were prioritized (as summarized in NRCS, 2017). Additionally, through the late 1970s and early 1980s, the U.S. Army Corps of Engineers' Lake Erie Wastewater Management Study recommended a management program for agricultural sources of pollution (Logan and Adams, 1981). This study identified conservation tillage as the most cost-effective practice to reduce erosion risk and improve water quality.

As a result, conservation efforts in the 1980s were primarily focused on increasing the adoption of conservation tillage in Northwest Ohio. This effort was considered successful, as the acreage of conservation tillage practices increased and the particulate phosphorus load to Lake Erie decreased. Conservation tillage was used on roughly 45 percent of cropland in the Maumee watershed by 1995 (NRCS, 2017).

NRCS (2017) documented that by 2012, existing conservation practices on the WLEB's cultivated croplands were responsible for an 80 percent decrease in sediment loss compared to if no practices were in place. Total phosphorus losses are 61 percent less thanks to these practices. These pollutant reductions largely addressed excessive hypoxic and eutrophic conditions in Lake Erie (Michalak et al., 2013; Baker et al., 2014a; Kane et al., 2014).

The NRCS (2017) study also documented sediment deposited in waterways throughout the watershed to be 65 percent reduced due to soil conservation. This has improved the ecological health of the waterways throughout the WLEB. Stream bed sedimentation and embeddedness is highly detrimental to in-stream (near-field) aquatic life (Henley et al., 2000). Ohio EPA historically documented sedimentation as the top cause of impaired to Ohio streams' aquatic life use. As conservation tillage acculturated, these issues progressively improved. Agricultural conservation has significantly improved stream impacts due to sedimentation in Ohio (Richards et al., 2009; Miltner, 2015).

Ohio EPA recently found the relative abundance of pollution sensitive fish species in the Tiffin River (a Maumee tributary) more than doubled since 1992 (Ohio EPA, 2015a). Most notably of these is the state listed eastern sand darter (*Ammocrypta pellucida*), a species of concern in Ohio. The eastern sand darter is exceptionally sensitive to excess silts and flocculent clays that can blanket clean sandy substrates required for feeding and reproduction. These are the first Ohio EPA records of eastern sand darters in the Tiffin River basin. Historically, the eastern sand darter was widespread throughout the Maumee River and the lower portions of its tributaries. But the fish was nearly eliminated by the early 1900s due to habitat degradation and changes in land use practices that accelerated delivery of silts and clays to river systems (Trautman, 1981). “Drastic improvements” of instream sediment impacts have also been documented in St. Joseph River tributary’s watershed compared to the early 1990s (Ohio EPA, 2015b).

While reductions to the direct export of soils, along with attached phosphorus, was largely considered a success, changes to row crop management brought unintentional consequences. It was noted in the early 1980s that “while no till can be expected to greatly decrease soil loss on land previously tilled, the main effect on phosphorus loads will be to significantly decrease the particulate phosphorus with no change or increase in soluble phosphorus” (Logan and Adams, 1981). This notable observation has important implications on today’s DRP export delivered to Lake Erie.

Legacy sources

Sharpley, et al. (2013) describes legacy phosphorus as what has accumulated in soils because of prior nutrient applications and land management. That paper explains that water energy can mobilize particulate phosphorus in episodic waves to various accumulation points in a watershed. These points can occur on fields, at stream edges, in stream channels, and all the way to the downstream collection point, such as Lake Erie. Mobilization of dissolved phosphorus occurs from these accumulations. Various processes drive this mobilization, many of which include transformations of the form of phosphorus (often referred to as cycling). Details of these cycling processes are explained in Section 2.2.4 of this section. There are a great many factors that that dictate these processes resulting in the overall movement of legacy phosphorus.

The texture of soils has been documented as an important factor regulating the movement of soil phosphorus. Sandy soils have a lower capacity to chemically hold phosphorus and can develop more flow pathways for dissolved phosphorus export compared to clay, silty, and loamy soils (Sharpley, 2006). Figure 16 shows the relationship of DRP overland runoff and soil phosphorus for two groups of soils from a central Pennsylvania study. Note the change points on this figure at certain soil phosphorus concentrations above which DRP runoff increases. Sharpley (2006) also documented similar change points for subsurface DRP loss; however, soil texture differences were not apparent.

Soil types vary throughout the Maumee watershed. The soil type and texture are important considerations in field-level nutrient management planning. This is discussed further in the Critical Source Assessment, Section 2.3.

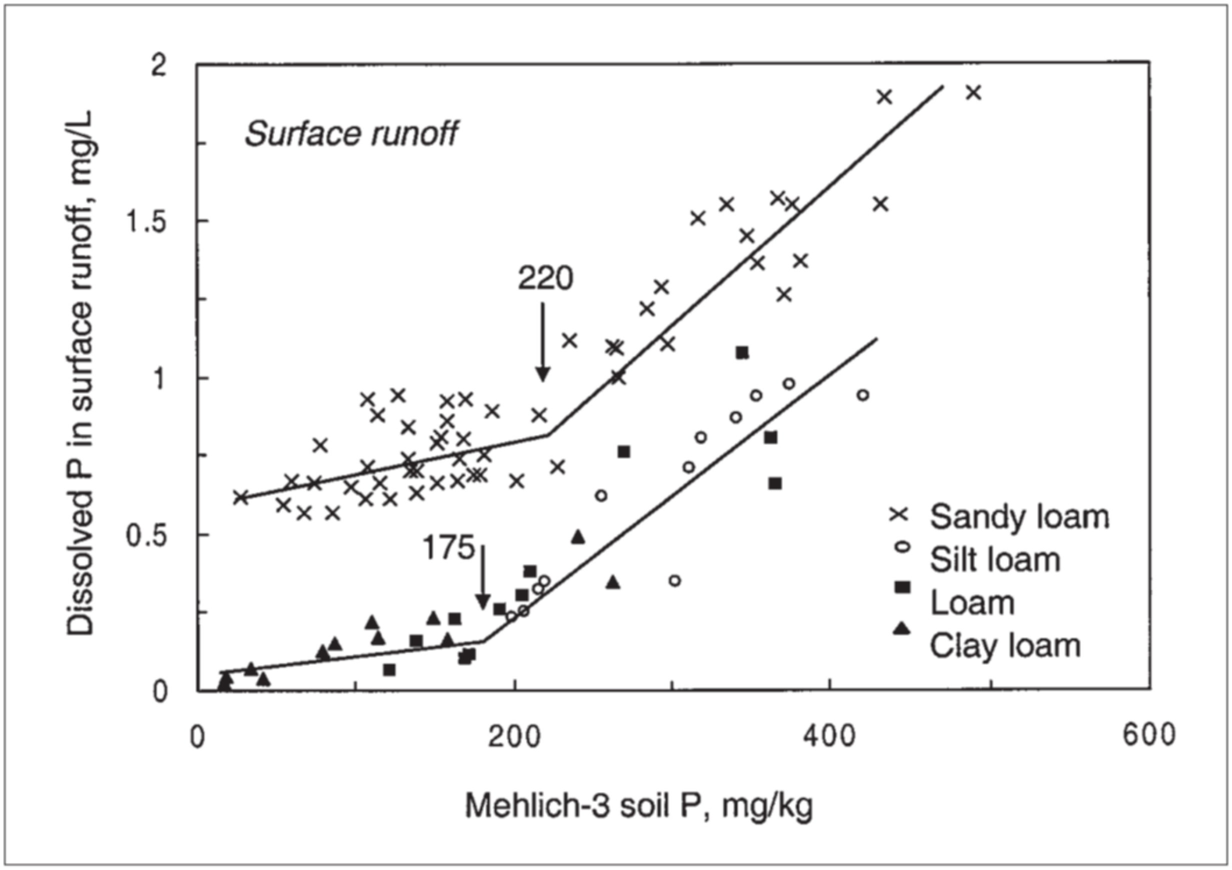


Figure 16. Relationship between DRP concentration in surface runoff and top layer soil P. (Sharpley 2006)

Legacy phosphorus is a persistent source of both total phosphorus and DRP to streams via tile and overland flow in the Maumee watershed, according to an ARS study published on the relationships of legacy phosphorus to various factors from 39 northwestern Ohio agricultural fields (Osterholz et al., 2020). Higher available soil phosphorus resulted in greater total phosphorus and DRP concentrations in tile and surface runoff. High flow events were found to drive greater nutrient concentrations in nearly all tile flows studied. The concentration to flow relationship is not as straightforward in surface runoff due to several factors, including dilution. However, the authors warn against extrapolating these results, partially because of limited surface runoff observations. Variation analyses found that tile flow concentrations are not as uniform as surface flow given similar flows. The authors suggest that this could be due to “activation” of macropores changing the flow pathways to the tiles before and during high flow events. Taking all relationships into account, the study suggests that there may be an available soil test phosphorus “threshold” above which DRP exports increase. This corresponds to the findings outlined in Sharpley (2006). Therefore, addressing elevated soil phosphorus in the most elevated fields will result in the greatest reduction of total phosphorus and DRP export concentrations. Osterholz et al. (2020) concludes by highlighting the “importance of identifying fields with enhanced risk of legacy phosphorus loss”.

Edge-of-field studies by the ARS is ongoing in the Maumee watershed to quantify the magnitude and mechanisms of legacy phosphorus movement (ARS, 2020).

While the Sharpley/ARS research noted in the above paragraphs considers any phosphorus remaining in soils from previous fertilization as “legacy”, other studies have narrowed this definition to soils containing soil phosphorus levels above certain thresholds. Farm soil data are generally proprietary information making detailed analysis challenging. Research examining pooled soil data has found that over 5 percent of the soil samples in the WLEB have available phosphorus concentrations at levels greater than 100 mg/kg Mehlich-3 soil test phosphorus

(Williams et al., 2015; Dayton et al., 2020). This is more than two times the level where additional phosphorus is not needed to achieve optimal yields.

OSU's Department of Food, Agricultural, and Biological Engineering has developed a public-private partnership with agricultural retailers to begin to understand the spatial extent of excessive accumulation of legacy soil phosphorus in a manner that protects the privacy of individual farm data. This effort has documented that elevated soil phosphorus often occurs in zones within fields rather than uniformly across fields (Brooker et al., 2021). This work also found fields with sandy soils frequently have elevated soil phosphorus. This study documented elevated soil phosphorus in fields with a history of the application of manure or municipal biosolids, including one field with livestock operations and ongoing manure applications. One field with past vegetable production and one former orchard were also identified with elevated soil phosphorus. Sharpley et al. (2013) outlines circumstances where elevated legacy phosphorus can result due to changes in agronomic phosphorus management.

Phosphorus from soils moves in waves downslope in a watershed to eventually be delivered to water bodies (Sharpley et al., 2013). Given advances in soil conservation, this often results in the accumulated soil phosphorus to arrive in waterways in the dissolved, DRP, form. Where legacy soil phosphorus is present at excessively high concentrations, the phosphorus export increases in tandem. Considering the threshold effect explained above, the phosphorus export that eventually occurs from elevated soil phosphorus may be much greater than from fields with soil phosphorus concentrations maintained in the typical agronomic range.

Soil and legacy sources contributing to phosphorus pollution

As explained in the fertilizer discussion above, the Guo et al. (2021) study highlighted a 29 percent lower than expected DRP exported load in 2019 (note the bright red dot on Figure 7 in panel A, several pages above). The 62 percent reduction in applied phosphorus fertilizer that year is postulated as the main reason for the observed DRP reductions. However, because DRP export reduction was less than half of the reduction of applied phosphorus, it suggests that legacy sources likely play an important role in export from fields. While 2019 was instructional, it remains uncertain exactly how to quantify the partition of DRP load between seasonally applied sources and legacy sources in a more typical year.

The understanding of legacy phosphorus as it moves through stream networks is a subject of active study. Streambank erosion, especially during high streamflow times, can be an important source of temporarily trapped legacy phosphorus (Williamson et al., 2021a). The cycling of phosphorus forms in stream channels plays a role in legacy phosphorus mobility and seems to have implications as to the availability of the phosphorus exported to Lake Erie. These factors are considered in more detail in the 2.2.4 subsection below.

Recent Maumee watershed modeling suggests that soil sources of phosphorus (defined similarly as legacy phosphorus in studies above) are contributing on average 18 percent of DRP and 45 percent of total phosphorus discharged from the watershed (Kast et al., 2021). This represents the greatest source of total phosphorus and second greatest source of DRP from this study. Similar to active fertilizer sources, soil sources were found to contribute more in wet years and less in dry years.

Many assumptions are required for modeling nutrient movement through a watershed, especially in the case of legacy phosphorus. Elevated soil phosphorus concentrations throughout the watershed are managed at the field scale, and knowledge of their precise spatial extent is unavailable outside producer level nutrient management planning. As noted in the fertilizer source discussion above, Kast et al. (2021) modeling used an assumed average soil phosphorus concentration based on soil samples throughout the watershed. Were an excessive number of fields to have much greater soil phosphorus, the modeled soil sources of exported phosphorus could be much greater. These uncertainties have been pointed out as one of the key challenges in nutrient reduction efforts to control lake eutrophication (Jarvie et al., 2013).

Ongoing modeling is examining distributing differences of soil phosphorus throughout the watershed including looking at applying the distribution of soil phosphorus throughout the watershed (HABRI/H2Ohio, 2020-2021). Following Arrueta Antequera (2020), this work will also consider simulating the effects of behavioral and landscape heterogeneity on nonpoint source pollution.

The Kast et al. (2021) modeling found soil sources increasing in the proportion of phosphorus delivered to Lake Erie when scenarios reduced the amount of fertilizer applied to row crops. These factors may result in a need to shift nutrient reduction implementation efforts or take other measures to address a lag in nutrient export. Muenich et al. (2016) used SWAT to examine how long it would take for legacy phosphorus reductions to meet Annex 4 targets given various modeling scenarios. This showed the total phosphorus lag to take much longer than DRP lag. The authors attributed this to lower mobility of total phosphorus. This agrees with the Guo et al. (2021) observed findings of 2019's DRP export below expectations given that year's stream flow, while total phosphorus was right on the relationship's predicted export.

Hydrology mattered a great deal to total phosphorus reductions in the Muenich et al. (2016) scenarios. In fact, total phosphorus targets were never met in modeling out 80 years into the future in even extreme reduction scenarios, such as no new fertilizer applied, when stream flow and rainfall conditions were held at elevated levels.

More information about SWAT modeling in the Maumee can be found in Appendix 2.

Soil and legacy source's role in increased DRP to Lake Erie

Kast et al. (2021) SWAT modeling noted the severity of Lake Erie HABs was likely driven by precipitation changes driving increased soil contributions of phosphorus to the watershed. Note that the increase has occurred at a time when soil erosion and particulate phosphorus has declined. Therefore, leaching of legacy phosphorus from soils is the most likely source of DRP increases.

Jarvie et al. (2017) documented changes in water quality from the Maumee, Sandusky, and River Raisin watersheds. All experienced similar DRP loading shifts as the Maumee. Net reductions of the particulate portion of total phosphorus and sediment were documented uniformly after 2002 while DRP increased. The work attributed 65 percent of the DRP load increase to "increased source availability and/or increased transport efficiency of labile phosphorus fractions". The authors link that DRP load increase to a combination of changes in agricultural land management that has shifted the type of phosphorus export from agricultural fields. The authors highlight the following as the leading management causes for this shift: "reduced tillage to minimize erosion and particulate phosphorus loss, and increased tile drainage to improve field operations and profitability". Choquette et al. (2019) uses different statistical approaches to also find land management changes explaining more of the increasing nutrient trends than hydrology increases.

Modern soil conservation has addressed a large proportion of direct soil erosion from agricultural areas. The environmental and agronomic benefits of soil conservation are well documented (Richards et al., 2009; Miltner, 2015). While unintentional consequences of these actions have been documented, reverting to farming practices that do not conserve soil is not an option.

However, the movement of phosphorus built up in soils via various pathways, often in the dissolved form, is clearly an important source requiring attention today. Areas where this legacy phosphorus is elevated are often described as critical source areas. The Great Lakes Advisory Board provides advice and recommendations to U.S. EPA on matters relating to implementation of the Great Lake Restoration Initiative. In 2021, this board's nutrients workgroup recommended that resources be prioritized in identifying critical source areas and reducing legacy phosphorus (GLAB, 2021). The International Joint Committee recommends that better soil phosphorus concentrations and vertical stratification databases be developed (IJC, 2018). Research outlined in this discussion

(Osterholz et al., 2020; Kast et al., 2021; etc.) completely agree with this priority. More is presented on the current state of identifying critical source areas in Section 2.3 below.

The voluntary implementation of agricultural soil conservation has produced great environmental successes over the years. Tri-state fertilizer standards have been updated recently. Practices exist to reduce legacy phosphorus, such as targeted soil phosphorus draw down and edge-of-field phosphorus filters. These actions should be considered for TMDL implementation recommendations addressing both agricultural fertilizer (often thought of as “live”) and soil (“legacy”) sources of phosphorus export.

2.2.1.3. Non-agricultural stormwater sources

Non-agricultural (Non-ag) stormwater sources of phosphorus exported to the Maumee watershed also contribute to total phosphorus and DRP loading. Non-ag stormwater contributions originate from 11 percent of Ohio’s portion of the Maumee watershed. This is calculated based on the summing the four developed land use categories in the 2019 National Land Cover Database and dividing by Ohio’s portion of the watershed (Dewitz, 2021). The natural and agricultural land use categories are therefore not included.

No matter the point of origin, non-ag stormwater pollution is diffuse, and precipitation drives its delivery. While the mechanisms delivering phosphorus from non-ag stormwater in permitted and non-permitted areas are the same, TMDLs require that non-ag stormwater be bifurcated based on if the stormwater’s source area is regulated under the Clean Water Act or not. The stormwater discharges from areas within regulated municipal separate storm sewer systems (MS4s) and from NPDES permitted stormwater facilities are considered a point source and receive a wasteload allocation in TMDLs. The remaining stormwater loads are considered nonpoint sources and are included in the TMDL’s load allocation. Sixty percent of the developed land area in Ohio’s portion of the Maumee watershed has been calculated as being part of the non-permitted nonpoint load in the load allocation in this TMDL.

Non-ag stormwater considered to be contributing to the nonpoint load in the Maumee watershed is much more spread out than stormwater from permitted areas. Small communities, country homesteads, and roads dominate these areas. Phosphorus contributions from roads may be a significant non-ag stormwater source in areas without permitted stormwater. Williamson et al. (2020) found that roads contributed up to 24 percent of suspended sediment in a rural Maumee River tributary in Indiana. Analysis in that tributary watershed determined that, of the 6-11 percent of the developed land, 5-6 percent was roads. That work, however, notes that sediment from road dirt contained the lowest proportion of phosphorus of the sediments tested in the study. This, along with relatively high organic carbon content could mean that sediment from roads may adsorb DRP within stream channels. More information about instream practices is presented in Section 2.2.4.

Stormwater from regulated MS4s and other NPDES permitted facilities is regulated because of the amount of impervious area, artificial drainage systems, total population, and/or density of human developed areas. This results in efficient pollutant delivery to receiving waters. These factors also allow for more effective implementation of pollutant reduction activities. For this reason, non-ag stormwater sources are discussed in more detail in the point source Section 2.2.2.

2.2.1.4. Ditch and streamside sources

Agricultural and developed land uses often alter and augment the natural drainage of the landscape. Removal of excess water and lowering of the water table allows for more fields to be available for productive crop and livestock use. Flood control is also culturally desired for built landscapes. Open ditches or culverted streams are an often-used tool to facilitate these drainage needs. As described in the legacy phosphorus discussion, ditches and streams can be a temporary stopping point for phosphorus enriched soils. Erosion from ditches and streams can contribute to phosphorus pollution downstream through the stream network. Other processes can mobilize DRP from this source as well.

When naturally occurring waterways or artificial channels are maintained to maximize drainage, they are most often channelized lengthwise and sculpted into a trapezoidal cross-section. The resulting ditches are stabilized and maintained with the intent to neither aggrade nor degrade material (NRCS, 2015). While this most efficiently moves water, instream sediment trapping, and therefore the phosphorus reduction service provided by aggrading sections of streams, are reduced (Brooks, 1988). Channelization and ditch maintenance also can reduce instream processes that trap dissolved phosphorus (Smith and Pappas, 2007). More is presented on these instream processes in Section 2.2.4. Ditching also often hydrologically disconnects channels from their floodplains, restricting the phosphorus reduction services from that interaction (Hopkins et al., 2018).

When left unmaintained, ditched channels regress back to more natural conditions with areas of both sediment accumulation and dispersal (Simon, 1989; Landwehr and Rhoads, 2003). This can also impact sediment mobility up and downstream of the ditched zoned with deposits locally changing velocities causing for points of channel incision (Simon, 1989). These issues can occur sooner after channelization where channel dimensions are constructed too wide (Landwehr and Rhoads, 2003).

Unaltered "natural" channels contribute to phosphorus loads due to erosion and instream processes in the same manner as channelized ditches. The size and the amount of channel alteration certainly factors into the magnitude of this source, however. Regardless, the remainder of the discussion of this source will use the generic term, "streambank sources".

Understanding the watershed scale impacts from streambank sources of phosphorus is challenging. Process based models, like SWAT, do not fully represent floodplain and streambank erosion processes and BMPs addressing sources from these areas (Kalcic et al., 2018). Modeling uncertainty is exacerbated when legacy phosphorus sources are contained within the stream channel in pooled areas or behind dams (Kalcic et al., 2018).

Fox et al. (2016) carried out a meta-analysis on streambanks as a source of sediment and phosphorus to streams. The various studies review documented that streambank and gully erosion could be the source of a wide range of phosphorus found in streams, from 6 and 93 percent. Multitudes of factors, many of them relating to stream velocity and channel dynamics (shape, degradation/stability, etc.), play into uncertainties resulting in such a wide range. This work stresses the importance of understanding the form of streambank phosphorus. However, several studies in the review do not investigate dissolved phosphorus or DRP specifically.

Eroding streambanks were found to contribute the most suspended sediment during high flow flows in a study of agricultural heavy watersheds in southern Minnesota (Williamson et al., 2014). However, that study found streambank material did not contribute the majority of channel sediments in streams where the edges of fields were removed from row crop use through the federal Conservation Reserve Program. This indicates that buffer areas along stream sides can reduce streambank sources of phosphorus export.

A recent paper calculated the contribution of streambanks to total phosphorus export throughout the state of Iowa (Schilling et al., 2022). This work used a simple equation based on channel dimensions linked to erosion that was inferred with remote collected light detection and ranging (LiDAR) data. Combining that analysis with previous streambank recession rate studies, allowed for the calculation of the amount of sediment being eroded from channels statewide. The authors applied this mass of eroded sediment to the average streambank phosphorus content they found from a sampling to determine the mass of total phosphorus contributed to streams from streambanks for the state. Comparing this with a calculation of how much total phosphorus is exported though the state's streams allowed them to determine that 31 percent of river exported total phosphorus in Iowa is from streambanks.

Calculating the proportion of phosphorus sourced from streambanks by analyzing the actual phosphorus being exported by streams is also being examined. Studies by USGS utilize sediment fingerprinting methods to understand the relative contribution phosphorus in stream's suspended sediments (Williamson et al., 2020). These methods have been applied to small streams in the Maumee watershed with the intent to understand the phosphorus contribution from streambanks and other upland sources. Antecedent soil moisture and vegetation cover prior to storm events appear to make a difference in streambank erosion (Williamson et al., 2021a). That study, looking at a Maumee tributary watershed, found phosphorus export was mainly in the DRP form when conditions were dry, and crops were on the fields. However, streambank erosion was the main source of exported total phosphorus when storms occurred when conditions were already wet.

Sediment fingerprinting research by the USGS in the Maumee watershed continues with the objective to improve estimates of the magnitude of streambanks as a phosphorus source. Preliminary indications show that streambanks can contribute a high proportion of suspended sediment in one Maumee tributary over a two-month monitoring period (Williamson et al., 2019). This work also includes analysis of the short-lived beryllium-7 isotope with the hopes of understanding if eroding soils, sourced from upland areas as well as streambanks, are from the surface or buried deeper. Scaling results up to larger watersheds, even to the entire Maumee watershed, is a long-term goal of this work.

Streambanks as a source of phosphorus is considered nonpoint within the TMDL framework in that it is unregulated by the Clean Water Act. It is also nonpoint in the sense that it is connected to precipitation driven hydrology. However, this is a source that is largely already existing in place, i.e., it is not dependent on ongoing activities such as regular fertilization. Contribution from upland legacy soil sources of phosphorus (largely described above) and instream processes interact with this streambank source. Once in the streambanks, slowing the export of phosphorus is the most reasonable approach to managing this source. As noted in the legacy and soil source section above, streambank sources will likely result in a lag of overall phosphorus export reduction even if upland phosphorus conservation efforts are greatly increased. Continued study by USGS and efforts described in Section 2.2.4 will help quantify this lag.

Channel alteration to improve drainage, i.e., ditching, disturbs stream systems' ability to store and process phosphorus. Practices such as two-stage ditches can provide a more stable structure to facilitate drainage needs (Kalcic et al., 2018). This stability allows for improved ecological functions such as sediment trapping and instream processing to contribute to overall net phosphorus reductions in a given period of time. This practice, and others, will be considered in the implementation recommendations for this report.

Reducing and slowing the amount of water delivered to streams during storm events can also reduce the net export of streamside phosphorus sources. Practices such as wetlands, especially in agricultural systems, and even more novel activities, such as small detention basins that can be used to irrigate crops during dry months, show promise in achieving suitable water management.

2.2.1.5. Natural sources

Natural sources of phosphorus, often considered the background, are known to contribute some load in most river systems. Weathering of soil and parent rock is described as the primary natural source of phosphorus (Holtan et al., 1988). Decomposition of aquatic life and washed off upland vegetation (such as leaf litter) can also be categorized as a natural source (Wither and Jarvie, 2008). For any of these sources to be considered natural they must be from undisturbed environments. For instance, eroded soil or leaf litter washed off from pristine land without human disturbances.

The amount of phosphorus delivered to streams from natural sources is considered very small compared to the human caused sources in disturbed watersheds (Wither and Jarvie, 2008). Even with 9 percent of the Maumee watershed area within Ohio classified as having natural land cover (Dewitz, 2021), it is understood that only extremely small areas, if any, are completely undisturbed. Because of this, the natural sources of phosphorus in the Maumee watershed are considered negligible. It is not a documented source in modeling efforts such as Kast et al. (2021) or Martin et al. (2021) and will not be itemized in this TMDL project.

Certainly, phosphorus was present and moved through the Maumee watershed and the WLEB before European settlement. Human land use disturbances have, in essence, overrun most of these natural sources. Therefore, if a greater proportion of land is placed into a natural state, or nutrient reduction implementation efforts mimic natural conditions, the proportion of natural sources would be expected to increase. However, because human land uses produce so much more phosphorus, the net effect would be a phosphorus reduction. This concept is often discussed regarding installing or enhancing wetlands for nutrient reduction. It should be considered when examining all nutrient reduction activities.

2.2.1.6. Atmospheric deposition

Unlike carbon and nitrogen, there is no stable gaseous phase of phosphorus in the Earth's atmosphere. The dominate source of atmospheric deposition of phosphorus globally is from mineral aerosols. In general, this is soil phosphorus mobilized by winds, often characterized as dust. In non-desert, industrialized areas such as the Great Lakes region biogenic aerosols and combustion deposits are primary sources (Mahowald et al., 2008). Based on monitoring data, Maccoux et al. (2016) calculated atmospheric deposition to Lake Erie's open water to contribute 6 percent of the total phosphorus load delivered to the whole lake. That study, and similar phosphorus accounting, incorporates atmospheric deposition of phosphorus to landmasses among all of the nonpoint sources. That is, atmospheric deposition is not itemized as a specific source when not over large bodies of water. While this source is clearly measurable, it is relatively uniform across the landscape on a regional scale making this approach reasonable. Because this TMDL only considers phosphorus exported from the Maumee watershed, direct atmospheric deposition will not be considered as a separate source.

2.2.1.7. Changes in watershed hydrology

Changes in precipitation amount, timing, and intensity present a complicating challenge to nonpoint source control of phosphorus. The earth's hydrologic cycle has been altered by human activities (Manabe and Stouffer, 1980; Milly et al., 2008; Abbott et al., 2019).

An ARS study by Williams and King (2020) examined hydrologic changes in the Maumee watershed. Twenty-three daily rainfall and 12 streamflow gages in and near the watershed were examined from 1975 through 2017. An overall increase in rainfall between 11 and 13 percent (see Figure 17) 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. A different statistical analysis approach of the Maumee River at Waterville and St. Marys River near Ft. Wayne gages found highly likely increasing streamflow trends in the days with the greatest 20 percent of streamflow (Choquette et al., 2019). That study did not find similar increases at the St. Joseph River near Ft. Wayne gage. The heterogeneity of hydrology in the watershed is discussed more below in Section 2.3 in considering critical source areas.

The Williams and King (2020) paper included implications of changing hydrology on phosphorus export in the Maumee watershed. It notes that agricultural conservation practices, such as improving soil infiltration and water holding capacities, has provided some increased water resiliency to the watershed. However, increased rainfall occurring via more extreme events (in relatively shorter periods of time) overwhelms the overall watershed water storage capacity. The authors say that this can directly increase DRP concentrations due to an increase of time with wet conditions. Therefore, many of the activities intended to address water management, especially subsurface tiling, play a role in facilitating increased DRP export.

Choquette et al. (2019) employs a different suite of statistical analyses to document trends on observed streamflow and nutrient exports. This work attributes about one-third of nutrient increase to increasing discharge trends. The remaining changes documented in this work occur due to greater nutrient concentrations in waters delivered throughout the Maumee watershed.

The Rowland et al. (2021) trend analysis explains that some, but less than half, of the DRP export is due to flow increases. Jarvie et al. (2017) attributes 35 percent of the historic DRP load increase to higher runoff volumes, likely exacerbated by increases in tile drainage and precipitation.

Overall, this implies that land management plays as much or greater a role in increasing nutrients as changes in hydrology. However, the two factors have had an additive impact on increasing nutrient loads.

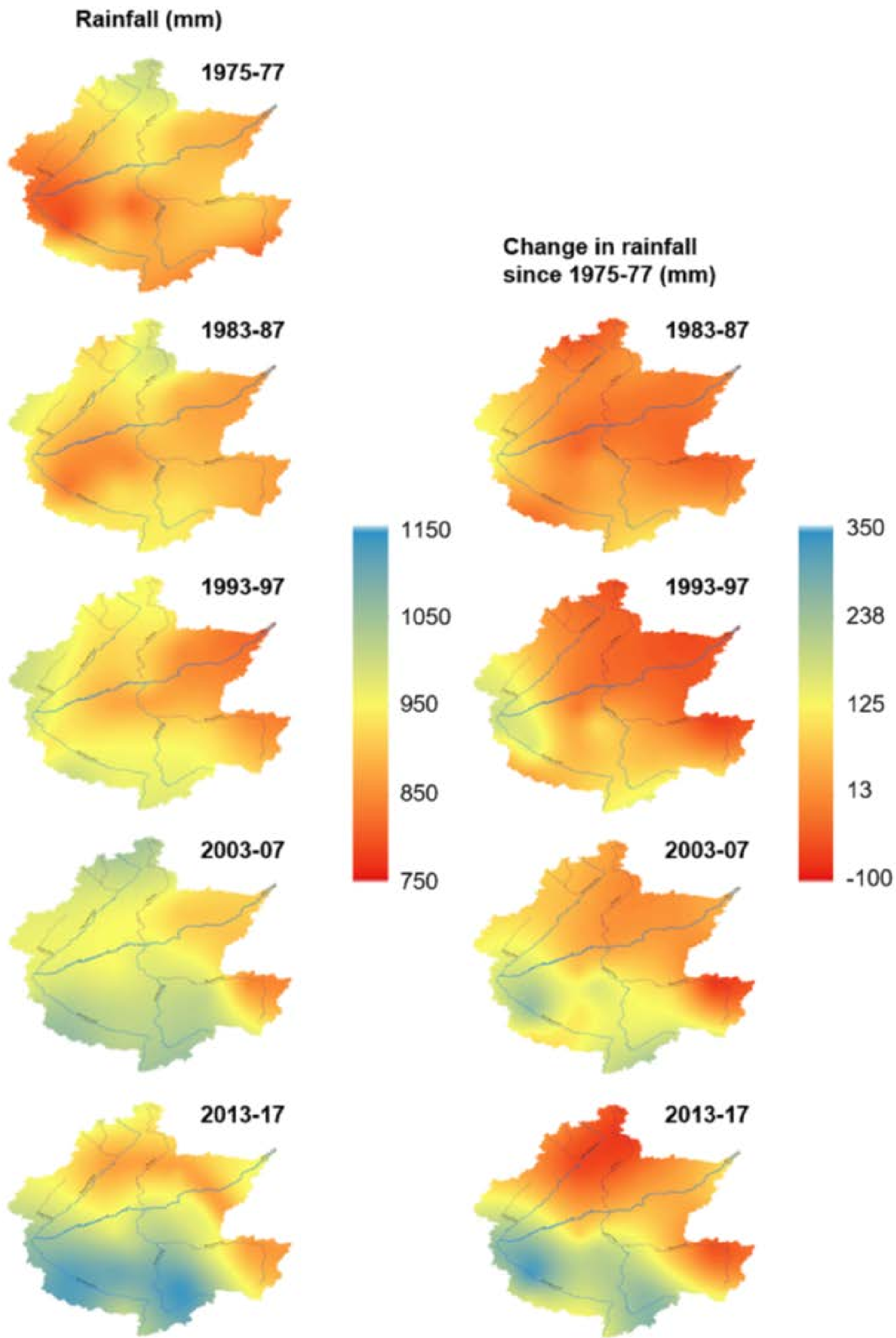


Figure 17. Rainfall trends for various time periods between 1975 and 2017. The right maps show the calculated differences from the 1975 to 1977 period. (Williams and King 2020)

Hydrology directly plays a role in all nonpoint sources discussed in this section as well as permitted stormwater sources, described below. Increased rainfall in the Maumee watershed has, and most likely will continue to, exacerbate controlling these sources. Note that there have been some modeling findings that impacts from climate warming may offset some of these issues due to increased evapotranspiration and decreased snowfall in the Maumee watershed (Kalcic et al., 2019). Regardless, hydrology must be considered when recommending, planning, and designing nutrient controls.

2.2.2. NPDES permitted point sources (including permitted stormwater) of phosphorus

This subsection describes permitted sources of phosphorus to the Maumee watershed. Ohio EPA regulates these sources via state of Ohio rules and in accordance with the NPDES framework. In TMDL budgeting, these sources fall within the wasteload allocations. The "major" municipal NPDES wastewater treatment plants, those treating sewage from the largest populated areas, contribute the greatest proportion of phosphorus among this category. Permitted stormwater from urbanized areas and some industrial sources are also included in this discussion. There are also many small sources of NPDES permitted phosphorus. Table 3 shows a breakdown of the various categories of permitted sources of phosphorus. These are explained throughout the remainder of this subsection.

Table 3. Summary of types of NPDES permitted sources. Detailed categories that are shaded in gray are not included in the phosphorus TMDL wasteload allocations.

Program	Permit Type	Major Category	Detailed Category
Treatment Facilities: Point source pipe(s) directly contributing waste to surface waters	**Individual NPDES Permit**: Facility-specific permits issued for each facility	**Public**: Treats a majority of municipal/human waste, most often delivered from public sewer systems	"Major": Plants that are permitted to treat about 1 million gallons a day or more
			"Minor": Plants that are permitted to treat less than 1 million gallons a day
		Industrial: Facilities that treat waste from industrial processes	Phosphorus discharging: Mostly commercial plants treating phosphorus at concentrations requiring treatment. e.g., food processing facilities
			Non-phosphorus discharging: Discharging plants that do not treat phosphorus at concentrations greater than background. e.g., most drinking water treatment plants
		Concentrated Animal Feeding Operation (CAFO)	Livestock operations meeting certain criteria requiring an individual permit; none in the Maumee watershed
	General: Permits that cover facilities with similar operations and wastewater characteristics	Phosphorus discharging	Discharging general permits considered to contribute phosphorus at concentrations greater than background, these include household sewage treatment systems and small sanitary discharges
		Non-phosphorus discharging	The several discharging general permits not considered to contribute phosphorus at concentrations greater than background
Stormwater:	**Individual**: Facility-specific permits	Facility based	Stormwater controls measures and pollution prevention provisions, very often included within individual treatment facility permits
		Municipal based	Phase I Individual MS4 Permits
	General: Permits that cover facilities or areas with similar operations	Facility based	Construction and multi-sector industrial general stormwater permits (aka, MSGP)
		Municipal based	Phase II Small MS4 General Permit
Beneficial Use	**Beneficial Use of Materials**: discharge of these materials is prohibited	Biosolids	Field application of biosolids generated by publicly-owned treatment works in Ohio
		Land application	Wastewater treatment effluent irrigation
			Industrial waste used for agronomic benefit

2.2.2.1 Permits for treatment facilities

Defining treatment facility permitting and its source contribution

Facilities that discharge directly to streams or other waterways are considered first. These act as what is typically considered a traditional point source. Unlike permitted stormwater, which is primarily driven by precipitation, these sources are more directly driven by treatment plant influent flow rates associated with receiving municipal sewage or industrial flows. Municipal and some industrial wastes contain concentrations of phosphorus that require additional management.

As seen on Table 3 above, treatment facility permits are first divided between individual and general permits. General permits are developed when the waste type and technology used to manage it are consistent and permit conditions can cover a large number of discharges.

Individually permitted treatment facilities that process primarily municipal/human waste are considered public permits by Ohio EPA. Municipal waste contains phosphorus due to nutrient inputs from human food consumption (Metson et al., 2012), detergents, and other activities. Ohio EPA divides these public permits into major and minor categories, which is largely determined by the volume of wastewater the facility is designed to treat. Plants that are permitted to discharge 1 million gallons a day or more of treated effluent are considered majors. There are 22 major, public, individual permits in the Maumee watershed, which are generally facilities operated by cities. Minor permits cover facilities operated by smaller communities or semi-public organizations treating human waste designed to discharge less than 1 million gallons a day of treated effluent.

Twenty-four communities in the Maumee watershed have (or had) permitted combined sewer overflows (CSOs), see Table 4. Communities with combined sewers have pipes that were historically designed to intentionally capture stormwater within the same sewers as sanitary wastewater. During heavy rainfall events, when the carrying capacity of these pipes is exceeded, CSOs are designed to discharge a mixture of stormwater and sanitary sewage to streams. Constructing new combined sewers is no longer permitted.

Table 4. Combined sewer overflow communities in Ohio's portion of the Maumee River watershed.

<table>
<tr><th>HUC-8 Name – Code</th><th>CSO Community</th><th>HUC 8 Name – Code</th><th>CSO Community</th></tr>
<tr><td>St. Joseph River – 04100003</td><td>Montpelier</td><td rowspan="4">Blanchard River – 04100008</td><td>Findlay</td></tr>
<tr><td>St. Marys River – 04100004</td><td>none</td><td>Dunkirk</td></tr>
<tr><td>Upper Maumee River – 04100005</td><td>Hicksville</td><td>Pandora</td></tr>
<tr><td>Tiffin River – 04100006</td><td>Fayette</td><td>Forest</td></tr>
<tr><td rowspan="9">Auglaize River – 04100007</td><td>Paulding</td><td rowspan="9">Lower Maumee River – 04100009</td><td>Defiance*</td></tr>
<tr><td>Ohio City</td><td>Wauseon</td></tr>
<tr><td>Payne</td><td>Delta</td></tr>
<tr><td>Van Wert</td><td>Deshler</td></tr>
<tr><td>Columbus Grove</td><td>Leipsic</td></tr>
<tr><td>Delphos</td><td>Swanton</td></tr>
<tr><td>Wapakoneta</td><td>Toledo†</td></tr>
<tr><td>Lima</td><td>Perrysburg</td></tr>
<tr><td></td><td>Napoleon</td></tr>
</table>

* Some Defiance CSOs discharge to the Auglaize River near its mouth to the Maumee River.

† Some Toledo CSO outfalls are outside of the Maumee River watershed and will not be included in this project.

Ohio EPA works to control CSOs through provisions in NPDES permits and using orders and consent agreements when appropriate. The agreements and permits require CSO communities to implement nine minimum control measures. Requirements to develop and implement Long-Term Control Plans (LTCPs) are also included where appropriate. Half of the CSO communities in the Maumee watershed are planning for complete separation and elimination of all CSOs, and in fact some of the communities listed on Table 4 have separated since the 2008 baseline year. Details about each communicates CSO status are presented in Section 3.

Bypasses from public wastewater treatment plants occasionally occur due to various factors overwhelming treatment capacity. These bypasses are prohibited unless certain conditions are met and a 'no feasible alternatives' analysis is completed. Steps are required to minimize the bypasses as part of this process, similar to CSO LTCPs.

Discharges from separate sewer systems occasionally occur due to various factors overwhelming sewer capacity. These sanitary sewer overflows (SSOs) are prohibited by the Clean Water Act and all NPDES permits. All communities with known SSOs must plan to eliminate these sources. All permittees are required to report SSO events, with various levels of monitoring, as a condition of their NPDES permit.

Individual NPDES treatment facilities that treat industrial wastewater from a specific facility are considered "industrial". On Table 3 these permits are divided based on whether their discharge is considered to contain phosphorus or not. Most of the industrial phosphorus discharging facilities in the Maumee watershed are related to the food processing category. Those considered as non-phosphorus discharging treat a variety of industrial wastes and include most drinking water treatment plants. This group of facilities has been determined to discharge phosphorus at levels that do not require additional oversight or control, often below background concentrations in the watershed. For this reason, they are not included in this TMDL's wasteload allocations.

There are no NPDES permitted CAFO facilities within the Maumee watershed. Large livestock operations are permitted as CAFFs by ODA. CAFFs are regulated through state operating permits, but not NPDES permits. CAFOs/CAFFs are discussed above, with fertilizer nonpoint sources, in Section 2.2.1.1.

Ohio EPA issues several general permits that cover activities resulting in non-stormwater related discharges of wastewater. Unlike individual NPDES permits, these permits cover a type of activity rather than a specific facility, then specific facilities that conduct that activity apply for coverage under the general permit. Therefore, many facilities are covered under each general permit, some in the thousands. The treatment technologies for these sources are consistent and eligibility criteria and/or appropriate limits within the general permit ensure individual evaluations are not needed to ensure water quality standards are met. Note that these facilities almost always contribute less pollutants than the minor public individual permits outlined above. General permits are divided into those considered to discharge wastes with phosphorus concentrations greater than the background and those at or below background concentrations. The general permits that include phosphorus containing discharges cover discharging household sewage treatment systems and small sanitary discharges (i.e., very small package plants, such as restaurants or mobile home parks). The non-phosphorus discharging general permits are not included in the wasteload allocations of this TMDL.

All individual NPDES permits require that effluent volume be monitored prior to being discharged to streams. Nearly all of these permits also require effluent total phosphorus monitoring. The frequency of required monitoring is greater for major public permits than minors. Monitoring of CSO discharges varies due to the different configurations of CSOs; however, permits for all CSO communities require some fashion of CSO monitoring.

Utilizing these monitoring data, Ohio's Nutrient Mass Balance reports that NPDES permittees contribute a five-year, spring loading season average of 6 percent of the Maumee watershed's total phosphorus load (Ohio EPA, 2020b). This proportion includes the calculated CSO loads and the load from the general permit for discharging household sewage treatment systems. The total phosphorus load from the other general permits were not included in Ohio's Nutrient Mass Balance methods and thus do not appear in the remaining figures in this section. However, they are accounted for in this TMDL, see Sections 3 and 4.

Figure 18 shows the breakdown of the 6 percent of total phosphorus spring load contributed by NPDES facilities by treatment facility category from Ohio EPA's Nutrient Mass Balance 2020 report (Ohio EPA, 2020b). This pie chart includes the combined NPDES facility loads from Michigan and Indiana. These "out of state" loads represent 28 percent of the total load from NPDES permitted sources. The other slices of the pie are from the various categories described above from Ohio facilities. The major public wastewater treatment facilities from Ohio are the largest of these categories, at 48 percent of the total NPDES permitted load, which is approximately two-thirds of the load from treatment facilities in Ohio.

Figure 18 also includes the calculated loads from CSOs and other wet weather bypasses, except SSOs. These sources from Ohio make up 2 percent of the spring load from NPDES permittees, or around 0.12 percent of the total spring phosphorus load. In 2020, Ohio EPA learned that the city of Maumee had SSOs that had been unreported for several years. The City entered into orders with Ohio EPA in July 2021, agreeing to pay a penalty and to take immediate actions to work to eliminate these SSOs. Preliminary estimates of the unreported total phosphorus load contributed from the city of Maumee's SSOs were calculated by Heidelberg University's NCWQR, which determined that these loads would have added less than 0.02 percent of the annual phosphorus load. Elimination of these SSOs is currently being planned with an evaluation study due in 2024. SSOs overall are a minor contribution to the total phosphorus load, and they are prohibited, therefore all implementation actions are geared towards elimination, and they will not be included in the TMDLs wasteload allocation.

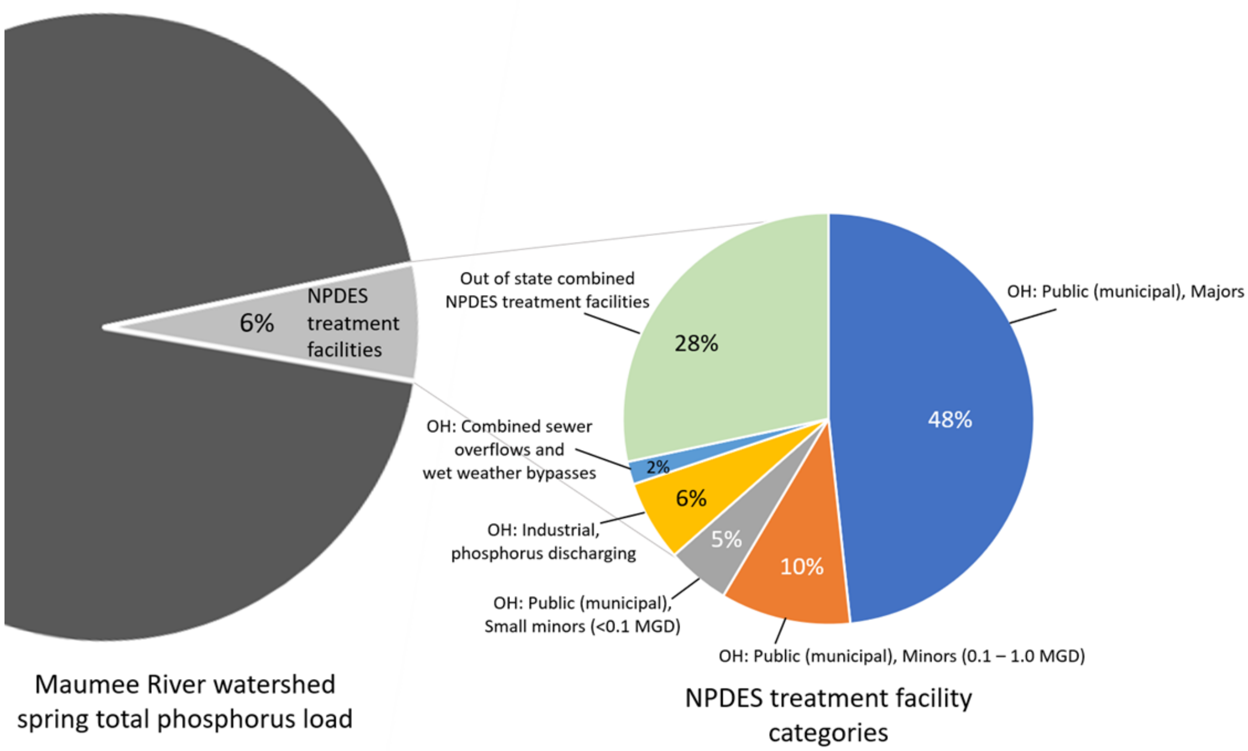


Figure 18. The left pie chart shows the five-year (2015-2019) average spring season total phosphorus Maumee River watershed load proportion of NPDES treatment facilities. The right pie chart breaks that 6 percent down by treatment facility categories. (Ohio EPA, 2020b)

There is a wide distribution in the amount of total phosphorus delivered from the 22 individual major public wastewater treatment facilities within Ohio's portion of the Maumee watershed. Figure 19 shows this distribution based on the five-year (2016-2020) average annual total phosphorus load proportions of these sources. The five largest facilities contribute 83 percent of the total. The remaining 17 major Ohio public facilities contribute 17 percent of this load. Figure 20 shows a breakdown of all 22 of these facilities. This figure outlines the five-year (2016-2020) average total phosphorus load and concentration for each facility based on Ohio Nutrient Mass Balance calculation methods (Ohio EPA, 2020b). The figure also shows the proportion of each facility's discharged flow of their permitted design flow rate.

Discharged total phosphorus concentrations of the facilities shown on Figure 20 indicate that phosphorus treatment is occurring at all plants.

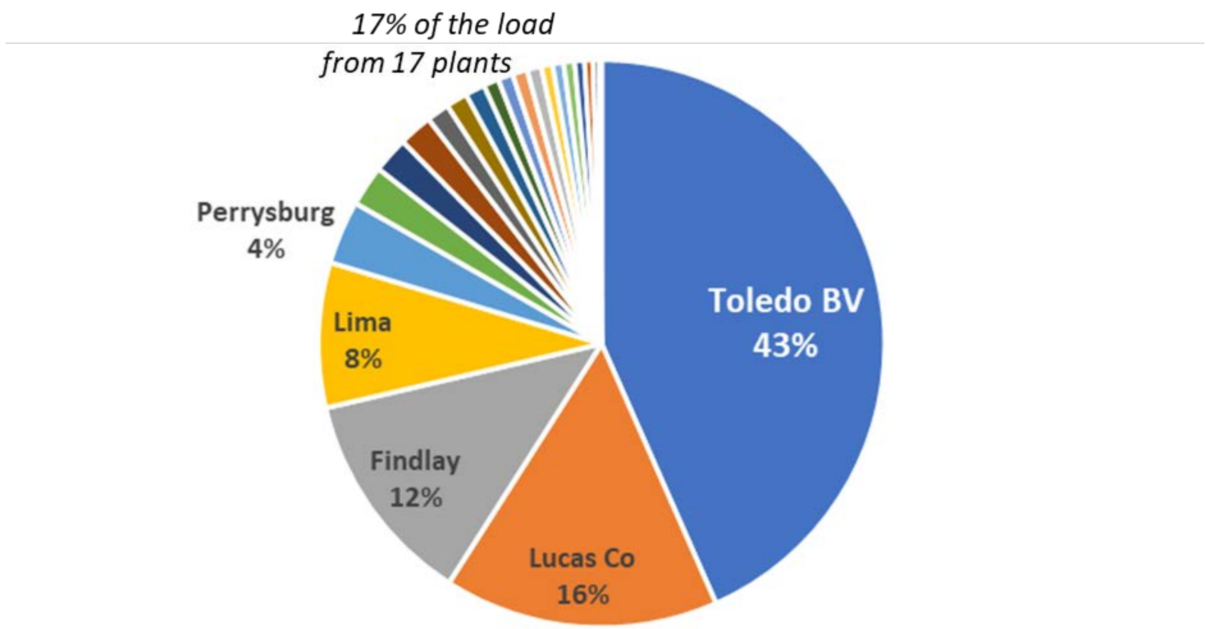


Figure 19. Pie chart showing the proportion of total phosphorus load from each individual public treatment facility within Ohio's portion of the Maumee River watershed. Loads based on the five-year (2016-2020) annual average calculated using Ohio Nutrient Mass Balance methods. (Ohio EPA, 2020b)

SWAT modeling described in Kast et al. (2021) examined NPDES permitted facility phosphorus source contributions from the Maumee watershed to Lake Erie. This work found these point sources contribute an average of 5 percent of the total phosphorus and 12 percent of the DRP during the spring loading season. As with Ohio EPA's Nutrient Mass Balance work, this modeling found permitted facility loads to fluctuate very little compared to hydrology-driven nonpoint sources. Because of this, facility-based point sources contribute a greater proportion in drier years and lesser proportion in the wettest years. The Kast et al. (2021) paper points out that on average, point sources contribute a similar proportion of phosphorus as manure fertilizer sources.

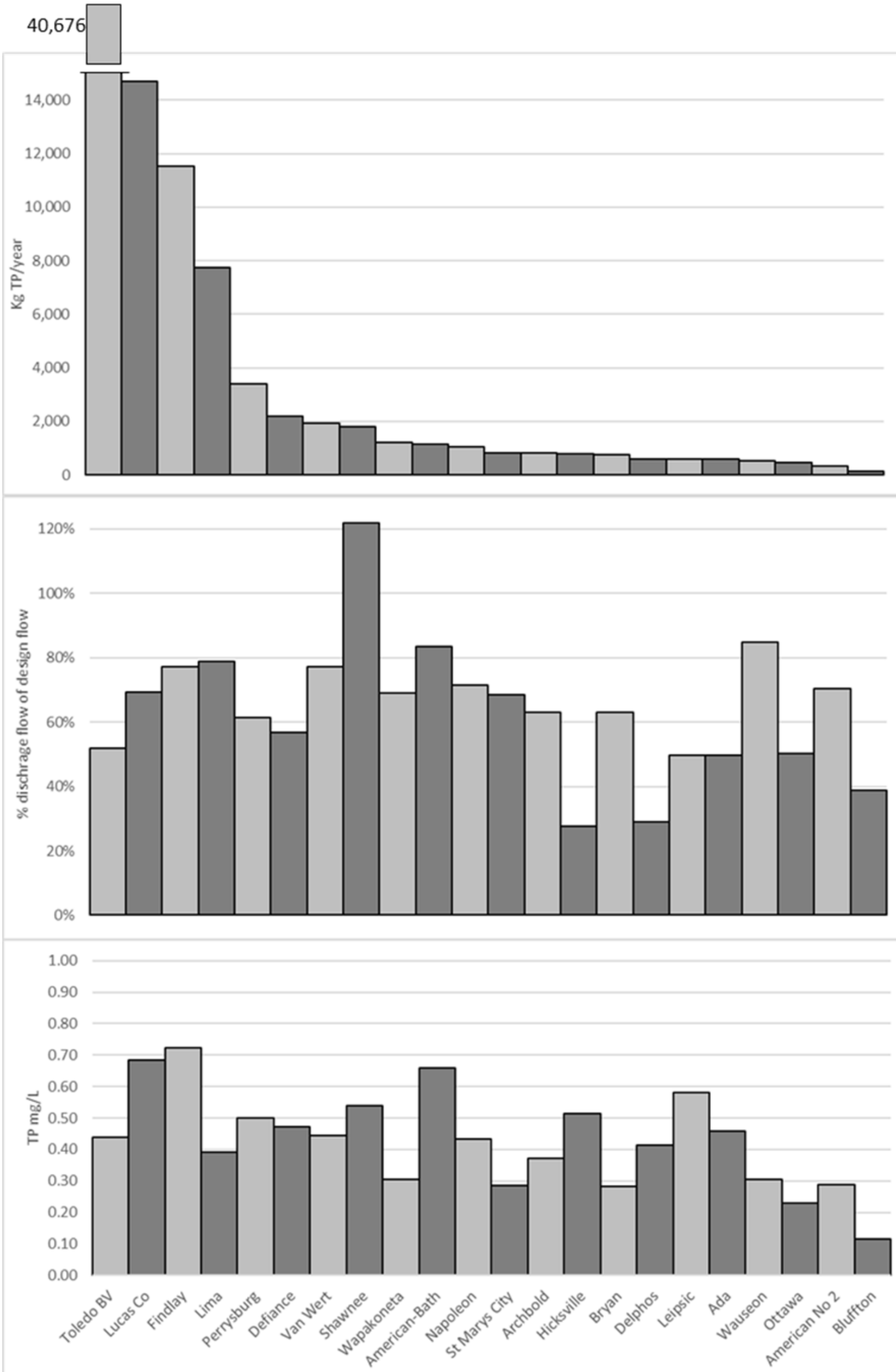


Figure 20. Three bar charts showing all major individual public treatment facilities within Ohio's portion of the Maumee River watershed. The top chart shows total phosphorus load. The middle chart shows the proportion of discharged flow of each facilities permitted designed flow rate. The bottom charge shows total phosphorus concentrations. All statistics show the five-year (2016-2020) annual average calculated based on Ohio Nutrient Mass Balance methods. (Ohio EPA, 2020b)

Existing facility-based (discharging) point source reduction efforts

Reducing phosphorus from municipal sewage wastewater treatment facilities and applicable industrial facilities has been ongoing in the state. Beginning with the GLWQA in 1972, municipal point source discharges were acknowledged as contributors to the nutrient loadings to the lake. The early versions of the GLWQA recommended that all major wastewater treatment plants (WWTPs) discharging within the Lake Erie basin meet a 1.0 mg/L total phosphorus effluent concentration. By 1980, the affected WWTPs were implementing reduction efforts to a level that nonpoint sources became the major contributor of phosphorus loading to the lake. A majority of the WWTPs began treating for phosphorus through the addition of metal salts to precipitate phosphorus and incorporating it into the solids waste stream.

Coupled with the treatment at the major WWTPs were reductions in the phosphorus content in laundry detergents. Beginning in the late 1980s, Ohio began limiting the allowed amount of phosphorus in household and commercial laundry detergents. In 2010, Ohio became one of 16 states that also included a requirement that dishwasher detergent could not contain more than 0.5 percent phosphorus. Not only did these measures reduce the influent phosphorus concentration to the WWTPs, but also reduced contributions from uncontrolled point sources such as CSOs and bypasses. In collaboration with the Ohio Lake Erie Phosphorus Task Force, the Scotts Company, LLC has removed phosphorus as a component of residential lawn fertilizers used for lawn maintenance. This effort has further reduced inputs from CSOs and MS4 permitted stormwater communities considered in Section 2.2.2.2.

For historical perspective, springtime total phosphorus from major public NPDES permittees dating back to 1995 are provided in Figure 21. This period was chosen to develop an understanding of total phosphorus loads from major facilities during the period of re-eutrophication of Lake Erie from the mid-1990s to the mid-2000s. The largest dischargers are city of Toledo Bayview WWTP, Lucas County WRRF, city of Lima WWTP, city of Findlay WWTP, and city of Perrysburg WWTP. These facilities are presented individually in the figure with the 18 remaining major municipal wastewater treatment facilities grouped together.

Major municipal facility loading remained relatively flat during the period of re-eutrophication of the WLEB (1995-2005), followed by a period where springtime total phosphorus loads show a downward trend (2005-2018). Total phosphorus load from major municipal facilities averaged 53 MTs per spring from 2004-2008 and 42 MTs per spring from 2014-2018. This was a net decrease of 22 percent for major municipal facilities in the Maumee River watershed from the period leading up to the 2008 base year and the most recent conditions. The downward trend is attributed to voluntary load reductions, mainly driven by the Toledo Bayview WWTP. In the five springs from 2004–2008, the Toledo Bayview WWTP discharged an average of 29 MT/spring but averaged 18 MT/spring for 2014–2018.

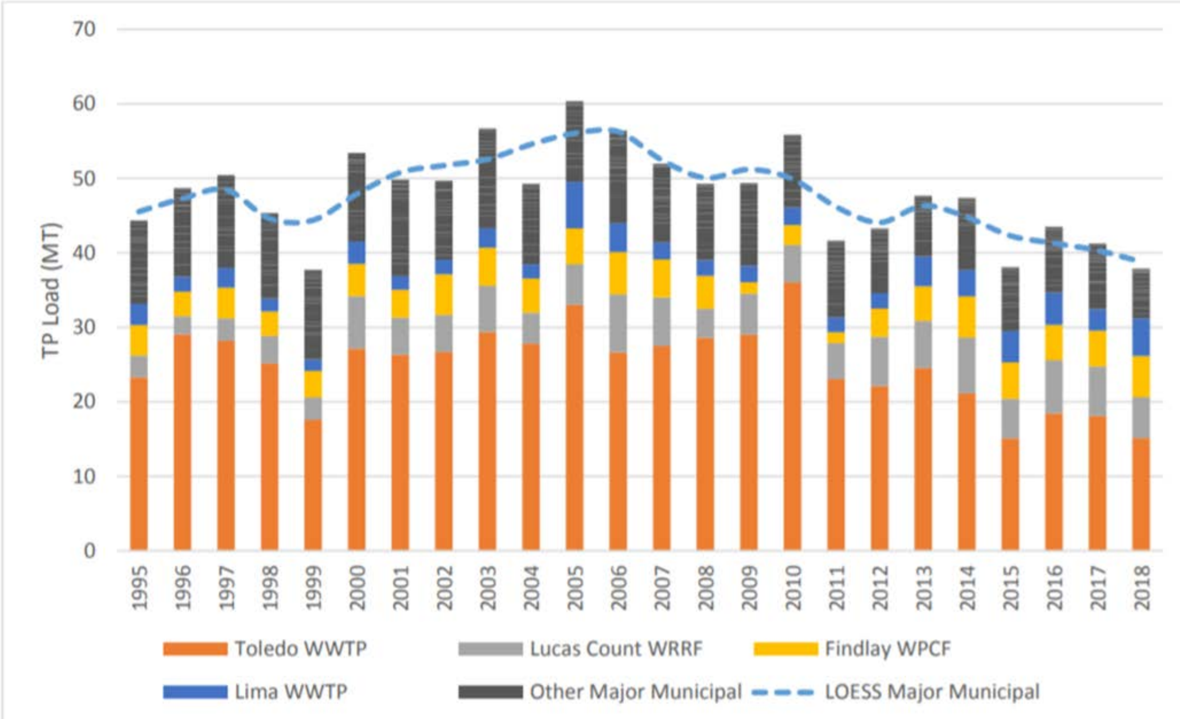


Figure 21. Springtime total phosphorus loads from major public facilities in the Maumee River watershed in Ohio's portion of the Maumee River watershed from 1995-2018. The LOESS line presents a locally weighted smoothing trend line.

The state of Ohio has invested in nutrient reduction efforts by offering financial assistance to communities with NPDES permits for wastewater treatment plant upgrades and CSO control projects. Through the Water Pollution Control Loan Fund, Ohio EPA has provided WLEB communities with over $1 billion in wastewater resource infrastructure project loan funds between 2009 and 2022 (to date). Nearly $88 million of these funds have been provided as principal forgiveness (OLEC, 2020b).

While major municipal WWTPs are required to achieve an effluent concentration of 1.0 mg/L to comply with their NPDES permits, many treatment plants consistently perform well below this level. One reason for this is to remain in compliance throughout varying flow rates, operating conditions, and process upsets. A facility would need to achieve a long-term average concentration of 0.73 mg/L in order to remain in compliance 99 percent of the time (U.S. EPA, 1991). Long-term averages lower than this value indicate that performance is better than what is needed to maintain minimum compliance.

Figure 22 shows the spring total phosphorus loads from phosphorus discharging facilities with individual permits in Ohio's portion of the Maumee River watershed from 2008-2018. Note that the "authorized load" shown in this figure is the total loads of all facilities if they were to discharge at their permitted design flow and total phosphorus concentration limit (or existing concentration for facilities without limits). This indicates that, as a whole, these facilities are discharging less than half of the phosphorus load allowable under their permits. The bottom chart on Figure 20, above, shows that treating to concentrations below the 1.0 mg/L permit limit explains much of this performance. The middle chart of that figure shows that actual average volume discharged being below the facility permitted design is also a factor.

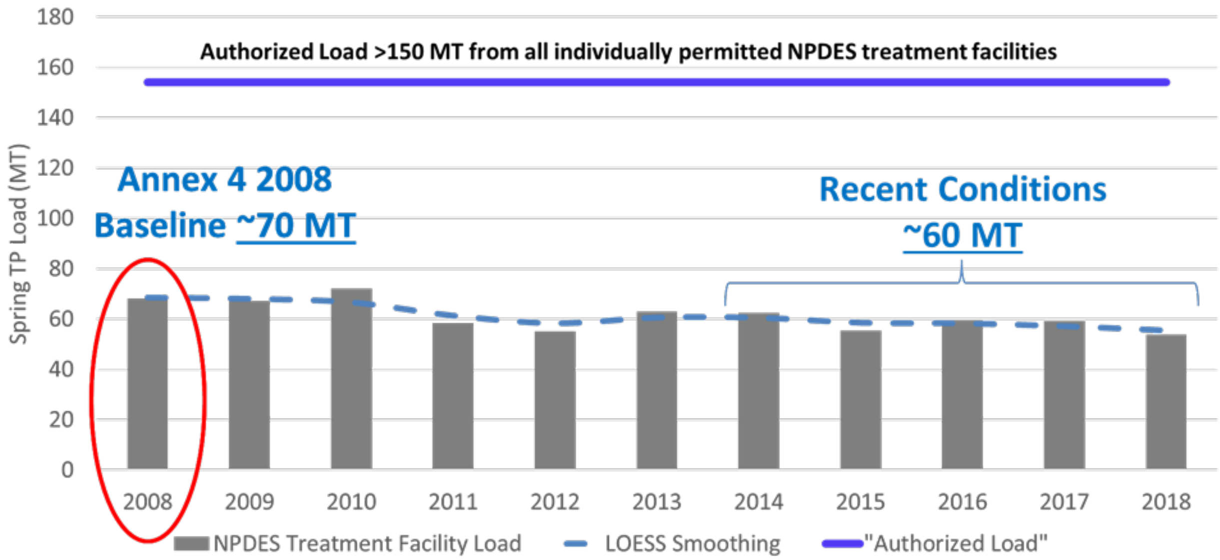


Figure 22. Spring loading season total phosphorus loads from phosphorus discharging public facilities with individual permits in Ohio's portion of the Maumee River watershed from 2008-2018. The authorized load bar shows the total loads of all facilities considering they were to discharge at their permitted design flow and total phosphorus concentration limit.

Permitted facilities have invested heavily in phosphorus reductions over the last several decades. Today, they contribute a relatively minor source contribution to the Maumee watershed's overall load. Incremental gains continue to be made through optimization.

2.2.2.2. Permitted stormwater

Stormwater discharges are generated by runoff from land and impervious areas such as paved streets, parking lots, and building rooftops during rainfall and snow events. Stormwater often contains pollutants in quantities that could adversely affect water quality. The primary method to control stormwater discharges is through the use of BMPs. Many of the watershed's stormwater discharges are regulated, considered point sources, and require coverage by an NPDES permit. Table 3, above, outlines the individual and general NPDES permits authorizing stormwater discharges.

Industrial facilities must apply to be covered by Ohio's Multi-Sector General Permit (MSGP) if they have the potential to discharge stormwater to a surface water of the state and participate in one or more of the 29 industrial sectors outlined the permit. Facilities in these categories that do not have industrial materials or activities exposed to stormwater may file a No Exposure Certification form to Ohio EPA in lieu of obtaining NPDES permit coverage and submitting an NPDES permit application. Facilities covered by the general permit must implement stormwater controls and develop a stormwater pollution prevention plan.

Many facilities that have individual public or industrial treatment facility permits (described in section 2.2.2.1) meet the requirements for the MSGP. In most of these cases, stormwater control measures outlined in the general permit are incorporated into the facility's individual permit for their treatment facility's discharge(s). This allows the facility to not have to apply for the general permit. Ohio EPA also has the discretion to require a facility to apply for an individual NPDES permit for stormwater controls. This most often happens for facilities with a history of known stormwater control issues. Stormwater controls outlined in an individual facility NPDES permit are similar to the MSGP; however, additional regulatory scrutiny occurs at individually permitted facilities.

Ohio EPA also maintains a general permit to limit the impacts of stormwater from construction sites. Projects that disturb one or more acres of ground must apply for this general permit. Projects that disturb less than one acre but are part of a larger plan of development or sale also need to be permitted to discharge stormwater. Conditions of the Construction General Permit require BMPs to control sediment export during soil disturbances, as well as the implementation of non-sediment pollutant controls for other activities related to construction (e.g., fuel storage, concrete rinse, fertilizer storage/application). Post construction practices that provide extended water detention and enhanced infiltration are intended to reduce and slow water and pollutants movement out of the developed area.

U.S. EPA and Ohio EPA's stormwater programs addressed municipal-based stormwater runoff in two phases. Phase I of the stormwater regulations required NPDES permits for discharges from MS4s serving large and medium municipalities. The size of population the MS4 services dictates if it is considered a large or medium municipality. These Phase I MS4s are required to obtain an individual NPDES permit. Toledo is the only Phase I MS4 community in the Maumee watershed.

The Phase II MS4 regulations address stormwater runoff of areas serving populations less than 100,000, termed small MS4s. More particularly, small MS4s located partially or fully within urbanized areas, as determined by the U.S. Census Bureau, and on a case-by-case basis outside of urbanized areas that Ohio EPA designates into the program. Small MS4s are permitted in Ohio via a general permit. There are several communities within the Maumee watershed covered by the MS4 General Permit (e.g., suburban Toledo communities, Findlay, Lima, Defiance, and Bowling Green).

All MS4 permits require the development of a stormwater management program. These permits encourage green infrastructure BMPs such as bioretention areas, vegetated swales, and permeable pavements. The Phase I Toledo MS4 permit requires additional measures such as inspections of industrial and commercial stormwater discharges, as well as monitoring outfalls from various land uses and to assess BMP performance. Monitored parameters have include phosphorus and DRP.

Traditionally, stormwater controls have focused on the abatement of exporting solids. As most soils are rich in phosphorus, these efforts address phosphorus export, mostly in the particulate form. Some states in the U.S. have more directly included nutrient export considerations into their stormwater permitting programs. For instance, several states require that nutrient removal rates be calculated for practices outlined in stormwater plans. Ohio EPA is studying how such a framework could fit into Ohio's stormwater permitting program in a manner that is scientifically sound.

Stormwater behaves in the manner of nonpoint source pollution in that it is driven by precipitation. In Ohio EPA's Nutrient Mass Balance reports, all stormwater is grouped within the coarse nonpoint source category (Ohio EPA, 2020b). However, TMDLs require that permitted stormwater be included within the point source wasteload allocation. Because of this, the land area covered by stormwater permits has been estimated for this project. Section 3.9 below outlines the details of this accounting. It finds that 4.3 percent of the watershed's total area within Ohio is covered by Ohio stormwater permits.

With the Maumee being an agriculturally dominated watershed, much less direct study of nutrient export from developed land stormwater has occurred within the watershed. Similar to unregulated nonpoint sources, hydrology drives stormwater runoff and is an important factor when considering this source.

A study of various residential communities in Florida found DRP dominated the phosphorus runoff in more than 90 percent of storm events monitored (Yang and Torr, 2018). This was attributed to the decomposition of plant material such as leaf litter, grass clippings, and eroded soils when conditions were wet. After prolonged dry periods, more soil-bound particulate phosphorus was found to runoff in that work. Trees, especially when streetside, were found to contribute the majority of phosphorus load from residential areas in a St. Paul, Minnesota study (Janke et al., 2017). USGS examined the impact of both leaf litter and the delivery of phosphorus via streets in a study of urban areas in Wisconsin (Selbig et al., 2020). This work found that frequent municipal street cleaning/sweeping can reduce total phosphorus and DRP load export by up to two-thirds compared to controls without street cleaning.

A study (Hobbie et al., 2017) examining nutrient budgets, also in St. Paul's urban areas, found pet waste dominated the phosphorus inputs to the system. While this brings up a different residential source, the study found greater overall phosphorus export was due to high density of streets facilitating the stormwater runoff.

Older research, such as a detailed study of residential areas in Madison, WI, in the 1990s, found lawns and streets to contribute the majority of total phosphorus and DRP (Waschbusch et al., 1999). The actual role of lawn fertilizer is often discussed as an urban stormwater source. In collaboration with the Ohio Lake Erie Phosphorus Task Force, since 2012 the Scotts Miracle-Gro Company has removed phosphorus as a component of residential lawn maintenance fertilizers in Ohio. This follows a similar trend of not including phosphorus in lawn fertilizers across the country. An expert panel convened to look at urban stormwater for the Chesapeake Bay Partnership (Aveni et al., 2013) documenting various studies examining lawn fertilizer phosphorus bans. These studies found phosphorus concentration reductions in both total phosphorus and DRP by about a quarter compared to pre-phosphorus lawn fertilizer bans.

Residential areas are generally considered to contribute less pollutants to stormwater overall than from more intensive urban land uses based on a meta-analysis of urban stormwater studies (Simpson et al., 2022). That study found land use types predict stormwater quality better than the density of impervious surfaces. It also determined that dissolved nutrients, such as DRP, are less associated with solids and other pollutants most often examined from stormwater sources.

Modeling non-agricultural stormwater runoff has not been a priority in the Maumee watershed. Kast et al. (2021) modeled the watershed with a simulation considering agricultural fertilizers (both manure and commercial) were not applied and point sources were not discharging. Results from this simulation found over 55 percent total phosphorus and over 75 percent DRP reductions from the baseline spring loads. The authors note that soil sources, including legacy phosphorus, are very likely contributing much of the remainder of phosphorus export. Combined with information presented above, and the overall small proportion of developed land, stormwater from developed land is expected to be minor source of phosphorus to the Maumee.

The Maumee watershed has a dense network of continuous water quality monitoring stations at streamflow gages (further explained in Section 2.2.5). One of these stations, Wolf Creek at Holland, a Toledo suburb, drains an area of much greater density of developed area than the rest of the monitoring stations. As explained in Section 2.2.5, the available data for the Wolf Creek station shows reduced total phosphorus and DRP FWMCs compared to the more agricultural land use dominated stations. This substantiates the general understanding of the overall magnitudes of phosphorus export from urban lands vs. agricultural dominated watersheds. These factors were considerations used in Ohio's 2020 Domestic Action Plan's far-field total phosphorus targets developed for small watershed management units (OLEC, 2020b). In that work, the state considered all developed land runoff to contribute load total phosphorus at a rate half that from agricultural lands. This is concept is expanded upon in the baseline condition load calculations for this TMDL effort (Section 3).

The information presented in this section supports the continuation of stormwater BMPs. Water detention and retention can slow flow and potentially settle out pollutants that have runoff. Practices to increase ground water recharge and evapotranspiration show some promise in minimizing urbanization disturbances (Winston et al., 2016).

2.2.2.3. Permitted beneficial use

Biosolids

Ohio EPA's biosolids program regulates the beneficial use of biosolids generated by publicly owned treatment works in Ohio (OAC 3745-40). The goals of the biosolids program are to protect public health and the environment, encourage the beneficial reuse of biosolids and minimize the creation of nuisance odors. Beneficial use requires that biosolids are used for an agronomic benefit displacing other agricultural fertilizers discussed above in Section 2.2.1.1. Table 5 outlines the amount of biosolids applied and number of acres they were applied to in Ohio's portion of the Maumee over the last several years.

Table 5. Summary of annual beneficial use of biosolids in the Maumee watershed.

Land Application of Class B Biosolids		
Year	**Dry Tons**	**Acres**
2016	10,659	3,080
2017	7,634	2,957
2018	7,797	2,730
2019	9,851	3,118
2020	8,275	2,353
Average	8,843	2,847

Discharges from the storage and beneficial use of biosolids are prohibited and they will not receive a wasteload allocation in the TMDL. Runoff from agricultural fields, where appropriate management actions are followed, is agricultural stormwater and is part of the load allocation. Overall, biosolids are a small source of agricultural nutrients in the Maumee watershed. On average, biosolids were beneficially used as a source of agricultural nutrients on less than 3,000 acres per year in the Maumee watershed from 2016 to 2020.

Land application

Ohio EPA issues state permits that allow facilities to beneficially reuse liquid industrial wastes or land apply treated wastewater. These systems must be designed so discharges to waters of the state do not occur. Industrial liquid wastes must provide an agronomic benefit while protecting human health and the environment and treated wastewater must meet effluent limits in accordance with OAC 3745-42-13. These facilities are issued individual permits that contain different conditions specific to the treated wastewater or liquid industrial waste. There are three facilities authorized to land apply treated effluent and five facilities beneficially reusing liquid industrial waste with Ohio EPA state permits. These facilities will not receive a wasteload allocation in the TMDL.

2.2.3. Household sewage treatment systems

Residential homes not serviced by a municipal sewage treatment system maintain individual household sewage treatment systems (HSTS). HSTS fall into one of two main treatment types:

Onsite (non-discharging) or leach field systems percolate septic tank effluent through the soil. Soil microbes treat the effluent and there is no point source discharge from these systems.

Discharging systems provide enhanced treatment by creating an aerobic environment where microorganisms digest organic carbon and nitrogen is oxidized to non-toxic inorganic forms (i.e., nitrates). Effluent is then discharged to surface waters. Phosphorus treatment is minimal in discharging HSTSs.

Ohio Department of Health (ODH) rules for sewage treatment systems require that all new and existing systems are issued an operation permit with an identified maintenance schedule, and for discharging systems, a sampling schedule to ensure the system is meeting discharge standards. As of Jan. 1, 2015, all new and modified discharging systems are required to be covered by Ohio's general NPDES permit (OHK000004).

Both non-discharging and discharging HSTS systems can fail to treat waste as designed. Soils receiving septic tank effluent from non-discharging systems can become overloaded, sometimes this causes effluent to surface or short circuit, reducing treatment and resulting in discharges to surface water. A common failure of discharging systems occurs due to malfunctions of the mechanical components. In these cases, waste is minimally treated and exported pollutants are elevated.

Upon identification of a failing system, local health departments establish specific action plans and timeframes for correction of the nuisance conditions. These plans may include repair, alteration, or replacement of the sewage treatment system or connection to public sewers, where available.

In the TMDL accounting, phosphorus loads from HSTS can be considered nonpoint or point sources depending on if each HSTS is permitted. Non-discharging systems are not covered by Ohio EPA's general permit. Their load is accounted for as a nonpoint source in the TMDL's load allocation.

By design, discharging systems contribute a phosphorus load to the watershed. Because these are a permitted source, the loads fall into the point source category for TMDLs and are included in the wasteload allocation.

To account for HSTS source contributions, the population using HSTSs, partitioning of two major system types, and failure rates for these systems must be calculated. Ohio's Nutrient Mass Balance Report finds HSTS to contribute the smallest total phosphorus load to the Maumee watershed among its three coarse source categories. This is 2 percent for the average spring loading season (Ohio EPA, 2020b; also see Figure 6 above).

The Toledo Metropolitan Area Council of Governments (TMACOG) member-driven planning partnership has estimated critical areas with high densities of HSTSs in the Maumee watershed in Ohio (TMACOG, 2018). This work includes a detailed survey of HSTS locations. Dense areas of residences serviced by HSTS, most often in unincorporated communities, have been identified as these critical sewage areas. These are important as they identify the densest and therefore most cost-effective areas where HSTS pollution abatement can be targeted.

ODH will continue to work with local health departments to ensure implementation of their Operation and Maintenance Tracking Programs for sewage treatment systems as required in the OAC. ODH will provide options and resources for implementing operations and maintenance tracking including identification of failing sewage treatment systems within targeted watersheds. The number of discharging HSTS covered by Ohio EPA's HSTS General Permit will continue to grow as existing systems are upgraded and new ones are installed.

2.2.4. Instream processes

Instream processes such as biological activity or sedimentation can capture and release phosphorus. They also can change the chemical form of phosphorus which may have important implications to Lake Erie HABs. Which process dominates can vary in space and time, with season and streamflow levels playing key roles. Understanding these processes advances knowledge of phosphorus sources but can also provide insight on ways to store and slow the export of phosphorus. These processes are subject to active research and many unknowns still exist.

Soil particles eroded from fields and stream banks become sediments that are carried by swiftly moving water. Particulate phosphorus attached to suspended sediment settles at spots with slower moving water, such as natural pools and behind dams. Once deposited in stream channels, especially in pools, this sediment can be again resuspended when higher stream flows create the necessary forces (Sharpley et al., 2013).

During times of low streamflow and in warmer months, soluble phosphorus, most often represented with DRP, is sunk in the stream network due to incorporation by biological growth, predominantly by benthic algae (Dodds, 2006). This phenomenon has been observed by Ohio EPA. DRP concentrations in the Maumee River near the Waterville monitoring station are often near or below detectable levels during warm, low flow conditions with excessive benthic algae mats covering the streambed. Most of this captured DRP is released back to the stream as the algae dies or is washed off in high flows, and via other processes (Withers and Jarvie, 2008). This process is important in the near-field setting as excessive benthic algae can be deleterious to a stream's local ecological health.

DRP can also adsorb into or desorb out of stream bed sediments due to biogeochemical reactions. This is generally dependent on the nature of the sediment and DRP water concentration (Taylor and Kunishi, 1971; Kunishi et al., 1972). Stream bed sediment is known to have a certain phosphorus equilibrium concentration. When DRP concentrations in waters overlying bed sediments are greater than the sediments' equilibrium concentration, DRP can be adsorbed. Conversely, DRP can desorb from bed sediments into overlying waters when the water's DRP concentration is below the equilibrium; this is often described as "internal" loading. Stream bed equilibrium concentrations vary and are largely dependent on the chemical and geological nature of the sediment. Certain conditions are more favorable for this type of exchange to occur (Sharpley et al., 2007), and rates can vary greatly based on these conditions (Froelich, 1988).

ARS studies of ditches in the Maumee watershed have found that adsorption of DRP in ditches does occur. Fine sediments trapped by aggrading ditches remove relatively more DRP than recently dredged or "dipped" ditches (Smith and Pappas, 2007). The implications of these findings support the above implementation suggestion that more stable ditching practices be installed (i.e., two-stage ditches) rather than the traditional trapezoidal channels.

A review of delivery and cycling of phosphorus in rivers (Withers and Jarvie, 2008) noted that phosphorus transformations are expected to be the greatest under low flow conditions during the spring and summer, especially driven by instream algal activity and other eutrophication processes. That work notes, "most phosphorus inputs delivered under very high flows will be flushed through without entering the stream biogeochemical pathways." With most of the phosphorus exported from the Maumee watershed occurring during high flow periods (Baker et al., 2014a) this may indicate that instream processes are not of prime concern for this project.

However, it has been shown that during high flows it is possible for suspended sediment to adsorb soluble phosphorus in the flowing water. DRP has been found to transform to the particulate form through adsorption to instream suspended solids during high flow conditions at several Maumee watershed tributaries in a soon to be published study (King et al., in preparation). This work showed this novel process in 77 out of 78 samples in the flowing water. Another study that examined a small Maumee watershed tributary also found sediment carried by high flows may be adsorbing dissolved phosphorus (Williamson et al., 2021a).

Williamson et al. (2021b) focused on the anomalous stream flows, land management, and pollutant delivery that occurred in 2019. Several tributary monitoring stations throughout the Maumee watershed were examined. This work found that the 2019 reduction of DRP, but not total phosphorus, observed at Waterville (discussed above and shown in Figure 7 from Guo et al. 2021) did not occur at many of the smaller watershed monitoring stations. Williamson et al. (2021b) explains that this very well could have occurred due to desorption of sediment-bound phosphorus in those stream channels due to that year's reduced DRP ambient water concentrations. This provides more evidence that in stream cycling of phosphorus may have implications on a magnitude important to consider. It also provides insight as to the time lag that might occur for phosphorus export to reduce after phosphorus watershed imports are abated (as discussed by Muenich et al., 2016; Jarvie et al., 2013).

The King et al. (in preparation) study explains that the implications of the stream-water suspended sediment adsorbing DRP means the process can potentially be providing an environmental service. The paper suggests that transforming DRP to a less available particulate form during higher flows may account for reducing DRP exports to Lake Erie by 24 percent, thus decreasing HABs by 61 percent. As explained above, long term reductions in sediment delivery to the Maumee watershed may mean that this ecosystem service has likewise declined. This possibly plays a role in the DRP increase in western Lake Erie tributaries since the mid-1990s (as shown by Rowland et al., 2021).

Instream cycling and even trapping of DRP is an area of very active study in the Maumee watershed and similar watershed systems.

A USGS research project has measured sediment nutrient processes throughout the Maumee River watershed in 2019 and 2021. This work, being led by Dr. Becky Kreiling, involves measuring phosphorus source/sink dynamics at approximately 80 sites throughout the basin. To understand the capacity of phosphorus that sediment can store, the phosphorus saturation ratio will also be determined at each site. Instream flux rates of nitrogen are also included in this work. Models of sediment nutrient dynamics based on land use and sediment physiochemical variables are now being developed and various publications are expected within the next year from this effort (Kreiling, 2021).

A project being led by Dr. James Hood at OSU (HABRI, 2019) will evaluate when and where rivers within the Maumee watershed are sources or sinks of phosphorus. Separate methods for assessing low and high flow conditions will be incorporated. The high flow methods will expand upon the King et al. work (in preparation) which was performed by the same lab. Detailed field studies will be used to understand spatial patterns in sediment stocks, phosphorus content, and aspects of phosphorus cycling. This will allow for the sources and sinks of phosphorus to be mapped throughout the Maumee River's watershed stream network. The results from this work will be used to develop and parameterize instream phosphorus cycling into OSU's existing SWAT model for the Maumee (more on modeling below). With the coupling of instream processes to upland BMP modeling, the overall results of this project will improve what is known about BMPs that best address DRP reductions. This project's completion date is scheduled to be Dec. 31, 2022.

Another project out of Dr. Hood's lab (HABRI, 2020/2021) includes an evaluation of the sources and chemistry of sediment moving through the Maumee stream network. Methods will be employed to understand how long sediment of various sources takes to move though the watershed. Then an examination of the phosphorus cycling will occur with a focus on phosphorus sorption to and desorption from these sediments. Incorporating this work with the findings from the study noted in the paragraph above, the King et al. (in preparation) work, and the Williamson et al. (2021a) study will facilitate an improved understanding of how sediment source influences the sediment-DRP exchange during stream transport in high flow events. This project's completion date is scheduled to be Dec. 31, 2023.

A large, paired watershed study currently occurring within the Maumee watershed (ARS, 2019) will provide additional insight to nexus agricultural BMPs, nutrient and sediment runoff, and instream processes. Monitoring for this study is being organized by the USDA ARS/NRCS Conservation Effects Assessment Project (CEAP) program with Heidelberg University's Dr. Laura Johnson as the lead. It focuses on two small watersheds within the Blanchard River sub-watershed. Water quality and hydrology measurements are taking place in both watersheds to quantify loads. One will be held as a control while the other will be treated with a dense suite of BMPs. The BMPs selected will focus most on those promising to reduce DRP runoff (e.g., nutrient management, phosphorus removal structures) and those that retain water (e.g., drainage water management, blind inlets). OSU's Dr. Jay Martin has obtained a USDA Regional Conservation Partnership Program (RCPP) grant to augment funding for BMP initiatives and provide additional research and monitoring as part of this project. This project's original completion date was scheduled to be October 2022. However, the RCPP grant funding BMPs is expected to continue through at least 2027. Therefore, research findings from this work should continue for several years.

USGS is undertaking a study to examine most of the factors outlined in the two Hood studies noted above in Wisconsin's Fox River that feeds the Green Bay of Lake Michigan (Kreiling, 2021). This work will characterize the sources of sediment nutrients in streams, study the instream interactions (sources and sinks), and incorporate its findings into watershed models. The intent of this work is to improve sediment and nutrient export reductions to Green Bay management decisions. This has yet to begin with a project completion date expected in two to three years.

NRCS and ARS are just starting a multiphase CEAP project examining various aspects of legacy phosphorus (NRCS, 2021). This project covers study areas all across the country, including the WLEB. This work will develop a database that quantifies the contribution of legacy phosphorus at the edge-of-field and watershed scale from across the large study area. Watershed management recommendations will be made based on this work. What is learned of phosphorus cycling/movement will then be incorporated into an array of watershed models. This is a multimillion-dollar project with the completion date of 2026.

Recommendations to the IJC in 1980 on Great Lakes bioavailable phosphorus management strategies, noted that phosphorus discharge to streams, "have a markedly different effect on a downstream lake…compared to the effect that would result if phosphorus were discharged directly to the lake" (Lee et al., 1980). Location of the phosphorus discharge plays a role as less cycling expected or at least less time of streambed contact is expected. Dr. James Larson with USGS is researching how nutrients (N, P, and C) are transformed in the Maumee River mouth in Toledo. For this project, samples were collected at numerous sites in the river mouth three times in 2021 (May, July, and Aug.). The study continues with plans for repeat sampling in 2022 (Kreiling, 2021).

Estuary and lake dynamics utilizing monitoring that moves with pollutant masses (i.e., Lagrangian sampling) have been studied in the lower Maumee River and throughout the Maumee Bay. Employing these methods, Baker et al. (2014b) found rapid deposition of suspended sediment and particulate phosphorus as the river water enters the bay during high/storm flow periods. These findings keep the emphasis on the DRP as the main driver of western Lake Erie HABs.

Taken as a whole, these complex processes can be of importance to the export of phosphorus from the Maumee watershed. This TMDL project focuses on nutrients delivered to Lake Erie during the spring loading season (March through July). The DRP that is captured in stream channel primary production, especially in the later part of this season, may provide a measurable service. However, the magnitude of this service is assumed to be minimal, mainly impacting concentrations during lower flow periods. Alterations to headwater streams and ditches has implications to the erosion and movement of sediment. They also play a role in capturing or releasing DRP. The DRP transformed to particulate form by suspended solids throughout the watershed may play a larger role in understanding the changes of DRP loads to western Lake Erie over time. This process seems to occur during higher flow periods. The loads of suspended solids have changed as has the rate and magnitude of streamflow.

How to best use the understanding of instream processes to achieve phosphorus export reductions is a work in progress. Ongoing studies may provide more evidence to the overall implications of the whole of these processes. In addition to promoting stream channel stability, other implementation actions that maximize instream processing, or "sinking", of DRP may prove useful in the portfolio of recommendations.

2.3. Critical source areas and overall heterogeneity of sources in the Maumee watershed

The Maumee watershed is approximately 5.3 million acres. While its land use is dominated by agricultural row crop production, the landscape is heterogenous. Land management activities (such as row crop drainage practices) change in response to that geographic heterogeneity. These factors result in disproportionate pollutant loads being delivered from different parts of the watershed. Areas with higher relative pollutant losses are often termed critical source areas (CSAs). Analysis of modeling and water quality monitoring provides evidence for CSAs of various spatial scales throughout the Maumee watershed. This section will present the current state of knowledge of Maumee watershed CSAs.

First, though, a review of the watershed's major ecological and geographical zones.

Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources; they are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. Ecoregions are directly applicable to the immediate needs of state agencies including the development of biological criteria and water quality standards as well as the establishment of management goals for nonpoint source pollution. They are also relevant to integrated ecosystem management, an ultimate goal of most federal and state resource management agencies. The following factors are considered when determining ecoregions: geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (this paragraph's content from U.S. EPA, 2012). The Maumee watershed drains two ecoregions at the level III resolution as defined by U.S. EPA (2012), the Huron/Erie Lake Plains and the Eastern Corn Belt Plains (Figure 23).

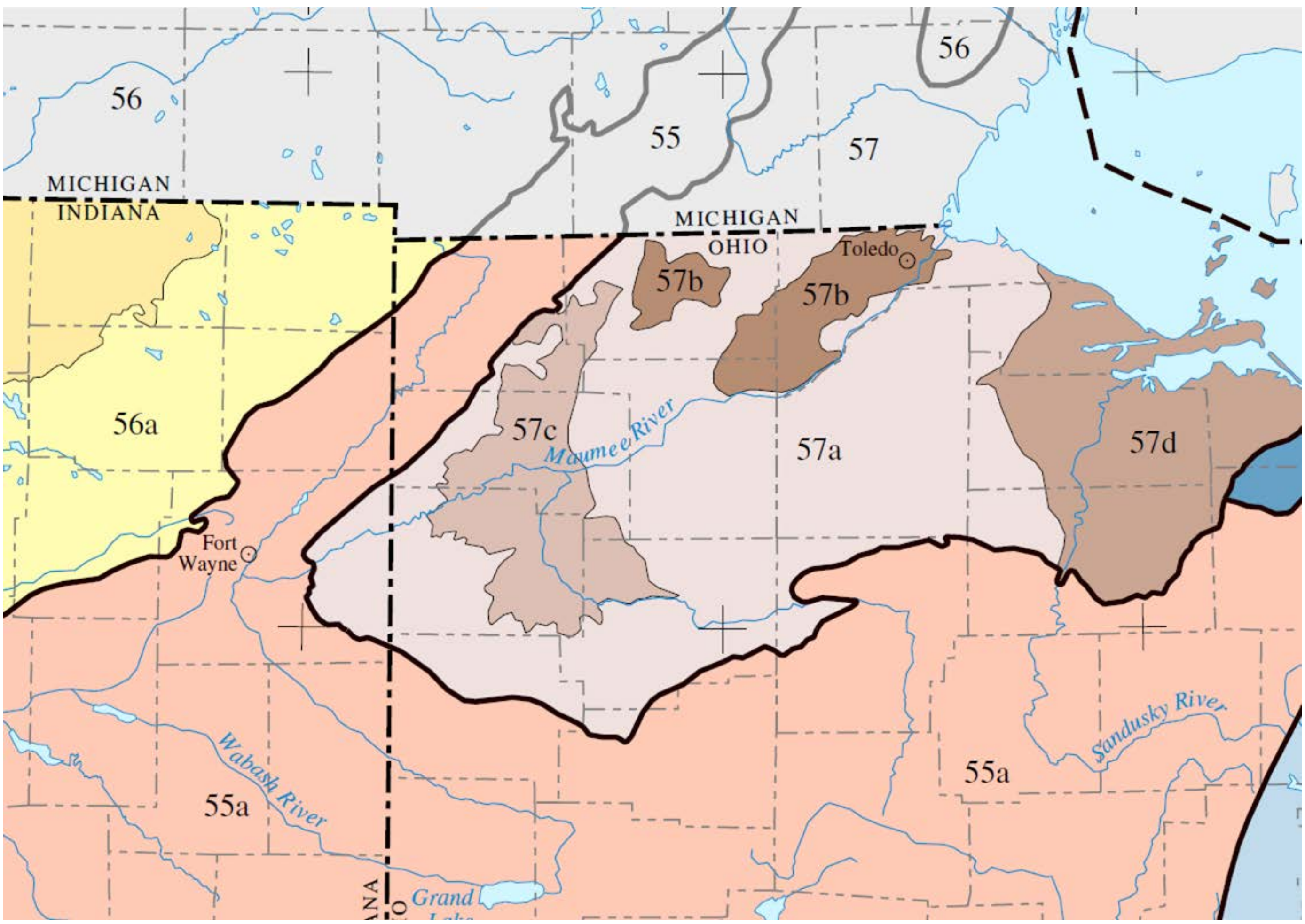


Figure 23. Ecoregions of the Maumee River and adjacent watersheds.

Labels starting with the number 57 on Figure 23, show the Huron/Erie Lake Plains ecoregion. This area covers broad, fertile, nearly flat plains punctuated by relict sand dunes, beach ridges, and end moraines. The soils in this ecoregion were the most poorly drained of all ecoregions in Ohio. Today, most of the area has been cleared and artificially drained. It now contains highly productive farms producing corn, soybeans, livestock, and vegetables. Three subcategories (level IV) of this ecoregion exist in the Maumee watershed (U.S. EPA, 2012).

Much of the Maumee watershed in Ohio is drained by the Huron/Erie Lake Plains, Maumee Lake Plains level IV ecoregion (labeled 57a on Figure 23). This area is naturally poorly drained and contains clayey lake deposits, water-worked glacial till, and fertile soils. Elm-ash swamp forests and beech forests that once existed have been replaced by productive, drained farmland (U.S. EPA, 2012).

A portion of the Huron/Erie Lake Plains in the Maumee watershed is classified as being in the Paulding Plains level IV ecoregion (labeled 57c on Figure 23). This area drains much of the Auglaize and Tiffin rivers' watersheds. This lake plain area is characterized by clayey lacustrine sediment and extensive, very poorly drained, illitic (clay) soils. The near-level to level and depressional topography supported mostly elm-ash swamp forest but now has been cleared and drained for soybean, small grain, corn, and hay farming. Surface drains are much more common in this zone, compared to Maumee Lake Plains, presenting different nutrient management challenges. Very sluggish, low-gradient streams and many ditches are typically turbid and have very high loads of suspended clay (U.S. EPA, 2012).

The final level IV ecoregion within the Maumee watershed's Huron/Erie Lake Plains is the Oak Openings (labeled 57b on Figure 23). This is a belt of low, often wooded, sand dunes and paleobeach ridges that are situated among the broad, nearly flat, agricultural plains of the Maumee Lake Plains. This area drains small tributaries north of the Maumee River in its downstream reaches, central Fulton County and much of Lucas County. Well-drained, sandy soils are common and originally supported mixed oak forests and oak savanna; poorly-drained depressions with wet prairies were also found. Today, general farms, residential development, oak woodland, and sand quarries occur in the Oak Openings region (U.S. EPA, 2012).

The Eastern Corn Belt Plains, level III ecoregion, are primarily a rolling till plain with local end moraines. Corn, soybean, wheat, and livestock farming is dominant and has replaced the original beech forests and scattered elm-ash swamp forests. The Maumee portion of this ecoregion is noted as having less productive soils and more tile drainage compared to other areas of the Eastern Corn Belt Plains across the Midwest. This ecoregion generally rings the upper portions of the Maumee watershed to the west and south (labeled 55a on Figure 23). It primarily drains the two tributaries that form the Maumee River (the St. Joseph and St. Marys rivers), the headwaters of some of the upper Auglaize River tributaries, and the upstream portion of the Blanchard River watershed (U.S. EPA, 2012).

Watershed models have been used to identify CSAs of nonpoint sources in watersheds. An advantage of using the SWAT model is that pollutant loads can be determined while finding CSAs. For instance, a study of several agriculturally dominated watersheds in Oklahoma found 22 percent of sediment and phosphorus export loads were from only 5 percent of the area (White et al., 2009). Various methods have been used to structure SWAT and other models to determine CSAs in the Maumee. These will be discussed throughout the remainder of this section.

The use of tributary water quality monitoring stations also provides evidence to compare portions of the Maumee watershed. This is water quality monitoring at USGS streamflow gages in a fashion similar to the station on the Maumee River at Waterville, described above. Combined, Heidelberg's NCWQR and USGS currently maintain 29 of these stations in the Maumee watershed in addition to Waterville (see Figure 24). More detail on these stations and results data have been compiled in OLEC (2020a). Monitoring at the majority of these stations did not start until after 2014. For many of them, there is only now enough results to begin detailed analyses. This section will present some of these new analyses in considering CSAs. These sites will also be used for tracking progress of nutrient reductions as outlined in the implementation section of this TMDL.

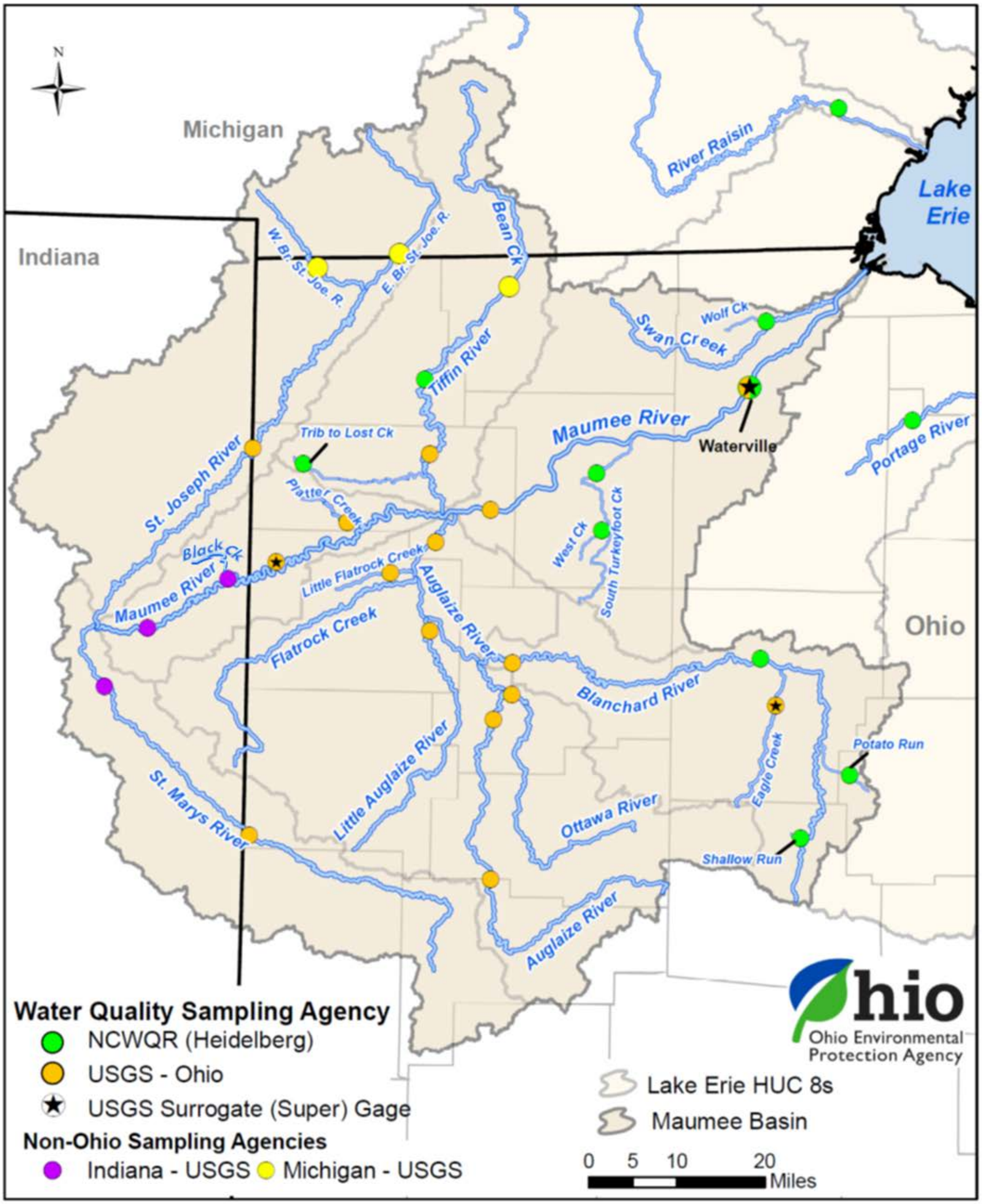


Figure 24. Network of continuous water quality monitoring stations throughout the Maumee River watershed at USGS streamflow gages. The various water quality sampling agencies are noted.

2.3.1. Ohio's 2017 WLEB Collaborative Implementation Framework and Scavia et al., 2016

A detailed effort by Scavia et al. (2016) uses ensemble modeling to examine nutrient export in the Maumee watershed's HUC-12s (small watershed management units). This report considers the results from modeling analyses carried out by its coauthors, a wide range of resource experts from University of Michigan, OSU, ARS, LimnoTech (a consultancy), Heidelberg University, USGS, The Nature Conservancy, and Texas A&M. Five SWAT models and one SPAtially Referenced Regressions on Watershed attributes (SPARROW) model are examined and aggregated. One product of this report is the identification of "hotspot" subwatersheds. These hotspots are determined by agreement among the various models on the top 20 percent of nutrient export (Figure 25). Note that the work that went into the Scavia et al. (2016) report was later published in an academic journal by Scavia et al. (2017).

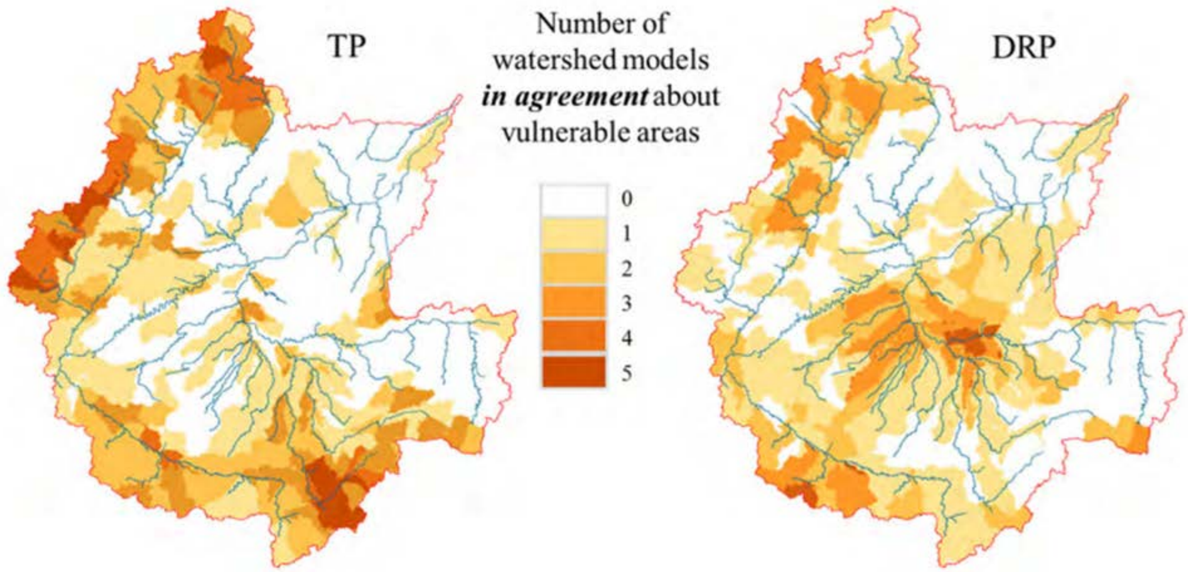


Figure 25. Potential "hotspots" of nutrient export to WLEB in the Maumee River watershed identified by comparing multiple models. Scale is 0 to 5 based on models in agreement. There were six models used in the total phosphorus map, however all six models did not agree on any area. Only five models are used in the DRP map. (Scavia et al. 2016)

In early 2017, the state of Ohio released a collaborative implementation framework report intended to serve as a pathway for developing the state's first Domestic Action Plan (OLEC, 2017). Utilizing results from the Scavia et al. (2016) report and various other data sources, this report divided the Ohio Maumee watershed HUC-12s into three priority levels for phosphorus loss. Twenty-four HUC-12s were identified as the top priority. These top priority HUC-12s were each assigned to one of four primary phosphorus loss source mechanism categories. The following briefly summarizes these categories as outlined in the OLEC (2017) report:

- Fourteen of the 24 top priority HUC-12s were identified due to a high density of soils in the hydrologic group D. These soils were characterized by very low infiltration rates even when drained. Most of these HUC-12s are in the Paulding Plains portion of the Erie Huron Lake Plaines ecoregion. The low infiltration rates may result in reduced effectiveness of subsurface drainage systems, so drainage practices could include surface enhancements that may promote surface runoff. The SWAT models generally identify these regions as being a high source of DRP loading. The models predict the potential for elevated DRP loading when subsurface drainage intensity is high. Twelve of these 14 HUC-12s are south of the mainstem Maumee River.
- Five of the top priority HUC-12s were identified with the primary source of phosphorus bound to sediment eroded from agricultural fields. These areas, within the Eastern Corn Belt ecoregion, have some of the highest overall land slopes due to being crossed by glacial end moraines. The greater energy generated by these slopes increases the potential for soil erosion and thus particulate phosphorus. Four of these five HUC-12s are south of the mainstem Maumee River.
- Two HUC-12s were identified as being top priorities due to high livestock density. Rather than basing this on modeling results, the Collaborative report used results from water quality monitoring and other available sources of data to determine these watersheds. One of these two HUC-12s is south of the mainstem Maumee River.

- Finally, three HUC-12s fell into the top priority due to various landscape characteristics. These watersheds were identified by the Scavia et al. (2016) ensemble modeling report as hotspots, but do not fall into any of the three previous categories listed above. All three of these HUC-12s are south of the mainstem Maumee River.

It is important to understand that all pollutant modeling has limitations of resolution. These start with the inputs and are carried through modeling computations into the outputs. One limitation with regards to the SWAT models examined in Scavia et al. (2016) is that existing row crop agricultural practices (for example, planting, tilling, and fertilizing) and pollutant reduction BMPs are not input with geographic detail at the HUC-12 level. Since that effort, SWAT modeling advances have been made in the Maumee models. Many of those studies have been discussed above. Before explaining the modeling studies regarding CSAs, the more recent Ohio efforts toward nutrient reduction are outlined next.

2.3.2. Ohio's 2018 and 2020 Domestic Action Plans

In 2018, the state of Ohio progressed past the priority subwatershed concept used in the 2017 Collaborative with the release of the Ohio Domestic Action Plan 1.0 and subsequent 1.1 update (OLEC, 2018). While the ensemble modeling from Scavia et al. (2016) was still discussed in these documents, emphasis was put on the need for phosphorus reductions throughout the entire Maumee watershed. These documents also stressed the continued support for the water quality monitoring network, described in the section above, which was maturing to close to its current, i.e., 2022, state.

The Ohio Domestic Action Plan was updated in 2020 with new material relevant to identifying CSAs in the Maumee watershed (OLEC, 2020b; herein referred to as "Ohio DAP 2020"). In this report, the emphasis on phosphorus reductions throughout the entire Maumee watershed was combined with new analyses on the geographic variations of phosphorus delivery. At the basin scale, Ohio's nutrient mass balance methods were augmented with relevant literature review of phosphorus sources to distribute nonpoint sources of total phosphorus to three land use/cover categories: agricultural, developed, and natural. Ohio DAP 2020 calculations were carried out for the Annex 4 targets base spring season of 2008. This resulted in determining that 85 percent of Ohio's contribution of total phosphorus load was sourced from agricultural lands. Developed land contributed about 6 percent, comparable to the 7 percent total load from wastewater treatment facilities. Note that developed land in the Ohio DAP 2020 analysis did not divide non-agricultural stormwater from permitted or unpermitted areas as described in this TMDL. The Ohio DAP 2020 work found that HSTS and natural lands contribute around 2 percent and 1 percent of the watershed's total phosphorus spring 2008 base load, respectively.

The Ohio DAP 2020 analysis also analyzed the spring 2008 base load distribution throughout the Maumee watershed's HUC-12s. To determine this, a hydrology analysis was carried out of stream gages throughout the watershed. Similar to results documented by Williams et al. (2020), this work determined that the southern, and particularly southwestern, part of the watershed does deliver relatively more water. This analysis was used to determine a hydrologic weighting factor for each HUC-12. This, combined with the land use/cover distribution carried out at the basin scale, results in calculated total phosphorus yields for each HUC-12. Figure 26 shows the spring 2008 baseline total phosphorus yield (mass per area) results for Ohio's Maumee watershed HUC-12s.

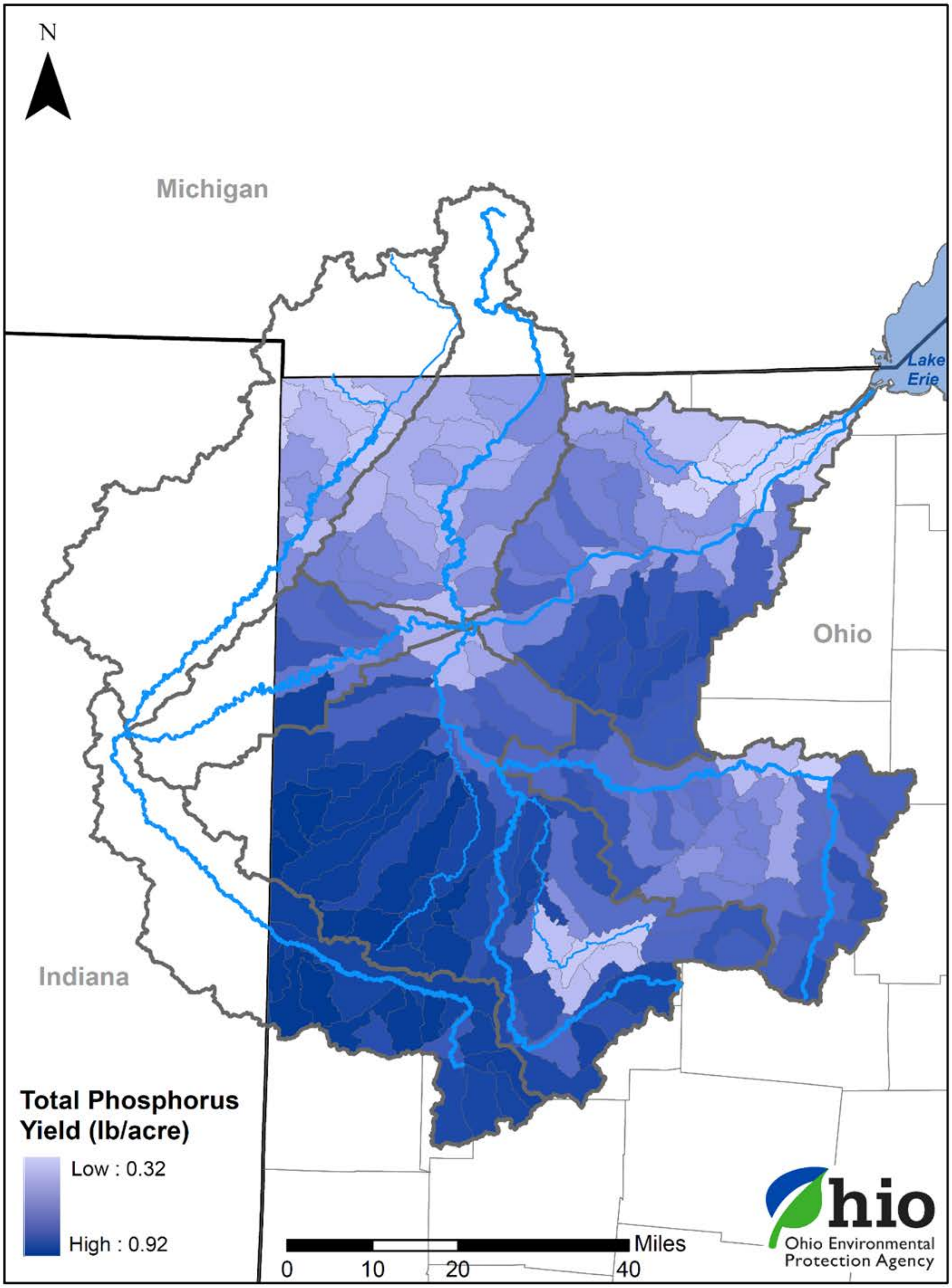


Figure 26. Total phosphorus yield from the landscape by HUC-12 in the Maumee watershed for the spring 2008 base condition from the 2020 Domestic Action Plan (OLEC, 2020b).

Based on this work, the part of the watershed south of the mainstem river contributes a greater proportion of total phosphorus. While higher stream discharge in the south factors into this, land use is also important. Note on Figure 26 the lighter shaded HUC-12s around the Lima, Findlay, and Defiance developed areas. This reflects the fact that the Ohio DAP 2020 method calculated developed land to contribute half the total phosphorus compared to agricultural lands before accounting for the hydrologic weighting factor.

The Ohio DAP 2020 provided the spring 2008 baseline total phosphorus loads for the three land use categories and HSTS for each Maumee watershed HUC-12 within Ohio. It also calculated a "landscape target" by taking a 40 percent cut from the total of those four sources. The intent of this work was to provide watershed managers with quantifiable targets that could be used for implementation planning.

2.3.3. Ohio EPA's 2020 Nutrient Mass Balance Report

Another state of Ohio led effort to discuss Maumee CSAs is Ohio EPA's 2020 Nutrient Mass Balance Report (Ohio EPA, 2020b). This report included an analysis of several Maumee watershed subwatersheds. This includes major portions of seven tributaries in the Maumee: the St. Joseph and St. Marys rivers to the Ohio/Indiana state line, most of the Tiffin, Ottawa, and Blanchard rivers and the upper portion of the Auglaize River (Figure 27). The area included in this analysis covers 52 percent of the total Maumee watershed.

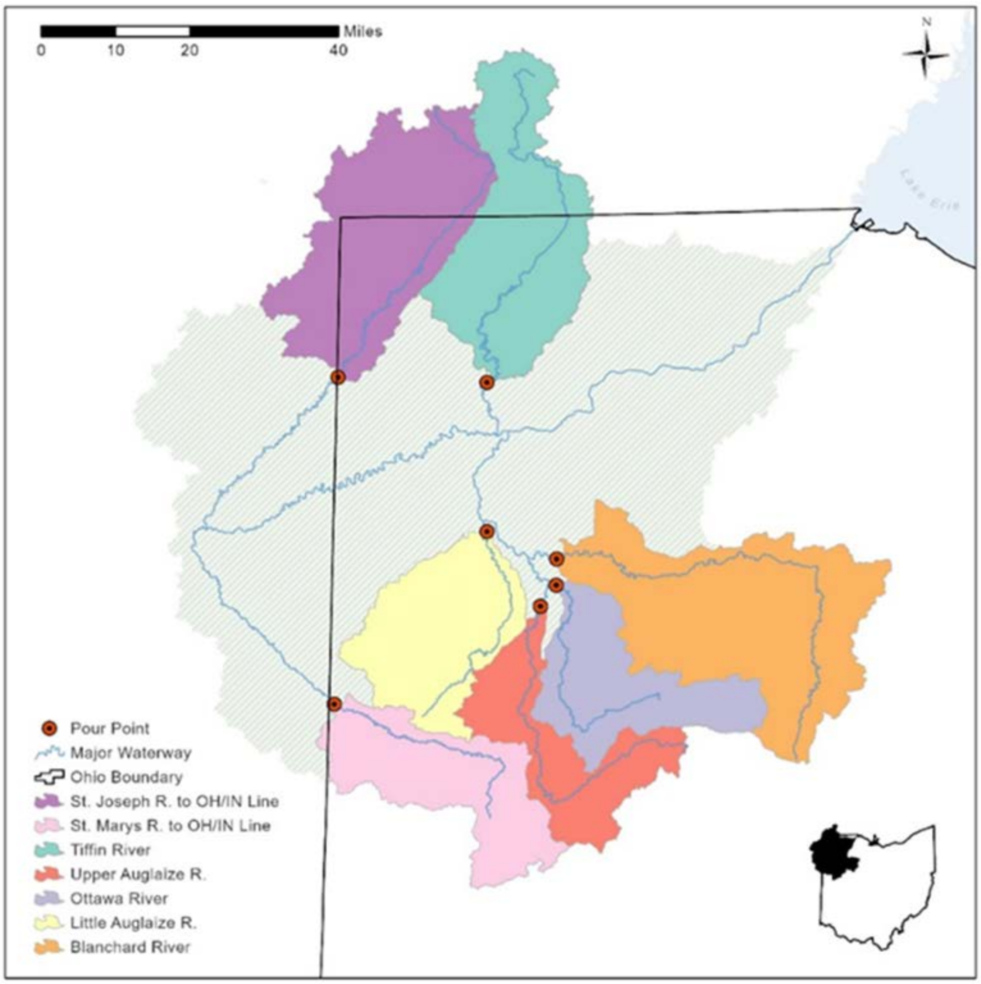


Figure 27. Maumee River subwatershed areas included in the Nutrient Mass Balance 2020 analysis. (Ohio EPA, 2020b)

In general, the Maumee watershed is dominated by agricultural production, which occupies 77 percent of the total watershed. However, as noted on Figure 3, above, there is a higher proportion of natural areas north of the Maumee River mainstem. Figure 28 shows land use for the seven tributaries included in the Nutrient Mass Balance 2020 subwatershed analysis. The land use in this figure only characterizes the area upstream of the pour point on each tributary (the same area the map in Figure 27). Of these subwatersheds, the two northern tributaries, the St. Joseph and Tiffin rivers' watersheds, drain the highest percentage of natural lands. The Ottawa River watershed has the greatest percent of developed land due to it draining the greater Lima area. The Blanchard River watershed drains the developed Findlay area, but because it is an overall larger watershed, developed land does not take up as much a proportion. The St. Marys and Little Auglaize rivers' watersheds drain the greatest percentage of agricultural land among these seven tributaries.

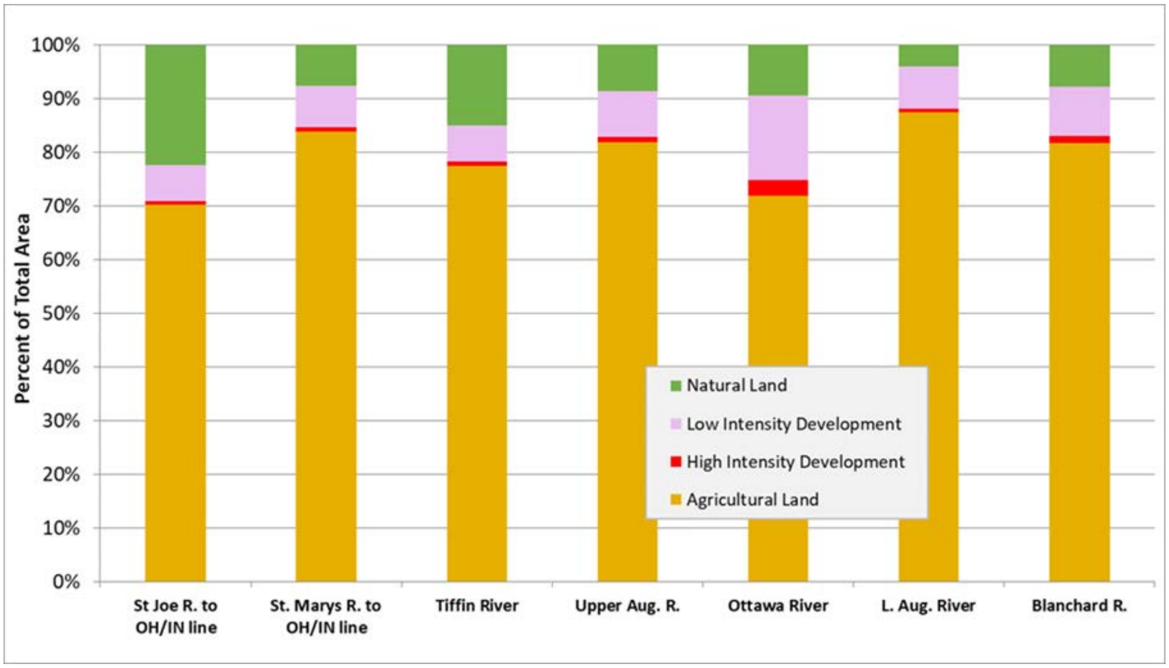


Figure 28. Distribution of major land use and land cover categories Maumee River sub-watersheds. Shown as percent of total watershed area. Stacked bars represent the area indicated by the map in Figure 27. Material and documentation. (Ohio EPA, 2020b)

Figure 29 shows the nonpoint source total phosphorus yield of the Maumee subwatersheds for water year 2018, as presented in the 2020 Nutrient Mass Balance. This represents the amount of nonpoint source normalized by the land area in each tributary's watershed, presented in pounds per acre. The stacked bars in Figure 30 shows total phosphorus loading sources. It is important to note that because nutrient loading is primarily driven by high streamflow events, comparing different watersheds by only looking at one year of data can be influenced by localized weather. That is, some watersheds may have had more runoff producing rain events than others in water year 2018.

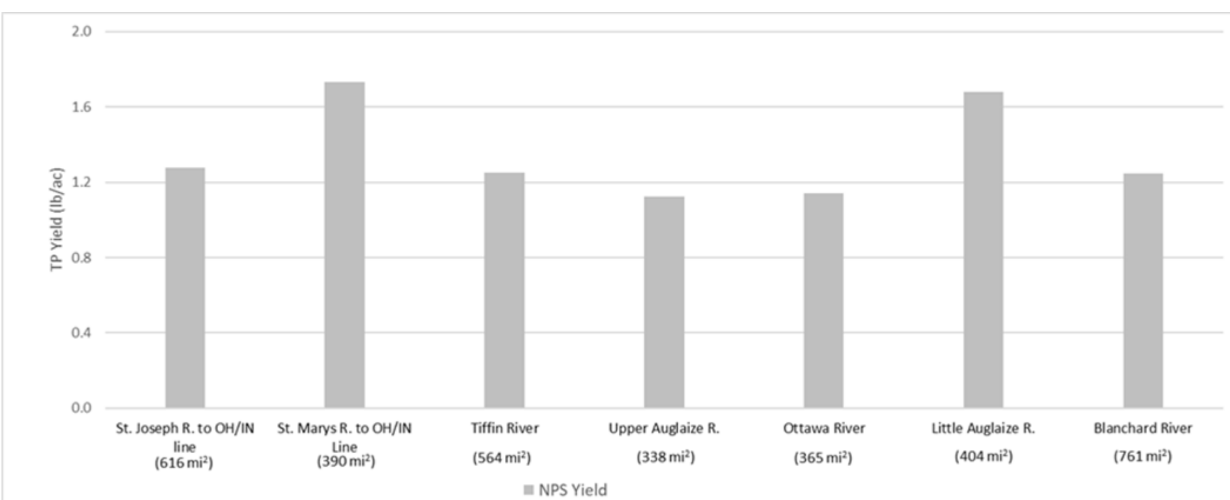


Figure 29. Total phosphorus nonpoint source yields for subwatersheds of the Maumee River shown on Figure 27 for water year 2018. (Ohio EPA, 2020b)

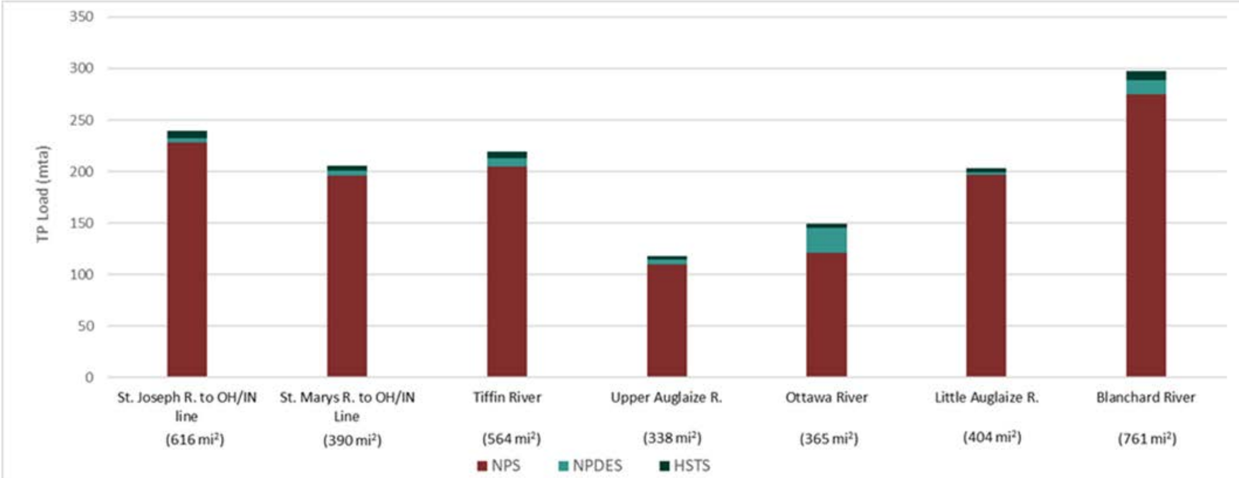


Figure 30. Total phosphorus loads, in metric tons, for subwatersheds of the Maumee River shown on Figure NMB-SUB-MAP for water year 2018. (Ohio EPA, 2020b)

Like the greater Maumee River watershed, nonpoint source dominated the total phosphorus loading in all tributaries. Even considering this caveat, on Figure 30 the order of greatest to least total loads for each tributary is roughly the same as the largest to smallest watershed areas (areas are noted below each tributary's name in Figure 29 and Figure 30). However, differences among the watersheds are apparent.

On Figure 30, the tributary with the greatest permitted wastewater NPDES load is Ottawa River. This reflects the population and industry in the greater Lima area.

On Figure 29, the Little Auglaize and St. Marys watersheds have the greatest nonpoint source yield for total phosphorus of all the tributaries examined. As noted above, these two subwatersheds drain the largest amount of agricultural area.

Reduced loading in the St. Joseph and Tiffin rivers' watersheds is likely due to the greater amount of natural area in these watersheds. The 2020 Nutrient Mass Balance points out the upper Auglaize River watershed stands out as having a lower water year 2018 FWMC and nonpoint source yield. This subwatershed also drains a higher relative proportion of natural lands. However, the upper Auglaize River watershed had a relatively higher FWMC in the water year 2017 when it received a greater amount of streamflow yield compared to water year 2018.

Overall, this analysis uses real monitoring data and Nutrient Mass Balance methods to provide supporting evidence to the results of the Maumee HUC-12 far-field total phosphorus targets work in the 2020 Domestic Action Plan (OLEC, 2020b). Both analyses indicate that the southern section parts of the Maumee watershed contribute greater amounts of total phosphorus relative to the other tributaries.

2.3.4. Published modeling on Maumee watershed critical source areas

USGS maintains a modeling program called SPARROW. This uses a hybrid mass balance and statistical approach to simulate pollutant transport. "SPARROW models simulate long-term mean-annual transport given source inputs and management practices similar to a given base year", Robertson et al. (2019). The 2019 publication outlined phosphorus and nitrogen transport for the complete Great Lakes Basin using 2002 as its base year.

Figure 31 shows the total phosphorus load broken down by sources for the seven Maumee HUC-8 watersheds based on this modeling approach. Data used to develop this figure were provided as supporting information from the Robertson et al. (2019) publication. It is important to note the loads on this figure are calculated as what the entire HUC-8 contributes; this includes parts of the watersheds in Michigan and Indiana. The two Maumee and one Auglaize HUC-8s results do not include upstream loads delivered to those watersheds, i.e., only loads "produced" within each HUC-8 is shown. Also note that these figures were produced using statistical models which differs from the Nutrient Mass Balance reports shown above and new analysis provided below which are based on water quality monitoring.

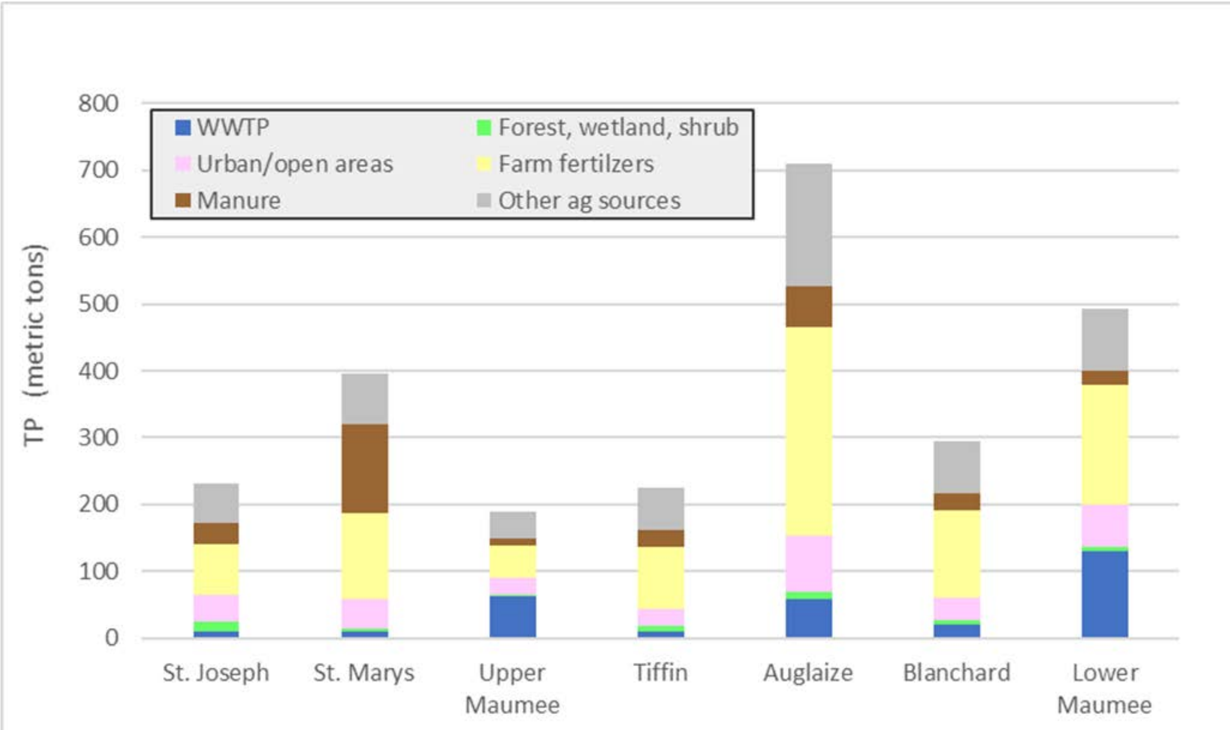


Figure 31. Total phosphorus loads in the Maumee River watershed HUC-8s with sources shown based on SPARROW modeling of the 2002 base year. Figure developed from supporting information provided by Robertson et al., 2019.

The Robertson et al. (2019) paper does not provide a detailed explanation of what it categorizes as other agricultural sources. It describes these as loads in addition to fertilizer and manure, "which represents general losses from agricultural areas, such as natural sources and increased losses caused by agricultural activity". Soil stored/legacy sources of phosphorus, which are described several subsections above, likely contribute to this category.

Figure 32 shows the total phosphorus load for each HUC-8 watershed plotted against its drainage area. Note that the drainage area of contributing watersheds to the lower Maumee and Auglaize HUC-8s are not included in this calculation. The St. Marys, Blanchard, and Tiffin HUC-8s all drain similar sized areas, which allowed for an interesting comparison. As previously noted, the northern Tiffin watershed contributes only about half as much as the southern St Marys'. The yield for the Tiffin watershed from this analysis is 0.29 MT/mi^2 while the St. Marys' is 0.50 MT/mi^2. Additionally, the lower Maumee and St. Joseph HUC-8s have similar sized drainage areas. Again, the northern watershed, St. Joseph, contributes markedly less than the lower Maumee. The St. Joseph's yield is 0.21 MT/mi^2 and the lower Maumee's is 0.46 MT/mi^2. The Auglaize and Blanchard watersheds' yields are in between the four HUC-8s already noted at 0.43 MT/mi^2 and 0.38 MT/mi^2, respectively.

A different statistical examination of stream flows and nutrient monitoring reported similar heterogeneity in the Maumee watershed. Choquette et al. (2019) documented increasing higher stream flows in the St. Marys near Ft. Wayne gage while nearly flat trends in the St. Joseph River near Ft. Wayne gage. This work also found increasing total phosphorus annual yields at two St. Marys sites while reducing yields at the lower St. Joseph gage. The study calls out greater flow regulation and less extensive row crops in St. Joseph watershed compared to the St. Marys watershed as a potential explanation for these findings. Certainly, spatial differences in stream discharge, as documented by Williams and King (2020) play a role as well.

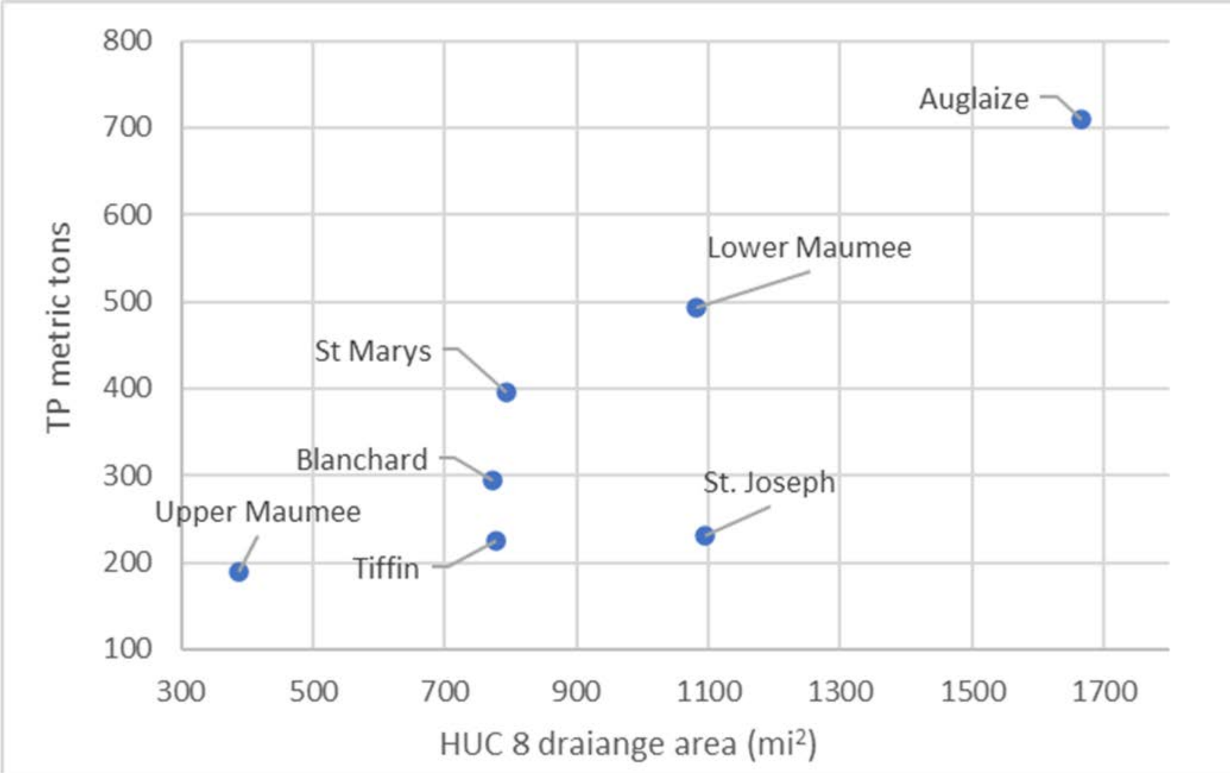


Figure 32. Total phosphorus loads in the Maumee River watershed HUC-8s plotted against the HUC-8s drainage area from SPARROW modeling of the 2002 base year. Figure developed from supporting information provided by Robertson et al., 2019.

CSAs were evaluated through a multi-SWAT model evaluation by Evenson et al. (2021). For each model, the 20 percent of HUC-12 subwatersheds (of the 252 HUC-12 subwatersheds in the Maumee watershed) with the highest export of flow, total phosphorus, DRP, total nitrogen, and total suspended solids were identified as CSAs. The CSAs between models were then evaluated statistically and graphically to determine patterns.

Generally, the multi-modeling did not agree on the location of CSAs: "the overwhelming majority of HUC-12s identified as CSAs were identified as such by a minority of models" (Evenson et al., 2021). This observation suggests that the models are not as accurate at the HUC-12 scale, probably due to calibration mostly at the large-basin scale, but also perhaps reflecting underlying weaknesses in SWAT.

The quantity of fertilizer application per HUC-12 subwatershed was evaluated within the CSAs to determine if the quantity of fertilizer applied was correlated to CSA identification. The authors generally found that CSAs were more likely to be identified in areas with higher fertilizer application, but that fertilizer application did not explain much of the variation of model outputs (Evenson et al., 2021). They concluded that "fertilizer application rates were only weakly related to nutrient export and thus CSA location for most [of the SWAT] models" (Evenson et al., 2021).

In the statewide soil phosphorus balance study by Dayton et al. (2020), noted above, all but two counties that drain the Maumee watershed were found to have a negative phosphorus balance trend by 2014. Only Mercer and Lucas counties were found to have phosphorus inputs that exceeded outputs. The increase in Mercer County is most likely due to an increase in livestock farms around the Grand Lake St. Marys watershed, outside of the Maumee watershed. Negative phosphorus balances were found in the two counties neighboring Mercer within the Maumee watershed: Van Wert County to the north, and Auglaize County to the east. This study also found Paulding and Hancock counites were among the four counties with the greatest statewide decrease in soil phosphorus balance.

2.3.5. Ohio EPA analysis of Maumee watershed phosphorus monitoring data

The following presents new analysis on the results from the tributary water quality monitoring stations presented above and shown in Figure 24. The total phosphorus and DRP spring season FWMCs and loads used have been calculated by whichever organization monitors each site, either Heidelberg's NCWQR or USGS. Daily loads and concentrations are also examined for several stations monitored by USGS. These results are calculated based on extremely robust sampling programs and all stations are at USGS streamflow gages with continuous discharge monitored.

Ohio EPA also collects water quality monitoring data from stream sites throughout the state, including the Maumee watershed. An extensive number of samples, well over 10,000, have been collected at hundreds of sites throughout the watershed over several decades. These samples intend to reflect conditions impacting near-field beneficial uses, mostly aquatic life use. The vast majority of these samples have been collected during summertime, low flow conditions. These conditions make pollutant sources that continuously discharge, such as wastewater treatment plants, appear more prominent. Runoff driven sources, such as most nonpoint sources, are conversely less apparent due to this sampling bias. These samples differ from the NCWQR and USGS samples in that Ohio EPA collects relatively few samples at many locations. While Ohio EPA's data collection is useful to understand near-field impacts to streams throughout the watershed, they are of much less value in understanding nutrient delivery relevant to this TMDL. The NCWQR and USGS samples are collected expressly to understand seasonal and annual loads. Thousands of samples are collected at a small number of key locations with continuous streamflow gaging. Every single high flow event and either a daily or weekly steady-flow condition is sampled at these sites. Because of the extremely high quality of data for understanding loads is available from NCWQR and USGS, Ohio EPA's water quality samples will not be used for this analysis.

Figure 33 shows the total phosphorus and DRP spring loads for three years, 2018 through 2020, plotted against each station's drainage area. Stations that are north and south of the Maumee River mainstem, as well as the mainstem river stations, are each noted with different symbols on this figure. Note that unlike the results from the SPARROW modeling, shown above, these are the measured loads at each station. Therefore, all the load that passes each monitoring station, including loads captured upstream by "nested" monitoring stations, are included in these results. As expected, the magnitude of loads generally increases with increasing drainage area. However, there are some visible differences between the southern and northern sites, especially in the 2019 and 2020 years for both parameters. The southern tributary sites appear to be on a higher load to drainage area trend than the northern sites in this analysis.

Loads are calculated as the product of streamflow and concentration with applicable unit conversion factors. An examination of streamflow and concentrations helps to understand the difference between the northern and southern tributaries, as well as some of the loads labeled on Figure 33. Figure 34 shows the normalized spring stream discharge for all Maumee watershed monitoring stations from 2014-2020, again with the same symbols for stations' geography. In some of the years, most of the southern sites appear to have greater streamflow than the majority of the northern sites; however, this is not always the case (see 2018). This is an indication that the northern sites overall experienced more precipitation in the 2018 spring – an apparent anomaly compared to the other years examined on this figure.

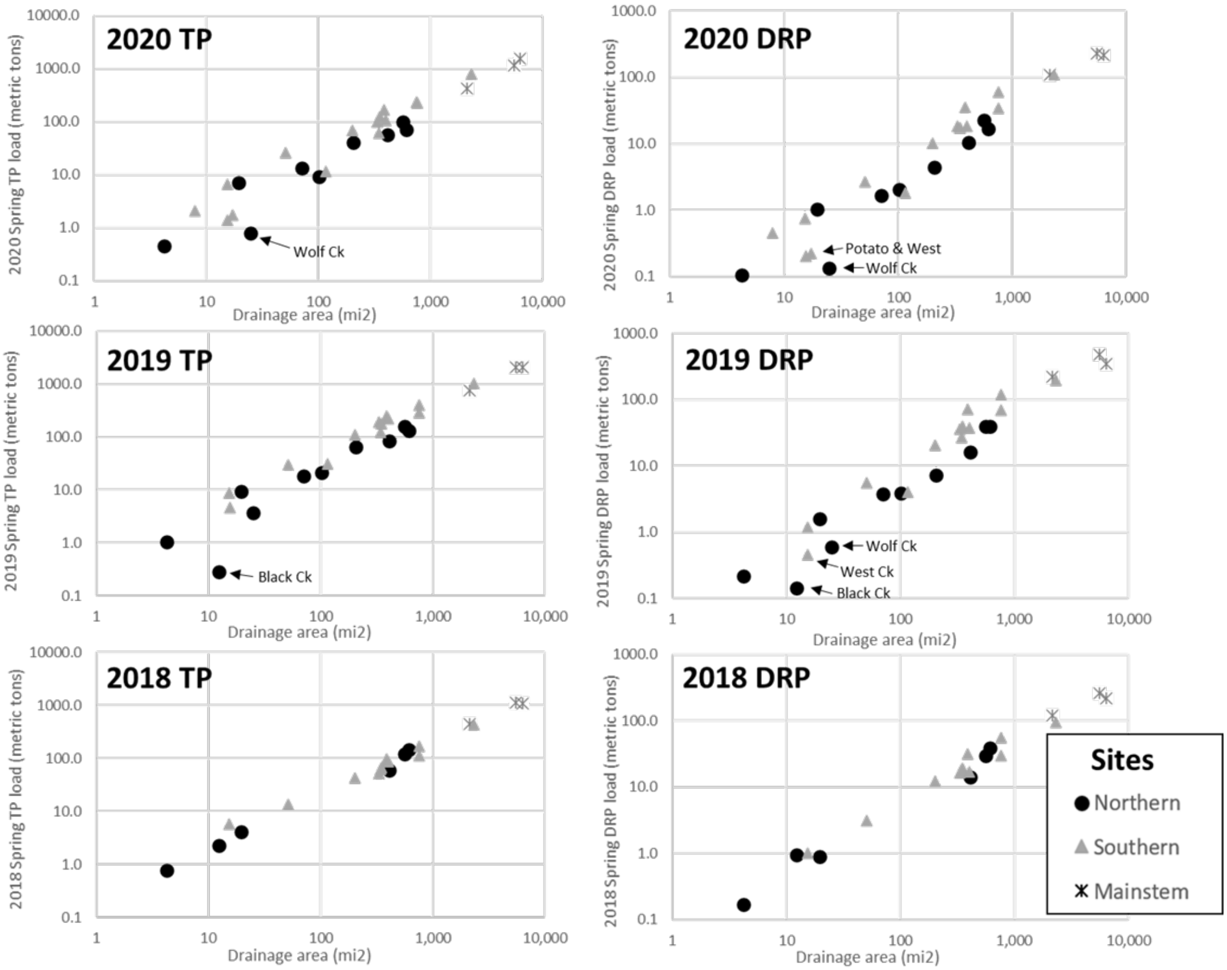


Figure 33. Total phosphorus (left) and dissolved reactive phosphors (right) loads for three different years plotted against monitoring station drainage area. Stations north and south of the Maumee River mainstem and stations on the mainstem are shown with different symbols. Not all stations have available data for each year.

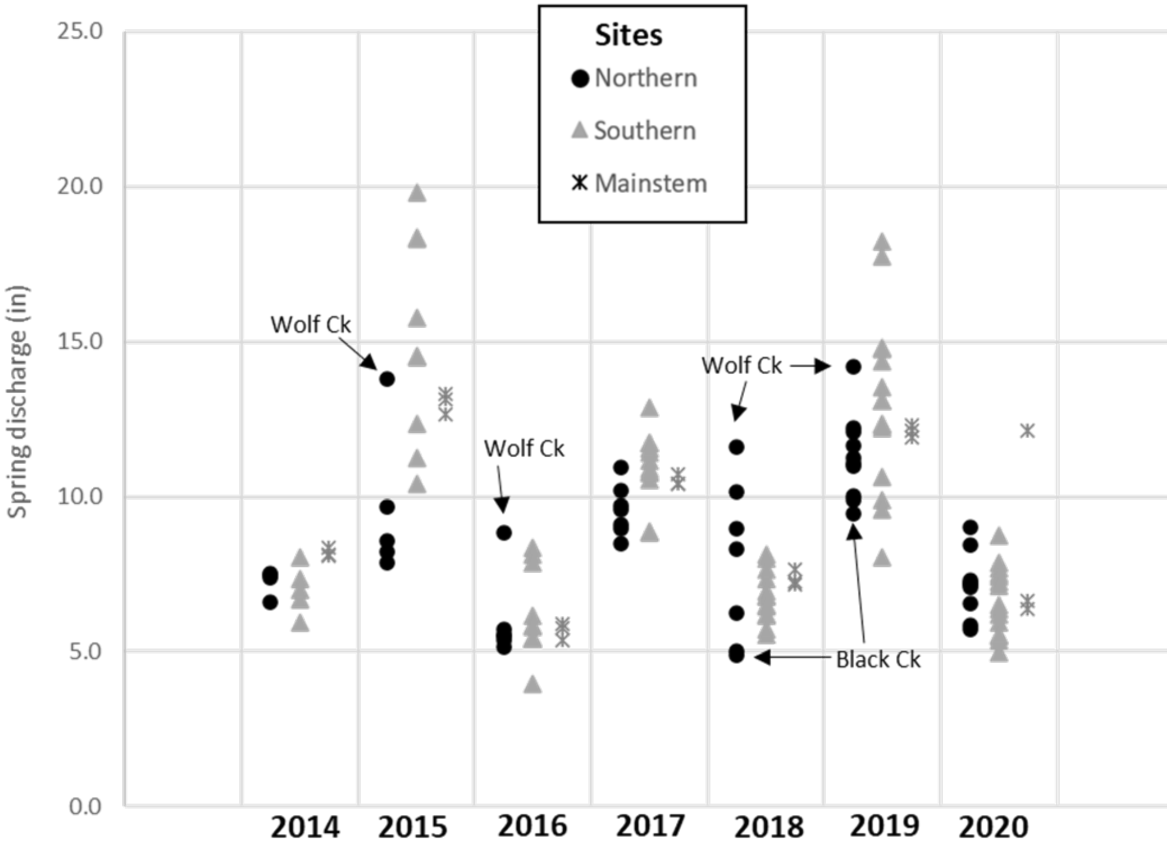


Figure 34. Spring stream discharge water yield for all Maumee watershed monitoring stations with available water quality data 2014 through 2020. Stations north and south of the Maumee River mainstem and stations on the mainstem are shown with different symbols. Not all stations have available data for each year.

Figure 35 shows the flow-weighted mean total phosphorus and DRP concentrations of all stations for the spring seasons of 2018 through 2020. Notably, the southern sites generally have more elevated FWMCs than the northern sites. Figure 36 shows the FWMCs for all years available for each station from 2014 through 2020. Again, the southern sites having more elevated total phosphorus and DRP FWMC overall is noticeable when examining FWMCs in this figure.

Figure 37 shows the distribution of daily spring season DRP concentrations for the key tributaries included in Ohio's 2020 Nutrient Mass Balance study, with map shown above in Figure 27. This analysis includes all daily DRP concentrations available for each assessment site (period of record for each site is listed on Table 6). The interquartile range (the half of the distribution within the boxes; between the 75th and 25th percentiles) of these distributions continue to show similar trends as noted above with FWMCs. Most notable is the difference between the northern St. Joseph River and southern St. Marys River. The Ottawa and Auglaize rivers, both draining southern watersheds, are also noticeably higher than the northern Tiffin River. The Little Auglaize River, draining a southern watershed, however, appears to be closer to the lower concentration northern sites. That station experiences backwater when the mainstem Auglaize River is elevated. Days when backwater conditions occurred at the Little Auglaize station were removed from this analysis.

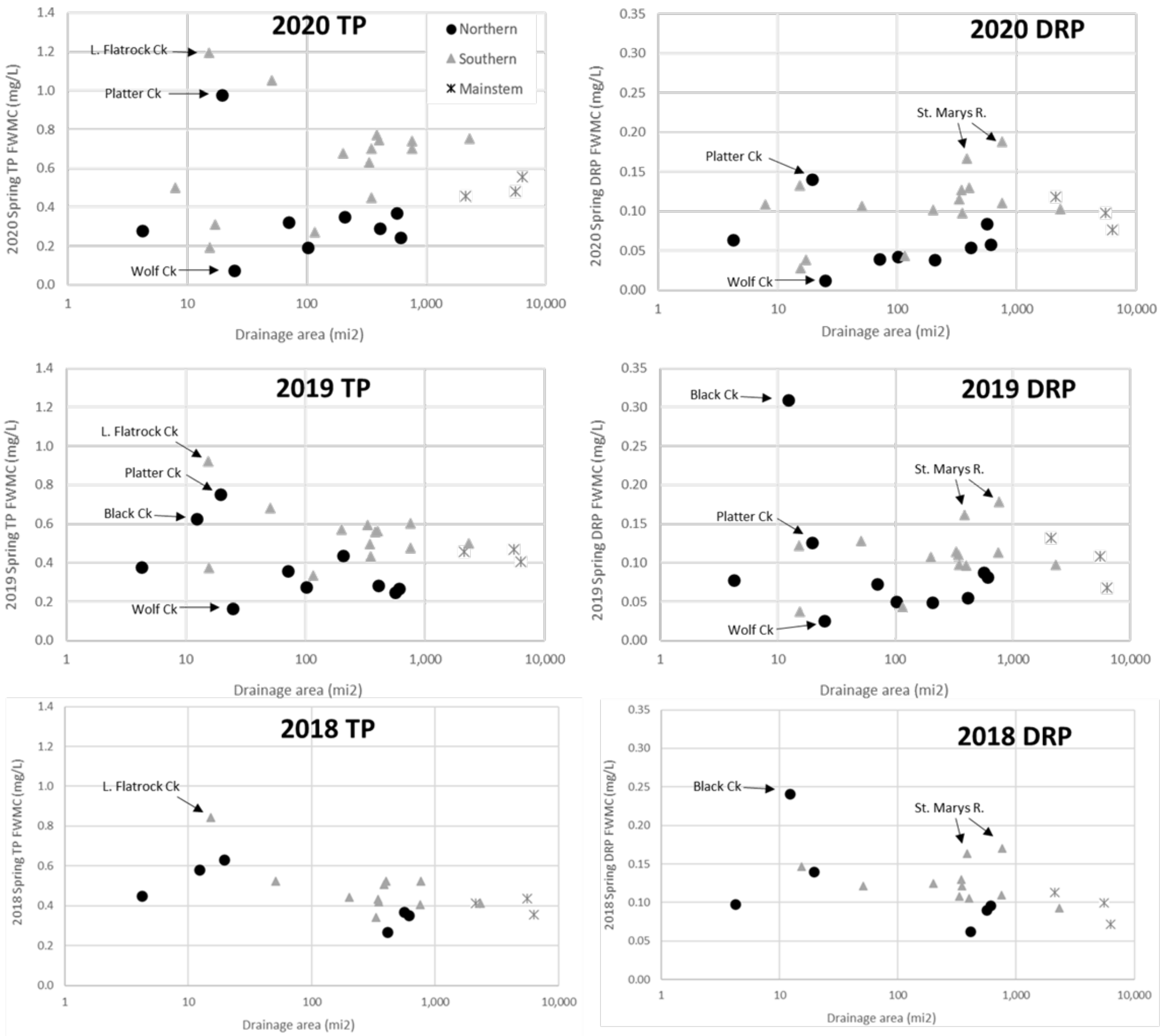


Figure 35. Total phosphorus (left) and dissolved reactive phosphors (right) FWMCs for three different years plotted against monitoring station drainage area. Stations north and south of the Maumee River mainstem and stations on the mainstem are shown with different symbols. Not all stations have available data for each year.

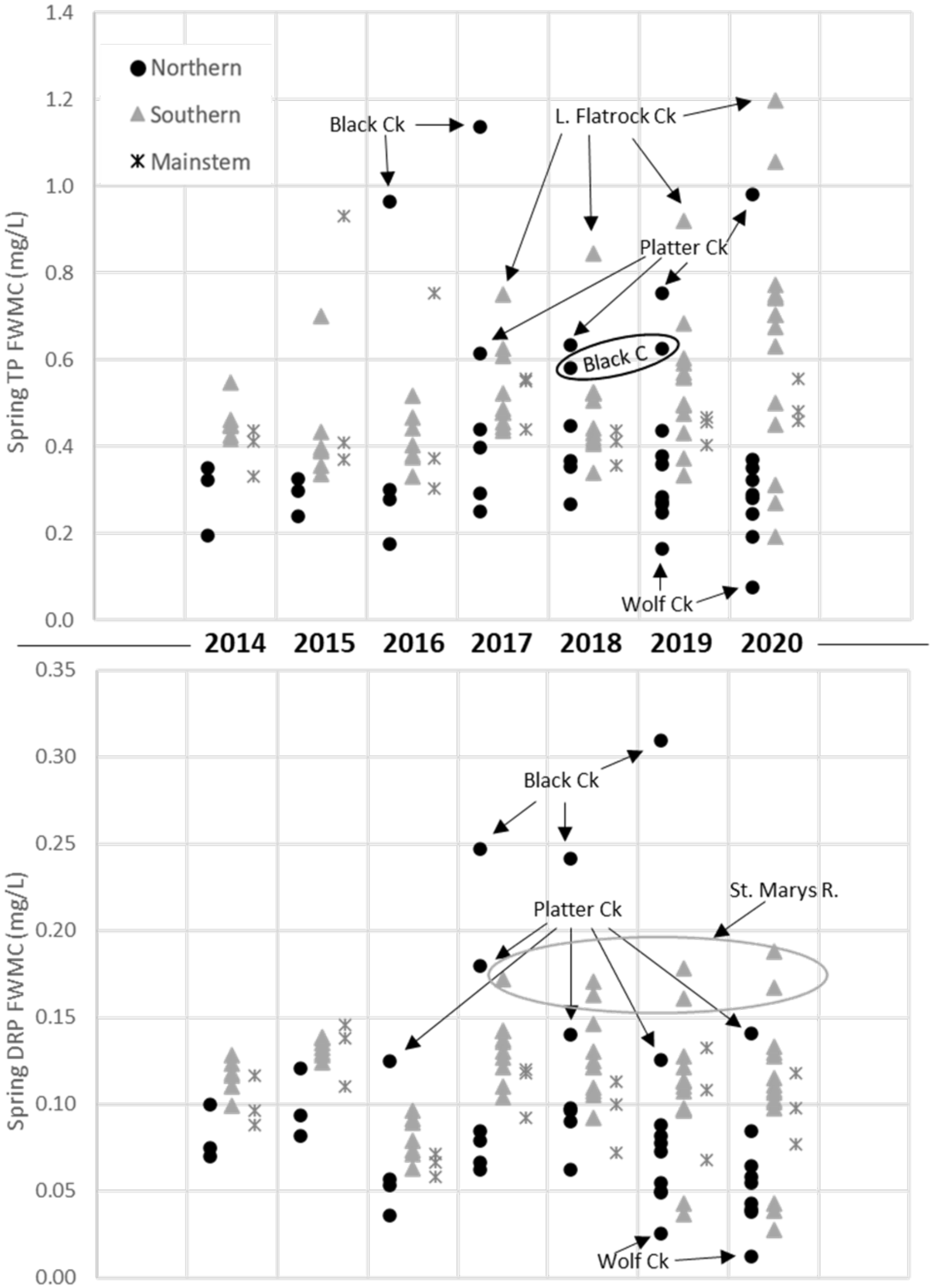


Figure 36. Total phosphorus (top) and dissolved reactive phosphors (bottom) spring FWMCs for all Maumee watershed monitoring stations with available water quality data 2014 through 2020. Stations north and south of the Maumee River mainstem and stations on the mainstem are shown with different symbols. Not all stations have available data for each year.

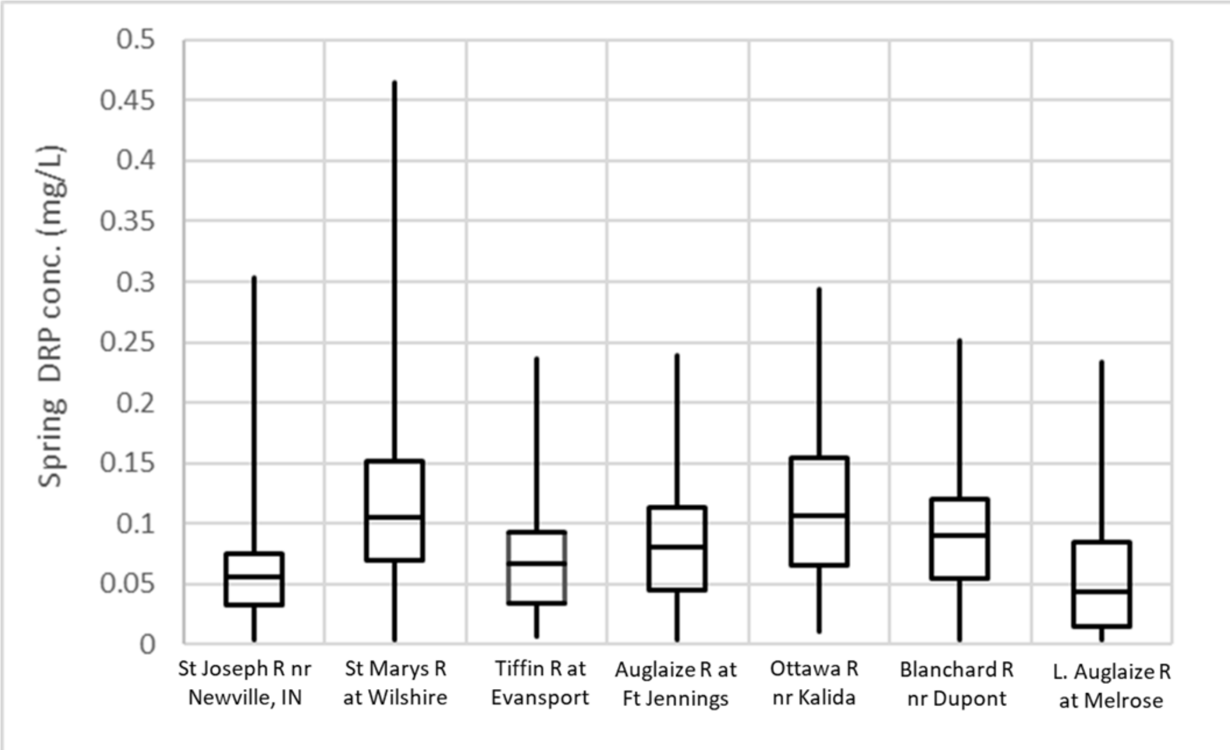


Figure 37. Distribution boxplots of spring DRP daily concentrations for select Maumee watershed tributary monitoring stations. A map of these stations' watersheds is shown above in Figure 27.

Table 6. Median daily spring DRP concentration broken down by flow regime for select water quality monitoring stations. Values over the Annex 4 FWMC DRP target of 0.05 mg/L are bolded. Those 0.15 mg/L or greater are underlined.

Site	Median spring DRP conc. (mg/L) at various flow regimes*					Period of record: Spring seasons
	High	Moist	Mid	Dry	Low	
04178000 St Joseph R nr Newville, IN	**0.09**	0.04	0.04	**0.06**	NA	2017-2020
04181049 St. Marys R at Wilshire	**<u>0.18</u>**	**0.14**	**0.06**	**0.08**	**<u>0.15</u>**	2017-2020
04183038 Black Ck nr Harlan, IN	**<u>0.20</u>**	**0.06**	**0.06**	**0.09**	**<u>0.18</u>**	2016-2019
04183979 Platter Ck nr Sherwood	**0.12**	0.05	0.01	0.01	NA	2017-2020
04185318 Tiffin R nr Evansport	**0.10**	**0.06**	**0.05**	**0.08**	**0.10**	2014-2020
04186500 Auglaize R nr Fort Jennings	**0.12**	**0.08**	**0.05**	**0.08**	**<u>0.18</u>**	2014-2020
04188100 Ottawa River near Kalida	**0.12**	**0.08**	**0.08**	**<u>0.17</u>**	**<u>0.24</u>**	2014-2020
04190000 Blanchard R near Dupont	**0.13**	**0.08**	**0.07**	**0.11**	**0.12**	2014-2020
04191058 L. Auglaize R at Melrose†	**0.11**	**0.06**	0.02	0.01	NA	2015-2020
04191444 L Flatrock Ck nr Junction	**0.14**	**0.10**	**0.07**	**<u>0.16</u>**	NA	2017-2020

* Flow regimes exceedance percentile range: High 0-10, moist 10-40, mid 40-60, dry 60-90, low 90-100.
† Little Auglaize River results not included in this analysis when river was in backwater conditions.

In order to bring streamflow into the analysis of daily DRP concentrations, several stations were plotted with a concentration exceedance curve. Figure 38 shows an example of one of these curves. Note that the daily concentrations are plotted based that day's streamflow exceedance percentile. The curve is broken up into five flow regimes that Ohio EPA regularly uses to assess pollutants. In this St. Marys River example, more elevated DRP concentrations are observed in the higher flow regimens compared to the mid-range flows. Concentrations are slightly higher in the mid-range flows compared to the dry conditions. There are very few concentrations in the low flow regime mainly because these are concentrations only from the spring season, and lower flows generally occur outside of March through July.

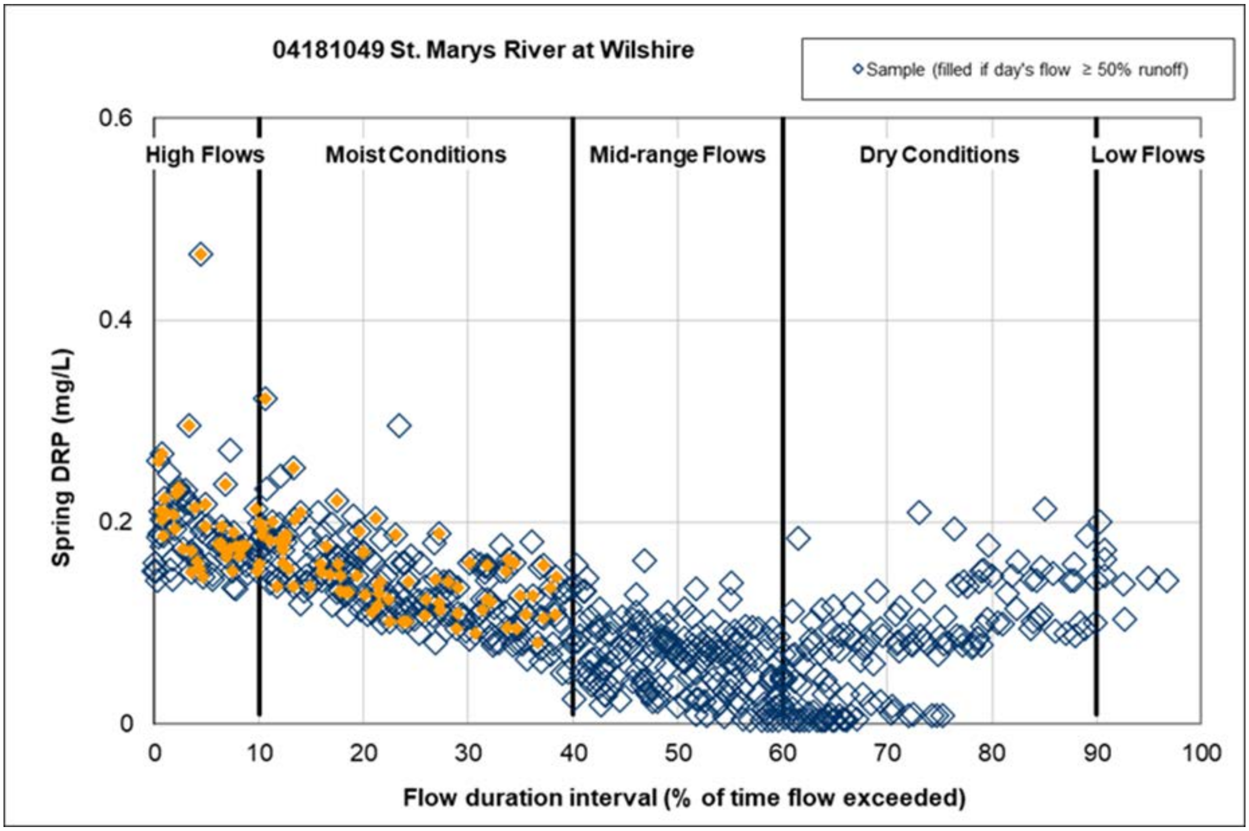


Figure 38. Concentration exceedance curve of spring DRP daily concentrations of the St. Marys at Wilshire sampling location. Diamonds represent daily concentrations throughout the 2017 through 2020 spring seasons. Filled diamonds indicate days where streamflow had greater than or equal to 50 percent runoff based on baseflow separation methods.

Table 6 and Table 7 show the median and 75th percentile spring season daily DRP concentration in the same subset of sites examined in Figure 37, with a few additional stations, broken down by flow regime. The majority of the phosphorus export occurs during higher flows, as explained above in this source assessment, and therefore a focus should be on the high and moist flow regimes on these tables. The same general trends as observed in the St. Marys River example, Figure 38, is present for most sites. The middle flow condition has the lowest DRP concentrations. The concentration increases from the mid flow condition with greater streamflow. And a somewhat less steep increase occurs as stream flows reduce to the dry and low conditions. However, the Ottawa and Blanchard rivers stations have a steeper increase in the lower flow conditions than the other sites. This is expected due to the major wastewater treatment plants upstream of these stations. As stream flow decreases, the plants continue to discharge at steady rates, the influence of their concentrated effluents becomes observable.

The St. Joseph and Tiffin rivers' sites, both representing a sizable portion of the northern drainage area, are reduced compared to the southern tributaries, best examined by the St. Marys, Auglaize, Ottawa, and Blanchard rivers sites on the tables. As suggested by modeling data reported earlier in this CSA section, the southern tributaries contribute more phosphorus loads than the northern tributaries. The results presented here confirm with observed water quality data that this occurs.

Table 7. 75th percentile daily spring DRP concentration broken down by flow regime for select water quality monitoring stations. Values over the Annex 4 FWMC DRP target of 0.05 mg/L are bolded. Those 0.15 mg/L or greater are underlined.

Site	75th pert. spring DRP conc. (mg/L) at various flow regimes*					Period of record: Spring seasons
	High	Moist	Mid	Dry	Low	
04178000 St Joseph R nr Newville, IN	**0.11**	**0.07**	**0.06**	**0.07**	NA	2017-2020
04181049 St. Marys R at Wilshire	**<u>0.21</u>**	**<u>0.16</u>**	**0.09**	**0.10**	**<u>0.16</u>**	2017-2020
04183038 Black Ck nr Harlan, IN	**<u>0.27</u>**	**0.10**	**0.09**	**0.09**	**<u>0.20</u>**	2016-2019
04183979 Platter Ck nr Sherwood	**<u>0.15</u>**	**0.07**	0.02	0.01	NA	2017-2020
04185318 Tiffin R nr Evansport	**0.14**	**0.08**	**0.07**	**0.09**	**0.10**	2014-2020
04186500 Auglaize R nr Fort Jennings	**<u>0.16</u>**	**0.11**	**0.08**	**0.11**	**<u>0.20</u>**	2014-2020
04188100 Ottawa River near Kalida	**<u>0.15</u>**	**0.14**	**<u>0.15</u>**	**<u>0.21</u>**	**<u>0.28</u>**	2014-2020
04190000 Blanchard R near Dupont	**<u>0.15</u>**	**0.11**	**0.11**	**0.12**	**<u>0.16</u>**	2014-2020
04191058 L. Auglaize R at Melrose†	**0.14**	**0.09**	0.04	0.03	NA	2015-2020
04191444 L Flatrock Ck nr Junction	**<u>0.17</u>**	**<u>0.15</u>**	**0.13**	**<u>0.37</u>**	NA	2017-2020

* Flow regimes exceedance percentile range: High 0-10, moist 10-40, mid 40-60, dry 60-90, low 90-100.

† Little Auglaize River results not included in this analysis when river was in backwater conditions.

Figure 39 summarizes by HUC-8 the distributions of Ohio HUC-12's nonpoint source total phosphorus yield (mass per area, in pounds per acre) for the 2008 spring base year based on the methods used in the Ohio's 2020 Domestic Action Plan (OLEC, 2020b). This work is summarized above with a map showing these results in Figure 26. This new conceptualization is presented here to summarize the differences from the northern versus southern parts of the Maumee watershed. The interquartile range of HUC-12 total phosphorus yields for the northern St. Joseph and Tiffin HUC-8s is completely below the St. Marys, Auglaize, and Blanchard HUC-8s in the south. The upper and lower Maumee HUC-8s are transitionary between the northern and southern HUC-8s.

The figures and tables described here show that concentrations delivered from all monitored stations are greater than the Annex 4 target for the Maumee River at Waterville. Therefore, while evidence points to the fact that the southern watersheds deliver a greater amount of phosphorus load to the Maumee River, and should therefore be considered CSAs, the phosphorus reductions are still required throughout the greater Maumee watershed.

The following paragraphs examine some specific watersheds based on results from individual monitoring stations.

The St. Marys River at Wilshire site monitors the St. Marys River close to where it flows out of Ohio and into Indiana. This assessment site has consistently elevated DRP concentrations compared to most other sites. On Figure 36 this site, and the other St. Marys assessment site further downstream in Indiana, is noted to have the highest concentration of DRP for every year monitoring occurred, with the exception of Black Creek and Platter Creek's 2017 result. The St. Marys River watershed is the most southwestern HUC-8 of the greater Maumee watershed. It has experienced among the greatest increases in rainfall (Figure 17) and has some of the densest agricultural land use (Figure 28).

Platter Creek stands out as having relatively elevated phosphorus concentrations based on its drainage area (Figure 35) and compared to other "northern" sites (Figure 36). This small, direct to the Maumee River watershed is only just north of the mainstem in western Defiance County. DRP concentrations are more elevated in higher flows (Table 6 and Table 7). Dense agricultural use while being on the margin of more elevated hydrology, makes this watershed's phosphorus exports appear more like a typical "southern" watershed.

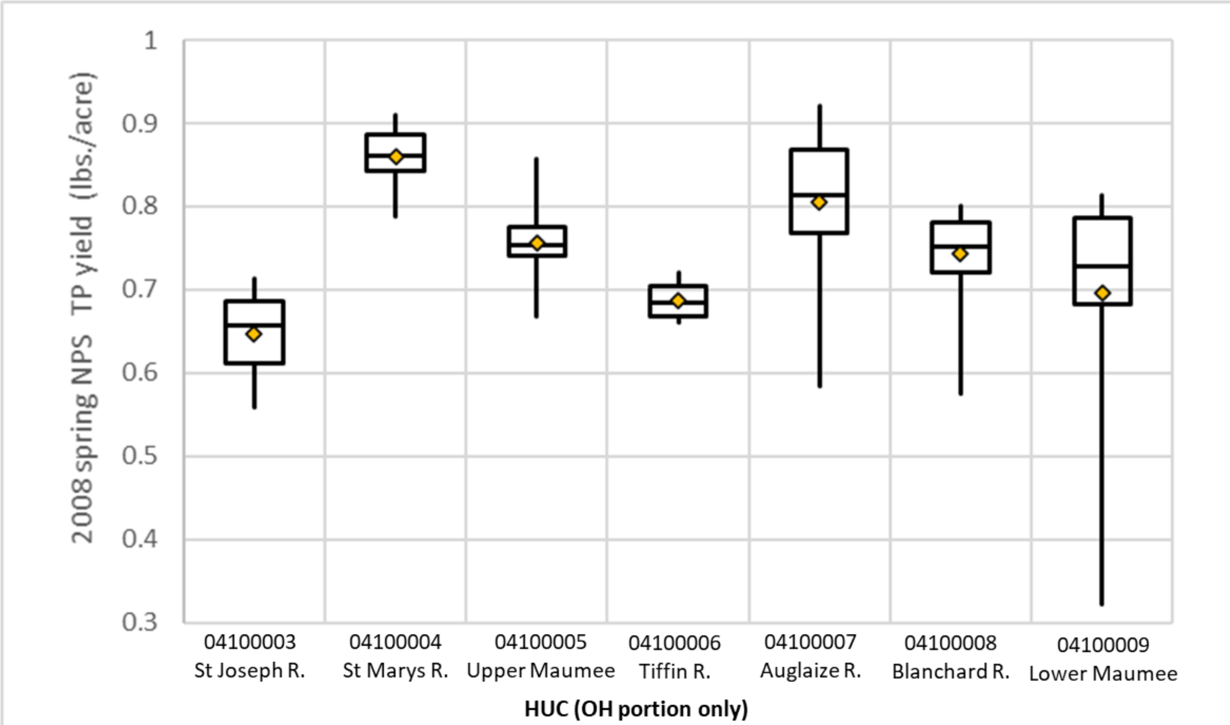


Figure 39. Distribution boxplots of spring 2008 HUC-12 total phosphorus daily nonpoint source yields, in pounds per acre, summarized by HUC-8s. Average HUC-12 yield for each HUC-8 shown with a diamond. From far-field target analysis explained above and documented in the 2020 Domestic Action Plan. (OLEC, 2020b)

Black Creek stands out on several of the figures and tables presented in this section. This is a small, direct to the Maumee River tributary in Indiana. Its drainage area is close to the Maumee River north of the mainstem. Because of this geography, this assessment site has been plotted as a northern site in many of the figures shown below. However, both total phosphorus and DRP concentrations for Black Creek are very elevated compared to all other assessment sites, see Figure 36. The exported phosphorus load from Black Creek is not elevated in relation to its drainage area size, however, as noted for 2019 in Figure 33. This is because of relatively lower stream discharge measured, see Figure 34. This is a densely row cropped watershed with some unique management practices. However, being in Indiana, this watershed will not be discussed further. Much published research is available regarding Black Creek, see Williamson et al., 2019, 2020, 2021a, and 2021b.

Little Flatrock Creek is another small, monitored tributary in Paulding County. This Auglaize River tributary drains part of the Paulding Plains described above as having very poorly drained, high clay soils. This watershed is within the area of the watershed with greater precipitation and denser agriculture. Elevated phosphorus concentrations are expected. Monitoring results for the Little Flatrock station show very elevated total phosphorus concentrations, but not among the top DRP concentrations relative to all assessed stations (Figure 35 and Figure 36). When examining Little Flatrock's DRP concentrations broken down by flow regimes, however, they are among the highest in the dry flow condition, suggesting a more continuous source is present (Table 6 and Table 7). Table 8 and Table 9 show the median and 75th percentile, respectively, of the daily DRP to total phosphorus load ratio for select assessment broken down by flow regimes. Little Flatrock has the lowest ratio of sites assessed on both tables for the high flow regime. These observations suggest that the increased clay sediment material suspended may be adsorbing DRP in higher flows relative to other monitoring stations. This phenomenon is described in the instream processes discussion above in Section 2.2.4.

Table 8. Median daily spring DRP to total phosphorus load ratios broken down by flow regime for select water quality monitoring stations. Values over 50 percent are bolded.

Site	Median spring DRP:TP load at various flow regimes*					Period of record: Spring seasons
	High %	Moist %	Mid %	Dry %	Low %	
04178000 St Joseph R nr Newville, IN	28	25	30	36	NA	2017-2020
04181049 St. Marys R at Wilshire	30	36	28	29	38	2017-2020
04183038 Black Ck nr Harlan, IN	38	**57**	**59**	**66**	**80**	2016-2019
04183979 Platter Ck nr Sherwood	22	34	18	12	NA	2017-2020
04185318 Tiffin R nr Evansport	28	27	31	43	45	2014-2020
04186500 Auglaize R nr Fort Jennings	26	33	39	**53**	**75**	2014-2020
04188100 Ottawa River near Kalida	25	41	**53**	**68**	**71**	2014-2020
04190000 Blanchard R near Dupont	24	28	42	**58**	**60**	2014-2020
04191058 L. Auglaize R at Melrose†	18	27	19	15	NA	2015-2020
04191444 L Flatrock Ck nr Junction	16	30	28	17	NA	2017-2020

* Flow regimes exceedance percentile range: High 0-10, moist 10-40, mid 40-60, dry 60-90, low 90-100.

† Little Auglaize River results not included in this analysis when river was in backwater conditions.

Table 9. 75th percentile daily spring DRP to total phosphorus load ratios broken down by flow regime for select water quality monitoring stations. Values over 50 percent are bolded.

Site	75th pert. spring DRP:TP load at various flow regimes*					Period of record: Spring seasons
	High %	Moist %	Mid %	Dry %	Low %	
04178000 St Joseph R nr Newville, IN	34	32	35	42	NA	2017-2020
04181049 St. Marys R at Wilshire	35	41	35	38	40	2017-2020
04183038 Black Ck nr Harlan, IN	47	**62**	**63**	**73**	**83**	2016-2019
04183979 Platter Ck nr Sherwood	31	45	32	18	31	2017-2020
04185318 Tiffin R nr Evansport	36	35	42	**51**	**51**	2014-2020
04186500 Auglaize R nr Fort Jennings	35	45	**60**	**72**	**82**	2014-2020
04188100 Ottawa River near Kalida	32	**51**	**63**	**74**	**75**	2014-2020
04190000 Blanchard R near Dupont	35	38	**55**	**66**	**65**	2014-2020
04191058 L. Auglaize R at Melrose†	30	42	34	25	NA	2015-2020
04191444 L Flatrock Ck nr Junction	24	40	39	18	NA	2017-2020

Wolf Creek stands out as the only monitoring site in the Maumee watershed with more developed land. The Wolf Creek monitoring station drains over 28 percent developed land within the western suburbs of the greater Toledo area (compare this developed land to the land cover of the major tributaries monitored in the 2020 Nutrient Mass Balance; Figure 28). The Wolf Creek monitoring station is notable for having relatively elevated stream discharge, see Figure 34 among all stations. This makes sense as a more developed watershed is expected to have reduced groundwater seepage and evapotranspiration compared with more agriculturally dense watersheds. Wolf Creek also stands out as having the lowest total phosphorus and DRP concentrations of all assessed watersheds (Figure 35 and Figure 36). The reduced concentrations are low enough to offset the elevated stream flows in Wolf Creek resulting in lower phosphorus loads. In Figure 33 the Wolf Creek load is labeled for the two years of its results as being well below watersheds of similar drainage area.

2.4. Summary of phosphorus sources

This section provides a summary of the many sources of phosphorus that the Maumee watershed exports to the Maumee Bay/western Lake Erie system. Table 10 provides a list of the types of sources outlined in this assessment.

Table 10. Summary of various phosphorus sources in the Maumee watershed.

	Sources	Subcategory	Primarily driven by hydrology?
Nonpoint sources	Agricultural fertilizer	Commercial	Yes
		Manure	Yes
	Sediment sources	Soil erosion	Yes
		Legacy	Yes
	Streambank erosion		Yes
	Instream (stored P export)		Sometimes
	Nonpoint stormwater		Yes
	Nonpoint (onsite) HSTS		No
	Natural lands		Yes
Point sources	Wastewater treatment plants	Individual NPDES	No
		General NPDES	No
	Permitted stormwater	MS4 NPDES	Yes
		General facility- based NPDES	Yes
		General construction NPDES	Yes
	Discharging HSTS		No
	Agricultural fertilizer	Biosolids	Yes

Several studies have confirmed that a large majority of the phosphorus loads are the result of nonpoint sources. While a range of analyses share this finding, this TMDL does not rely on a single, definitive accounting for the proportions of detailed sources. For instance, Ohio's 2020 Domestic Action Plan calculated 84 percent of the spring total phosphorus load from Ohio's portion of the Maumee watershed is from agricultural lands (OLEC, 2020b). A SWAT modeling source assessment (Kast et al., 2021) calculated agricultural fertilizers and soil sources to contribute around 95 percent of the total watershed's spring total phosphorus load. And the statistical SPARROW modeling (Robertson et al., 2019) determined that agricultural sources contribute about 73 percent of the entire watershed's annual load, using an older, 2002, base year.

Rather than selecting a particular study to definitively represent source contributions, this assessment intends to take a weight of evidence approach towards phosphorus sources. Many sources contribute to the phosphorus load. Nonpoint source, particularly nonpoint sources from agriculture, dominate this load. However, there are some areas of greater uncertainty. For instance, the contribution of streambanks has not been studied or modeled as intensively as many other sources. And an understanding of the extent of elevated soil phosphorus, that can contribute to export via legacy phosphorus, is only just beginning to be understood.

This source assessment also examines the late 1990s–early 2000s increasing DRP export trend. Earlier reductions in phosphorus export from excessive sediment loss and poorly operating wastewater treatment plants have largely addressed historic water quality issues to Lake Erie and the watershed's tributaries. However, some of the land use changes that addressed sediment erosion may have helped set the stage for the DRP increases. Hydrological changes, largely due to changes in precipitation, are also a factor contributing to the DRP increase. Understanding these issues provides context for addressing elevated DRP with the intent of reducing the annual western Lake Erie HABs.

The overall intent of this section is to provide scientific rigor to assist in decisions for the TMDL's implementation recommendations. Addressing DRP movement with source management, in addition to the traditional soil conservation, has great promise for targeting DRP export. Practices that manage and slow the movement of water through the watershed also appear to be poised to address this problem. Phosphorus reduction is required throughout the Maumee watershed, as evidenced by elevated concentrations at all monitoring stations; however, there are more opportunities for reduction in some parts of the watershed.

This assessment should serve as part of the backbone to this TMDL project. As the science of understanding phosphorus movement and remediation actions progresses, this assessment will incrementally become out-of-date. The adaptive management approach of developing and implementing a TMDL, explained in detail in Section 5, allows for new science to be incorporated as time progresses.

3. Analysis Methods

This section explains the details of the numeric TMDL development. It reviews the target being used to address impairments. Descriptions of the modeling methods used to determine baseline sources and initial TMDL allocations of total phosphorus makes up most of this section. Model verification methods and discussions of other required TMDL considerations complete the section.

3.1. Targets

Details regarding the development, justification, and ultimate selection of the targets for this TMDL are outlined in this project's published Loading and Analysis Plan (Ohio EPA, 2022). In summary, the targets used are based on the Annex 4 Objectives and Targets Task Team Final Report, "Recommended Phosphorus Loading Targets for Lake Erie" (Annex 4, 2015). Phosphorus load targets apply to the Maumee watershed during the spring period of March 1 to July 31.

The Annex 4 2015 targets document explains total and DRP load targets for the Maumee River to the Waterville, Ohio monitoring point of 860 MT and 186 MT, respectively, for this spring loading period. These target loads are expected to result in WLEB HAB blooms at or equal to the blooms observed in 2004 or 2012, which are considered years with mild, acceptable sized blooms, 90 percent of the time. With targets framed in this manner, they are translated to be met in nine out of 10 years.

Only total phosphorus is used to develop TMDL allocations in this project. However, in recognition of its importance, DRP is incorporated into this TMDL and specifically addressed in several ways. The Annex 4 2015 targets were developed for the Waterville, Ohio monitoring location on the Maumee River. Ohio EPA extrapolated the Waterville total phosphorus target to the mouth of the Maumee River. Table 11 shows both the Waterville and river mouth targets applicable to this TMDL. As explained in this project's Loading and Analysis Plan, this equates to a 39.2 percent reduction from the 2008 baseline condition used to set these targets.

FWMC that corresponded to these loading targets are also provided in the Annex 4 2015 targets document for the Maumee River. These are 0.23 and 0.05 mg/L for total phosphorus and DRP, respectively. These concentration targets provide a benchmark to track progress of load reduction. FWMCs are used instead of standard concentrations as this statistic is less sensitive to stream flow fluctuations. This is a helpful addition to the load targets especially during spring seasons that may be a great deal wetter or dryer than the norm. TMDLs are inherently load based planning tools, therefore the target concentrations are not included in this TMDL project's allocations. The FWMC targets are, however, included in the Ohio Domestic Action Plan and will be evaluated to facilitate adaptive implementation.

Table 11. Maumee watershed nutrient TMDL total phosphorus targets.

Location	Total Phosphorus Spring (March-July) Target
Maumee River at Waterville, Ohio 41.4998, -83.7140	860.0 metric tons[#]
Maumee River at mouth/Maumee Bay 41.6937, -83.4682	914.4 metric tons[#]

[#] To be met 9-of-10 years to account for interannual flow variability for the March-July period in extreme years.

3.2. Sources of data

Table 12 outlines the data used to determine baseline conditions and reduction allocations for this TMDL. Further details of data used are explained throughout Section 3.

Table 12. Sources of data used to develop this TMDL project with data processing details noted.

Data	Source	Details
Watershed pour point loads	NCWQR at Heidelberg	Results are calculated by NCWQR with water quality monitoring concentrations and stream flow data. Available at ncwqr.org. (NCWQR, 2022)
Water quality concentrations	NCWQR at Heidelberg	One to three samples collected daily with refrigerated samplers. Samples are lab analyzed weekly.
Stream flows	USGS Ohio-Kentucky-Indiana Water Science Center	Continuous stream flow stage monitoring converted into stream flow following detailed protocols. Available at waterdata.usgs.gov/nwis.
Land use	National Land Cover Database – USGS' Earth Resource Observation and Science Center	Definitive land cover database for the United States. Both 2011 and 2019 datasets used. (USGS, 2014; Dewitz, 2021)
NPDES effluent data	Discharge monitoring records	Facility submitted monitoring effluent concentration and flow rate data as required by NPDES permits. Publicly available from Ohio EPA upon request.
HSTS served population	Ohio EPA GIS analysis	Analysis combining population data and unsewered areas.
Population	U.S. Census	2010 Census GIS data. Available at census.gov.
Unsewered areas	TMACOG Nutrient Source Inventory	Analysis and GIS data of unsewered areas. (TMACOG, 2018)
Permitted stormwater areas (MS4)	Based on U.S. Census population densities	MS4 areas within the Maumee watershed were determined by Ohio EPA staff via GIS analysis.
Permitted stormwater areas (facility based)	Ohio EPA GIS analysis	Used various aerial imagery and property parcel geospatial data to delineate permitted stormwater areas.

3.3. Methods to assess baseline loads

The baseline condition for the Annex 4 2015 targets that this TMDL utilizes is the spring season (March 1 through July 31) of 2008. Because of this, the baseline condition loads developed for this TMDL will be based on an accounting of this five-month period of that year.

The source assessment of Section 2 outlined a great deal of process-driven modeling efforts that have examined the Maumee watershed, such as the SWAT and SPARROW models. Additional discussions of modeling efforts occur in the implementation actions sections of this report and Appendix 2. These studies are extremely helpful in understanding sources and guiding implementation of pollutant reductions. Picking one, or an ensemble of these models to determine baseline conditions and TMDL reduction allocations, however, would impose several disadvantages to this project. As explained in this project's Loading and Analysis Plan (Ohio EPA, 2022), the myriad of assumptions required to parameterize and calibrate mechanistic models would result in a more inflexible TMDL than the alternative. Because of this, Ohio EPA is employing an empirical based mass balance method for this TMDL.

In the Ohio DAP 2020, Ohio EPA augmented the state's Nutrient Mass Balance method to differentiate nonpoint source loads (Appendix A in OLEC, 2020b). This involved determining the total phosphorus loads delivered from agricultural, developed, and natural areas. This TMDL employs a similar method that was used in the Ohio DAP 2020 to calculate baseline loads for this TMDL. Changes from the Ohio DAP 2020 method for this TMDL mostly consider the details regarding point sources. This includes careful accounting for discharging and stormwater NPDES permitted facilities and communities. Refer to Table 3, in the earlier source assessment section, to see the various point source categories included in this TMDL. The source assessment also includes details about the various point source types that are accounted for in this part of the report.

The remainder of this subsection, 3.3, walks through the baseline condition calculation methods for this TMDL.

3.3.1. Pour point load estimation

Central to this modified Nutrient Mass Balance method is a monitoring point, herein the pour point, where near-continuous data is collected by the National Center for Water Quality Research. The pour point on the Maumee River is at Waterville, Ohio (USGS Gage No.: 04193490). Data are collected one to three times daily, resulting in the ability to calculate an accurate annual load at that location.

The load calculated at this point is the sum of daily loads based on the product of USGS daily flow and NCWQR daily nutrient concentrations (NCWQR, 2022).

3.3.2. Baseline overall loading calculation

Equation 1 shows the overall loading calculation. The load discharged by wastewater treatment facilities are within the regulatory authority of Ohio EPA and represented as WT in equation 1. In addition to waste treatment facilities, loads from CSOs are also regulated by Ohio EPA. HSTS contributions are estimated separately. The landscape derived loads are separated into two categories: load calculated upstream (UPST) from the pour point and load calculated downstream (DST) of the pour point. The landscape loading terms include loads from agricultural, developed, and natural lands. These components of loading are presented schematically in Figure 40. Details of how all these sources were determined are explained in the following sections of this report.

$$Total\ Load = WT + CSO + HSTS + Landscape_{UPST} + Landscape_{DST} \quad (1)$$

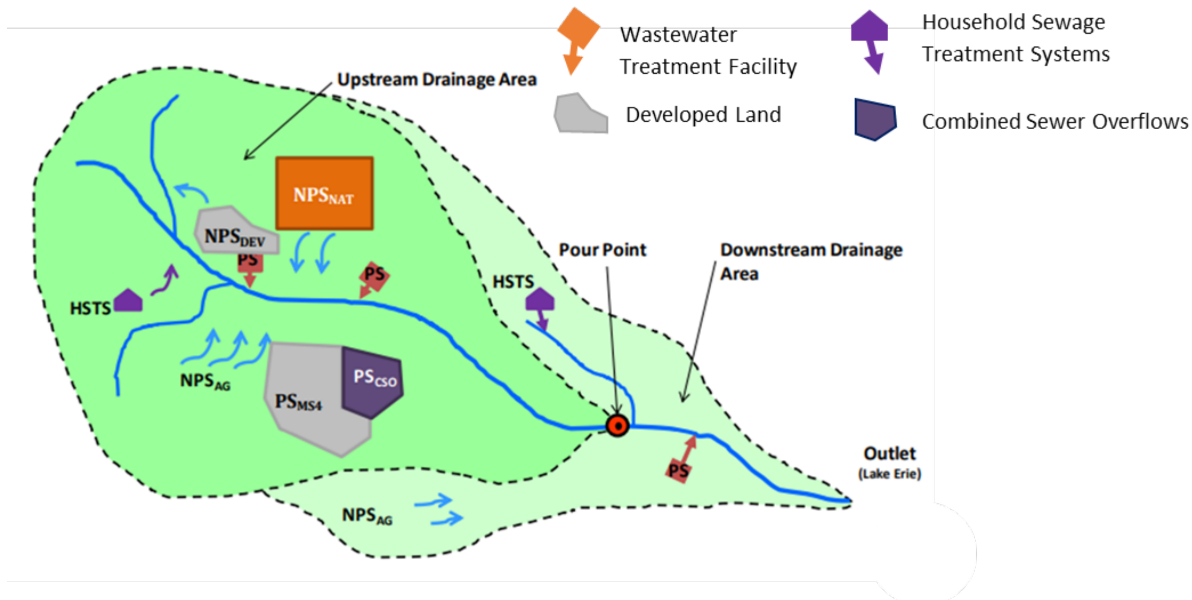


Figure 40. Schematic of sources represented in modified Nutrient Mass Balance.

3.3.3. Baseline loads from wastewater treatment facilities

Wastewater treatment facilities report operational data to Ohio EPA. All facilities are required to report flow volume. Phosphorus is reported at each facility dependent on factors such as the potential for 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 a wastewater treatment facility.

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

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

The total phosphorus concentration denoted [TP] in Equation 2, must be estimated from either reported data or assumptions based on similar facilities. Within the Maumee watershed, wastewater treatment facilities are generally accounted for in two categories: public facilities and industrial facilities. The public facilities are further broken down into subcategories: major [≥1.0 million gallons per day facility design flow (MGD)], significant minor (≥0.5 MGD and <1.0 MGD), minor (≥0.1 MGD and <0.5 MGD), package plant (<0.1 MGD), and controlled discharge lagoons (any size).

To estimate the phosphorus concentration, each facility is placed into one of four groups depending on the type of plant and available phosphorus monitoring data. The groups and approaches for calculating phosphorus concentrations are: 1) industrial facilities reporting phosphorus concentrations – use the median concentration of phosphorus reported during the calculation period; 2) industrial facilities not reporting phosphorus concentrations – use similar facilities or other means to estimate phosphorus concentrations; 3) sewage treatment facilities reporting phosphorus concentrations – use the median phosphorus concentration from the calculation period; and 4) sewage treatment facilities not reporting phosphorus concentrations – use the median phosphorus concentration from similar facilities. Nutrient concentrations estimated for five classes of municipal effluent and are presented in Table 13.

Table 13. Facility classes by design flow.

Group	Type	Design Flow (MGD)	Median Concentration of Group (mg/L)
Industrials	All Industrial Permits	--	N/A
Major Municipal	Sewage Treatment	≥ 1.0	0.54
Significant Minor Municipal	Sewage Treatment	0.5 to 1.0	1.72
Minor Municipal	Sewage Treatment	0.1 to 0.5	2.07
Controlled Discharge	Sewage Treatment	Varies	1.92
Package Plant	Sewage Treatment	< 0.1	3.54

Wet-weather events often result in increased wastewater flows within collection networks, either by design in combined sewer communities or inflow and infiltration. 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), CSOs and SSOs. SSOs typically report occurrences but not volume. Therefore, SSOs are excluded from the analysis unless flow volumes are reported. This report uses a wet weather loading nutrient concentration of 0.75 mg/L for total phosphorus, the median concentration of 131 samples reported from September 2014 to August 2017 by two Ohio sewer districts that are required to monitor total phosphorus at select CSO outfalls in their NPDES permit. When bypasses go through primary treatment, 15 percent removal is assumed by Ohio EPA to account for settling and sludge removal. This value is set to be greater than the 6 percent removal from septic tanks but not as high a removal rates observed when fine solids are removed via extended settling and/or anaerobic digestion.

The Maumee watershed includes wastewater treatment facilities that are outside of the state of Ohio. Data on monthly loads were 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 in the lumped out-of-state (OOS) load. Facilities identified as controlled dischargers were excluded from the OOS analysis because using the data maintained in ICIS results is a gross overestimation of discharge volume. This is because ICIS averages the discharge of only days a discharge occurred. No associated count of days that discharge occurred is reported. Due to this being a very small fraction of the OOS wastewater load, it is more practical to not include this source. 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.

3.3.4. Baseline home sewage treatment system loads

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

Equation 3 outlines this overall method.

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

where,

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

$\text{Nut}_{\text{Yield}}$ = Annual yield of nutrient per person $\left(\frac{\frac{\text{lb}}{\text{year}}}{\text{person}}\right)$

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

$\text{DR}_{\text{onsite, working}}$ = nutrient delivery ratio for onsite working systems

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

$\text{DR}_{\text{onsite, failing}}$ = nutrient delivery ratio for onsite failing systems

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

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

The per capita nutrient yield in household wastewater was determined by literature review. A study by Lowe et al. (2009) reported a median nutrient yield as 0.511 kg-P/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 (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 adsorption systems. In these systems, wastewater percolates through the soil matrix where physical, chemical, and biological processes treat pollutants. Phosphorus is usually considered to be effectively removed in these systems. Beal et al. (2005) reviewed several studies and reported findings including: greater than 99 percent phosphorus removal; 83 percent phosphorus removal; and slow phosphorus movement to ground water. In a nutrient balance study, MPCA assumed that HSTS with soil adsorption systems removed phosphorus at 80 percent efficiency (Wilson and Anderson, 2004). For this study, 80 percent efficiency will be used for these systems. This is because the studies reviewed by Beal used fresh soil columns that did not consider a reduction in efficiency with system age.

Another category of systems included in the mass balance study is soil adsorption systems that are failing to function as designed. Failure of systems is caused by a myriad of problems, so literature values are not available for phosphorus removal. For this method, the assumption is made that failing systems still involve some level of soil contact; therefore, total phosphorus removal will be in between the value of a direct discharge and a soil adsorption system. The value used for this study is 40 percent total phosphorus 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 trains to treat wastewater and discharge directly to streams. Like septic tanks, they are designed to remove suspended solids, but sludge removal is limited to periodic pumping. Lowe et al. (2009)

studied septic tank influent and effluent and determined that there was a 6 percent reduction in total phosphorus. This study will use the same 6 percent reduction observed by Lowe et al. (2009).

The final component needed to estimate HSTS loading is the relative proportion of system types, split into three categories: 1) working soil adsorption systems; 2) failing soil adsorption systems; and 3) systems designed to discharge. ODH is tasked with regulating the treatment of household sewage. In 2013, ODH published the results of a survey of county health departments in 2012 as an inventory of existing HSTS in the state by Ohio EPA district (Table 14). The Maumee River watershed is in the northwest district.

TMACOG refined the Ohio portion of the HSTS estimate from Ohio EPA's Nutrient Mass Balance Study (TMACOG, 2018). Study improvements included refined sewershed areas for NPDES facilities and completing HSTS loading estimates at the HUC-12 subwatershed scale. The improvements for the Ohio portion of the HSTS load are incorporated into this study.

Table 14. Proportions of total HSTS systems grouped into categories for Ohio's Nutrient Mass Balance Study. 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

3.3.5. Baseline loading from the landscape

Central to calculating the load from the landscape is the pour point load described in Section 3.3.1 above. The calculation of the load from the landscape upstream of the pour point is the total load at the pour point minus the wastewater treatment facilities and HSTS loads upstream of the pour point. The landscape load calculated at this point includes loads contributed by all land uses. This subsection explains how the lumped landscape load is empirically broken down to different land use types.

Note that the permitted stormwater is determined after this landscape load is calculated and explained in Section 3.3.6.

Using land use to break down total loading from the landscape is based on the concept that there are unique and important differences in loads from different parts of the landscape. To do this in the context of an empirical mass balance, a ratio of the loads from different parts of the landscape is defined. Field scale data from different land uses is needed to define the contributions of different land use types. A review of literature was completed to summarize field scale data for different land uses. Land use was lumped into three broad categories discussed below: 1) agricultural land, 2) developed land, and 3) natural lands. These uses were aggregated from the 2011 National Land Cover Database (NLCD) (USGS, 2014), as shown in Table 15.

The purpose of the literature review is to index yields from the three broad landscape categories to each other, as described below in Section 3.3.5.4 by Equations 4 through 6. The range of values from each category within the landscape will vary, however the emphasis here is on the average. Variation within these categories is complex and the data may not be available at an appropriate spatial scale. For example, soil test phosphorus and tillage practices vary across small areas but are summarized at the county or zip code level.

Table 15. Land use recategorization from NLCD land use types to broader landscape mass balance groups.

NLCD Land Use Type	Mass Balance Group
Cultivated Crops	Agriculture
Hay/Pasture	Agriculture
Developed, High Intensity	Developed
Developed, Low Intensity	Developed
Developed, Medium Intensity	Developed
Developed, Open Space	Developed
Emergent Herbaceous Wetlands	Natural
Evergreen Forest	Natural
Deciduous Forest	Natural
Herbaceous	Natural
Open Water	Natural
Shrub/Scrub	Natural
Woody Wetlands	Natural
Mixed Forest	Natural

3.3.5.1. Baseline agricultural lands loads

Agriculture comprises nearly 78 percent of the landscape in the Maumee watershed with approximately 93 percent of that area represented by cultivated crops. The abundance of the agricultural land means that its contribution weighs heavily into the average load conveyed to the pour point near the Maumee River outlet. Edge-of-field monitoring networks and modeling efforts have been employed to improve knowledge of nutrient loss from agricultural fields in Ohio. Much of this research is led by the USDA Soil Drainage Research Unit (SDRU) at OSU. A recent study spanning water years 2012–2015 summarized edge-of-field phosphorus loading from 38 field sites throughout the corn belt region of Ohio. The study reports an average annual total phosphorus yield for this period of 1.1 lbs./acre (Peace et al., 2018). USDA's NRCS-CEAP estimated an annual average of 1.9 lbs./acre of total phosphorus loss at the edge of agricultural fields based on the 2012 conservation condition (NRCS, 2017). The NRCS-CEAP effort used modeling results to describe phosphorus losses across the broader landscape than can be represented in the monitoring network. The results for annual loss observed by the Soil Drainage Research Unit edge-of-field data collection ranged from ~0.1–4 lbs./acre (Peace et al., 2018) were within the distribution of the NRCS-CEAP modeling effort. An earlier report by the Ohio Lake Erie Phosphorus Task Force II (Ohio Phosphorus Task Force II, 2013) estimated an average annual loss of total phosphorus yield of 2.05 lbs./acre from cultivated cropland after a review of the literature.

3.3.5.2. Baseline developed lands loads

Developed lands are defined by the amount of impervious surface that they represent (Table 16). Within the Maumee watershed approximately 11 percent of the landscape is classified as developed land. Approximating the percent imperviousness as the center of each class and the relative proportions of each class, developed land is approximately 27 percent impervious in the Maumee watershed. Across the pervious-impervious landscape nutrient loads are described by stark differences in the volume of runoff and nutrient concentrations in the runoff.

Research pertinent to Ohio has been carried out on developed land in the upper Midwest and the Northeast. Some of the studies were executed to quantify the impact of removing phosphorus from lawn fertilizers, an action that has since been largely implemented in Ohio. In a Wisconsin study total phosphorus loss from turf grass plots were 0.05–0.61 lbs./acre/year over three monitoring years, 2005–2007 (Bierman et al., 2010).

Table 16. NLCD land use classes for developed land (adapted from USGS, 2014) and the percentage of each class within the Maumee River watershed's developed land.

Class	Description	% of Maumee
21	Developed, Open Space – areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	55
22	Developed, Low Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 percent to 49 percent of total cover. These areas most commonly include single-family housing units.	30
23	Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 percent to 79 percent of the total cover. These areas most commonly include single-family housing units.	10
24	Developed, High Intensity – highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80 percent to 100 percent of the total cover.	5

The primary impact of impervious areas within the developed landscape is increased runoff. Data from U.S. EPA's Nationwide Urban Runoff Program showed the lowest event mean total phosphorus concentrations on commercial land when compared to other developed land uses, except for open spaces (U.S. EPA, 1999b). However, this is compounded by increases in runoff as the amount of impervious area increases. As imperviousness increases in commercial and industrial areas, runoff volumes exceed 50 percent of observed rainfall compared to less than 10 percent for lawns (Bannerman et al., 1993; U.S. EPA, 1999b). The same studies reported mean total phosphorus concentrations that were approximately 2.5 times greater for lawns when compared to streets and 5-10 times greater when compared to parking lots. Annual loads across the developed landscape start to balance across the landscape as concentrations are elevated in low runoff areas and lower in higher runoff areas.

3.3.5.3. Baseline natural lands loads

Natural lands are grouped as areas within the watershed that are generally not managed with nutrient inputs (Table 15). Most of the research on the natural landscape has been focused on enhancing the capacity of natural lands to serve as nutrient and sediment sinks. However, across the broader landscape natural lands represent a wide variety of landforms that serve as sources and sinks (Hornbeck et al., 1987; Swank and Waide, 1988). While the distribution of loads from agricultural and developed lands were always reported as positive loads, natural lands are represented by a distribution of both positive and negative loads. Without adequate monitoring data to compare with other land uses, a small positive bias of 0.1 lbs./acre/year is assumed for natural lands.

3.3.5.4. Baseline landscape loading summary

The literature supports the assumption that agricultural lands are the highest yielding of the three defined categories. Annual agricultural loads reported in the region ranged from 1.1 – 2.05 lbs./acre/year on average. Developed land had results that were less than 0.1 – 0.6 lbs./acre/year on turfgrass and similar values from the impervious landscape, albeit due to increased runoff at lower concentrations. The natural landscape is not well described with field scale monitoring data across the diverse natural landscape, but a small positive load of 0.1 lbs./acre/year is assumed. The ratio that is used to define the relative contributions at the pour point are that agricultural land yields twice as much per acre as developed land (2:1) and agricultural land yields 10 times as much per acre as natural lands (10:1). Small changes in these ratios will not result in large changes in the breakdown of the total load because the equations are constrained by the large proportion of the landscape represented by agricultural production.

Equations 4 through 6 define the relative contribution of the landscape load at the pour point.

$$\frac{Landscape_{up}}{Area_{up}} = \frac{Landscape_{AG}}{Area_{AG}} + \frac{Landscape_{DEV}}{Area_{DEV}} + \frac{Landscape_{NAT}}{Area_{NAT}} \quad (4)$$

$$Landscape_{DEV} = Landscape_{AG} * 0.5 \quad (5)$$

$$Landscape_{NAT} = Landscape_{AG} * 0.1 \quad (6)$$

Note that each component in Equation 4 is normalized by area, signifying that these are yields, not total loads. $Landscape_{up}$ and $Area_{up}$ indicate the landscape load and area upstream of the pour point, respectively. Agricultural, developed, and natural land areas are denoted AG, DEV and NAT, respectively.

The series of equations gives the relative load from each sector at the pour point that can then be used to estimate the load downstream of the pour point from the nonpoint source. To do this, the upstream loads are converted into yields for each land use. The yield is then used to determine the nonpoint source downstream by assuming the same yield from the upstream area applies to the downstream area for each component of the landscape. This calculation is necessary because it is not possible to measure load directly due to the lake influence on the river downstream of the pour point.

3.3.6. Baseline permitted stormwater

There are several groups of permitted stormwater that must be broken out from the baseline condition basin-wide load calculation. These are described in detail above in the source assessment within Section 2.2.2.

The area covered by MS4 permitting is based on existing U.S. Census geospatial data. The MS4 coverage area was cut out to the Maumee watershed via a GIS analysis. The individually permitted city of Toledo MS4 area was further broken out of the MS4 area within the Maumee using GIS analysis. This resulted in an amount of area within the Maumee watershed for the Toledo MS4 area and the remainder of MS4 areas covered by Ohio EPA's MS4 General Permit (OHQ000004).

Stormwater is also permitted based via facility based NPDES permits. These may be included in individual NPDES permits or by the Multi-sector General Permit (OHR000007). The areas for all facilities permitted in both categories have been delineated in GIS by Ohio EPA staff. Areas for 41 individual NPDES permits that include stormwater controls and over 250 facilities covered by the Multi-sector General Permit were determined. Facility based permitted stormwater areas that are within the Toledo and general MS4 areas are removed from the MS4 areas for the TMDL calculations.

Figure 41 shows example results for part of the Maumee watershed of the delineation of various types of permitted stormwater.

Construction activities covered by Ohio EPA's general permit (OHC000005) are accounted for in a different manner due to the transient nature of these operations. When filing for coverage of this permit, permittees must state the construction site location and number of acres impacted. Ohio EPA carried out an analysis on the number of acres within the Maumee watershed covered by this permit for the most recent five years of available data (2017-2021). Assuming most operations do not span greater than a year, the average annual area coverage by this permit was determined to be used for TMDL calculations.

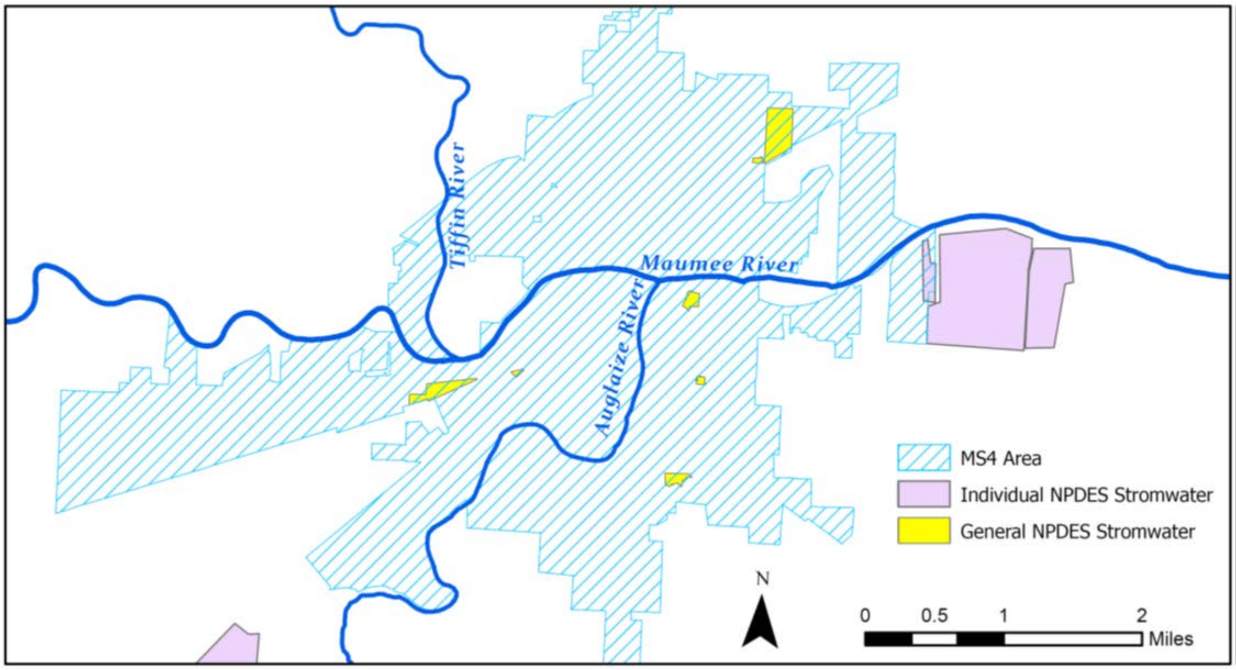


Figure 41. Map showing the permitted stormwater area delineated around the Defiance, OH area.

In order to calculate the baseline total phosphorus loads for the MS4, facility based, and construction permitted stormwater areas, the percent of area that falls into each category is taken out of the total landscape load from the developed load portion. The remainder of the developed land is combined with the agriculture and natural lands to be the final total nonpoint source.

3.4. Modeling the target condition – proposed allocations

The following outlines the proposed total phosphorus allocation methods for meeting the TMDL. Like the baseline conditions, these allocations are applicable to the spring loading season of March through July. Also like the baseline conditions calculations, reductions will be calculated via an empirical means. This is rather than using scenario(s) outputs from a process-based model. Additional discussion on this modeling will be included in the implementation recommendations section of this report in order guide those recommendations.

This is the Preliminary Modeling Results step in this TMDL project. This step is designed to provided stakeholders with detailed results prior to when the actual proposed TMDL allocations are presented. There is an expectation that these methods, and subsequent results, will be altered after careful consideration by stakeholders and further discussions with Ohio EPA.

The potential that phosphorus reductions can be met in the fashion outlined by these methods has been carefully considered. This is explained in detail in the Reasonable Assurances part of this report, Section 6. The allocations must sum to the seasonal target load of overall 914.4 MT of total phosphorus. The following subsections first presents the allocation method for each type of source. Then subsections are presented showing how the wasteload and load allocations are summarized. These reduction methods will only be carried out for loading to the Maumee watershed from the state of Ohio. An explanation on out-of-state boundary conditions is provided at the end of this subsection.

3.4.1. Allocations for permitted wastewater treatment facilities

This subsection outlines the details of proposed permitted treatment facilities total phosphorus allocations[1]. As explained above in Section 2.2.2.1, wastewater treatment facilities currently discharge well below their permitted allowance. The allocations for the wastewater treatment facilities are based on an objective of preserving the baseline total phosphorus reductions already realized by this source. While this does not result in new reductions from what is currently being discharged, it effectively eliminates capacity between the currently authorized and actual loads shown above on Figure 22.

The concept of grouping most of the facility-based load is proposed in order to provide the most flexibility to permitted facilities. Implementing a grouped permitted loads could be achieved via a watershed general permit.

There are also over 100 facilities that contribute an extremely small amount of total phosphorus load to the Maumee watershed. These facilities are not being proposed to join the grouped load that would be included in the general permit. Rather, individual wasteload allocations are calculated with the expectation that baseline conditions will be maintained.

Calculation methods for CSO specific wasteload allocations are also presented in this subsection. These allocations represent long term control plans that each CSO community has either completely enacted or are in the process of enacting.

3.4.1.1. Proposed allocation methods for grouped wastewater treatment facilities

Facilities that are proposed to be part of the grouped load, which may result in a special TMDL general permit, are generally based on what are currently considered "majors" (see section 2.2.2). These are municipal wastewater treatment plants with an average design flow of one million gallons per day or greater. Significant minors that have an average design flow of greater than half a million gallons per day are also included. Several industrial facilities that have been previously identified as contributing significant amounts of total phosphorus are also included. The facilities included in the grouped load are shown below in this subsection.

The sum of the load that all facilities within this group contributed during the 2008 spring season is used to determine the total allowable load for the group. This reflects the objective of not exceeding the baseline load from these sources.

While each facility's baseline, 2008 spring season load, is used to determine the grouped load allocation, this load is not what is used to determine each facility's individual wasteload allocation. If that were to be done it would reward the facilities that were not maximizing total phosphorus reductions in 2008 and penalize facilities that were optimizing controls the most. Rather, a tiered system of determining the grouped facilities individual wasteload allocations is proposed. This system is intended to reflect 1) the magnitude of facilities' loading contributions, 2) the existing ability to treat total phosphorus at each facility, 3) the objective that the cumulative facility-based load does not increase from the 2008 baseline. This calculation method also allows for a certain amount of allowance for future growth to be reserved for new or expanding facilities.

It is important to note that having an individual wasteload allocation for each permitted facility is a required component of any TMDL. This applies to these facilities that are being proposed to be grouped and implemented upon via a general permit or similar action. Additional discussion on the general permit is in Section 5.

[1] Total phosphorus wasteload allocations for facilities included in near-field TMDL reports in the Maumee River watershed are not impacted by this TMDL. Please see Appendix 4 for additional information.

Table 17 shows the tiered approach for determining the individual wasteload allocation for each facility proposed to be in the grouped load limit.

Table 17. Different tiers for calculating wasteload allocations for the facilities in the proposed grouped load.

Grouped Permit WLA Tier	Description	Wasteload Allocation Calculation Method
GP1	Municipal wastewater treatment plants with average daily design flows greater 10 MGD	Average daily design flow at a total phosphorus concentration of 0.37 mg/L (the expected long term average total phosphorus discharge concentration where a 0.5 mg/L monthly limit exist) for the 153 days of the spring season.
GP2	Municipal wastewater treatment plants with average daily design flows between 1 and 10 MGD	Calculated for each facility as their average design flow divided by the sum of all the GP2 design flows and then multiplied by the remainder of load available after accounting for the other grouped permit tiers. This results in a concentration of 0.44 mg/L (~0.60 mg/L monthly limit) over the 153 days of the spring season.
GP3	Minor municipal wastewater treatment plants with average daily design flows between 0.5 and 1 MGD; several industrial facilities	Average daily design flow at a total phosphorus concentration of 0.73 mg/L (the expected long term average total phosphorus discharge concentration where a 1.0 mg/L monthly limit exist) for the 153 days of the spring season.
GPX	Industrial facilities included in grouped WLA	Calculation methods are specific to each facility and described below.
Grouped permit AFG	1.4 metric tons of total phosphorus reserved for future growth	This amount of load can accommodate new effluent treating about 7 MGD at the 0.37 mg/L (GP1) level.

WLA = Wasteload allocation MGD = Million gallons per day AFG = Allowance for future growth

The following paragraphs provide more details on these wasteload allocation tiered groups. Table 18 lists the facilities proposed to be included in the grouped load and what tiered group they fall into.

GP1 – There are four facilities that have an average daily design flow greater than 10 MGD. These are all municipal wastewater treatment plants that currently have a monthly total phosphorus limit of 1.0 mg/L. Setting an individual wasteload allocation based on average design flows and a total phosphorus concentration of 0.37 mg/L is reflective of a long-term discharge concentration average if the facilities were to have monthly limits of 0.5 mg/L. This average monthly limit is derived using Table 5-2 from the U.S. EPA TSD for Toxics Control (U.S. EPA 1991). To calculate the monthly limit from the long-term average value of 0.37 mg/L, a coefficient of variation of 0.6 and 10 samples collected monthly are assumed. Due to the large size of these facilities marginal costs of optimizing for phosphorus treatment is more inexpensive than facilities in the other tiers.

GP3 – These are facilities that currently do not have total phosphorus limits in their individual permits. These six municipal wastewater treatment plants are designed to operate with a daily average discharge between 0.5 to 1 MGD. Individual wasteload allocations for these facilities consider a total phosphorus concentration that would be discharged were they to have a monthly limit of 1.0 mg/L, which is 0.73 mg/L (following guidance mentioned above, U.S. EPA, 1991). The permitted average design flow is used to calculate the wasteload allocation for all but one of these facilities. Due to the plant design, the wastewater treatment plant for the city of Paulding does not have an official design flow. In place of a design flow, the 95th percentile of the average monthly discharged flow rates for the most recent five years of available data.

GPX – This tier includes eight industrial facilities that have all demonstrated discharging effluent with total phosphorus loads that require additional considerations and are included in the grouped WLA. There are a variety of different methods utilized for calculating each facility's wasteload allocation. These differences are necessary based on the unique nature of the facilities. The following explains these differences:

2IF0004 – PCS Nitrogen Ohio LP: This facility has a total phosphorus load limit due to a near-field TMDL. The total phosphorus concentration used to calculate the individual wasteload allocation was at 0.73 mg/L as a long-term average value and the flow was 4.33 MGD. This is the total phosphorus concentration assumed to be consistent with optimizing cooling water additive used to meet a monthly limit 1.0 mg/L (following guidance mentioned above, U.S. EPA, 1991). The flow is the 95th percentile monthly average discharged by the facility. PCS Nitrogen does not use biological treatment and could be further optimized to lower phosphorus concentrations.

2IG00001 – Lima Refinery: This facility does not currently have total phosphorus load and concentration limits. However, due to the nature of this facility's operations, it has been discharging very low concentrations of total phosphorus in recent years (spring season medians ranging from 0.16 to 0.22 mg/L in the five seasons ending 2021). The facility has also recently implemented a water conservation project that reduced total discharge substantially. The individual allocation accounts for the lower flow values achieved from the water conservation project and meeting a limit consistent with 0.37 mg/L as a long-term average (assumed to be equivalent to a monthly average concentration of 0.5 mg/L). Since the facility is currently discharging effluent consistent with these considerations, additional technology has not been considered.

2IH0021 – Campbell Soup Supply Company: This facility has had a total phosphorus concentration limit for several permit cycles. The permit's average design flow used for permitting wasteload calculations is 10 MGD, and the actual average daily flows have averaged 5.5 MGD for the spring seasons 2017 through 2021. The facility utilizes biological treatment and has been evaluated with the GP2 subcategory of municipal wastewater treatment facilities.

2IH00110 – Cooper Farms Cooked Meats Van Wert: With no existing total phosphorus permit limit, this facility has voluntarily reduced the total phosphorus concentration of their effluent discharges. Current discharge concentrations are approximately 1.0 mg/L, whereas spring median concentrations from 2008 through 2011 ranged from 18.7 to 23.85 mg/L. Because of this, the individual wasteload allocation for this facility is set at their second greatest load calculated for the last five spring seasons, 2017 through 2021. Note that this is similar to how the wasteload allocations is calculated for minor wastewater treatment plants (see Section 3.4.1.2).

2IK00002 – G.A. Wintzer and Son Co: This facility has no existing total phosphorus limits in its permit; it utilizes biological treatment and discharges at elevated concentrations compared to similar-sized municipal wastewater treatment facilities. Median spring season total phosphorus concentrations have ranged from 4.7 to 13.1 mg/L in the last five seasons, 2017 through 2021. Since no total phosphorus controls currently exist at this plant, their wasteload allocation is calculated in the same fashion as facilities in the GP3 tier.

2IW00010, 2IW00070, 2IW00190 – McDowell/Bowling Green, Delta, and Napoleon water treatment plants: These three drinking water treatment plants use reverse osmosis treatment that utilizes phosphorus containing additives to clean membranes. The wasteload allocation for these facilities assumes they will meet a long-term average concentration of 0.73 mg/L, consistent with optimizing the use of treatment additives to meet a monthly average limit of 1.0 mg/L (following guidance mentioned above, U.S. EPA, 1991).

Grouped permit allowance for future growth – The 1.5 metric tons of total phosphorus reserved for future growth is calculated based on if 7 MGD of future flow were to be discharged at the long-term average concentration of 0.37

mg/L. This concentration is used because this TMDL is proposing that new or expanding major treatment facilities will be permitted with a monthly concentration limit of 0.5 mg/L. See the Allowance for Future Growth Section 3.7 for more information about this reserved load.

GP2 – There are 20 major municipal wastewater treatment plants with average design flows less than 10 MGD in this tier. All these facilities have an existing monthly total phosphorus limit of 1.0 mg/L in their permits. The total wasteload allocations for all facilities in this group is set as the remainder of the grouped wasteload allocation after the other individual wasteloads for the other tiers (GP1, GP3, GPX, and the grouped permit AFG) have been assigned. Within this tier that load is distributed to each facility based on their average design flow (i.e., each facility gets the percent of the total GP2 tier wasteload allocation equal to their design flow divided by the sum of all GP2 facilities' design flows). Employing this method has two advantages. The first is that it completely allocates the remaining group wasteload. The second advantage is that it essentially solves for the wasteload allocation of the facilities in this group to be considered at a concentration between the GP1 and GP3 group. This results in a long-term average of 0.44 mg/L or what would be expected with a monthly concentration limit of about 0.60 mg/L (following guidance mentioned above, U.S. EPA, 1991).

Table 18. Different tiers for calculating wasteload allocations for the facilities in the proposed grouped load.

Tier	Permit #	Facility Name
GP1	2PF00000	Toledo Bay View Park WWTP
GP1	2PK00000	Lucas Co WRRF
GP1	2PE00000	Lima WWTP
GP1	2PD00008	Findlay WPCF
GP2	2PD00002	Perrysburg WWTP
GP2	2PD00013	Defiance WWTP
GP2	2PB00042	Hicksville WWTP
GP2	2PD00006	Van Wert WWTP
GP2	2PD00019	Wapakoneta WWTP
GP2	2PD00029	Delphos WWTP
GP2	2PD00018	Bryan WWTP
GP2	2PD00026	St Marys City WWTP
GP2	2PD00028	Ottawa WWTP
GP2	2PD00000	Napoleon WWTP
GP2	2PD00017	Archbold WWTP
GP2	2PB00050	Ada WWTP
GP2	2PK00002	Shawnee No 2 WWTP
GP2	2PC00005	Bluffton WWTP
GP2	2PB00040	Leipsic WWTP

Tier	Permit Number	Facility Name
GP2	2PD00016	Wauseon WWTP
GP2	2PH00007	American-Bath WWTP
GP2	2PH00006	American No 2 WWTP
GP2	2PD00003	Montpelier WWTP
GP2	2PB00025	Swanton WRRF
GP3	2PB00034	New Bremen WWTP
GP3	2PC00004	Columbus Grove WWTP
GP3	2PB00048	Cridersville WWTP
GP3	2PB00003	Delta WWTP
GP3	2PB00046	Elida WWTP
GP3	2PD00027	Paulding WWTP
GPX	2IF00004	PCS Nitrogen Ohio LP
GPX	2IG00001	Lima Refinery
GPX	2IH00021	Campbell Soup Supply Company
GPX	2IH00110	Cooper Farms Cooked Meats Van Wert
GPX	2IK00002	G.A. Wintzer and Son Co
GPX	2IW00010	McDowell/Bowling Green WTP
GPX	2IW00070	Delta WTP
GPX	2IW00190	Napoleon WTP

WWTP and WRRF are wastewater treatment plants of municipal sewage.
WTP are drinking water treatment plants.

3.4.1.2 Proposed allocation methods for minor and general wastewater treatment facilities

The remainder of wastewater facilities receiving a wasteload allocation in this TMDL contribute a relatively small portion of the total facility based wasteload allocation.

These are over 110 municipal and semi-public individual permitted wastewater plants and 10 industrial facilities considered within the wasteload allocation. With only a few exceptions, the individual wasteload allocation for each of these facilities is set based the second greatest spring season load each facility has discharged in the last five spring seasons (2017-2021). Many of these facilities do not monitor total phosphorus in their effluent. Similar assumption to those used to calculate the 2008, baseline, loads were used to determine these facilities total phosphorus concentrations (see Section 3.3.3).

The exceptions to this calculation method are for wastewater plants that have not reported any effluent flow during this time period. In those cases, assumptions are made to determine an appropriate discharge from which to calculate the facility's individual wasteload allocation. The names and permit numbers of these facilities are reported in Appendix 3 of this report along with the actual wasteload allocation results (see Section 4.1).

A small allowance for future growth is explicitly reserved for these small individually permitted facilities. This load, 0.1 metric tons of total phosphorus per spring season, is being set aside for the use of new or expanding small facilities that may discharge phosphorus to the Maumee watershed in the future. This action is considered part of the allowance for future growth and explained further below in Section 3.7.

A single wasteload allocation is calculated for the load contributed from Ohio's Small Sanitary General Permit (OHS000005). There are currently 11 facilities in the Maumee watershed covered by this permit. Facilities covered by this permit must have an average design flow less than 25,000 gallons per day; however, Ohio EPA is aware that most discharge significantly less than this amount. In order to allocate adequate load for facilities covered by this general permit, a daily discharge flow rate of 12,500 gallons per day is used to calculate the wasteload allocation. A total phosphorus effluent concentration of 2.5 mg/L is assumed for these plants for this calculation. Ohio EPA is aware that there are many small sanitary treatment systems that are currently unpermitted across the state. The Agency is steadfast in its efforts to bring these facilities into compliance either by permitting them under this general permit or by tying their influent to existing individually permitted wastewater treatment plants. Because of this potential for additional plants being covered by this general permit, the existing number of 11 plants is increased to 25 for the wasteload allocation calculation of this general permit. This action is considered part of the allowance for future growth and explained further below in Section 3.7.

3.4.1.3. Proposed allocation methods for combined sewer overflow and other wet weather events

All 24 CSO communities within the Ohio portion of the Maumee watershed have plans to address their systems. Half of these communities have planned for complete separation of storm and sanitary sewers. The CSO wasteload allocation for these communities is zero load.

For the other 12 communities, there is an expectation of some CSO discharge events once control plans are completed. Six of these communities each have developed hydraulic models to estimate the amount of CSO discharge during a typical year at their completed plans level of control. The wasteload allocation for these facilities is calculated by determining the product of that typical year flow rate, an assumed total phosphorus concentration of 0.75 mg/L, five-twelfths in order to calculate the spring season period, and a conversation factor. The 0.75 mg/L assumption is based on an assessment of CSO data documented in Ohio EPA (2020b).

Using five-twelfths of the planned annual control plan discharges for the TMDL's spring season wasteload allocation assumes discharge occurrences average out evenly throughout the year. This assumes that 42 percent or five-twelfths of the level of control discharges will occur from March 1 through July 31. Since all communities' LTCP controls are not finished yet (and therefore level of control is not yet realized) and considering every system is different, assumptions with which to estimate the timing of future occurrences are very imprecise. Ohio EPA has observed that 38 to 62 percent of discharge events for the eight most active CSO communities occurred during this TMDL's spring season from 2017 through 2021. The 42 percent assumption is within this range, and Ohio EPA considers using 42 percent an acceptable approach rather than estimating a different proportion considering the challenges noted above.

A different wasteload allocation calculation method is required for the six remaining CSO communities that do expect to have some discharges upon completion of their control plans but have not developed a hydraulic model for their control plan. This is because the flow rate is unknown for the releases that may occur once control work is complete. The wasteload allocation is calculated by reducing the baseline, 2008, CSO load by 80 percent based on our expectations from communities with hydraulic models and similar levels of implementation.

The SSOs are prohibited by the Clean Water Act. All communities with known SSOs must plan to eliminate these sources. Because of this, there are no wasteload allocations given for SSOs.

CSO provisions are tied to a communities NPDES permit. Table 19 summarizes the wasteload allocation being used for each of the 24 CSO communities.

Table 19. Wasteload allocation method for CSO communities.

Community/Permittee	Permit #	Wasteload Allocation Method
Toledo Bay View Park WWTP	2PF00000	Level of control hydraulic model flow and a 0.75 mg/L total phosphorus concentration used to calculate WLA.
Lima WWTP	2PE00000	
Findlay WPCF	2PD00008	
Wapakoneta WWTP	2PD00019	
Napoleon WWTP	2PD00000	
Defiance WWTP*	2PD00013	
Hicksville WWTP	2PB00042	WLA set at an 80 percent reduction of the calculated baseline, 2008, CSO load.
Van Wert WWTP	2PD00006	
Wauseon WWTP	2PD00016	
Delta WWTP	2PB00003	
Delphos WWTP	2PD00029	
Payne WWTP	2PA00019	
Perrysburg WWTP	2PD00002	WLA set to zero to reflect complete sanitary and storm sewer separation upon completion of CSO long term control plan.
Montpelier WWTP	2PD00003	
Fayette WWTP	2PB00045	
Paulding WWTP	2PD00027	
Ohio City WWTP	2PB00030	
Columbus Grove WWTP	2PC00004	
Dunkirk WWTP	2PB00061	
Pandora WWTP	2PB00029	
Forest WWTP	2PB00044	
Deshler WWTP	2PC00002	
Leipsic WWTP	2PB00040	
Swanton WRRF	2PB00025	

* Ohio EPA is expecting Defiance to provide the results of their level of control hydraulic modeling in August of 2022. Prior to that point, the WLA for this facility is temporarily calculated based on an 80 percent reduction of their calculated baseline, spring 2008, CSO load.

3.4.2. Allocations for permitted stormwater

Permitted stormwater shares a close relationship with nonpoint source loads as they are primarily driven by precipitation events. Natural infrastructure projects, such as wetlands or two-stage ditches, are an effective means of managing stormwater. Implementing these projects in communities involves diverse partnerships and have been a component of nonpoint source planning efforts throughout the basin. To encourage these partnerships to continue, reductions targeting natural infrastructure are allocated to the nonpoint source. Implementing source control and green infrastructure is more appropriately managed by storm water utilities.

For this TMDL's allocations, MS4 allocations are set based on a 20 percent reduction from their baseline condition. This is approximately half the reduction set for the nonpoint source load allocation.

The non-MS4 regulated stormwater sources have been calculated to contribute only 7.8 percent of the total baseline regulated stormwater load and less than 0.2 percent of the total watershed baseline load. These permits have conditions that require management actions that improve pollutant source control compared to other stormwater areas. Because of the small contribution and existing measures to control phosphorus, additional reductions are not included in these source's wasteload allocations. The wasteload allocations for non-MS4 regulated stormwater sources are set equal to their baseline load.

3.4.3. Allocations for home sewage treatment system loads

As described in the baseline conditions methods, soil adsorption onsite and discharging HSTSs are accounted using specific calculations. For a TMDL, these types of systems are allocated differently. Discharging systems are expected to be covered under Ohio EPA's general permit (OHK000004). Being a permitted source, this pollutant allocation is considered part of the wasteload allocation. The onsite HSTSs are not point sources and are therefore part of the load allocation.

No extra load reduction is expected from discharging systems. Therefore, the wasteload allocation for this source is set at the calculated baseline load.

The calculation for baseline soil adsorption onsite HSTSs explains that many of these systems are failing. The load allocation for this source sets an expectation that progress is made addressing these failed onsite systems. Specifically, this allocation method proposes that half of the failing systems are addressed. For the allocation, the load produced by these repaired systems is reduced to have them contribute the same amount that is discharged from properly working onsite systems. Therefore, the total load allocation for onsite HSTS is the sum of 1) the load from the baseline, 2008, properly working systems, half of the baseline failing onsite systems considered repaired, and the other half of the baseline failing onsite systems still considered discharging at the failing rate.

3.4.4. Wasteload allocation summary

The various wasteload allocation methods appliable to the point sources of total phosphorus in this TMDL are summarized on Table 20. The sum of the allocations for all categories is the total wasteload allocation.

Table 20. Wasteload allocations method summary.

Program	Permit Type	Major Category	Wasteload Allocation Method Summary
Treatment Facilities: Point source pipe(s) directly contributing waste to surface waters	**Individual NPDES Permit**: Unique permits issued for each facility	**Public**: Treats a majority of municipal/human waste; most often delivered from public sewer systems	"Major": WLA included in the grouped wasteload that could be implemented via a general permit. Grouped WLA determined by these facilities 2008 effluent. Individual WLAs re-distributed, see **Section 3.4.1.1**
			"Minor": WLAs set at the 2nd greatest load in the last five spring seasons, see **section 3.4.1.2**
			Combined Sewer Overflows: Separate WLAs calculated for each CSO community based on their long-term control plan, see **Section 3.4.1.3**
		Phosphorus Discharging Industrial: Facilities that treat waste from industrial processes	Facilities with current total phosphorus limit and other special cases included in grouped WLA, see **Section 3.4.1.1**
			Facilities with minimal total phosphorus discharges. WLAs set at the 2nd greatest load in the last five spring seasons. See **Section 3.4.1.2**
	General: Permits that cover smaller facilities	Small sanitary general permit	WLA set based on assumptions, see **Section 3.4.1.2**
		Discharging HSTS general permit	WLA set at the baseline condition total load, **see Section 3.4.3**
Stormwater: Regulated nonpoint sources	**Individual**: Unique permits	Facility based	MS4 stormwater sources' WLA set based on a 20 percent reduction from baseline conditions. All other permitted stormwater receives WLA's consistent with the estimated baseline conditions, see **Section 3.4.2**
		Municipal based (Phase I MS4s)	
	General: Generic permits	Facility based (aka MSGP)	
		Municipal based (Phase II Small MS4 general permit)	
		Construction general permit	
Beneficial Use	Beneficial use of materials	Biosolids	Discharge of materials to surface water is prohibited and agricultural stormwater from land application fields is captured in the TMDL's load allocation.
		Land application	

3.4.5. Allocations for nonpoint sources

The allocations for all nonpoint source load, except for the onsite HSTS load, is grouped together and termed the "nonpoint source landscape load" in this method. This reflects the allocation calculated for the land area grouped in agricultural and natural lands use plus the developed that is not accounted for by the permitted stormwater (as noted above in 3.4.2). This load allocation is determined by giving this source the remaining total phosphorus load available of the target after all other allocations, noted in the subsections above and including an explicit margin of safety described below in Section 3.6, have been taken.

Due to the nature of this allocation calculation method, and the manner in which nonpoint source implementation actions are proposed to be carried out, the nonpoint source landscape load allocation is not itemized by land use or any other means. Just one total allocation value is provided. This is similar to the specific land use far-field targets for each HUC-12 watershed management unit in Ohio's part of the watershed that have been published in Ohio's Domestic Action Plan (OLEC, 2020). Like this TMDL, the Ohio DAP HUC-12 targets are also based on the Annex 4 overall watershed target.

A separate load allocation for the onsite HSTS is provided in the results section. The sum of the nonpoint source landscape and onsite HSTS allocations is the total load allocation.

3.4.6. Out-of-state boundary condition and resulting Ohio targets

The baseline conditions of phosphorus load were calculated for the entire watershed draining to the Maumee River, including the areas within Michigan and Indiana. However, the allocations calculated in this TMDL are only for load delivered from within Ohio's borders. This includes reductions for streams that flow into Indiana. All streams that flow into Ohio from Indiana and Michigan are assumed to be at a boundary condition that meets the same reduction rate of 39.2 percent from the 2008 baseline condition. The baseline conditions assessment, described above, found that 75 percent of the existing total phosphorus load delivered to the Maumee watershed is from Ohio. Note that Ohio makes up 73.3 percent of the area in the watershed, which is very close to the load proportion. Applying the 39.2 percent reduction to the baseline loads determined from outside of Ohio results in an out-of-state boundary condition target load of 228.7 MT of total phosphorus. Of that boundary condition, 79 percent, 180.7 MT of total phosphorus per spring season, is assigned to Indiana. Michigan is assigned 21 percent of the boundary condition with 48.0 MT of total phosphorus. Considering only the part of the total watershed target that Ohio is responsible for, the 914.4 MT complete watershed total phosphorus target becomes 685.8 MT. This is the value that the Ohio allocations will sum to in this TMDL.

3.5. Model verification methods

Because a mass balance method is being employed to develop TMDL baseline sources and allocations, statistical model calibration and validation tests used for mechanistic or process-based models are not applicable. The uncertainty of the components that go into the mass balance method are discussed in the margin of safety, Section 3.6 of this report.

A verification of the mass balance method's ability to predict loads is carried out for this project. As explained above in Section 3.3.5.4, total phosphorus loads were estimated throughout the watershed by land use and regional stream discharge patterns. This was initially done to support the development of Ohio's 2020 Domestic Action Plan to set planning targets for HUC-12 subwatersheds. Using these adjustment factors the load was balanced for the area upstream of Waterville based on 2008 observed load at the Waterville pour point. The land use and hydrology downstream of Waterville were then used to estimate that part of the watershed's total load (along with the discharging permitted wastewater treatment plants). This model verification tests the model's predictive ability for this unmonitored area downstream of Waterville.

Stream water quality monitoring stations upstream of Waterville exist throughout the Maumee watershed as explained in Section 2.3 of this report (also see Figure 24). For this verification, the loads for several of these upstream monitoring stations are calculated by the same approach used to determine HUC-12 landscape target in the 2020 Domestic Action Plan (OLEC, 2020b).

To do this, first the load of the entire Maumee watershed upstream of Waterville is "balanced" using the spring season load at the Waterville monitoring station for 2017 through 2021. After accounting for NPDES facilities and HSTS loads, the nonpoint source load is determined. The method considers the different loading by area yields for agricultural, developed, and natural land use, as described in Section 3.3 of this report. A hydrologic weighting factor was applied to each HUC-12. This weighting factor is discussed in Section 2.3.2 of this report, and in Appendix A of OLEC, 2020b.

In order to determine the load for each upstream monitoring station for these five spring seasons, a subset of the load from the total watershed draining to the Waterville monitoring station is determined. This is carried out in two steps. First, the landscape load for all complete HUC-12s upstream of each monitoring station is summed. For the HUC-12 that each monitoring station resides, the total landscape load for that HUC-12 is cut to include the proportion of load that equals the proportion of area within the HUC-12 that drains to the monitoring station. The second step is adding the load from the discharging NPDES facilities and HSTSs upstream of each monitoring station. This results in the total modeled load at each monitoring station. These steps were carried out for ten upstream monitoring stations, each for five spring seasons, 2017 through 2021.

For this verification, loads for the upstream stations are also calculated in the same spring seasons using a simple drainage area ratio of the Waterville loads. The drainage area ratio loads are determined by multiplying the Waterville load, for a given season, by the proportion of drainage area of the upstream station's watershed compared to the entire Waterville drainage area. For instance, the Ottawa River's monitoring station drains 350 square miles, and the Waterville station drains 6,330 square miles. Therefore, for the drainage area ratio method, the Ottawa River's station load is 5.5 percent of the Waterville's spring load for each season being examined.

This results in two modeled loads: the mass balance method and the drainage area ratio method. These two types of modeled loads have been calculated for ten upstream stations for five seasons (2017 through 2021) each. Note that the actual observed loads at the upstream stations were not used in the calculations for these two methods of modeled loads.

The verification of the mass balance method occurs by comparing the two methods of modeled loads with the observed loads at each upstream station. Section 4.3 presents the results of this work. Graphical examination, dimensionless, and error performance measures are reported to present an overall qualitative rating of this model verification.

3.6. Margin of safety

The Clean Water Act requires that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load allocations, wasteload allocations, and water quality. U.S. EPA guidance (U.S. EPA, 1999a) explains that the MOS may be implicit (i.e., incorporated into the TMDL through conservative assumptions in the analysis) or explicit (i.e., expressed in the TMDL as loadings set aside for the MOS).

For this TMDL, both implicit and explicit MOSs are used. Overall, conservative assumptions are made through TMDL development and implementation. Most importantly, this is a data driven process utilizing continuously collected monitoring data to calculate the TMDL.

The following bullets explain the conservative assumptions that provide an implicit MOS for this project:

- Ohio used a conservative value for associating bloom density with toxicity in its method of assessing Lake Erie's recreation use impairment due to HABs. The value of 20,000 cells/mL used for the impairment assessment would not be expected to exceed toxicity thresholds for bathing waters; maintaining cyanobacteria density below this level also limits formation of scums where toxins can be concentrated. (Ohio EPA, 2020a; Davis et al., 2019)

- The following two sub-bullets explain that the water quality targets were developed using detailed modeling and have been tested empirically. These can be considered part of the implicit MOS because they provide a high degree of confidence that the targets will lead to the desired ecosystem response.

    - Multiple models were used to derive the phosphorus target that will manage Lake Erie's HAB size (Annex 4, 2015). This work was carried out and published by a binational group of experts and reviewed by an external extramural science advisory board to the United States federal government (U.S. EPA SAB, 2017).

  - In recent low-flow years (2004 and 2012), loads were consistent with the phosphorus targets and resulted in HABs of an acceptable size. This empirical evidence adds certainty to the modeled targets.

- The mass balance model is based on loads calculated from high quality sampling data.
  - The USGS streamflow data that goes into the loading calculations, involves continuous stream stage monitoring, streamflow discharge measurements, and the development of a rating curve connecting the two measurements. McMillian et al. (2012) reports that uncertainty in measuring stream stage is relatively small. That report notes that measuring discharge is more complicated than stage measurements, and therefore introduces more of the uncertainty in the overall measurement. In general, however, the greatest potential for streamflow gaging uncertainty is in the stage-to-discharge relationships. And these errors increase when streamflow is extrapolated beyond the observed stage-to-discharge relationship. Typical confidence bounds for overall streamflow gaging uncertainties range from +/- 10 to 20 percent for in-bank medium or high flows, and +/- 40 percent for out of bank high flows (McMillian et al., 2017). Those values include streamflow measurements worldwide. In the United States, USGS employs robust quality control measures that reduce the inherent uncertainties in streamflow gaging and continues to improve their methods (Holtschlag, 2022). Only non-provisional, fully approved USGS daily streamflow data are used for the load calculations in this TMDL. Therefore, a small amount of uncertainty is expected in this TMDL's calculations due to the streamflow measurements component.
  - The total phosphorus sample concentrations and load calculations are monitored and calculated by Heidelberg's National Center for Water Quality Research. This program collects three samples every day of the year from the Maumee River at the Waterville sampling station. Depending on if the stream discharge is stable or changing, one, two, or all three of the samples collected will be analyzed. More samples are analyzed if stream discharge is changing. With this large number of samples collected, straightforward numeric integration is employed to calculate the daily total phosphorus loads. This results in low bias and high precision (Richards, 1998).

- Wastewater treatment plants are monitored at a high frequency. Large facilities, representing the majority of the load in this category, are sampled several times per week. These plants are required by their permits to have high standards for their water quality and flow volume monitoring.

- The mass balance model is intrinsically conservative because it is indexed to monitored data and is not using watershed characteristics to predict loads.

- Wet weather and household sewage treatment loads are estimated using robust methods that Ohio has published in several iterations of the Nutrient Mass Balance Report (Ohio EPA, 2020b).

- The phosphorus data used to calculate the TMDL will continue to be tracked and will ensure environmental response is not overstated based on BMP implementation.

In summary, conservative decisions were made in developing the model for the TMDL to reduce uncertainty. These considerations contribute to an implicit MOS for the TMDL. As explained above, however, uncertainty is still present and justifies additional consideration for an explicit MOS. An explicit MOS of three percent is reserved from the total phosphorus loading capacity. This load is reserved prior to allocations for point and nonpoint sources and is 20.6 metric tons (see Section 4.1).

The explicit MOS accounts for the unknown factors in both calculating baseline conditions and uncertainty in the relationship between sources receiving a LA and a WLA. While much of this error cannot be explicitly measured, some error can be evaluated numerically. As shown in Section 4.2, the model verification demonstrated error in estimating load for the unmonitored area downstream of the pour point of 19.2 percent. The three percent explicit MOS accounts for six times the load needed to account for this error. This provides additional reserved load for the less quantifiable sources of error listed above.

3.7. Allowance for future growth

An allowance for future growth (AFG) in a TMDL can be used to, "account for reasonably foreseeable increases in pollutant loads" (U.S. EPA, 1999a). Some TMDL projects provide an explicit amount of load, often calculated as a proportion of the target (e.g., 2 percent). The AFG used in a TMDL is often tied to observed and expected human population growth and shifts in industrial activities that may impact the production and delivery of pollutants. Having AFG set aside in a TMDL can be useful for permitted point sources especially when new facilities are proposed after a TMDL is developed and accepted by U.S. EPA.

Population growth throughout Ohio's portion of the Maumee watershed has been essentially flat for the past 10 years with only very small ups and downs locally. The most populated county, Lucas, lost 2.4 percent of its population between the 2010 and 2020 U.S. Census. Wood County, the second most populous county with more than three times fewer people than Lucas County gained 5.4 percent. However, Allen County's population, which is close behind Wood's, lost 3.9 percent (U.S. Census, 2021). The remainder of the counties in the watershed experienced either population loss or a very small increase during the same decade. Additionally, population projections do not predict a large influx of people in the Maumee watershed (Mehri et al., 2020).

As explained in Section 3.4.1, there is 1.5 MT of total phosphorus reserved as AFG for the discharging permitted point sources. The majority of this AFG, 1.4 MT, is reserved for the discharging point sources that are within the proposed general permit. This AFG will be available to new and expanding facilities that meet the conditions outlined in this TMDL's implementation recommendations. The remaining 0.1 MT of total phosphorus is reserved to account for unforeseen circumstances that would not be authorized through the proposed general permit. This could include a smaller treatment facility or unforeseen changes to a community's plan to address wet weather contributions.

Wastewater treatment plants are expected to continue ongoing optimization for phosphorus removal. The use of a general permit for the largest wastewater treatment facilities provides opportunities for trading to offset growth. Any new or upgrading major wastewater treatment plants are expected to meet an individual monthly total phosphorus concentration limit of 0.5 mg/L prior to being allotted any of the AFG described above.

As noted in Section 3.4.1.2, additional load from what is currently being discharged was added to the existing small sanitary general permit wasteload allocation. This measure is taken in order to anticipate more facilities that will be covered by this existing general permit.

Reserve capacity is not required for new or expanding permitted MS4s. For new or expanding permitted MS4s, the mass associated with the load allocation for the nonpermitted area will be transferred to the permitted MS4. This will increase the wasteload allocation for the MS4 area. Pollutant load reductions will then be assigned to the new or expanding permitted MS4 area consistent with the reductions needed for the TMDL.

This TMDL provides no wasteload allocations to CAFO/CAFF livestock operations. No livestock operations in the watershed are currently designed to discharge non-agricultural stormwater. In most circumstances they are prohibited from discharges that would receive a wasteload allocation, and industry trends do not indicate interest in using the Alternative Management Standards that could allow some load to be authorized with a WLA. Because of these factors, there is no expectation that CAFO/CAFF operations will need a WLA in the future.

Livestock operations do contribute to the nonpoint source phosphorus load via agricultural stormwater from the land application of manure. This project does not divide nonpoint sources but instead groups them into a single load allocation. The cumulative load of all contributing nonpoint sources must meet the TMDL's load allocation. If new land uses (such as new or expanding livestock facilities) start operation in the watershed, they are expected to attain the same level of phosphorus control as the existing land use. Because of this construct, reserving AFG for nonpoint sources is not necessary.

3.8. Seasonality and critical conditions

Federal regulations (40 CFR 130.7I(1)) require that TMDLs take into consideration seasonal variation in watershed conditions and pollutant loading.

3.8.1. Seasonality

The impairments this TMDL project addresses are a result of HABs that occur annually in western Lake Erie during the summer and fall seasons. Several aspects of this project directly consider seasonal variation in loading and lake response.

The assessment method for Ohio's recreation use applicable to Lake Erie HABs impairment is based on the summer/fall HAB seasons (Ohio EPA, 2020a, section F). Within July through October, the aerial extent of the western Lake Erie open water assessment unit is evaluated, via satellite imagery, for HABs during twelve 10-day windows. If three or more 10-day frames indicate excessive HAB conditions that exceed the assessment goals in any given year, then that year is counted as an exceedance year. If any two or more years in a rolling six-year window are in exceedance, then the unit is determined to be impaired. These factors were developed to take into consideration the spatial and temporal variation of Lake Erie's HABs to adequately determine the significance of the annual summer/fall bloom in making the impairment determination. They also provide a thorough assessment of seasonal changes that may occur during blooms.

Phosphorus pollutant reduction targets are correlated with the HABs to serve as actionable acceptable levels related to Ohio's impairment metrics. These targets were developed by the binational Annex 4 subcommittee of the GLWQA (Annex 4, 2015). The phosphorus that directly contributes to the growth of the HABs was determined by the subcommittee to be primarily delivered with springtime snowmelt and rain. This resulted in targets limited to phosphorus delivered to Lake Erie from the Maumee River in the "spring" March 1 through July 31 period each year. The TMDL allocations are therefore only applicable during this spring season.

This report's source assessment (Section 2) has taken into consideration the wide range of research pertaining to phosphorus export. A key point noted throughout is the link to hydrology, particularly large storm events in the spring, which drives a majority of phosphorus export through the stream networks in advance of the HAB summer and fall season. The comprehensiveness of the source assessment is intended to provide guidance on pollutant reduction implementation recommendations. This includes those that are seasonal in nature and explicitly address the spring runoff and its relationship to relevant seasonal agricultural practices such as fertilizer application.

3.8.2. Critical conditions

Ohio EPA considers this a "far-field" TMDL because the pollutants of concern are causing impairment to waters "far" downstream from their source. Phosphorus delivered by the stream network that makes up the Maumee watershed is the cause of the HAB impairments in western Lake Erie.

Impairments to designated uses within the Maumee watershed stream network are considered "near-field". This project does not address near-field impairments due to phosphorus pollution. Near-field impairments are addressed by near-field TMDLs. Where no existing TMDL addresses a near-field impairment, a future TMDL is still required. For a list of areas with existing near-field phosphorus TMDLs in the Maumee watershed, see Appendix 4.

The timing of phosphorus delivery, within the targeted "spring" period, is not relevant. Nor is geographic zone from which phosphorus reduction occurs. It makes no difference if the targeted amount of phosphorus reduction occurs from a very small area (within the Maumee watershed) during a very short period of time (within the spring period) compared to being completely spread out in space and time. Therefore, critical conditions of this TMDL are any combination of environmental factors that results in meeting the phosphorus-reduction targets.

While this far-field approach provides some flexibility in implementing pollution controls, the reality is a substantial reduction from nonpoint sources is required. For success, certain recommended implementation actions, such as agricultural nutrient management planning, will have to cover a significant amount of additional acreage throughout the watershed. Additional, more targeted improvements to nutrient reduction practices are also needed where critical sources areas are identified. The reasonable assurances section (Section 6) discusses this further.

4. Results

This section presents the results of the TMDL allocations, the allocation calculation to the Waterville monitoring gage, and the results of the mass balance model verification.

4.1. Allocations

All allocations are for total phosphorus, as explained in this project's loading analysis plan (Ohio EPA, 2022). Reducing the DRP portion of total phosphorus as much as possible is an explicit goal of the implementation plan for this TMDL.

Spring season allocations are presented in metric tons and daily allocations as kilograms. To express these seasonal allocations as a daily load it is divided by 153, or the number of days in the March-July period. In each of those units, all allocations are rounded to the nearest tenth when greater than one. Allocations less than one are rounded to two significant figures. Results less than 0.0010 are given in scientific notation.

Table 21 shows the total allocations for the nonpoint source load, point source wasteload, and margin of safety. This table also includes the out-of-state boundary conditions, refer to Section 3.4.6. Table 22 presents the summary of wasteload allocation. Allocations for individual NPDES permits are included in Appendix 3. The end of Appendix 3 includes an analysis of the loads for five recent spring seasons from permitted discharging facilities that are recommended to be grouped and managed by a general permit. This analysis finds that the general permit cap would not have been exceeded, were the general permit in place, during those spring seasons. The load allocation breakdown is shown in Table 23.

Table 24 shows the areas determined for permitted stormwater sources based on the accounting methods described above. The area for the individual NPDES facility permits is a sum of the areas for all 41 facilities with stormwater provisions. These facilities are itemized in Appendix 3. The area within Ohio's developed land of the watershed is also presented on this table. These areas sum to 40 percent. The stormwater from the remaining 60 percent of Ohio's developed land is considered part of the nonpoint source load allocation.

Table 21. TMDL allocation totals.

Allocation type	Spring season total phosphorus (metric tons)	Daily total phosphorus (kg)
Boundary condition: Michigan	180.7	1,180.9
Boundary condition: Indiana	48.0	313.6
Wasteload allocation	109.3	714.6
Load allocation	555.9	3,633.2
Explicit margin of safety (3%)	20.6	134.5
TOTAL	914.4	5,976.8

Table 22. A summary of the wasteload allocation totals.

Wasteload allocation	Spring season total phosphorus (metric tons)	Daily total phosphorus (kg)
Wasteload allocation, total	**109.3**	**714.6**
Individual permitted discharging NPDES facilities*	73.6	481.1
Combined sewage overflows*	0.37	2.4
Discharging small sanitary general permit (OHS000005)	0.45	3.0
Discharging HSTS general permit (OHK000004)	14.2	92.9
Individual permitted stormwater facilities*	0.57	3.8
Multi-sector stormwater general permit (OHR000007)	0.88	5.7
Construction general permit (OHC000005)	0.39	2.5
Individual MS4 permit – Toledo (2PI00003)	2.7	17.8
General MS4 general permit (OHQ000004)	16.1	105.3

* Itemized wasteload allocation for these facilities are listed in Appendix 3.

Table 23. Load allocation breakdown.

Load allocation	Spring season total phosphorus (metric	Daily total phosphorus (kg)
Load allocation, total	**555.9**	**3,633.2**
Grouped landscape nonpoint source load	547.0	3,575.4
Onsite HSTS	8.8	57.8

Table 24. Areas within permitted stormwater.

Wasteload allocation	Area		% of developed land within Ohio
	$Mile^2$	Acres	
Multi-sector stormwater general permit (OHR000007)	7.21	4,612	1.4
Individual NPDES permits with stormwater (multiple permits)	4.71	3,016	0.9
Construction general permit (OHC000005)	3.17	2,031	0.6
General MS4 general permit (OHQ000004)	165.41	105,863	31.8
Individual MS4 permit – Toledo (2PI00003)	27.96	17,895	5.4

4.2. Model verification

Section 3.5 explains the model verification methods. The overall objective of this verification is to assess the mass balance method's predictive ability for loads downstream of the Waterville monitoring station. To do this, the mass balance method is projected to 10 upstream monitoring stations to determine the spring season's total phosphorus load for five spring seasons (2017-2021). The spring load for these station-years is also calculated using a drainage area ratio approach. Table 25 shows the average results for each upstream station assessed with these two methods compared to the observed load at each of these stations. Figure 42 presents these results graphically.

Table 25. Model verification results. Modeled loads using the mass balance and drainage area ratio methods compared to observed spring loads with summary statics. All load results are shown in metric tons, averaged for the 2017-2021 spring seasons (except where footnoted).

Monitoring station gage	Drainage area (mi^2)	Average spring TP load (MT) 2017-2021		
		Observed	Mass balance method	Drainage Area weighted method
04178000 St. Joseph R. near Newville	610	98.3	118.5	147.5
04181049 St. Marys R. at Wilshire	386	149.2	108.7	93.3
04185000 Tiffin R. at Stryker	410	59.9	89.9	99.1
04185318 Tiffin R. near Evansport	563	113.7	123.9	136.1
04185935 Auglaize R. near Kossuth	201	62.5	53.3	48.6
04186500 Auglaize R. near Ft. Jennings	332	112.1	88.7	80.3
04188100 Ottawa R. near Kalida	350	119.5	90.6	84.6
04189000 Blanchard R. near Findlay*	346	89.0	82.0	90.1
04190000 Blanchard R. near Dupont	756	199.1	185.0	182.8
04191058 L. Auglaize R. near Melrose	401	134.4	110.9	96.9

* The 2021 observed spring season load was not available for this station at the time of this analysis. Therefore, for appropriate comparison, 2021 is also not included in the two modeled averages on this table for this station.

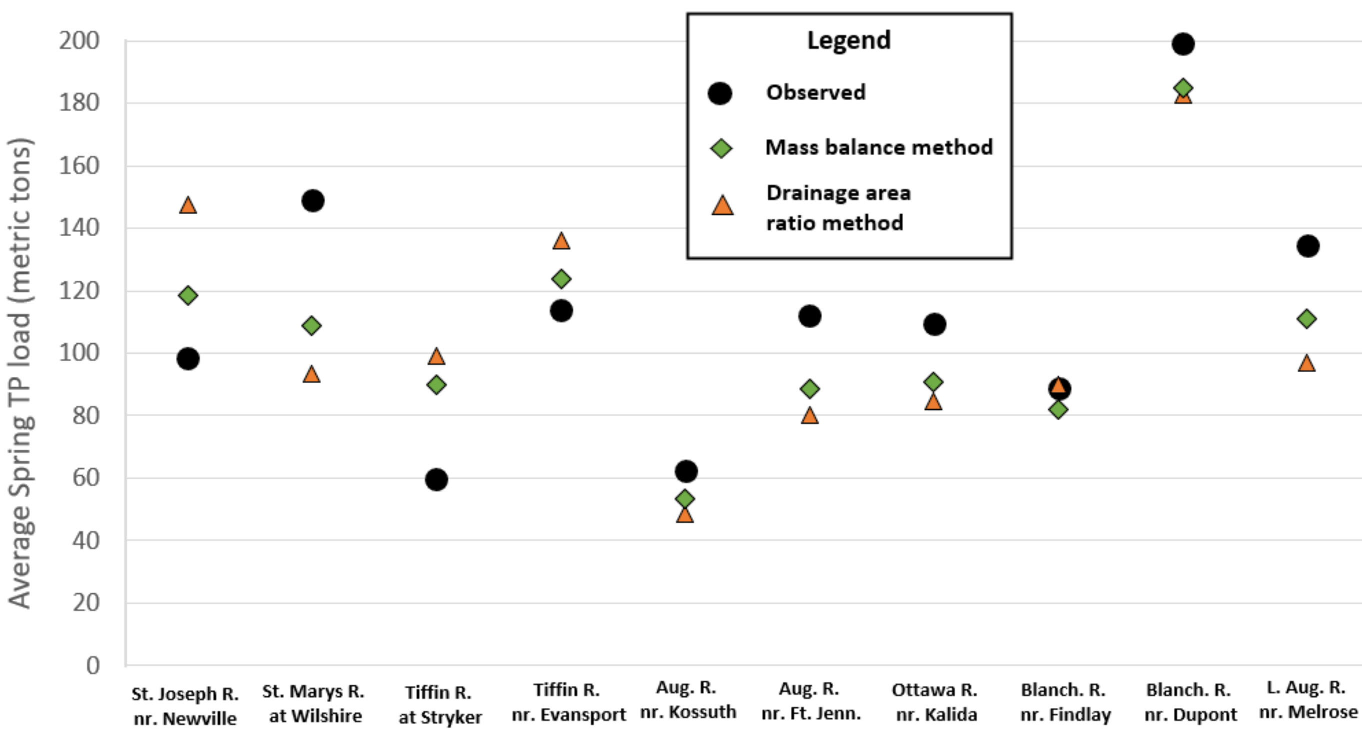


Figure 42. Model verification exercise results. For each monitoring station, the average 2017 through 2021 spring season total phosphorus load is shown. Symbols indicate load for observed and both modeling methods. The Blanchard River near Findlay station does not include the 2021 spring season load in any analysis.

As explained throughout Section 2.3, watershed size generally predicts the magnitude of load delivered with larger watershed areas producing more load. Two pairs of the stations included in this verification, the Tiffin and Blanchard rivers stations, are “nested” sites. In each of these pairs, one station is upstream of the other. Therefore, the greater load at the downstream station in each of these nested pairs is expected.

Moriasi et al. (2015) recommends a variety of performance measures when evaluating water quality models. These recommendations are intended to be used when comparing process-based models (such as SWAT and Hydrologic Simulation Program – FORTRAN [HSPF]). However, grouping the results of the 10 stations modeled for the two types of modeling employed in this verification allows for some of these statistical tests to be carried out.

The dimensionless Nash Sutcliffe efficiency (NSE) test determines the relative magnitude of the modeled to observed variance. This essentially provides a rating of the noise compared to information of the fit. For phosphorus modeling, Moriasi et al. (2015) suggest an NSE greater than 0.65 indicates a “very good” fit. When examining the grouped averages of the two types of modeling to the observed loads, the mass balance method has an NSE of 0.96; the NSE for the drainage area ratio method is similar at 0.91.

The percent bias (PBIAS) test examines the average tendency of simulated data and provides a statistic for the overall estimation of bias. Values greater than zero suggest an overall underestimate, whereas values less than zero indicate an overestimate. In grouping the 10 stations averaged observed loads compared to the two modeling methods results in a PBIS of 6.8 percent for the mass balance method and 6.1 percent for the drainage area ratio method. This indicates a slight underestimation in both methods (mass balance method underestimates slightly more than the drainage area ratio method). However, both results are considered a “good” fit for nutrient modeling by Moriasi et al. (2015).

The standard regression analysis again averages the observed or predicted (modeled) loads for each station and provides several summary statistics that can be used to compare performance of modeling methods. The coefficient of determination (R^2) from is considered a benchmark performance evaluation. The closer this static is to one, the better the fit of the modeled dataset to observations. Moriasi et al. (2015) recommends the use of such scatter plot analysis when the datasets do not contain extremely high values that may skew such assessments. To best quantify this fit, the regression’s gradient, or slope, along with its y-intercept are recommended to also be presented with R^2. A slope of 1.0 and y-intercept of 0 are optimal.

Summary statistics from the regression analysis show different performance for the two modeling approaches. The R^2 for the mass balance method is 0.72 with a slope of 0.72 and y-intercept of 24 MT. Compared to the drainage area ratio method’s R^2 of 0.40 with a slope of 0.59 and y-intercept of 39, the mass balance method has a higher (better) R^2, closer slope to one, and closer y-intercept to zero. These metrics provide evidence that the mass balance method results in a tighter (better) relationship with the observed loads compared to the drainage area ratio. This analysis is quite evident when graphically observing these two regressions results in Figure 43.

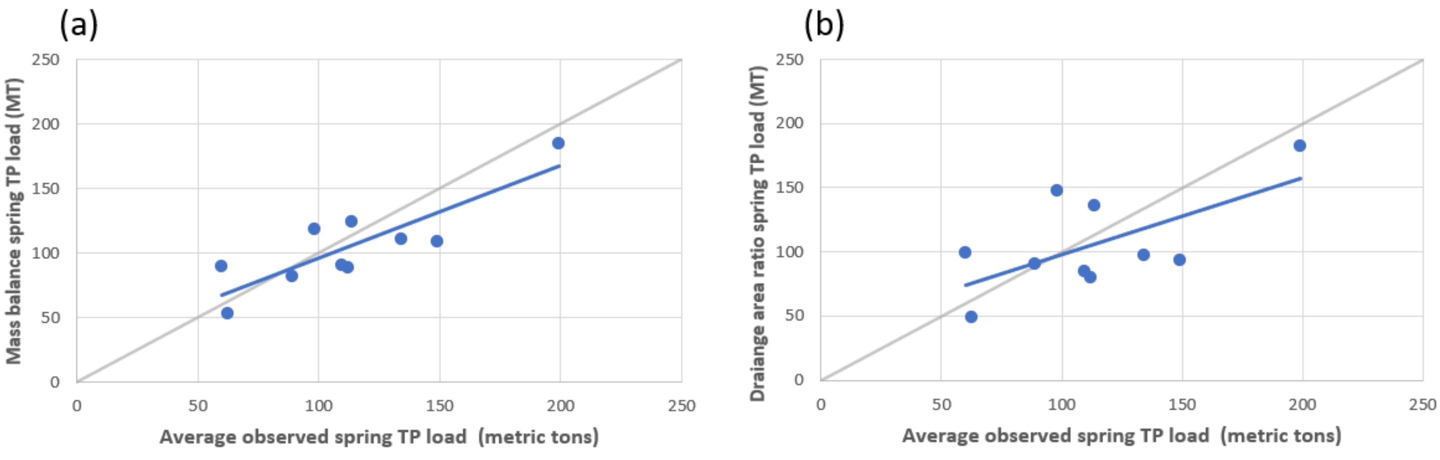


Figure 43. Model verification standard regression analysis. Panel a shows spring total phosphorus load from the mass balance model plotted against the average observed load (dots indicate five-year average load for each assessment unit). The blue line represents a linear regression of this relationship. The gray line shows a 1:1 relationship for comparison. Panel b contains the same information for the drainage area ratio modeling method.

This regression analysis shows that the mass balance method is superior to the drainage area ratio model. Therefore, it is reasonable to use the mass balance method to calculate TMDL loadings downstream of the Waterville monitoring station.

The verification also helps quantify some of the uncertainty in the mass balance method. The standard error for each of the monitoring stations is the percent difference of the average modeled/predicted load compared to the average observed load. Some stations have a positive average standard error, indicating a model overestimation, and some have a negative average standard error. The average of the absolute value of all 10 station's average standard error results in 19.2 percent. This can be considered the mass balance method's model verification overall standard error. The TMDL's load allocation (prior to reserving a margin of safety) for the area downstream of the Waterville monitoring station is 17.8 MT of total phosphorus. Applying the 19.2 percent verification standard error to this 17.8 MT results in 3.4 MT of load that could be considered required to be reserved as a margin of safety accounting for modeling uncertainty. The reason this only applies to the area downstream of the Waterville monitoring station is because the load calculated for the area upstream of Waterville is based directly on observations. The explicit margin of safety reserved in this TMDL is greater than 3.4 MT, however, due to additional reasons further explained in Section 3.6.

5. Preliminary Implementation Plan

Within the preliminary modeling results, the implementation plan will present the framework for implementation for feedback from stakeholders. With that feedback, and through additional outreach, the complete implementation strategy will be developed for the draft TMDL report. The TMDL development process in Ohio leverages adaptive management. Figure 43 presents a conceptual model of what that process looks like.

The TMDL process was started based on assessments that identified impairments in the WLEB. The development of the TMDL includes the initial implementation strategy to meet the load and wasteload allocations needed to restore the impaired conditions of the WLEB. A component of that strategy in a system like this one where there are still unknown or poorly known processes (such as instream phosphorus cycling for example) is a process of adaptive management.

Adaptive management starts with setting goals, or establishing milestones, to provide clear targets for implementation measures. Implementing the strategy is given equal weight in the graphic, but it is the most resource intensive part of the process that involves many local, state, and federal agencies, nonprofit organizations, and individuals. To inform adaptive management we need to monitor the watershed and the lake to link implementation to the desired environmental response. We need to evaluate that information by defining metrics which turn the monitoring data into information. Then we can use that information to adjust the strategy if necessary.

The preliminary implementation strategy will lay out the framework for the initial strategy and propose ideas for milestones, implementation actions, monitoring, evaluating progress, and adjusting the strategy moving forward.

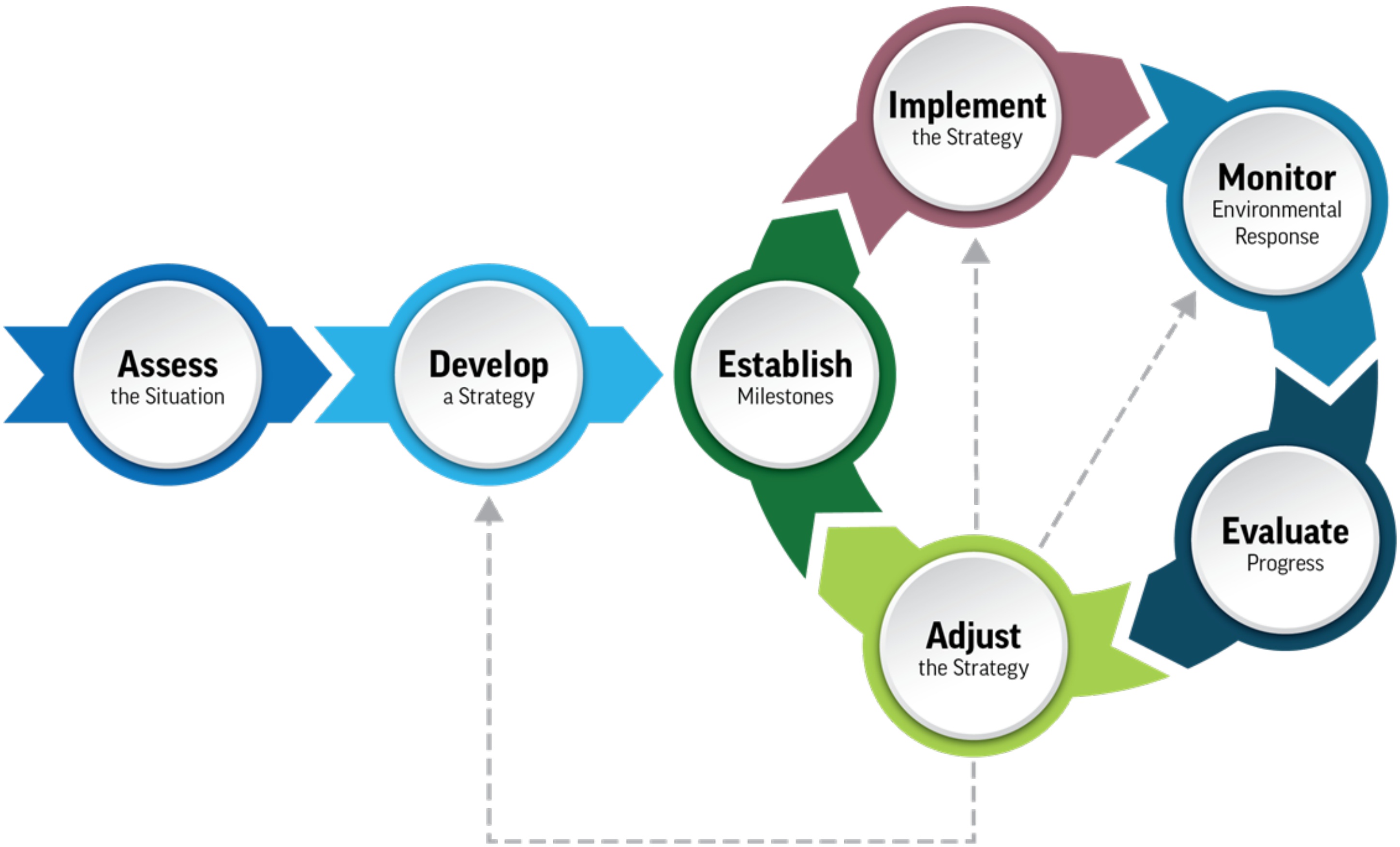


Figure 44. Conceptualization of TMDL implementation with adaptive management.

5.1. Develop the strategy

Overall, the strategy needs to identify where it is believed, based on best available science, that implementation efforts can achieve the needed reductions to meet the TMDL in a cost-effective manner. Implementation opportunities were considered that would address the source categories discussed in Section 2 of this report. The potential impact and relative costs of implementation of specific management actions work to inform the allocations for different sources and the specific actions identified to implement the strategy in Section 5.3. Figure 44 shows how these sources were conceptually linked to implementation opportunities. Management actions identified for sources and remaining loads consistent with the TMDL are divided into the wasteload allocation for point sources and the load allocation for nonpoint sources. Improving nonpoint source sinks manages phosphorus from both point and nonpoint sources which allows the implementation plan to promote more cost-effective practices on the landscape where they effectively manage phosphorus from all sources. Figure 45 shows how reductions are planned for the major source categories of point sources, nonpoint source sinks, and nonpoint source management.

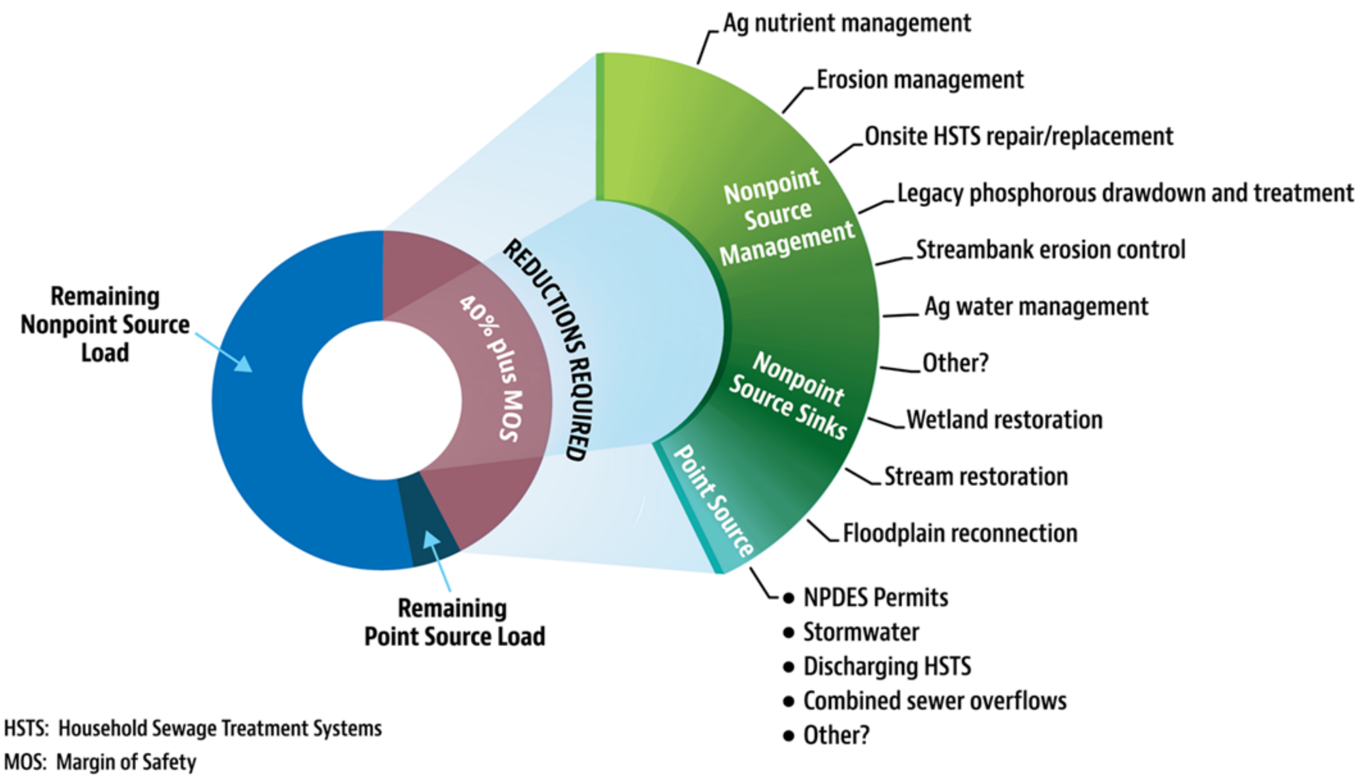


Figure 45. Implementation opportunities were considered to address all sources of phosphorus in the watershed.

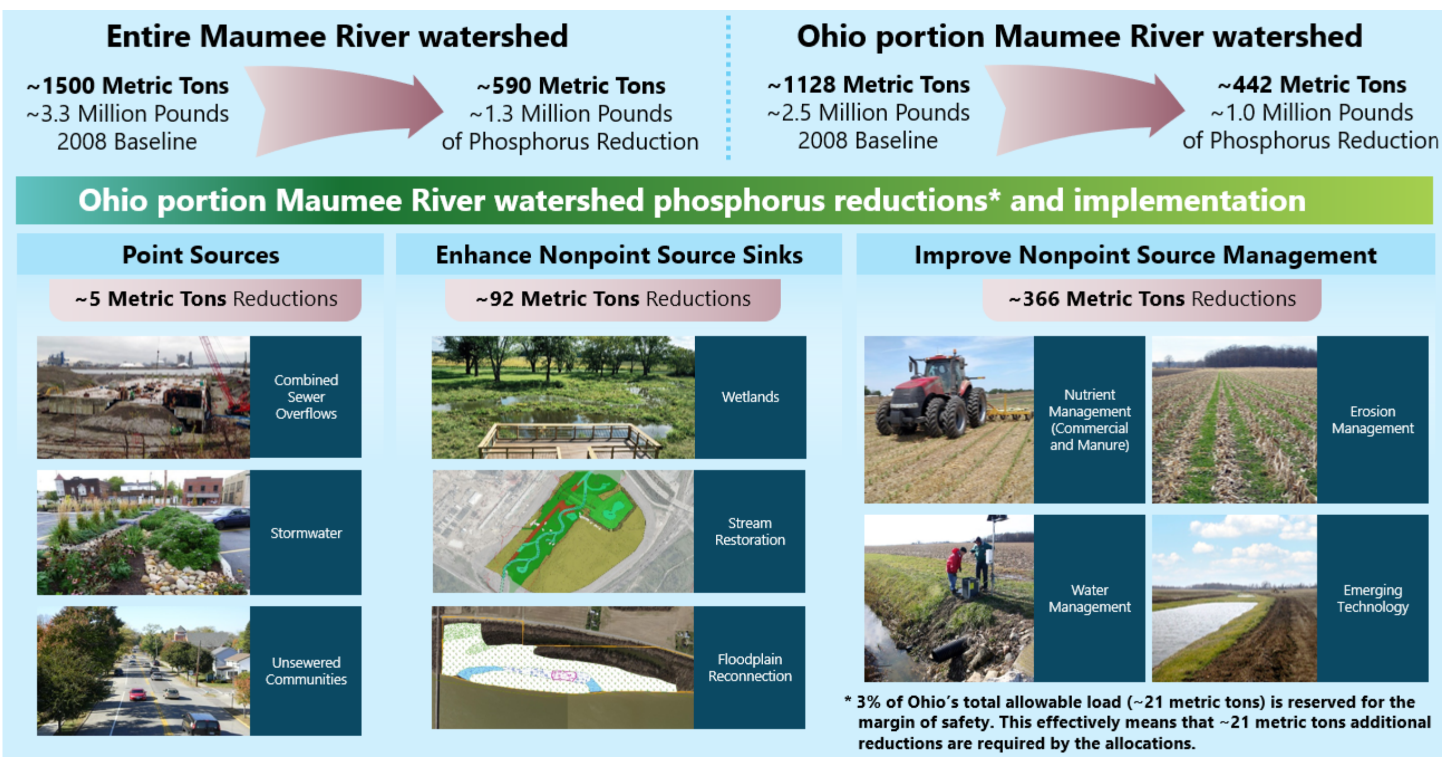


Figure 46. Implementation to achieve the reductions needed to meet the TMDL is accomplished by managing all sources in the watershed.

Implementation efforts have been underway for over a decade, and research, funding, and policy changes have started to shape the response to the monumental challenge of addressing today's water quality issues in Lake Erie. International cooperation has set the goal posts for phosphorus management to address HABs. The Great Lakes Restoration Initiative (GLRI) at the federal level and Governor DeWine's H2Ohio initiative, among others, have focused resources on addressing HABs in Lake Erie. Farmers are being tasked with changing the ways they farm and how they think about their link to water quality.

Historically, nonpoint source phosphorus management focused on managing soil loss with the results bearing out within the Maumee watershed. Fish species, such as the big-eyed chub and sand darters, that are sensitive to sediment have been expanding their presence throughout their historic range. That success, in part, is thought to have contributed to today's challenges and we now know that phosphorus management extends beyond the soil surface. At the same time, these challenges are exacerbated by increasing precipitation in the Great Lakes Region with recent years precipitation that ranking among the wettest years on record.

Nonpoint sources are the largest component of the total load, consequently they have been and will continue to be the focal point of management efforts. Tackling the nonpoint source challenge focuses on addressing key resource concerns for nutrient management, erosion management, water management, and considerations for emerging technologies. Section 5.3 details specific actions that work together to implement these actions.

Recognizing the magnitude of the challenge of managing nonpoint source phosphorus loads, a focus on managing how water moves across the landscape is included in the strategy. Efforts to slow and hold water within the watershed have focused on restoring wetlands, stream channels, and floodplain connectivity, thereby restoring the functions once provided by these areas of the landscape. These functions provide phosphorus sinks and compliment source management as a means of achieving load reduction targets.

While point sources have substantially reduced phosphorus from historic levels, ongoing efforts to manage combined sewer overflows, stormwater, and failing household sewage treatment systems in unsewered communities will continue this trend. Management actions are also needed to ensure that existing facilities maintain the level of performance currently achieved through ongoing optimization, designing new infrastructure to perform to higher standards, and considering new technologies that cost effectively manage phosphorus while promoting sustainability.

Section 5.3 details specific actions that work together to implement this strategy.

5.2. Establish milestones

Ultimately, the goal of TMDL implementation is to restore the beneficial uses of Lake Erie and delist the impairments. That goal alone is not enough, knowing that achieving success will be the culmination of many actions that that incrementally improve the watershed. Additional programmatic milestones are being considered that will allow implementation programs to measure interim success and adjust where needed. Figure 46 identifies milestones under consideration. These are broadly categorized as planning & development milestones (characterized in red); and implementation milestones (characterized in blue).

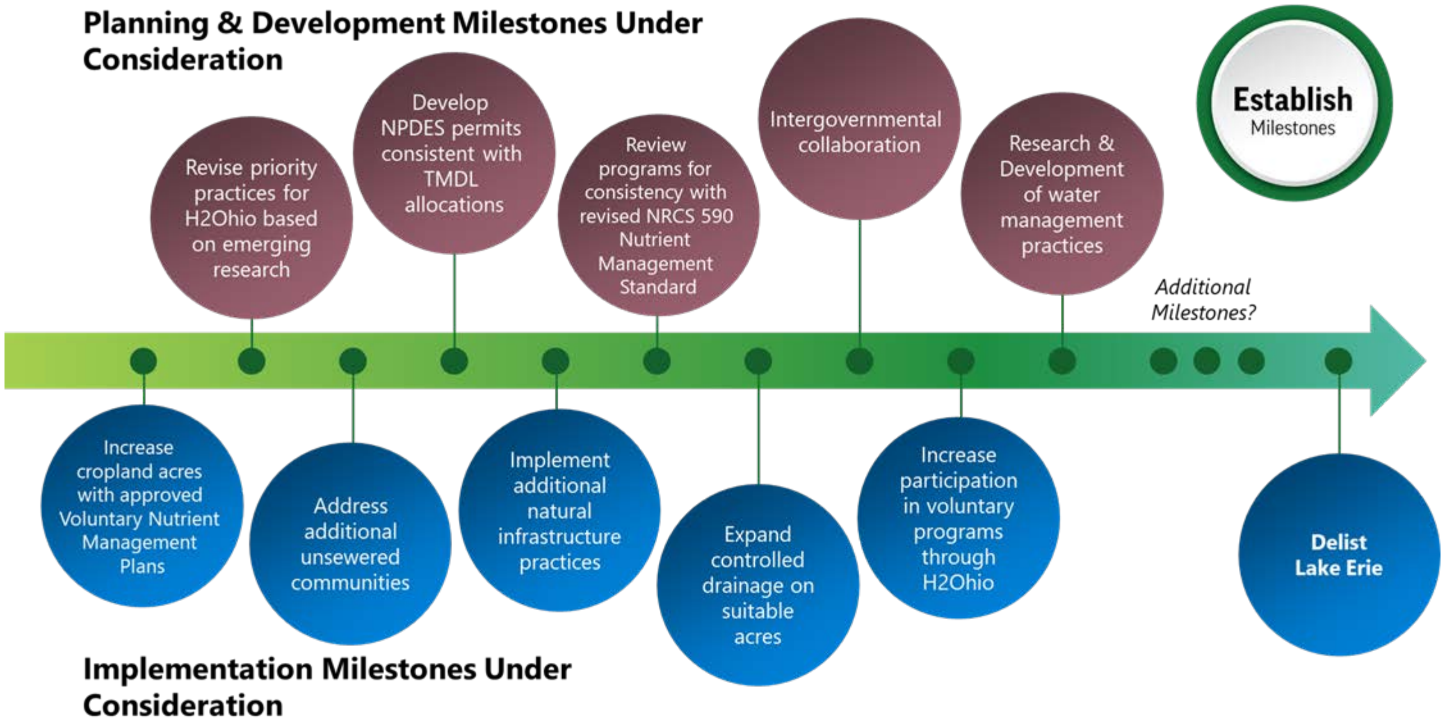


Figure 47. Establishing milestones gives implementation programs opportunities review effectiveness and make adjustments where progress is not meeting expectations.

Planning and development milestones to promote program development and coordination are needed for successful implementation. The following planning milestones are under consideration:

- To ensure H2Ohio has the maximum impact, agricultural BMPs need to adapt to emerging research.
- Following establishment of this TMDL, Ohio EPA will have to develop NPDES permits consistent with the strategy.
- Ohio programs rely on the NRCS 590 nutrient management standard (which was recently revised)—these updates are considered during program reviews.
- Continue close intergovernmental coordination – ensuring regular meetings between implementing state and federal agencies for consistent goals and objectives.
- Water management is as important to our success as nutrient management, but many promising practices are not universally accepted. Continuing research and developing practice standards will facilitate water management as this TMDL progresses.

Implementation milestones are those that measure change on the landscape. These could be changes associated with quantifying implementation measure or improvements in water quality. The following implementation milestones are under consideration:

- Increasing the cropland acres with approved voluntary nutrient management plans.
- Addressing unsewered communities.
- Implementing natural infrastructure.
- Expanding controlled drainage. This is one way to manage water. It is not appropriate for all fields or situations so identifying a milestone needs to recognize these limitations.
- Increase participation in voluntary programs through H2Ohio.
- Delist Lake Erie.

These types of actions all require coordination among many partners, including all levels of government, nonprofit organizations, and individual landowners. Tracking these projects is often tied to the organization providing funding. A milestone would need to account for all these actions. These milestones will be refined through ongoing coordination with implementing agencies and using stakeholder feedback. Some milestones could include numeric thresholds where a metric being evaluated is quantifiable and others may rely on narrative interpretations of ongoing progress. Both will provide valuable feedback as implementation progresses.

5.3. Implement the strategy

5.3.1. Point source management

Point sources are broadly managed as stormwater and wastewater treatment facilities. These are discussed in separate sections below because they are monitored and managed differently.

5.3.1.1. Stormwater

Stormwater is managed separately from wastewater treatment facilities because stormwater discharges are managed through a diffuse network of pipes and conveyances rather than a discrete outfall. The discharges are also not continuous and are irregular in nature. Because of this, monitoring stormwater discharges is more challenging than discharges from treatment facilities. This challenge drives the expression of limits for managing stormwater through the implementation of BMPs.

There are several permits that have conditions related to the discharge of stormwater:

- Individual permits for Phase I MS4 communities
- General permits for Phase II small MS4 communities
- Individual permits for facilities that have stormwater requirements
- Muti-sector general permits for industrial stormwater discharges
- Construction general permits for construction activities disturbing >1 acre

The management activities for meeting the wasteload allocation (WLA) in the Maumee watershed nutrient TMDL varies for each of these permits. Implementation recommendations will vary by each permit type, but emphasis is placed on two guiding principles: 1) BMPs that have a greater effect on phosphorus loading in the springtime and 2) BMPs that emphasize the management of DRP.

Phosphorus is typically managed in stormwater in different ways that affect permitting:

- Manage sources of phosphorus (e.g., lawn fertilizers, lawn debris, pet waste, etc.).
- Manage the volume of stormwater discharged from a site (e.g., infiltration and retention practices).
- Manage concentrations of phosphorus with filtration practices.

NPDES permits are one way that these practices are required but other actions also promote the implementation of phosphorus management. There are other local, state, and federal efforts that influence phosphorus sources and management in the watershed's most urbanized landscapes. The use of phosphorus for lawn maintenance has been limited reducing this phosphorus source statewide outside of the stormwater permitting program. Other initiatives have promoted water retention and filtration to promote wildlife habitat and water retention. Local park districts have worked to expand their footprint and enhance land preservation and water retention. The largest urbanized area in the watershed (Toledo) is within the Maumee Area of Concern (AOC) which has a specific objective to improve wildlife habitat. The H2Ohio initiative has increased the funding for natural infrastructure and communities have been critical partners for getting projects implemented. These efforts contribute to ongoing reductions accounted for in the Load Allocation that are not accounted for through the NPDES permits for these facilities and communities.

General Permit for Small MS4 Communities

Small MS4s are required to comply with requirements contained in the NPDES Small MS4s General Permit. Small MS4s are required by the NPDES permit to develop a Stormwater Management Program that contains six minimum control measures. The NPDES Small MS4 General Permit (OHQ000004) contains more specific requirements for small MS4s in TMDL watersheds. The requirements apply to small MS4s identified in Appendix A of the General Permit (the listing includes Small MS4s with wasteload allocations in current, approved TMDL reports). The fact sheet that accompanies the General Permit contains more specific information on the requirements for the identified Small MS4s in TMDL watersheds (epa.ohio.gov/dsw/storm/index).

Due to timing of the NPDES Small MS4 General Permit renewal and the drafting of this TMDL, only small MS4 communities listed in Appendix A of the permit will be required to follow the near-field phosphorus TMDL related requirements during the term of the renewed general permit. The additional phosphorus allocation to small MS4 communities identified in the draft TMDL report will be incorporated into the next renewal of the NPDES Small MS4 General Permit (renewal in 2026). The renewal will include communities affected by the allocations and additional measures to direct phosphorus reduction activities to improve management of DRP.

The cost will vary for each small MS4 depending upon the number of pollutants causing water quality issues within a watershed, the types of pollutants and size of small MS4 (number of watersheds the MS4 is in), and the current level of BMP implementation. The cost may include the extra time in developing materials, distributing materials, additional construction site inspections of sites in noncompliance, education of contractors on green infrastructure practices, additional street sweeping and catch basin cleanouts, etc. There is one new requirement for post-construction stormwater management that will likely be an additional cost to the small MS4 communities with applicable TMDLs. These requirements are contained in the existing permit. Twenty-one of 34 permittees in the watershed are already required to implement these actions because they are included in near-field TMDLs.

- Retrofit one existing stormwater practice that solely provides a peak-discharge function to meet the performance standard for an extended detention post-construction practice; or
- Perform restoration of at least 300 linear feet of channelized stream where natural channel stability and floodplain restoration will reduce stream erosion; or
- Update an ordinance or other regulatory mechanism to require OHC000005 Table 4b practices and/or other green infrastructure practices where feasible; or
- Install one or more Table 4b practices to treat a minimum of one acre of existing impervious area developed prior to 2003.

Individual MS4 Permit for Toledo

Similar to the Small MS4 General Permit, Toledo's individual NPDES permit (2PI00003) requires the development of a Stormwater Management Program and the implementation of BMPs that target the six minimum control measures. In addition, Toledo's permit contains conditions for inspecting industrial and commercial stormwater dischargers, BMP performance monitoring, and representative seasonal outfall monitoring. The outfall monitoring has included total phosphorus and DRP. While Toledo's MS4 permit is currently in the process of being renewed, a draft permit has not yet been public noticed. Toledo and other individual permits typically include the same performance standards as the Small MS4 General Permit discussed above. Due to timing of the NPDES permit renewal and the drafting of this TMDL, Toledo's draft permit will likely contain many of the near-field phosphorus TMDL related requirements listed in the discussion about the current Small MS4 General Permit. The phosphorus allocation to the city of Toledo identified in the draft (far-field) TMDL report will be considered in the next renewal of the City's NPDES MS4 Permit.

Multi-sector General Permit (MSGP) and Individual Permits for Industrial Stormwater

Facilities that have coverage under the general permit (OHR000007) have discharges of stormwater exposed to industrial activities. Some facilities elect to have the conditions of the general permit incorporated into an individual permit for the facility. When this is done the conditions from the active MSGP are used to incorporate necessary conditions into the individual permit. The permits require installation of BMPs that minimize the discharge of pollutants from the site. Industrial activities must also meet all local government construction stormwater requirements. Many of the required BMPs result in improved management of phosphorus leaving the site including:

- Good housekeeping practices
- Spill prevention and response procedures
- Erosion and sediment controls
- Management of runoff
- Employee training
- Dust generation and vehicle tracking of industrial materials

If an industrial facility owner/operator obtains coverage under the NPDES Multi-sector Stormwater General Permit or has equivalent coverage under an individual NPDES permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL.

Construction General Permit

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in Ohio's NPDES Construction Stormwater General Permit (OHC000005). Construction activity must also meet all local government construction stormwater requirements. BMP requirements that will result in compliance with the WLA include:

- Preservation methods
- Erosion control practices
- Runoff control practices
- Sediment barriers and diversions
- Post-construction stormwater controls

If a construction site owner/operator obtains coverage under the NPDES Construction Stormwater General Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL.

5.3.1.2. Wastewater treatment facilities

The TMDL analysis showed that 20 percent of NPDES-permitted treatment facilities account for more than 85 percent of the point source waste load allocation. These discharges are largely municipal wastewater treatment facilities with some industrial facilities that contribute phosphorus at similar magnitudes. The WLA was set based on the level of control demonstrated in 2008 which, through optimization and other actions, has been maintained when evaluated collectively. However, when the total WLA is distributed equitably to individual facilities, not all facilities would meet the individual allocation every season. To implement the WLA, a general permit is proposed to facilitate flexibility for permitted facilities. If a facility receives coverage under the general permit, Ohio EPA will not include a WLA consistent with the individual allocations in their individual permit.

- Implementing individual WLAs would trigger compliance schedules for many facilities, even though, as a whole, the level of control among the wider community may be at an appropriate level when looking at far-field impacts given existing efforts to manage phosphorus.
- A general permit gives the option to manage compliance as a seasonal load averaged across the community. That is consistent with how ongoing implementation efforts have considered the impact of treatment facilities on phosphorus loading.
- A general permit provides 'de facto' trading by allowing loads across the community to be grouped. This option may be appealing because in this framework existing technology would be optimized to comply with the WLA, thus avoiding capital expenditures because the cumulative load limit is met. New and expanding facilities would be expected to utilize newer technology and then optimize that technology.
- A general permit is a good framework to facilitate formal trading as well. Trading could promote collaboration that allows for implementation where it is cost effective, either through point-to-point or point-to-nonpoint source trading.

Following this flexible permitting proposal facilities should be able to continue to optimize and operate existing facilities to maintain the WLA, without incurring additional costs. To maintain the loading capacity and ensure compliance is maintained, opportunities to optimize treatment should continue to be evaluated. Opportunities include:

- Continued optimization of new and existing treatment processes
- Including phosphorus in pretreatment evaluations
- Side stream treatment
- Nutrient recovery
- Spray irrigation of treated effluent

As individual facilities grow or new facilities are proposed, an opportunity is presented to utilize more advanced technology at a marginal cost compared to an unplanned upgrade triggered by a compliance schedule. To maintain capacity in the WLA and manage growth, we propose that new, expanding, or upgrading biological treatment facilities with an average daily design flow equal to or greater than 1 million gallons will receive a monthly average concentration limit of 0.5 mg/L. A 2021 study on the life cycle cost of nutrient treatment technologies completed by U.S. EPA calculated the cost of facilities capable of meeting a 0.5 mg/L limit compared to technology that would meet a 1.0 mg/L limit would increase the capital costs by 10 to 30 percent and annual operating costs by approximately 10 percent (U.S. EPA, 2021). Specific project costs will involve many factors specific to an individual facility design including but not limited to:

- Space available for facility construction
- Existing infrastructure that can be repurposed in new design
- Influent characteristics

Should an NPDES permit holder determine that compliance with the TMDL is technically and/or economically unattainable and that permittee is eligible for a variance, the permittee may submit an application for a variance to the underlying WQS (e.g., the narrative criteria for algae) used to develop the proposed effluent limitation in accordance with the terms and conditions set forth in OAC 3745-1-38(D).

The remaining 80 percent of facilities together contribute less than 15 percent of the load from permitted facilities. These facilities may not have phosphorus-specific controls and the WLA in the TMDL is consistent with the existing performance. Additional phosphorus reductions are not proposed for these facilities. Existing efforts to promote optimization, regionalization, and onsite discharge will continue but have not been accounted for as reductions expected to meet the WLA.

5.3.2. Modifications of point sources implementation

Final, approved TMDL reports may be modified. In the future, Ohio EPA may make changes to the load and/or wasteload allocations in the Maumee Watershed Nutrient TMDL report when new information becomes available, or circumstances arise during the implementation of the TMDL report suggests such modifications are appropriate. Ohio EPA will notify U.S. EPA Region 5 and the public regarding any shifts in loading it makes within the sum of the load allocations or within the sum of the wasteload allocations. Any changes or re-allocation between the WLA and load allocations (LA) or changes in the TMDL's loading capacity will be made available for draft public review and comment following the same procedures as a draft TMDL report and submitted to U.S. EPA Region 5 for review and approval as a revised TMDL. New information generated during TMDL implementation may include monitoring data, BMP effectiveness information, and land use information. For shifts in loading within the sum of the WLAs, Ohio EPA will provide public notice as part of the NPDES permitting process. Ohio EPA will make such shifts only in the event that the shifts will not result in a change to the sum of the WLAs, the sum of the LAs, and the total loading capacity. In addition, any adjusted WLAs or Las will be set at a level necessary to implement the applicable water quality standards. Reasonable assurance will be provided where appropriate. The Agency will notify U.S. EPA Region 5 of any anticipated changes to this TMDL 30 days prior to proposing those changes.

5.3.3. Load allocation (nonpoint source) preliminary implementation plan

Achieving the reductions so nonpoint sources meet the load allocation can be accomplished both through source reduction and enhancing sinks within the landscape and assimilation with the stream network. The Maumee watershed has been the focal point for nutrient management in the WLEB watershed since HABs reemerged in the mid-2000s. In this timeframe a major shift in conservation planning for phosphorus management has also occurred. Historically, phosphorus management focused on surface losses driven by runoff and erosion because subsurface losses were perceived as negligible (King et. al, 2015). That perception has changed, and phosphorus management now encompasses subsurface transport with the understanding that dissolved forms of phosphorus are a critical fraction to total losses. In that time, the groundwork has been laid to facilitate implementation through planning, funding, policy, voluntary actions, and ongoing research.

5.3.3.1. Water quality planning

The state of Ohio has been at the forefront of developing a response to algal blooms in Lake Erie. Building on the work of the Ohio Phosphorus Task Force, Ohio participated in efforts at the federal level through the GLWQA of 2012 to link the harmful algal blooms and to specific amounts of nutrients measured in the tributary rivers, especially the Maumee.

The governors of Ohio and Michigan and the premier of Ontario committed to a goal of reducing phosphorus loadings to Lake Erie by 40 percent through the signing of the Western Basin of Lake Erie Collaborative Agreement (Collaborative), first in 2015 and again in 2017. The Collaborative was intended to serve as the precursor to the Ohio DAP. Ohio's DAP has advanced efforts toward the proposed nutrient reduction targets put forth in the GLWQA under Annex 4 (Nutrients).

To facilitate implementation, the state of Ohio has cooperated with the development of many other modeling efforts in the watershed. Results from prior SWAT modeling efforts in the Maumee watershed and similar landscapes are summarized in Appendix 2. Ultimately, Scavia et al. (2017), indicated that it would take a suite of BMPs targeted at high-yielding area (subsurface application of phosphorus fertilizer, cereal rye cover crop in years without wheat, and medium-quality buffers) to meet loading targets on average in the Maumee watershed using an ensemble of SWAT models. In a follow-up effort, Martin et al. (2019, 2020) concluded that only some models showed meeting the DRP targets under the highest levels of implementation considered using the more stringent 9-of-10 years metric for meeting the targets. The model review makes the following conclusions about implementation needs in the watershed:

- Implementation will need to be widespread.
- Accomplishing DRP reductions will be more difficult than meeting total phosphorus targets.
- No single BMP will meet loading targets and a suite of BMPs is necessary.
- BMPs targeted to higher yielding landscapes were more effective than random placement.
- It will take common and less common (even emerging) BMPs to meet the targets.

This work continues as a state priority and a current project is funded by Ohio through the Harmful Algal Bloom Research Initiative (HABRI) and via H2Ohio to use a SWAT model of the Maumee River watershed to evaluate the impact of ongoing implementation, including specific actions and scenarios based on H2Ohio programs. These efforts continue to improve the capability of the SWAT models to evaluate DRP, incorporate additional BMPs (including instream processes for DRP), and refine the baseline inputs to make results more meaningful. Together these efforts have improved our understanding of the watershed and identified a path forward that requires a high level of implementation.

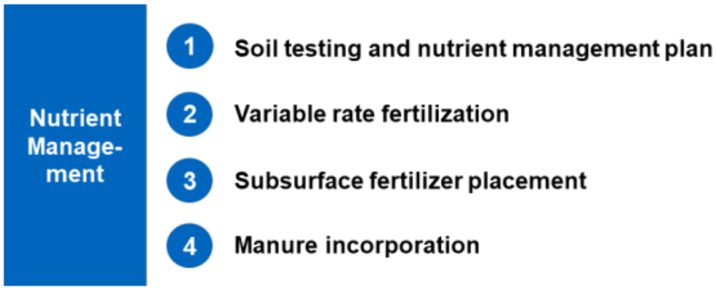
Several agricultural BMPs, including nutrient management plans, are broadly applicable and county conservationists can promote these directly with growers. However, consistent with modeling research summarized above (Martin et al. 2019; Scavia et. al 2017), targeted implementation of other practices is important in meeting the load reduction target efficiently. Ohio has continued to use development of implementation-oriented watershed plans for the most effective siting of structural practices.

Nine-element watershed plans [also known as Nonpoint Source Pollution Implementation Strategy (NPS-IS)] identify critical areas, organize stakeholders, set local goals and objectives for conservation practice implementation, identify implementers and funding sources, and most importantly, develop ready-to-go projects and conservation practice adoption and activity. These also establish project eligibility for federal funding (Ohio EPA, 2020c). These are written for 12-digit HUC-12 watersheds, which are typically about 26 square miles in area, and are a key mechanism for identifying load reduction opportunities.

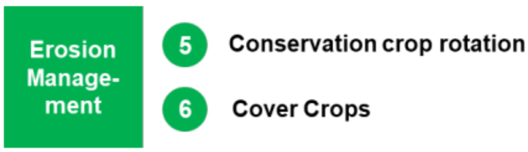
As part of the strategy outlined in the Ohio DAP, state agencies began including HUC-12 far-field load reduction recommendations in watershed planning efforts. Specific emphasis was placed on the development of plans that include these recommendations in the southern portion of the Maumee River watershed because elevated loading is observed in the region due to relatively higher stream discharge and a higher percentage of the landscape being committed to agricultural production.

The Ohio DAP identified 10 key practices for the focus of state efforts to streamline funding through the H2Ohio Initiative. These practices showed the greatest potential to accomplish phosphorus reductions due to the impact, both as the amount of the practice that could be used and the practice efficacy, and cost of the practices. These practices were divided into nutrient management, erosion management, and water management based on how they manage phosphorus loads.

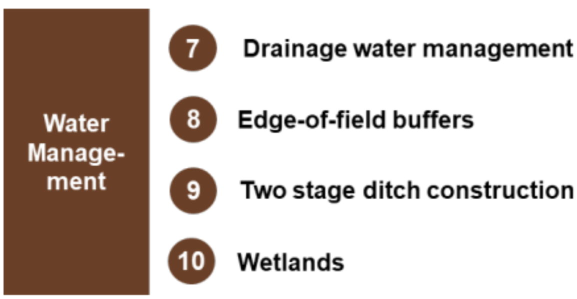
Nutrient Management is a generalized term for planning nutrient application events on the agricultural landscape. These characteristics are generally related to the 4R's of Nutrient Management — using the **right** nutrient source at the **right** rate and **right** time in the **right** place. There are four selected practices in this category:



Erosion Management seeks to slow or stop the loss of soil-attached nutrients by reducing soil disturbance and improving soil health. There are two selected practices in this category:



Water Management includes practices that slow water flow, settle sediments, and absorb nutrients. There are four selected practices in this category:



A key feature of effective water quality planning is identifying key resource concerns. Section 2.2 of this report describes the existing science regarding the contributions of phosphorus from nonpoint sources in the watershed. These sources are described in these major categories: agricultural row crop fertilizers (commercial and manure), agricultural soils and legacy sources, non-agricultural stormwater, ditch and streamside sources, and changes in watershed hydrology. BMPs do not cleanly manage just one source category so for planning purposes we need to link them to the key resource concerns identified.

Agricultural Row Crop Fertilizers (commercial and manure): Nutrient management BMPs are directly linked to improving management of fertilization. The fundamental tenant of managing fertilizers is soil testing and developing a nutrient management plan. This practice establishes a baseline for understanding nutrient needs on a farm as well as establishes the plan for how the 4R's can be successfully implemented for an individual field and producer. From the management plan additional resource concerns can be identified and addressed. One of the most effective ways to manage agricultural fertilizers is through improved incorporation into the soil profile; this practice is central to any scenario in SWAT modeling research that has shown DRP targets being met.

Agricultural Soils and Legacy Phosphorus: All soils contribute phosphorus to streams, however, enhanced drainage and phosphorus inputs to improve fertility have led to increased phosphorus levels in agricultural soils. Soil loss from agricultural fields contribute total phosphorus and DRP to streams and managing erosion is an important measure to continue facilitating. Increasing cropping diversity through conservation crop rotations and cover crops both provide opportunities to manage soil loss. Soil phosphorus levels have been increased in some agricultural soils to levels that exceed the need for agronomic production. These soils require additional consideration. The first step to managing these soils is identifying where they exist in agricultural fields. This is a critical function of nutrient management planning and soil testing. All or part of a field could have soil phosphorus that exceeds the threshold for agricultural need. In each of these cases there is an opportunity to reduce phosphorus fertilization while maintaining crop yield. Where whole fields have elevated phosphorus levels, fertilization can be avoided while crops mine phosphorus from the soil as a component of a nutrient management plan. When phosphorus is elevated in portions of a field variable rate fertilization affords the opportunity to avoid fertilization where phosphorus in not needed agronomically.

In some cases, the legacy phosphorus in agricultural soils can reach levels that are critical to manage for environmental losses of DRP. Ongoing research discussed in Section 5.2.5 details continuing efforts to understand where these areas are and how to manage them. Edge-of-field management through practices like phosphorus treatment wetlands or other emerging technologies are targeted at this source.

Ditch and Streamside Sources: Streams and drainage ditches can contribute phosphorus through erosion and remobilization of phosphorus that was previously assimilated. Many streams in the Maumee watershed are maintained to promote drainage and facilitate agricultural production. Traditionally, these ditches were maintained as trapezoidal channels which were effective at providing drainage. Two-stage ditches were identified as an opportunity to promote natural stream functions in these maintained channels. This design allows for deposition of sediments on established benches and reduces sheer stresses from high stream flows by lowering the elevation of peak flows. Other water management practices like controlled drainage and natural infrastructure practices also help manage erosive forces from peak flows.

Changes in Watershed Hydrology: Precipitation, especially in large storm events, have increased in the last two decades. These changes have been a major contributor to the increase in DRP loads in the Maumee watershed. Addressing nutrients in the watershed necessarily includes considerations of managing the water volume, not just the concentrations of nutrients. Natural infrastructure and controlled drainage have been identified as cost-effective management practices directed at water management. These practices help store water on the landscape so it can infiltrate or be lost through evapotranspiration. Ohio EPA, with 319 and GLRI funding have worked with landowners to install new and emerging water management technologies, including: cascading waterways, water reuse projects (storage and irrigation), and saturated buffers.

The DAP and nine element NPS-ISs are living documents that continue to develop and be revised as new information becomes available. Ongoing research continues to improve the understanding of practice efficacy, especially regarding management of DRP. Some key research projects are evaluating practices for managing elevated soil test phosphorus, watershed scale implementation efficacy for paired watersheds, efficacy of water management practices (saturated buffers and water reuse), edge-of-field research on BMP efficacy, and more. As these planning efforts continue Ohio will consider new information that is a result of these projects.

5.3.3.2. Policies

The establishment of a TMDL does not change law, regulation, or policies. Nonetheless, laws, regulations and policies do change, and Ohio's state agencies then implement those new regulations and policies. Several key regulatory and policy updates have been a part of Ohio's management of phosphorus in the WLEB as algal blooms have reemerged. Those include:

- Senate Bill (SB) 141 (2001): Formed the Division of Livestock and Environmental Permitting at ODA
    - ODA starts reviewing permits to install for CAFFs
    - Established Certified Livestock Manager (CLM) program, additional requirements

- NRCS 633 Waste Utilization practice standard updated (2003) – additional restrictions on liquid manure applications on tile drained lands including liquid application rates, macropore disruption, tile management, and winter application requirements
- NRCS 590 Nutrient Management practice standard updated (2012) – Added manure into nutrient management standard and incorporated phosphorus-index
- SB 1 (2015) – Expanded manure application restriction to smaller operations, required distribution and utilization of CAFF manure to use CLMs or have ag fertilizer applicator certification, established ag fertilizer applicator certification
- SB 299(2018) – Provided funding to support soil and water district staff at districts in the WLEB.
- NRCS 590 Nutrient Management practice standard updated (2020) – incorporates updated Tristate Standards, eliminates phosphorus-index, emphasis on drawdown for fields with elevated soil phosphorus

In addition to practices that have impacted nutrient management initiatives have also established new and prioritized funding opportunities in the WLEB, especially the Maumee watershed. The results of these efforts are discussed in the next section.

5.3.3.3. Initiatives and funding to facilitate implementation

Additional resources have been allocated through legislation and implementation initiatives. These efforts have spanned all levels of government in response to one of the most substantial water quality challenges facing Ohioans.

State initiatives

- **H2Ohio** – Launched by Governor Mike DeWine, this initiative was first funded by the General Assembly for the 2020-21 biennium with an investment of $172 million. A targeted priority of the initiative is reducing phosphorus and the WLEB and Maumee watershed have been prioritized as programs rolled out. Initiatives include promoting agricultural management practices, natural infrastructure, and addressing failing home septic systems.
- **Ohio EPA 319 Program** – The federal Clean Water Act amendments in 1987 created the national program to control nonpoint source pollution. Since 1990, Ohio EPA has annually applied for, received, and distributed Section 319 grant funds to address NPS caused water quality impairment to Ohio's surface water resources. Section 319(h) implementation grant funding is targeted to Ohio waters where NPS pollution is a significant cause of aquatic life use impairments. The cornerstone of Ohio's 319 program is working with watershed groups, ODA, ODNR, OLEC, local SWCDs, county engineers, and others who are implementing locally developed watershed management plans and restoring surface waters impaired by NPS pollution.
- **Ohio Lake Erie Protection Fund** – OLEC administers Ohio's Lake Erie Protection Fund, which was established to finance research and on-the-ground projects aimed at protecting, preserving, and restoring Lake Erie and its watershed. Projects focus on critical issues facing Lake Erie, including nutrient reduction, beneficial use of dredged material, water quality protection, fisheries management, wetlands restoration, watershed planning, invasive species, algal bloom research, Lake Erie ecological shifts, and environmental measurements. More than $12 million has been distributed to over 365 projects since 1993. The projects have also attracted significant amount of federal funding into Ohio, as projects are often used to match funds from various federal agencies.
- **Clean Lake 2020 Plan (SB 299)** – This bill provided funding toward a variety of programs aimed at supporting Lake Erie and reducing HABs. This included additional funding for SWCDs to support additional staff in WLEB counties where additional resources were being targeted and staff were needed for project coordination and implementation.

- **OSU Extension** – OSU Extension's mission is to "create opportunities for people to explore how science-based knowledge can improve social, economic, and environmental conditions". OSU Extension has a priority for programs to help people make informed choices and lead local efforts aimed at maintaining or improving environmental quality for future generations. Field specialists with OSU Extension in agronomic systems and manure nutrient management systems have specializations in nutrient management and applied research for better managing agricultural nutrients.
- **Ohio Sea Grant and Stone Lab** – Using a strong combination of research, education, and outreach efforts, as well as partnerships with academia, governmental agencies, and the private sector, Ohio Sea Grant works with the Lake Erie community to solve the region's most important environmental and economic issues. Ohio Sea Grant administers the Harmful Algal Bloom Research Initiative on behalf of the Chancellor of the Ohio Department of Higher Education.

Federal initiatives

- **USDS-NRCS**
  - EQIP – The Environmental Quality Incentives Program provides financial and technical assistance to agricultural producers and non-industrial forest managers to address natural resource concerns and deliver environmental benefits such as improved water and air quality, conserved ground and surface water, increased soil health and reduced soil erosion and sedimentation, improved or created wildlife habitat, and mitigation against drought and increasing weather volatility.
  - GLRI – Funding from the Great Lakes Restoration Initiative supplements NRCS funding from the Farm Bill. The funding is directed to priority watersheds in the Great Lake's region, including the Maumee watershed. Funding initiatives have emphasized on farm research through a network demonstration farms and edge-of-field research; building partnerships with other federal, state, and nonprofit organizations; and implementing practices to reduce phosphorus loads from agricultural fields.
  - Regional Conservation Partnership Program (RCPP) – The Tri-State Western Lake Erie Basin Phosphorus Reduction Initiative is a multi-state RCPP project that brings together more than 40 partnering organizations from Michigan, Ohio, and Indiana to reduce the runoff of phosphorus into the WLEB. RCPP promotes coordination between NRCS and its partners to deliver conservation assistance to producers and landowners. With RCPP, partners are in the driver's seat with technical and financial help from NRCS.
- **U.S. EPA GLRI** funding is allocated through five focus areas, all are geared to improving water quality in the Great Lake's and two include targeted actions that will improve phosphorus management in the Maumee watershed.
  - Focus area 1 is for Toxic Substances and Areas of Concern. The GLRI has a goal to delist the AOCs which include the Maumee AOC. The AOCs include a beneficial use for habitat loss and wildlife. Though the focus of these initiatives is not phosphorus management much of the lost habitat in the AOC is wetland or riparian in nature which places emphasis on restoring these ecosystems. These restoration efforts will restore crucial sinks and slow water as it moves across the landscape.
  - Focus Area 3 is specifically for nonpoint source pollution impacts on nearshore health, this includes targeted investments to reduce nutrient loads from agricultural watersheds (like the Maumee), reduce untreated stormwater runoff, and improve effectiveness of nonpoint source control and refine management efforts.

Local initiatives

Local communities have embraced the challenges of managing phosphorus contributions to Lake Erie with a vision shared by local governments and park districts. Many counties, communities, and other local organizations serve as partners for implementing projects in the Maumee watershed. Below two initiatives are highlighted which have specific water quality goals in their mission statements. These examples show how communities can engage with water quality improvement while promoting projects that provide ancillary benefits to the community through enhanced green spaces.

- **Metroparks Toledo:** Metroparks Toledo includes water quality in its mission statement with emphasis on increasing land holdings since 2003. Metroparks has more than 12,000 acres throughout the region, and much is in the Maumee watershed.
- **Defiance Land to Lake:** The Land to Lake initiative in Defiance promotes getting involved in protecting the water resources of the Maumee River through Defiance County. Projects promoted by the initiative include education, research (Upper Maumee Smart Watershed Pilot), and facilitating wetland restoration through the H2Ohio Program.

Nonprofit organizations

Nonprofit organizations provide additional staff to oversee project development, provide opportunities for the public to contribute to implementation efforts, and where needed, can facilitate land acquisition and maintenance for projects.

- **Black Swamp Conservancy:** Black Swamp Conservancy is a land trust dedicated to preserving and protecting natural habitats and family farms in northwest Ohio for the benefit of future generations. Preserved lands comprise the nearly 20,000 acres that have been permanently protected by the Conservancy since their founding in 1993. Much of that land retains private ownership but the Conservancy owns several properties and has been a partner to facilitate natural infrastructure implementation in the Maumee watershed.
- **The Nature Conservancy:** The Nature Conservancy has been a valuable partner for getting projects implemented in the Maumee River watershed. This includes oversight of GLRI funds targeting natural infrastructure and nutrient management projects.
- **Pheasants Forever:** Pheasants Forever volunteers, members, and staff work with farmers and landowners to complete conservation and wildlife habitat projects that compliment working farm and ranch operations. Staff include the "farm bill biologists" program which is supported through diverse partnerships with USDA-NRCS, Farm Service Agency, state wildlife agencies, and others. The program provides a "boots-on-the-ground" delivery system which collaborates with local farmers, ranchers, and landowners to educate and assist with enrollment in various voluntary incentive-based conservation programs.
- **Ducks Unlimited:** Ducks Unlimited includes a Lake Erie Priority Area for Ohio conservation projects. This has led to partnering to restore and protect wetlands in the WLEB, including the Maumee watershed. The organization has joined with ODNR as an implementing partner for the H2Ohio initiative.
- **Partners for Clean Streams:** Partners for Clean Streams is dedicated to the health of the streams and rivers of the greater Toledo region and the people who use them. They partner directly with citizens, businesses, governmental agencies, and other non-profit organizations to take local ownership of rivers, streams, and lakes. They work to connect these partners and volunteers to take actions making those waterways clean, clear, and safe.
- **Blanchard River Watershed Partnership:** The partnership began as an informal group in 2003. Since its inception, the BRWP has formed many working relationships with federal, state, and local agencies, such as the U.S. EPA, Ohio EPA, USDA, USGS, Soil and Water Conservation districts, the city of Findlay, the village of Ottawa, the village of Bluffton, County Commissioners, County Boards of Health, and many other agencies in the watershed. The group's mission is to "encourage water quality improvements to our geologically unique, northwestern Ohio watershed, through sustainable land use, collaboration, conservation, and

enhancement of natural and man-made resources". The partnership has been active in developing watershed action plans and facilitating projects in the Blanchard River watershed.

- **Ohio Agricultural Conservation Initiative:** This a partnership between agriculture, conservation, environmental, and research communities recognizes farmers for their dedication to advancing methods that improve water quality in Ohio and increasing the number of BMPs being implemented on farms.
- **Other Environmental Organizations:** Many more environmental advocates that promote water quality in Lake Erie are active in Ohio, including the Lake Erie Waterkeeper program, Alliance for the Great Lakes, Ohio Environmental Council, Lake Erie Foundation, Lake Erie Charter Boat Association, and others. These groups promote actions that improve water quality in Lake Erie and provide opportunities for citizens to be involved in solutions.
- **Other Agricultural Organizations:** Ohio has a diverse group of agricultural organizations representing interests across the industry, including Ohio Farm Bureau Federation, Ohio Corn and Wheat Growers Association, Ohio Soybean Council, Ohio Dairy Producers Association, Ohio Pork Council, Ohio Poultry Association, Ohio Agribusiness Association, and others. These organizations participate in and support initiatives promoting nutrient management in Ohio, including the Blanchard River Demonstration Farms Network and the Ohio Agricultural Conservation Initiative.

Pilot programs and initiatives

These pilot programs and ongoing initiatives have promoted novel frameworks that could facilitate additional implementation in the Maumee River watershed.

- **Conservation Technology Information Center's Phosphorus Load-Reduction Stimulation Program (PLUS-UP):** This pilot program was offered in 2022 and developed a market mechanism where companies are encouraged to purchase phosphorus credits. The pilot program was funded by a purchase of credits from Bayer Crop Science. The program is a 'pay for performance' program and with load reductions calculated using the Nutrient Tracking Tool.
- **Great Lakes Commission Erie P Market:** From 2016 to 2018, the Great Lakes Commission developed and piloted the Erie P Market to address the excessive runoff of pollution from agricultural land that contributes to the formation of algal blooms and dead zones in the Great Lakes. The project was designed to test water quality trading and stewardship crediting as nutrient reduction tools capable of crossing state and provincial boundaries in the WLEB.
- **Great Lakes Commission Conservation Kick:** The Great Lakes Commission launched Conservation Kick in March 2020 to create a water quality marketplace for the Great Lakes Basin. Building on the pioneering vision of the Great Lakes Basin Compact to efficiently and responsibly develop, use, and conserve the water resources of the Basin, Conservation Kick aims to keep soil and nutrients out of the Great Lakes and protect drinking water by allowing utilities, industries, businesses, nonprofit organizations, and concerned citizens to invest in water quality credits.

Additional voluntary actions

Improving water quality requires all available resources to be used. Among these are initiatives that are led by individuals or industry. Just as is the case with other funding initiatives, these actions may not be solely inspired for environmental management but none-the-less play an important role in nutrient management in the watershed. The following initiatives or actions have been industry led:

- **4R Nutrient Stewardship:** This initiative is a collaboration between the Fertilizer Institute, the International Plant Nutrition Institute, the International Fertilizer Industry Association, and the Canadian Fertilizer Institute. The 4Rs promote using fertilizer with the Right source, at the Right rate, Right time, and in the Right place. The initiative encourages considering the economic, social, and environmental dimensions of nutrient management to promote sustainable agriculture.

- **Phytase in Livestock Feeds:** Supplemental phosphorus is required in livestock diets, especially poultry and swine. Using dietary phytase to release phosphorus from forms in plants typically unavailable to livestock allows less dietary phosphorus to be added. This can decrease the amount of phosphorus in manure by 15-30 percent (Applegate et al., 2008). This practice has become more common as phytase has become more available and economical.

Demonstrating efficacy emboldens communities and agricultural producers to embrace change. Land management has changed over the years as technology has evolved. For example, gridded soil sampling and variable rate nutrient management have been embraced by many agricultural producers. This is a win-win because it saves costs to the producers in addition to its environmental benefits. While initial exposure to these practices can be facilitated by cost-share programs, long term success depends on the value being recognized by an agricultural producer and continued voluntary implementation.

5.4. Monitor environmental outcomes

The goal of the TMDL project is to restore the beneficial uses of Lake Erie through achieving phosphorus reductions. The ultimate measure of success is measuring the environmental outcomes that show that goal is met. That outcome is only expected to be realized when a high level of implementation is achieved so intermediate measures become important to track progress and inform adaptive management. Figure 47 shows how monitoring occurs at different levels across the landscape and data collected at those levels.

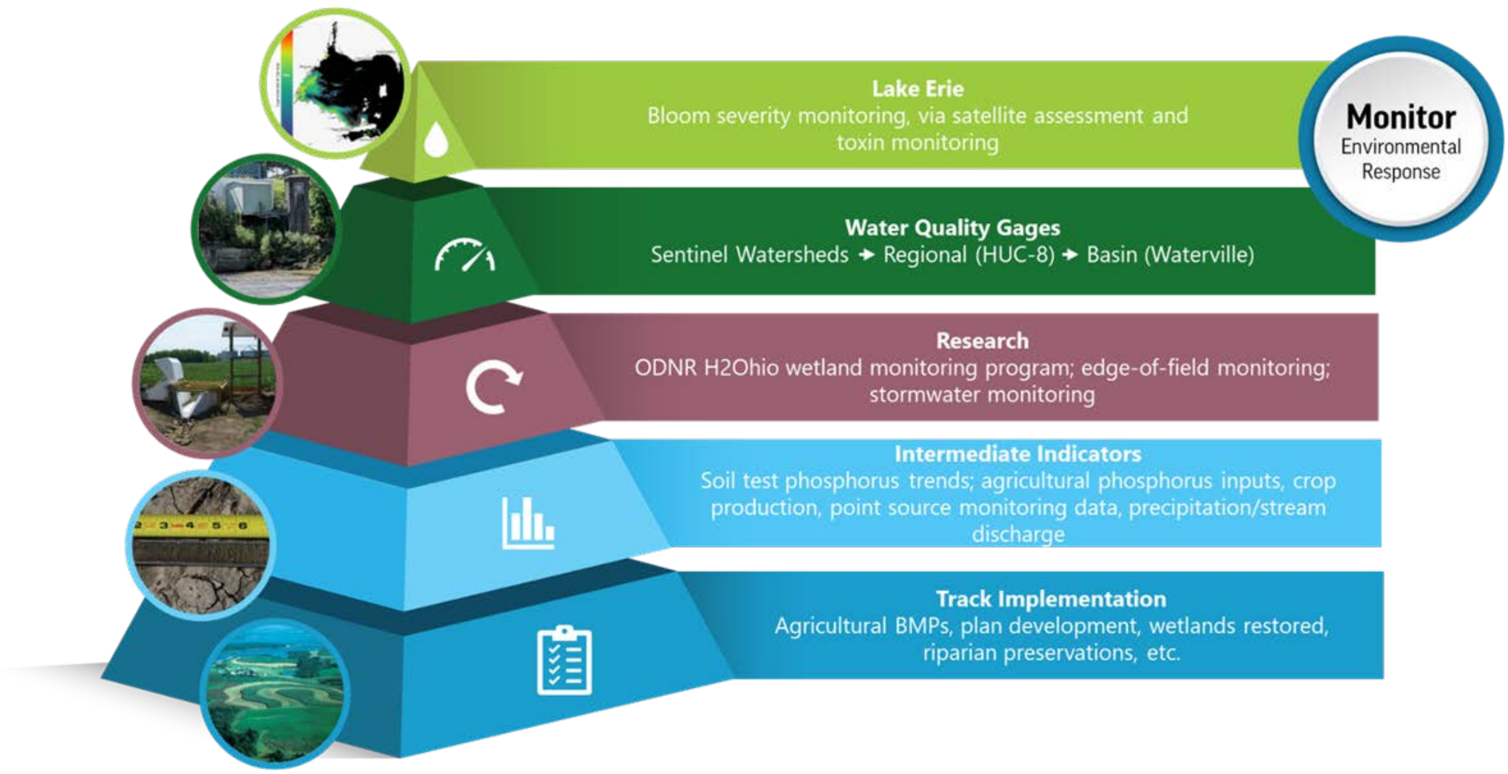


Figure 48. Monitoring activities at the base of the pyramid drive environmental responses monitored at the higher levels.

Starting at the base of the pyramid implementation measures are tracked. At this most fundamental level we can determine if programs are resulting in changes to the landscape. This level of monitoring included tracking management practices, like agricultural BMPs and natural infrastructure projects, and tracking planning activities like 9-element NPS-IS.

Moving up the pyramid, data is collected to monitor intermediate indicators that management practices are having real impacts on the landscape, this includes aggregated soil test phosphorus data (extent of legacy phosphorus), monitoring the inputs of agricultural fertilizers (commercial fertilizer and manure), crop production (crop removal of nutrients), monitoring data from point sources, and measures of watershed hydrology.

The next level up includes direct measures of water quality at the field or project scale. Here BMPs are monitored to ensure they are having the desired real-world impacts. Edge-of-field data for agricultural fields are collected largely by USDA-ARS researchers in the watershed through partnerships with many implementing agencies and private organizations. Implementing agencies have included monitoring components for natural infrastructure projects, including the H2Ohio wetland monitoring program. Stormwater monitoring has been facilitated in Ohio through NPDES permits, research priorities, and partnerships between planning agencies and communities. Where practice evaluations have focused on total phosphorus, ongoing research has emphasized understanding practice efficacy for DRP management. Ensuring these data are collected provides a basis for adapting to practices that ensure DRP management improves moving forward.

Then we move to load monitoring in streams throughout the watershed. These gaging stations are tiered starting with sentinel watersheds representing the varied characteristics throughout the watershed, then HUC-8 scale gages representing subregions in the watershed and culminating near the watershed mouth where chemistry and hydrology have been paired for more than 40 years, to show long-term loading trends at the basin scale. Monitoring locations are detailed in Section 2 of this report.

Monitoring data within Lake Erie are measures of ultimate success. Data collected includes algal toxins at drinking water intakes and satellite monitoring for the extent and duration of HABs. This data is collected by communities using Lake Erie as a public water supply and through the National Oceanic and Atmospheric Administration (NOAA) to capture routine satellite imagery of Lake Erie.

5.5. Evaluate progress

Monitoring data is important, but to make use of the data it requires additional effort to turn it into information. Metrics allow for an objective measure that can be used to evaluate success or lead to change. Figure 48 identifies potential metrics that are associated with the with the same monitoring levels identified in the previous sub-section.

Again, starting with the base of the pyramid metrics are identified that track implementation actions. There are existing structures to do this including tracking nearfield TMDLs and nine element plans by Ohio EPA, Ohio Agricultural Conservation Initiative metrics for agricultural BMPs, and NRCS-CEAP assessments.

Moving up a level, ways to summarize intermediate indicators are considered. Here summarizing trends in soil test phosphorus and trends in the agricultural phosphorus mass balance can serve as metrics for tracking these intermediate indicators.

Edge-of-field and project scale monitoring data are used to evaluate agricultural practices by the research community. The outcomes of the studies will be evaluated more so than identifying independent metrics. Currently, there are many active projects where results are expected in the next two to five years, including: H2Ohio's wetland study, the Army Corps P-optimal wetland study, a paired watershed project testing BMP efficacy in two small tributaries (Potato and Shallow Run), ongoing SWAT model evaluations of implementation scenarios, a legacy phosphorus project, and more.

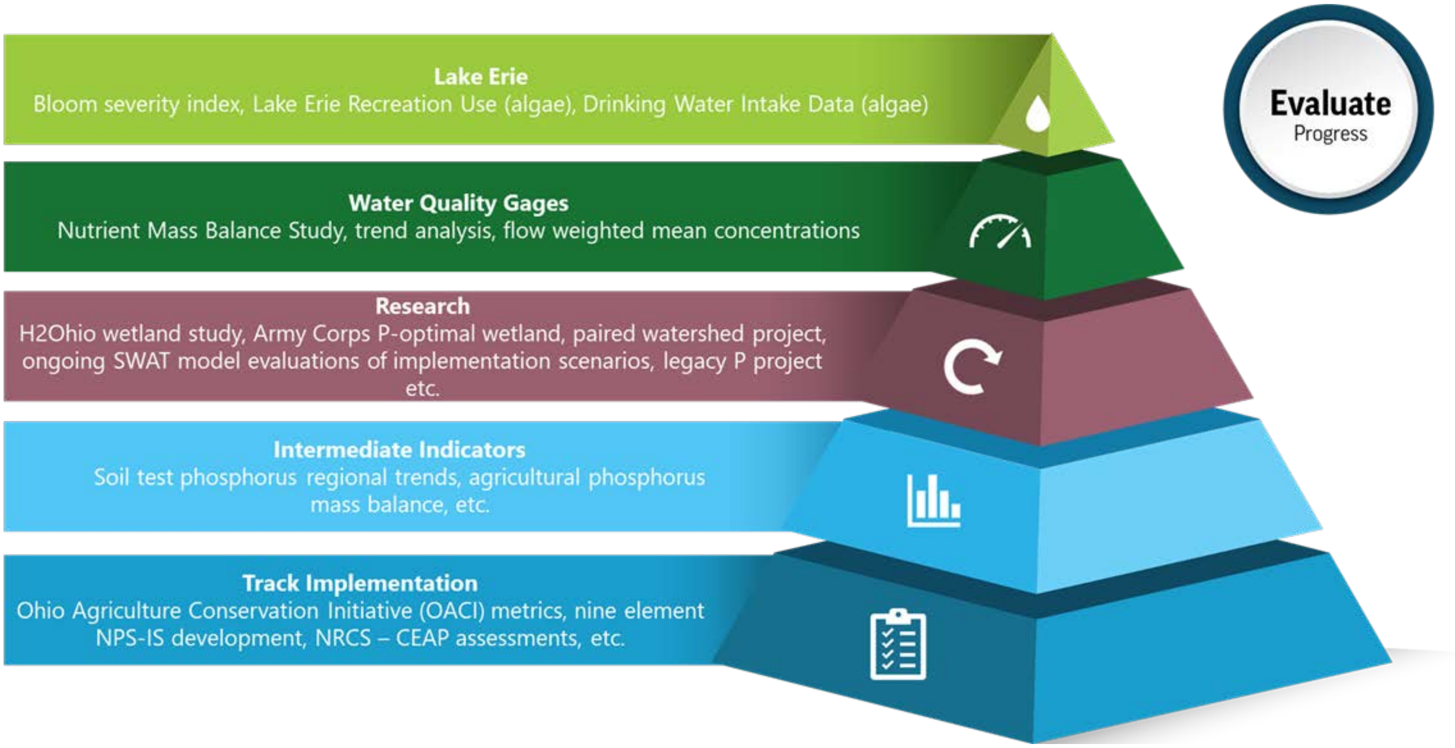


Figure 49. Metrics turn monitoring data into information that can be used to evaluate progress and adjust the strategy where needed.

Tributary load monitoring data can be summarized using FWMCs, trends analysis tools, and are routinely used for Ohio's Nutrient Mass Balance Study and by Annex 4 workgroups.

Lake Erie data is summarized by NOAA using the bloom severity index and through metrics developed in Ohio's Integrated Report. The Integrated Report metrics will determine ultimate success for this TMDL when Lake Erie impairments are delisted.

5.6. Adjust the strategy

To complete the adaptive management circle, information needs to be used to adjust the strategy, if necessary. Figure 49 shows when, why, and how adjustments would occur.

Adjustments can occur at any time as implementation programs develop. Individual programs get feedback on program effectiveness and work on program specific planning frames. Improving implementation is intrinsic to that process and while the TMDL provides useful information to the program, it does not change how implementing agencies operate. TMDL focused implementation evaluations are proposed to occur every two years to compliment evaluations made in Ohio EPA's Integrated Report. These evaluations will share updates on metrics as data becomes available, updates from research that has been published, and updates to programs that have occurred in the preceding years. The reports will also provide an opportunity to update milestones and generally report on progress.

The goal of adaptive management is to accelerate programs that do work, while looking for ways to improve or move away from ones that are not having the intended response. Therefore, changes in implementation actions could be driven by a metric that shows a program is not having a desired outcome or a metric could show that a practice is showing positive outcomes. State agencies might also adapt to policy changes that require additional implementation.

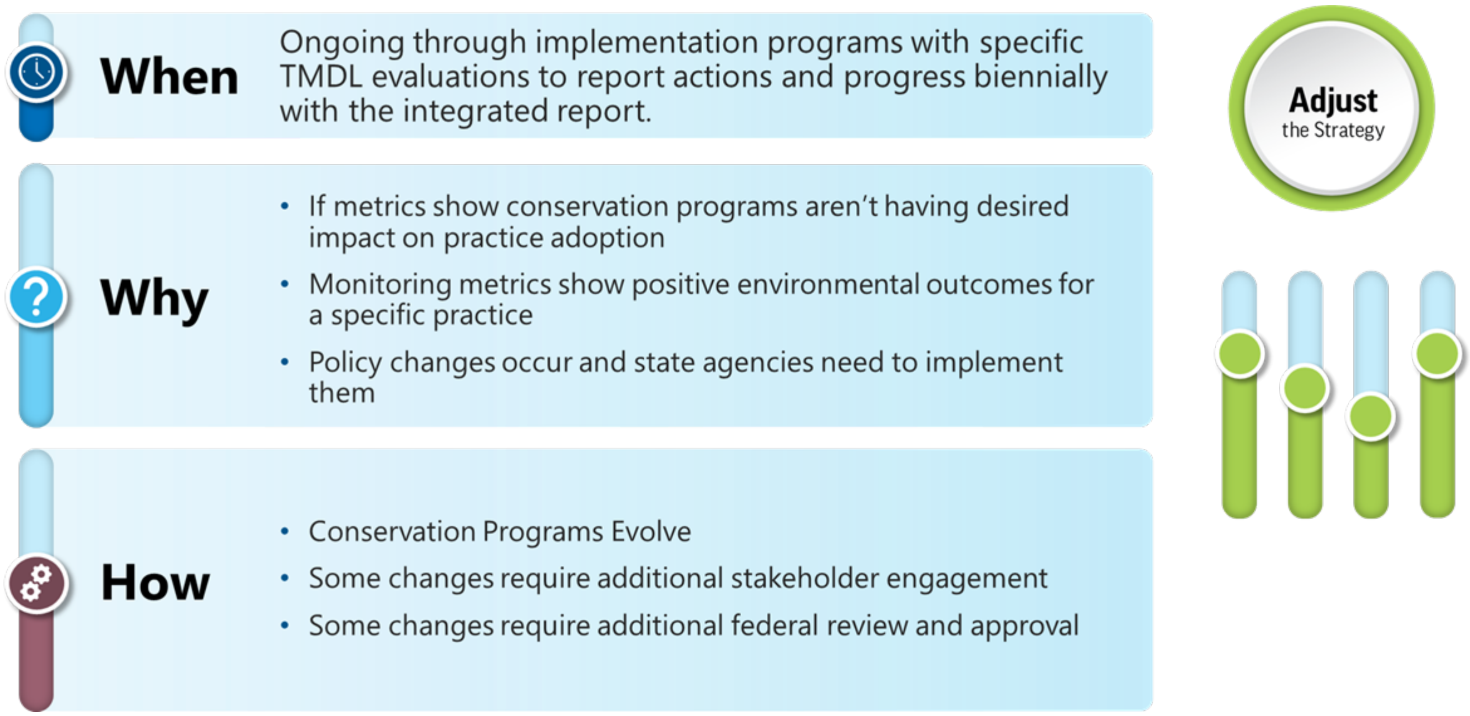


Figure 50. Adjustments made for adaptive management can occur at different times, for different reasons, and in different ways as implementation moves forward.

Not all adaptations to the implementation strategy happen the same way. Conservation programs evolving is 'part of the plan'; these do not require special considerations to improve programs. New research findings or updated analysis of monitoring results might affect the assumptions made to develop the TMDL, which would require additional stakeholder outreach by Ohio EPA. For example, if a change is proposed that affects the technology considered for compliance with NPDES permit limits. If new information suggests changes to the allocations or reasonable assurances, additional federal review and approval may be necessary. For example, if Annex 4 identifies different targets, the TMDL process would have to be revisited in whole, including federal review and approval.

6. Reasonable Assurances

When U.S. EPA approves a TMDL that allocates pollutant loads to both point and nonpoint sources, it determines whether there is reasonable assurance that the LAs will be achieved and WQS will be attained. U.S. EPA does that to be sure that the WLAs and LAs established in the TMDL are not based on overly generous assumptions regarding the amount of nonpoint source pollutant reductions that will occur. This is necessary because the WLAs for point sources are determined, in part, on the basis of the expected contributions to be made by nonpoint sources to the total pollutant reductions necessary to achieve WQS. If the reductions embodied in LAs are not fully achieved because of a failure to fully implement needed nonpoint source pollution controls, or that the reduction potential of the proposed BMPs was overestimated, the collective reductions from all sources will not result in attainment of WQS. As a result, U.S. EPA evaluates whether a TMDL provides reasonable assurance that nonpoint source controls will achieve expected load reductions.

Additional details on reasonable assurances will be part of the draft Maumee Watershed Nutrient TMDL report. Ohio EPA will detail actions that have been taken in the past, are currently underway, and future actions on the federal, state, and local level to demonstrate reasonable assurance. Past and current activities have been included in the 2022 Integrated Monitoring and Assessment Report, DAP 2020, and Module 3 of the Maumee Watershed Nutrient TMDL outreach videos. Future activities will include ongoing implementation of these programs and changes made as part of the adaptive implementation strategy discussed in Section 5 of this report.