

An aerial photograph of Lake Erie, showing the water's surface and surrounding land. A white rectangular box with a thin orange border is overlaid on the upper left portion of the image. Inside this box, the title and date are written in black text. The background image shows the lake's surface with some greenish-yellow patches, possibly indicating algae blooms or sediment. The sky is visible in the upper part of the image, and the land is visible in the lower and right parts.

Lake Erie

Binational Phosphorus Reduction Strategy

June 2019

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Prepared by the Great Lakes Water Quality Agreement Nutrients Annex Subcommittee:

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- U.S. Environmental Protection Agency (co-lead)
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- Ontario Ministry of Agriculture, Food and Rural Affairs
- Ontario Ministry of the Environment, Conservation and Parks
- Ontario Ministry of Natural Resources and Forestry
- Pennsylvania Department of Environmental Protection
- U.S. Department of Agriculture
- U.S. Geological Survey

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Preface

To combat the growing threat of toxic and nuisance algal development and the expansion of zones of low oxygen (hypoxia) in Lake Erie, the United States and Canada committed, through the 2012 Great Lakes Water Quality Agreement, to review and update binational phosphorus load reduction targets for Lake Erie by February, 2016.

In response to this commitment, following a robust binational science-based process and extensive public consultation, Canada and the U.S. adopted the following phosphorus reduction targets (compared to a 2008 baseline) for Lake Erie on February 22, 2016:

- **To minimize the extent of hypoxic zones in the waters of the central basin of Lake Erie**, a 40 percent reduction in total phosphorus (TP) entering the western and central basins of Lake Erie—from the United States and from Canada—to achieve an annual load of 6,000 metric tons to the central basin. This amounts to a reduction from the United States and Canada of 3,316 metric tons and 212 metric tons respectively.
- **To maintain algal species consistent with healthy aquatic ecosystems in the near-shore waters of the western and central basins of Lake Erie**, a 40 percent reduction in spring TP and soluble reactive phosphorus (SRP) loads from the following watersheds where algae is a localized problem:

- in Canada: Thames River and Leamington tributaries, and;
- in the United States: Maumee River, River Raisin, Portage River, Toussaint Creek, Sandusky River and Huron River (Ohio).

- **To maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the western basin of Lake Erie**, a 40 percent reduction in spring TP and SRP loads from the Maumee River in the United States.

With the adoption of new binational targets in place, the governments promptly began working with partners and stakeholders to develop domestic action plans (DAPs). These plans, which outline strategies for meeting the new targets in specific jurisdictions and watersheds, were published in 2018. Further work to establish targets that will minimize impacts from nuisance algae in the eastern basin of Lake Erie continues, and will be reviewed in 2020.

The purpose of this Lake Erie Binational Phosphorus Reduction Strategy is to describe the framework for binational cooperation under the GLWQA Nutrients Annex towards the achievement of the 2016 binational phosphorus reduction targets.

The strategy has four components:

1. An updated assessment of environmental conditions to guide lakewide nutrient management in Lake Erie (the last assessment was completed in 2011.¹);
2. A summary of the process used to develop the 2016 targets and allocate load reductions between the U.S. and Canada;
3. Binational priorities for implementation of measures to manage phosphorus loading, including the identification of watersheds that are a priority for nutrient control and binational priorities for research and monitoring; and
4. A description of how progress will be tracked using an adaptive management approach.

The Lake Erie Binational Phosphorus Reduction Strategy will be reviewed every 5 years, which also aligns with the frequency of DAP reviews. The Strategy will be updated as needed, to reflect significant changes to the targets, country allocations and/or binational priorities for implementation.

Acknowledgements

The Great Lakes Water Quality Agreement Nutrients Annex Subcommittee would like to acknowledge the contributions of its Objective and Targets Task Team to this strategy through the development of ecosystem objectives and phosphorus loading reduction targets for Lake Erie. The Great Lakes Water Quality Agreement Nutrients Annex Subcommittee would also like to acknowledge the contributions of our stakeholders and partners in moving the agenda forward, reviewing and commenting on the work of the Subcommittee and its Task Teams.

¹ Lake Erie LaMP. 2011. Lake Erie Binational Nutrient Management Strategy: Protecting Lake Erie by Managing Phosphorus. Prepared by the Lake Erie LaMP Work Group Nutrient Management Task Group.

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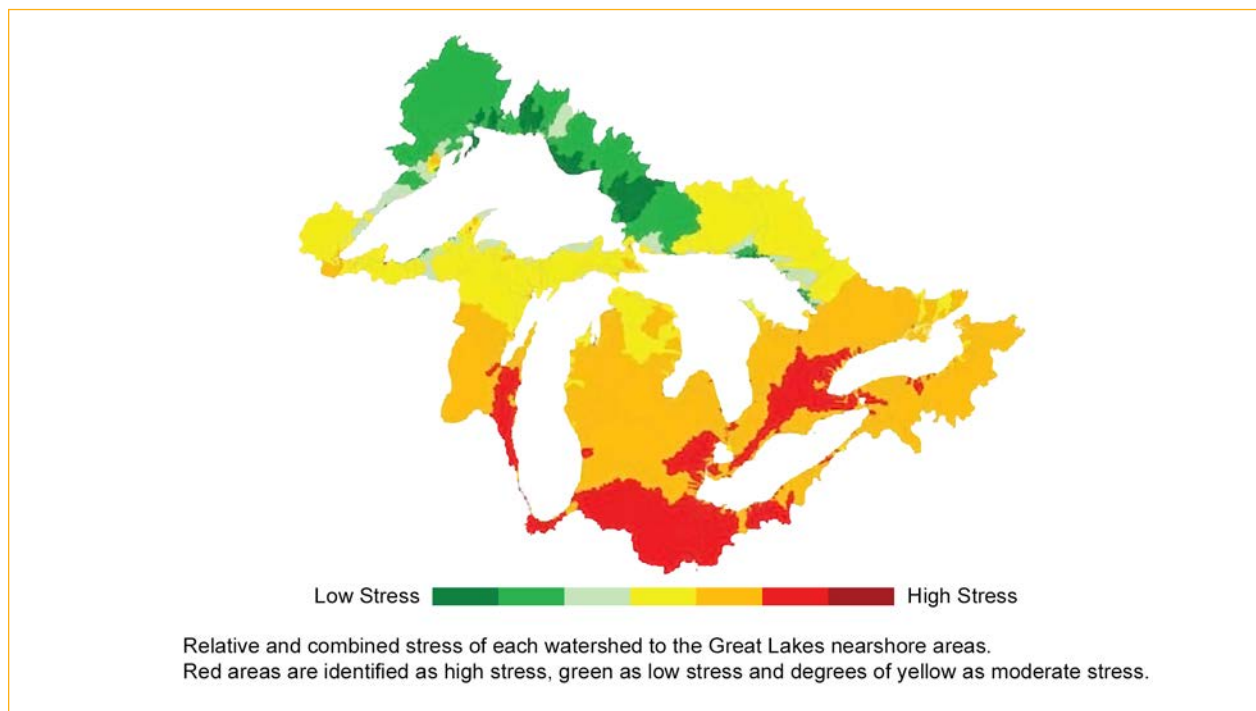
Assessment of environmental conditions

1.1 Background

Excessive algal blooms in the 1960s and 1970s were a major driver for the signing of the first Great Lakes Water Quality Agreement (GLWQA) in 1972. In that Agreement, the Governments of Canada and the U.S. agreed to reduce phosphorus loads to Lake Erie by more than 50 percent (from 29,000 to 14,600 metric tons per year). In the subsequent 1978 Agreement, the two countries

agreed to further reduce phosphorus loads to Lake Erie to 11,000 metric tons per year. Regulation of phosphorus concentrations in detergents, investing in sewage treatment, and developing and implementing best management practices on agricultural lands succeeded in reducing the loads to target levels, and algal blooms in Lake Erie decreased significantly throughout the 1980s. However, in the late 1990s, despite ongoing efforts to limit phosphorus discharges to Lake Erie, toxic and nuisance algal blooms began to increase.

FIGURE 1: Watershed Stressors



Source: Great Lakes Environmental Indicators (GLEI) Project, University of Windsor and University of Minnesota – Duluth, 2015.

Lake Erie is susceptible to excessive algal growth, in part, due to its physical characteristics. As the smallest of the Great Lakes by volume, Lake Erie is also the shallowest and is located in the southernmost portion of the Great Lakes basin, making Lake Erie waters the warmest and the most biologically productive of all the Great Lakes. Lake Erie is also exposed to the greatest stress from urbanization, industrialization and agriculture, and is the most populated of the Great Lakes, serving a population of over 11 million. Lake Erie: 1) receives the highest loads of phosphorus of all the Great Lakes; 2) surpasses all the other Great Lakes in the amount of effluent received from sewage treatment plants; and 3) is most subject to sediment loading due to the nature of the underlying geology and land use.

1.2 Lake Erie's three basins

Water moves through Lake Erie relatively quickly. Lake Erie has the shortest residence time of the Great Lakes: on average, water is replaced in Lake Erie every 2.7 years (by way of comparison, water replacement in Lake Ontario takes 6 years, and in Lake Superior it takes 173 years). Most of the water enters through the western basin of the lake, where it quickly (in a matter of days) flows into the central basin. From there, water moves through the eastern basin and eventually flows into Lake Ontario.

Along the way, nutrients and algae interact in unique ways in each of Lake Erie's three distinct basins. The western basin receives about 61 percent of the lake's entire annual total phosphorus load, while the central basin and eastern basin receive 27 percent and 12 percent, respectively. Differences in the types and/or densities of algae growing in each basin are due to differences in lake depth, water temperature, substrate, and the local influence of tributaries.

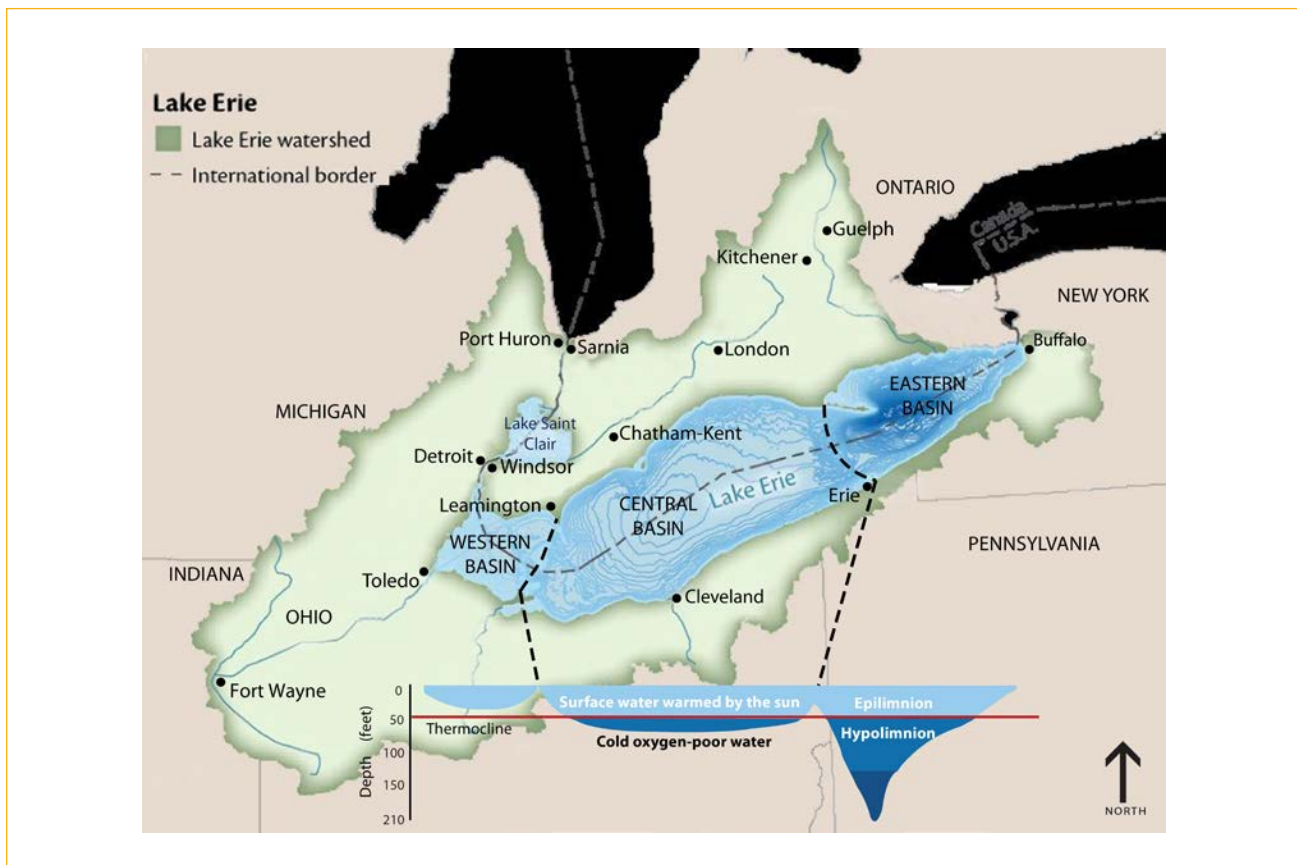
The Western Basin is very shallow, with an average depth of 7.4 meters (24 feet) and a maximum depth of 19 meters (62 feet). It is warm, and it receives most of the lake's total phosphorus load because of the size of the Detroit and Maumee Rivers. As a result, algal blooms dominated by the blue-green alga (cyanobacteria) *Microcystis aeruginosa* occur regularly, fouling shorelines during the spring, summer and fall. This species can form blooms that contain toxins (e.g., microcystin) dangerous to humans and wildlife.

The Central Basin is deeper with an average depth of 18.3 meters (60 feet) and a maximum depth of 25 meters (82 feet). Algal blooms that originate in the western basin often move into the central basin, as well. Blooms also form at the mouth of the Sandusky River, which delivers the third highest tributary load to the lake overall. Excess phosphorus also contributes to hypoxic (low-oxygen) conditions in the cold bottom layer of the lake (the hypolimnion) when algae die and decompose. This decomposition uses up the oxygen during the summer, leaving little to none for the aquatic community which suffocates or moves elsewhere, creating Lake Erie's "Dead Zone."

The Eastern Basin is the deepest of the three basins with an average depth of 24 meters (80 feet) and a maximum depth of 64 meters (210 feet). While the phosphorus levels in the eastern basin are generally much lower than the western and central basins, levels are still high enough to promote the excessive growth of *Cladophora*. *Cladophora* is filamentous green algae that grows on hard substrates in all of the

Great Lakes. *Cladophora* is not toxic, but it is a nuisance and can pose threats to human health. Beyond clogging water intakes and degrading fish habitat, odorous rotting mats of *Cladophora* on beaches encourage the growth of bacteria and are a factor in beach closures. The presence of *Cladophora* may create an environment conducive to the development of botulism, which results in bird and fish deaths.

FIGURE 2: Lake Erie Watershed and Bathymetry



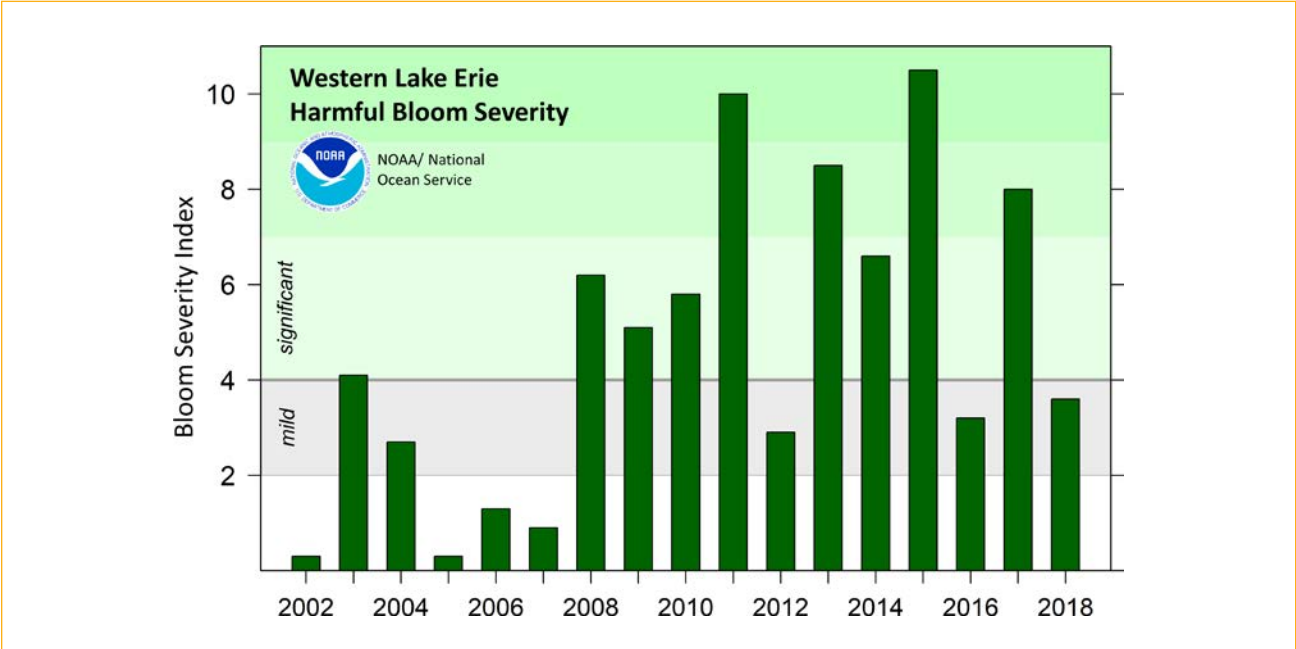
Source: Environment and Climate Change Canada, 2015.

1.3 Conditions are deteriorating

Toxic and nuisance algal bloom occurrences in Lake Erie have increased over the past decade, with record-setting blooms occurring in 2011 and 2015. The blooms threaten drinking water, increase costs associated with drinking water treatment needs, and occasionally force closures of treatment plants. They clog water intake systems, adversely impact commercial and recreational fishing activities and other recreational pursuits, and degrade fish and wildlife habitat and populations.

In 2011, concentrations of the algal toxin microcystin in the open waters of the western basin of Lake Erie were 50 times higher than the World Health Organization (WHO) limit for safe body contact, and 1,200 times higher than the limit for safe drinking water. In August 2014, algal toxins forced closure of the Toledo, Ohio drinking water treatment plant, and private water users on Pelee Island, Ontario, were warned not to bathe in, or drink, Lake Erie water. These incidents affected more than 500,000 people.

FIGURE 3: Temporal variation in Bloom Severity Index



Source: National Oceanic and Atmospheric Agency, 2018

Other signs of nutrient enrichment (eutrophication) in the lake include excessive nuisance algal growth in nearshore areas, and depletion of oxygen in bottom waters (created when algae die and decompose). Some of the hypoxia observed in the central basin is a natural phenomenon; however, since the early 2000s, the hypoxic (low-oxygen) area in the central Basin of Lake Erie has increased to about 4,500 km², on average, with the largest hypoxic event of 8,800 km² occurring in 2012. Hypoxic conditions can affect the growth and survival of fish species. In 2012, hypoxic conditions were responsible for tens of thousands of dead fish washing up on a 40 km stretch of shoreline between Eriean and Port Stanley, Ontario. In addition, beginning in the early 2000s, mats of *Cladophora* in the eastern basin of Lake Erie have caused beach fouling, undesirable odors from decomposing *Cladophora*, clogged industrial intakes and degraded fish habitat.

In summary, the lake is responding to high levels of nutrients in three negative ways, each of which appears to be intensifying. The three key nutrient issues to be addressed are: 1) the increasing frequency and extent of harmful algal blooms and associated toxins; 2) the decreasing availability of oxygen in the hypolimnetic waters in the central basin; and 3) the increasing growth of nuisance algae, like *Cladophora*, on the lake bottom.

The resurgence of harmful and nuisance algal blooms in Lake Erie is the result of complex interactions among multiple factors rather than one specific factor.

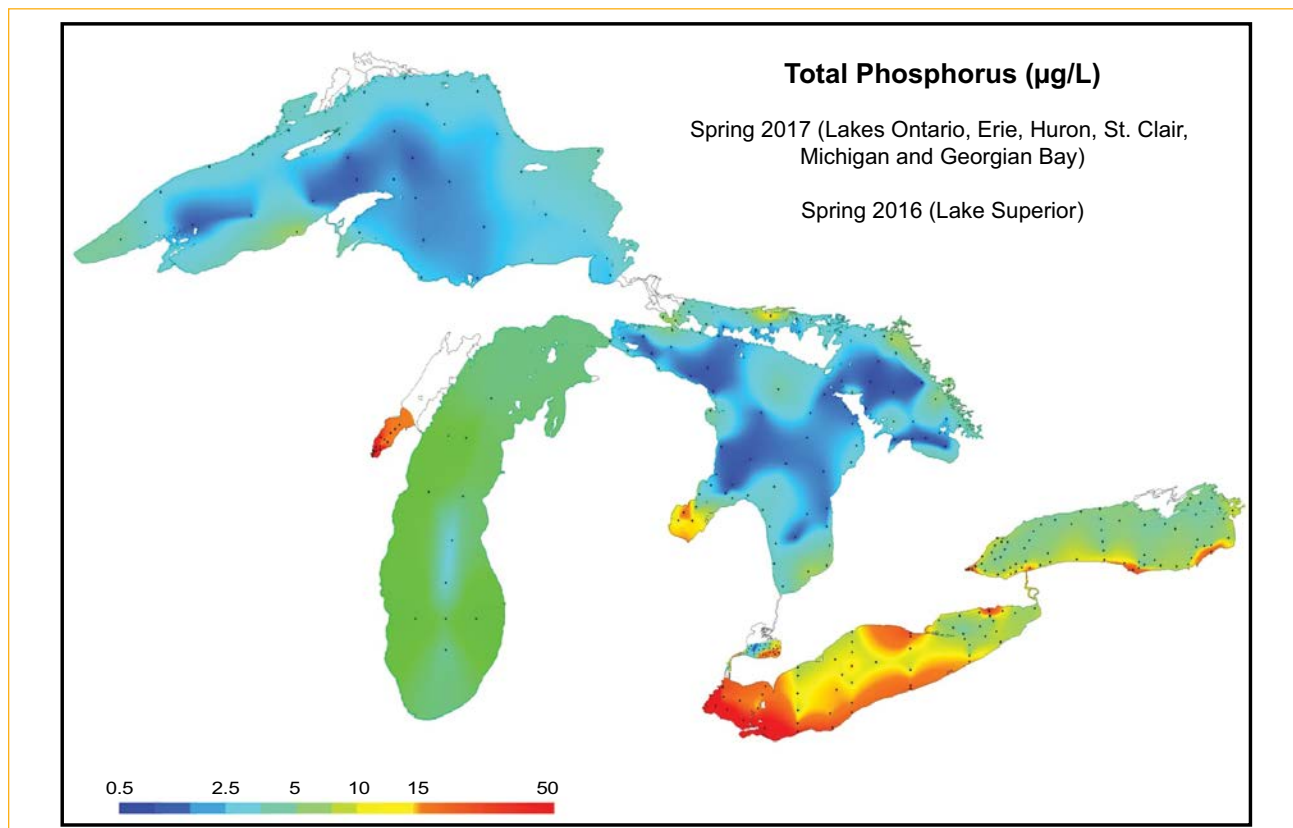
Data collected by Environment and Climate Change Canada and the U.S. Environmental Protection Agency show that, while phosphorus concentrations in the lake can be highly variable, the concentrations in the western and central basins consistently exceed the levels commensurate with a healthy ecosystem. Furthermore, in-lake nutrient cycling has changed due to the spread of invasive zebra and quagga mussels that became established in the lake in the 1990s. Invasive mussels retain and recycle nutrients in nearshore areas by filtering particles from the water column and subsequently excreting highly bioavailable phosphorus as a waste product. This alteration of nutrient flows is resulting in greater nuisance algal growth, such as *Cladophora*, in the nearshore regions, closer to where humans interact with the lake. Other changes contributing to the resurgence of algae include the loss of wetlands and riparian vegetation that once trapped nutrients, as well as release of sediment-bound residual (legacy) phosphorus from soils. Effects of climate change are also impacting nutrient concentrations. For example, increasing temperatures in recent years are creating longer growing seasons for algae, and more frequent high-intensity precipitation events during the spring are delivering nutrients during a time of year that is critical for promoting the intensity and duration of summer algal blooms. Add the intensification of land use to these factors and changes in land management, such as increases in fall application of fertilizers, or increases in urban runoff due to more hard surfaces, and it is clear that the combination of multiple factors are increasing the amount of phosphorus entering Lake Erie from land runoff and point sources.

1.4 Phosphorus: the limiting nutrient

Phosphorus is a naturally occurring and biologically active element that is a component of all biological tissue. It is an essential nutrient for plant and animal life, making it necessary for maintaining a healthy lake ecosystem.

Total phosphorus is a combination of dissolved and particulate forms. Particulate phosphorus is bound to soil particles and is readily transported by water and wind erosion, but is much less bioavailable and is less accessible to plants and algae. The dissolved form (known as “soluble reactive phosphorus”) is highly bioavailable and rapidly taken up by plants. High levels of soluble reactive phosphorus in water promote rapid growth of algae.

FIGURE 4: Total phosphorus concentrations in the Great Lakes, as measured during spring surveys in 2016 and 2017



Source: Environment and Climate Change Canada, and United States Environmental Protection Agency, 2019.

Phosphorus is the nutrient limiting algal growth in Lake Erie and is the focus of binational nutrient management efforts under the GLWQA. While many other nutrients are present in water, such as nitrogen, silica, carbon, and even trace metals, these nutrients are considered to be only secondarily or seasonally limiting. Consequently, actions limiting phosphorus loading from the surrounding watersheds are currently the primary strategy to address the problems associated with excessive algal growth. However, there is increasing evidence that both nitrogen and phosphorus should be considered as part of a more comprehensive nutrient management strategy to control harmful algal blooms. While the current strategy is focused on phosphorus reduction, the effects of nitrogen and other nutrients continue to be researched and monitored so that management decisions and actions can be adapted, if required.

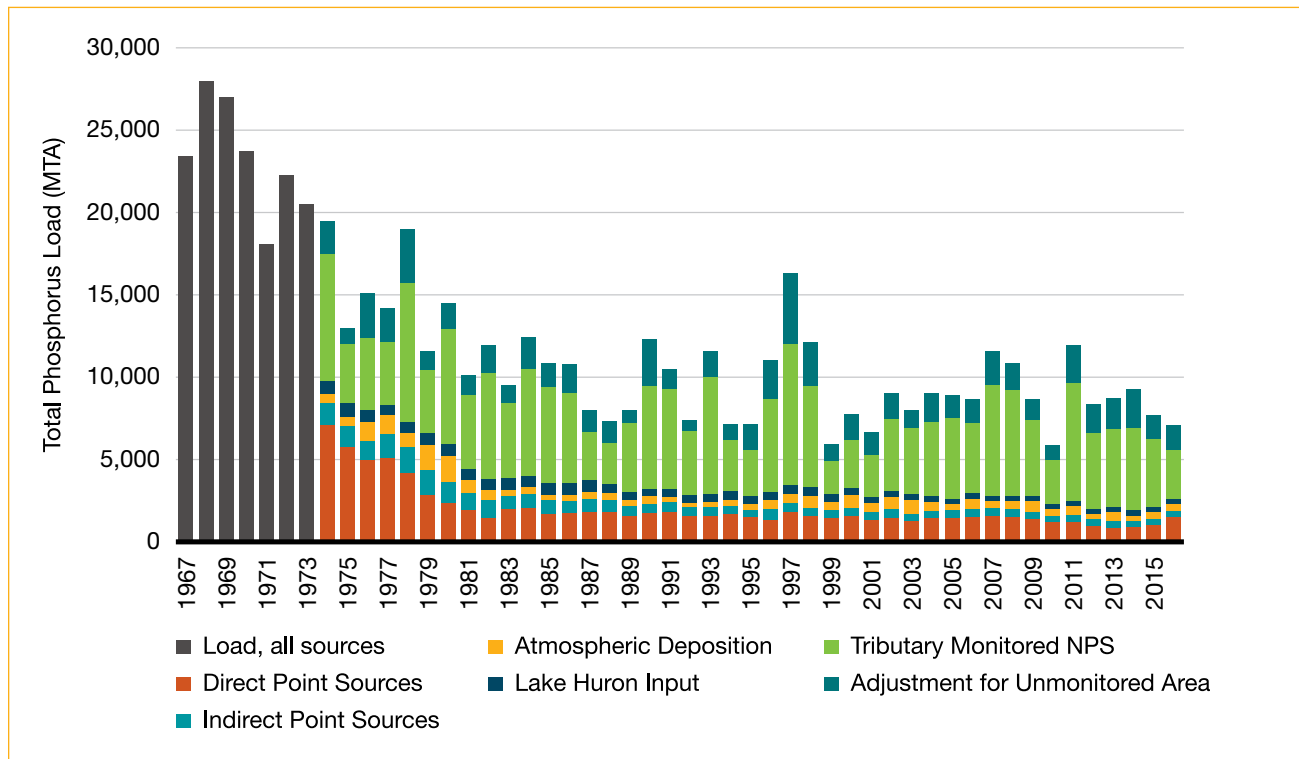
Phosphorus enters Lake Erie from point sources, such as treated effluent from municipal wastewater treatment facilities, as well as nonpoint sources (NPS) such as runoff from urban and agricultural landscapes. These sources contain a mixture of soluble reactive phosphorus and particulate phosphorus, with the proportion of each dependent on the particular activity and geographic location.

Phosphorus naturally cycles through air, water and soil and can change forms many times before it reaches Lake Erie, as well as once it is within the lake. Phosphorus is stored in and released from biological tissues and mineral particles in soils and sediments on lake and stream bottoms, flood plains, urban water systems and agricultural fields. These “legacy” sources of phosphorus can

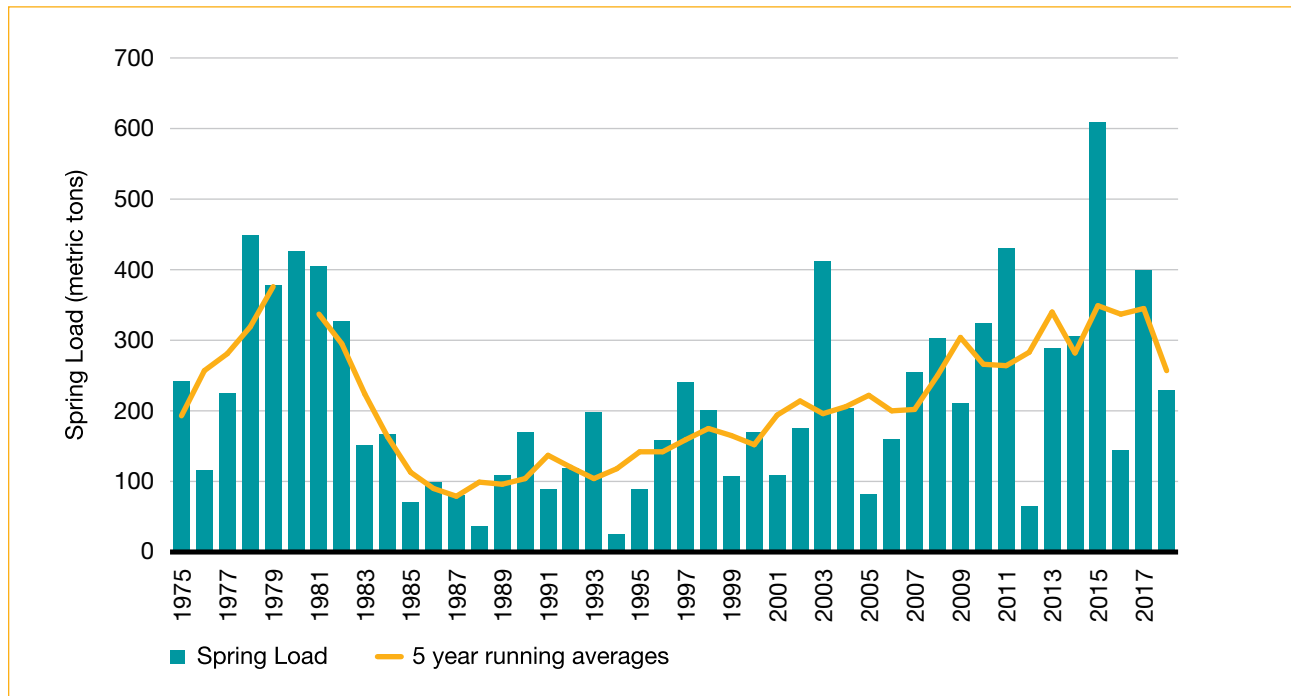
be re-mobilized and thus add to loadings — even when current practices are geared to phosphorus reduction. Actions to reduce phosphorus over time will help reduce the amount of legacy phosphorus available to the Lake Erie ecosystem.

Some sources of phosphorus (such as human sewage, animal manures, and fertilizers) are very high in soluble reactive phosphorus, and thus highly bioavailable. Controls of these sources can involve containment (e.g., manure storage) and often specialized treatment (e.g., wastewater treatment plants). Effective control of non-point sources can be more complex and requires particular attention to preventive actions (e.g., right source, right timing, placement, and rate of manure and fertilizer application) in addition to addressing hydrological factors in the landscape.

Overall, monitoring has shown that despite significant year-to-year variation in loads, the average annual amount of total phosphorus entering the lake has been relatively stable over the past 15 years. What appears to have changed however is that there has been a significant increase in the proportion of the phosphorus load to Lake Erie that is in dissolved form, as opposed to particulate form. The timing of when phosphorus is delivered to the lake is critical, as well. Non-point source runoff from the Maumee River during the spring period (March to June) has been shown to be the best predictor of cyanobacteria bloom biomass each year. Therefore, reductions in total phosphorus and soluble reactive phosphorus, especially under high flow conditions, are necessary to combat nutrient related problems in Lake Erie.

FIGURE 5: Annual loads of total phosphorus to Lake Erie from Canada and the U.S.

Source: Maccoux et al., 2016.

FIGURE 6: Annual spring SRP loads and 5-year running averages for the Maumee River

Source: Laura Johnson, Heidelberg University, 2018.

2

Update to Binational Phosphorus Targets, 2016

To combat the growing threat of toxic and nuisance algal development and the expansion of zones of low oxygen (hypoxia) in Lake Erie, the United States and Canada committed, through the 2012 Great Lakes Water Quality Agreement, to review and update binational phosphorus load reduction targets for Lake Erie by February, 2016.

In response to this commitment, Environment and Climate Change Canada and U.S. EPA convened a GLWQA Nutrients Annex Subcommittee in 2013, made up of representatives of federal, state, and provincial governments, Indigenous organizations, municipal and local governments, and other key partners, to review the interim phosphorus targets for Lake Erie, and to recommend revisions to those targets (if required). The Subcommittee engaged over 30 scientific experts on a binational workgroup (named the “Objectives and Targets Task Team”) to do this work. The Task Team’s full technical report can be accessed here: <https://binational.net/wp-content/uploads/2015/06/nutrients-TT-report-en-sm.pdf>.

Following a robust binational science-based process and extensive public consultation, Canada and the U.S. adopted phosphorus reduction targets for the western and central basins of Lake Erie on February 22, 2016. Further work to establish targets that will minimize impacts from nuisance algae in the eastern basin of Lake Erie continues, and will be reviewed in 2020.

2.1 Lake Ecosystem Objectives

Algae are an essential component of Lake Erie’s ecosystem. The goal is to identify and achieve the right level and type of algal growth to support a healthy and productive ecosystem.

The 2012 Agreement provides guidance in relation to what constitutes a healthy and productive ecosystem that is free from human induced eutrophication symptoms. There are six Lake Ecosystem Objectives (LEOs) related to nutrients:

1. Minimize the extent of hypoxic zones associated with excessive phosphorus.
2. Maintain the levels of algae below the level constituting a nuisance condition.
3. Maintain algal species consistent with healthy aquatic ecosystems in the near-shore waters of the Great Lakes.
4. Maintain cyanobacteria at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the Great Lakes.

5. Maintain an oligotrophic state, relative algal biomass and algal species consistent with healthy aquatic ecosystems, in the open waters of Lakes Superior, Michigan, Huron and Ontario.
6. Maintain mesotrophic conditions in the open waters of the western and central basins of Lake Erie, and oligotrophic conditions in the eastern basin of Lake Erie.

Based on the LEOs, The Nutrients Annex's Objective and Targets Task Team identified appropriate eutrophication indicators and quantitative benchmarks to determine loading targets to meet the benchmarks. For example, to meet LEO #1 (for hypoxia), the eutrophication response indicator is *dissolved oxygen concentration in the hypolimnion* of the central basin of Lake Erie and the benchmark is to achieve (at a minimum) an average dissolved oxygen concentration of *2.0 mg/L in August and September*.

Modeling experts from the United States and Canada applied nine different computer simulation models² to correlate changes in phosphorus levels with the eutrophication indicators. These models were built using the best available science for the Lake Erie aquatic ecosystem. By comparing and contrasting the results of these models, science experts were able to arrive at recommended phosphorus load reduction targets that would meet the Lake Ecosystem Objectives.

2.2 Phosphorus targets to meet LEOs

Following extensive public consultation during 2015, Canada and the United States adopted phosphorus reduction targets for the western and central basins of Lake Erie on February 22, 2016 (see Table 1 below). Addressing excessive algal growth and shoreline fouling in Lake Erie's eastern basin remains a priority; however, there was insufficient science to develop a target in 2016. In the interim, targeted research efforts are underway to improve our scientific understanding of factors contributing to *Cladophora* growth in the eastern basin. The viability of setting evidence-based numeric targets for the eastern basin will be re-evaluated in 2020.

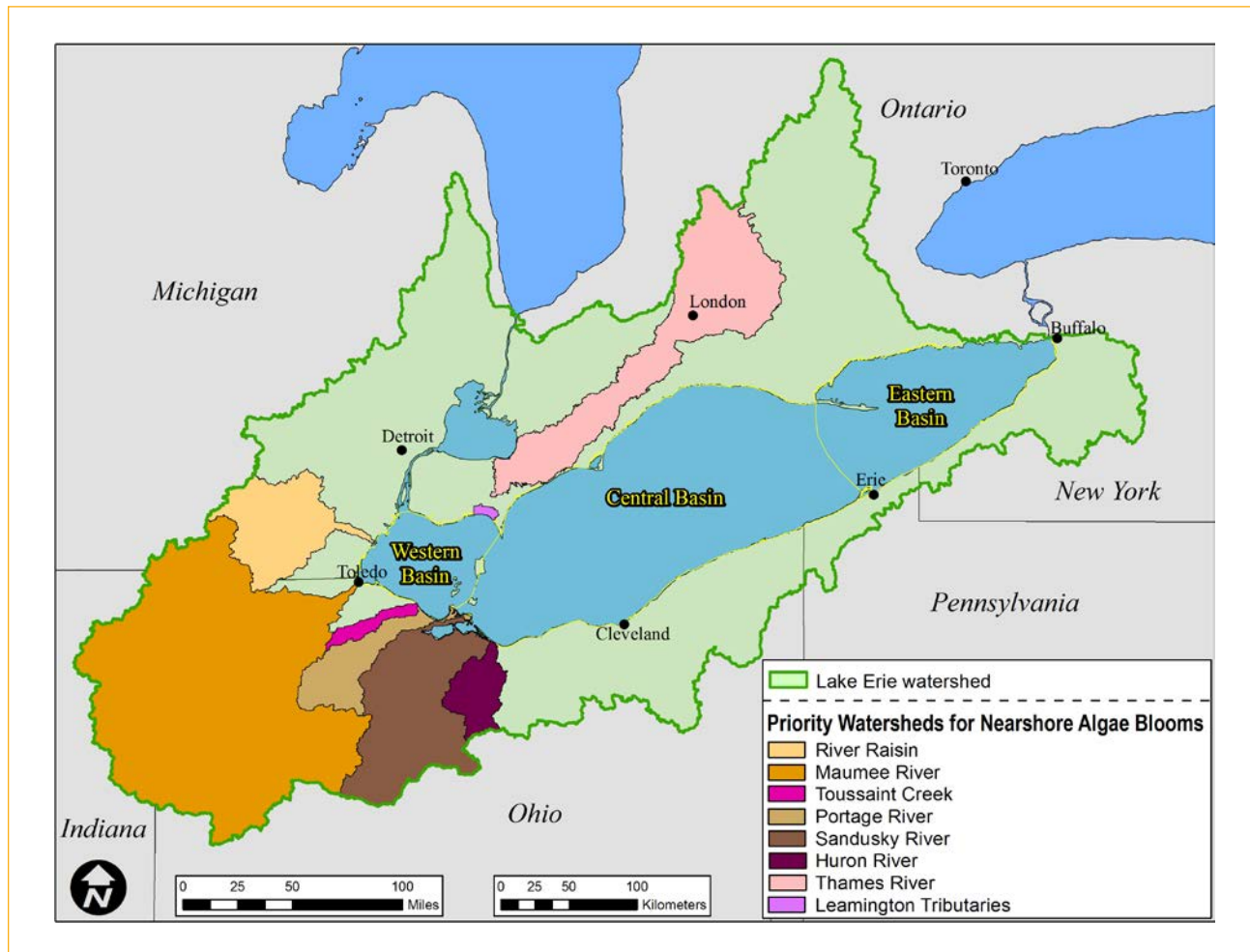
2 For further details on the modeling effort, see: <https://www.epa.gov/glwqa/annex-4-final-multi-modeling-report>

TABLE 1: Binational Phosphorus Load Reduction Targets

LAKE ECOSYSTEM OBJECTIVE	WESTERN BASIN OF LAKE ERIE	CENTRAL BASIN OF LAKE ERIE
Minimize the extent of hypoxic zones associated with excessive phosphorus loading, particularly in Lake Erie's central basin.	40 percent reduction from 2008 levels in total phosphorus entering the western and central basins of Lake Erie to achieve an annual load of 6000 Metric Tons to the central basin. This amounts to a reduction from Canada and the United States of 212 Metric Tons and 3,316 Metric Tons, respectively.	
Maintain algal species consistent with healthy aquatic ecosystems in the Nearshore.	40 percent reduction in spring (March – July) TP and SRP loads from the following tributaries where localized algae is a problem ³ : Thames River – Canada Maumee River – United States River Raisin – United States Portage River – United States Toussaint Creek – United States Leamington Tributaries – Canada	Sandusky River – United States Huron River, Ohio – United States
Maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health.	40 percent reduction in spring TP and SRP loads from the Maumee River (United States). This equates to a target spring load of 860 Metric Tons TP and 186 Metric Tons SRP.	Not Applicable

³ **Binational and domestic efforts to reduce phosphorus will not be limited to these tributaries alone.** These are a subset of the priority tributaries for nutrient control listed in Section 3.1. Additional tributaries or watersheds may be identified in a jurisdiction's domestic action plan as a priority for action to reduce phosphorus.

FIGURE 7: Watershed map of the Lake Erie priority tributaries for nearshore algae blooms



Source: U.S. Environmental Protection Agency, 2016.

2.3 Load Reduction Target Allocations by Country

The 2008 Water Year (October 1, 2007 – September 30, 2008) serves as the baseline for applying the 40% reduction targets to tributaries and direct dischargers in the western and central basins.

Total phosphorus loads to the central basin in 2008 were 9,528 MT.⁴ To achieve the loading target of 6,000 MT to the central basin of Lake Erie, a reduction of 3,528 MT is required. Each country agreed to reduce their load by 40% from 2008 levels. Therefore, the load reduction was allocated between the U.S. and Canada as follows:

TABLE 2: Target Allocations by Source

SOURCE	2008 TOTAL PHOSPHORUS LOAD (Metric tons per year of total phosphorus to the central basin)	REDUCTION REQUIRED (Metric tons per year of total phosphorus to the central basin)
Canadian tributaries and direct dischargers	533	212
U.S. tributaries and direct dischargers	8,301	3,316
Atmospheric Deposition	373	–
Lake Huron input	321	–
Total	9,528	3,528

⁴ The 2008 baseline values can be found in Maccoux et. al 2016: <https://doi.org/10.1016/j.jglr.2016.08.005>.

3

Binational Priorities for Implementation

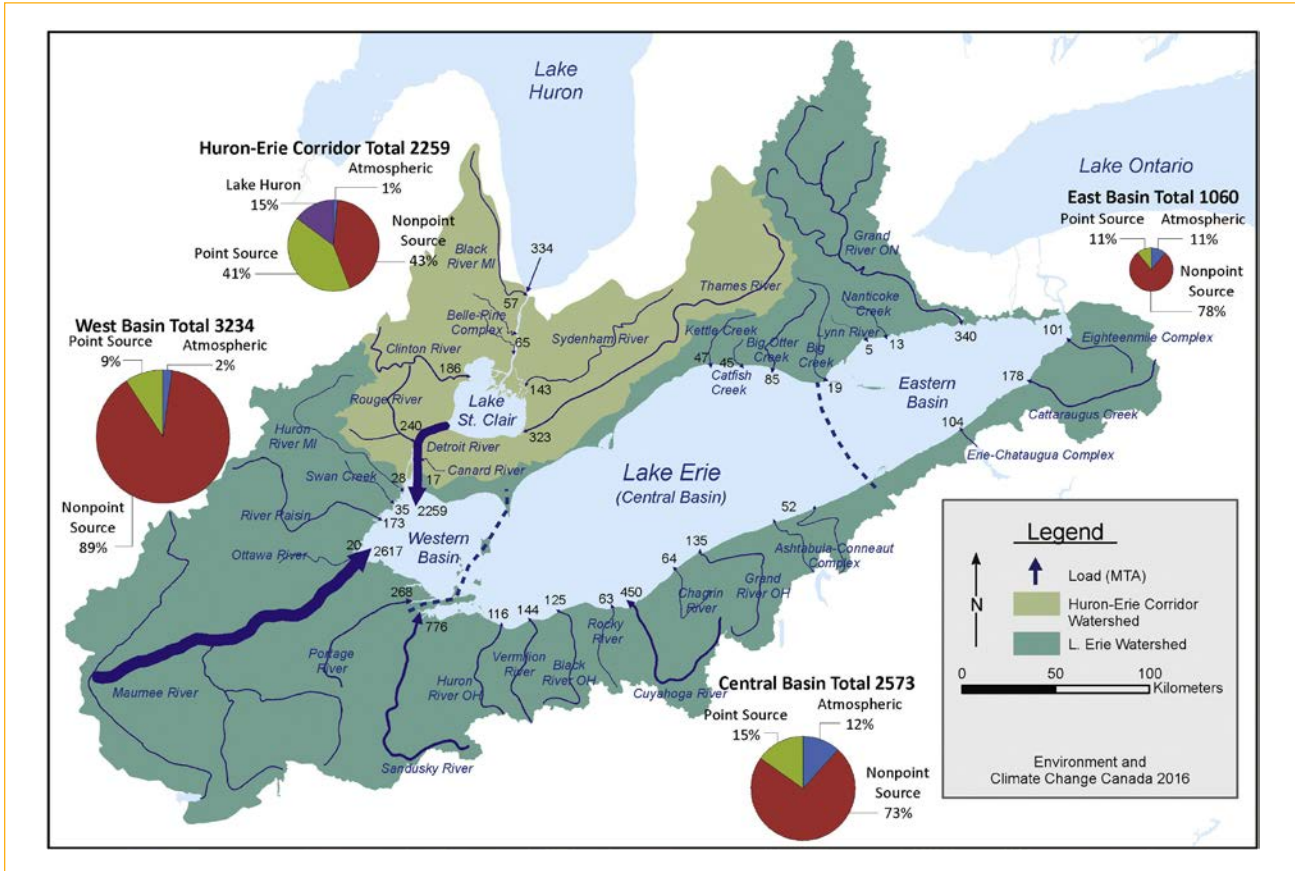
Reducing phosphorus loads to the western and central basins by 40% will take time and will require the adoption of a multi-barrier approach to prevent, capture and treat polluted runoff. In the Maumee River basin, for example, applications of multiple watershed models have demonstrated that the forty percent reduction goal could be achieved through the widespread adoption of conservation practices targeted to the areas where they are needed most. Similar analyses in Canada support the conclusion that phosphorus reduction targets are achievable but will require a widespread implementation of actions.

It is recognized that there is not one solution to addressing the problem, and that multiple management strategies are needed to control phosphorus from various sources and at multiple scales. Reducing nonpoint phosphorus losses during storm events in the non-growing season, especially the spring, is a key priority and will be critical to the success in preventing harmful and nuisance algal blooms in Lake Erie. Furthermore, it is clear that current efforts to limit excess phosphorus loading to Lake Erie – through measures such as implementing best management practices on agricultural lands and optimizing wastewater treatment – must continue and be enhanced.

3.1 Priority Tributaries for Nutrient Control

Most of the total phosphorus load to the lake is delivered from a few major tributaries: the Detroit River, which includes upstream tributary inputs from Lake Huron, the St. Clair River, as well as the Thames River in Canada, the Maumee and Sandusky Rivers in the U.S., and the Grand River in Ontario. The contribution of each river varies from year to year depending on annual discharge, which can be highly variable in response to the intensity, amount, and timing of precipitation.

Canada and the United States identified 14 priority tributaries in the Lake Erie basin: the Detroit River, Thames River, Leamington Tributaries, River Raisin, Maumee River, Toussaint Creek, Portage River, Sandusky River, Huron River (Ohio), Vermillion River, Cuyahoga River, Grand River (Ohio), Cattaraugus Creek, and Grand River (Ontario). These tributaries are believed to contribute most significantly to the observed eutrophication issues in the lake's three basins.

FIGURE 8: Average annual total phosphorus loads 2003–2013

Source: Maccoux et al, 2016.

As indicated in Figure 9 below, some tributaries contribute to both cyanobacteria growth and seasonal hypoxia and therefore reductions in annual TP, spring TP and SRP are required. The loading from the Detroit River, on the other hand, contributes to central basin hypoxia, but not to western basin cyanobacteria, so only reductions

in the total annual TP load are required. Two tributaries in the eastern basin – the Grand River in Ontario and Cattaraugus Creek in New York – were selected for further study to determine their potential contribution to nuisance *Cladophora* growth. Phosphorus reduction targets have not yet been determined for these tributaries.

FIGURE 9: Lake Erie Priority Tributaries for Nutrient Control

TRIBUTARY	EUTROPHICATION INDICATOR			
	Cyanobacteria: 40% Spring P Reduction		Central Basin Hypoxia: 40% Annual P Reduction	Eastern Basin <i>Cladophora</i> : *insufficient science to establish P reduction target at this time
	Western Basin Open-water	Nearshore		
Detroit River			X	
Thames River		X	X	
Leamington Tributaries		X	X	
River Raisin		X	X	
Maumee River	X	X	X	
Portage River		X	X	
Toussaint Creek		X		
Sandusky River		X	X	
Huron River (Ohio)		X	X	
Vermillion River			X	
Cuyahoga River			X	
Grand River (Ohio)			X	
<i>Grand River (Ontario)*</i>				X
<i>Cattaraugus Creek*</i>				X

* While targets for Eastern Basin *Cladophora* have not been established to date, the Grand River, Ontario and *Cattaraugus Creek* have been identified as priority watersheds.

3.2 Binational Strategies to Support Domestic Actions

In 2018, the United States and Canada released domestic action plans (DAP) that outline strategies and actions for meeting the new phosphorus load reduction targets. The DAPs can be accessed here: <https://binational.net/2018/03/07/daplanphosredinlakeerie>. The plans describe the specific measures each jurisdiction is implementing in collaboration with its partners to achieve binational phosphorus reduction targets for Lake Erie and, ultimately, to curb the growth of excess algae that threaten the ecosystem and human health.

Canada and the United States are working with the province of Ontario and Lake Erie States, Tribes, First Nations, and other stakeholders to implement the domestic action plans. These plans identify the actions required to meet the agreed upon phosphorus load reduction targets.

- Canada-Ontario: https://www.canada.ca/en/environment-climate-change/news/2018/02/the_governments_ofcanadaandontarioreleaseactionplantoreduceharmf.html
- United States: <https://www.epa.gov/glwqa/us-action-plan-lake-erie>
- Ohio: <http://lakeerie.ohio.gov/LakeEriePlanning/OhioDomesticActionPlan2018.aspx>
- Michigan: <http://www.michigan.gov/deqgreatlakes>
- Indiana: <http://www.in.gov/isda/3432.htm>
- Pennsylvania: <http://www.dep.pa.gov/Business/Water/Compacts%20and%20Commissions/Great%20Lakes%20Program/Pages/default.aspx>

There are currently no nutrient reduction targets for the eastern basin of Lake Erie. However, New York State is participating in the United States Domestic

Action Plan, and is committed to the development of a Lake Erie watershed plan and tributary monitoring program that supports the broader goals of the Domestic Action Plan, lakewide nutrient loading assessments and modeling efforts under the GLWQA Nutrients Annex. The Canada-Ontario Lake Erie Action Plan contains commitments for the eastern basin of Lake Erie including specific actions for the Grand River.

Each Domestic Action Plan is unique and the categories of actions outlined below are a synthesis of what can be found in the Domestic Action Plans referenced above. Readers are encouraged to read the Plans for specifics on the strategies and actions that each jurisdiction is implementing. Not all actions are a priority in every jurisdiction.

Strategy #1: Reduce Phosphorus Loadings from Agricultural Sources

In agriculturally dominated watersheds like the Maumee River and the Thames River basins, it is clear that adoption of agricultural management practices needs to be aggressive and widespread. New approaches are needed to increase and target the adoption of conservation and stewardship programs to maximize results. Each jurisdiction is seeking opportunities to improve the effectiveness of these programs and significantly increase the current rates of adoption.

A significant portion of the phosphorus that is contributing to the harmful and nuisance algal blooms and hypoxia in Lake Erie originates from surface and subsurface losses of commercial and organic fertilizer applied to agricultural land. Furthermore, historical applications of fertilizers are responsible for the accumulation of phosphorus in soils in some areas. The predominant sources and pathways (surface or tile) will vary in the region, depending on the land management, soil type and other factors.

The 4R Nutrient Stewardship Certification program encourages agricultural retailers, service providers and other certified professionals to implement proven best practices through the 4Rs, which refers to using the Right Source of Nutrients at the Right Rate and Right Time in the Right Place.

Key actions under this strategy include:

- Continue to encourage farmers to adopt on-farm best management practices (BMPs), emphasizing a “systems approach” (combinations of management practices) to comprehensively address concerns at the farm scale.
- Adopt 4R’s Nutrient Stewardship Certification or similar programs.
- Avoid nutrient applications on frozen or snow-covered ground.
- Implement and enforce fertilizer and manure application requirements where they apply.
- Prevent agricultural runoff by improving soil health and managing drainage systems to hold back or delay delivery of runoff through the use of saturated buffers, constructed wetlands or other drainage water management techniques.
- Reduce the impact of discharges from greenhouses on Lake Erie.

Strategy #2: Reduce Phosphorus Loadings from Municipal Sources

Cities, towns and villages contribute phosphorus from wastewater treatment plant discharges and stormwater runoff. Over the past 40 years, significant efforts have been made to reduce phosphorus loadings from wastewater treatment facilities, however further reductions from wastewater treatments plants are necessary.

Most wastewater treatment facilities in the basin are currently permitted to discharge 1.0 mg/L of total phosphorus. However, many are actually discharging at lower rates and others present opportunities to further reduce discharges even in the absence of significant investments in new treatment technologies or infrastructure. Actions to characterize and reduce phosphorus loads from other municipal sources will also be required.

Key actions under this strategy include:

- Optimize wastewater infrastructure.
- Encourage investments in green infrastructure and low impact development.
- Identify and correct failing home sewage treatment systems.
- Investigate water quality trading as a potential tool for managing phosphorus.

Ontario, Ohio, Indiana and Michigan have strategically reduced discharges from their highest loading wastewater treatment facilities using various methods described in their DAPs. In southeast Michigan, the Great Lakes Water Authority, largely through optimization methods has reduced phosphorus loads from the Detroit River by roughly 400 metric tons per year from the baseline 2008 level. By 2020, Ontario plans to establish a 0.5 mg/l total phosphorus legal effluent limit in Environmental Compliance Approvals for all wastewater treatment plants in the Lake Erie basin over 1 million gallons per day (3.78 million litres per day).

Strategy #3: Support Watershed Based Planning and Restoration Efforts

Implementation of actions to reduce phosphorus loading to the Lake occurs at multiple scales. Local watershed planning is the building block for these efforts and has cumulative impacts on the Lake.

Watershed management plans are being developed to protect and restore water resources within the watershed, including implementing actions that will reduce nutrient loadings to the lake. Jurisdictions are seeking opportunities to enhance or refine local watershed plans to meet the phosphorus reduction goals for the Lake. Watershed managers are seeking opportunities to leverage funding, utilize non-traditional funding sources, and consider innovative approaches to maximize phosphorus reductions.

Using local watershed plans (where available) as the starting point, implementation efforts are prioritized to critical sources and areas with a high risk of phosphorus loss. Implementation and monitoring is coordinated within these priority areas so that water quality improvements can be demonstrated.

Key actions under this strategy include:

- Develop or refine local watershed plans to meet the phosphorus reduction goals for the lake.
- Target watershed restoration efforts to areas most prone to phosphorus losses, including reducing legacy phosphorus in soils and sediments.
- Restore natural hydrology and ecological buffers to intercept nutrient runoff.

Strategy #4: Coordinate Science, Research and Monitoring

It is important that scientists from across the basin collaborate to assess conditions, identify science gaps and identify the research needed to fill those gaps. A top binational priority is to conduct the necessary research, monitoring and modeling to assess the effectiveness of phosphorus reduction actions on improving algae and hypoxia conditions in Lake Erie, and to track progress towards the

achievement of the phosphorus reduction targets and Lake Ecosystem Objectives. Furthermore, research and monitoring of nuisance benthic algae (*Cladophora*) must be coordinated to support the development of phosphorus reduction targets in eastern Lake Erie.

Key actions under this strategy include:

- Enhance in-lake monitoring of algae and hypoxic conditions and conduct research on the factors contributing to these conditions.
- Improve monitoring of phosphorus loads in tributaries and watersheds.
- Invest in research and demonstration initiatives to improve knowledge and understanding of the effectiveness of BMPs, particularly BMPs to control soluble reactive phosphorus.
- Conduct research on factors driving toxicity in harmful algal blooms, including the role of nitrogen.
- Apply ecosystem models to improve our ability to predict future ecosystem conditions.

Strategy #5: Enhance Communication and Outreach

Successful implementation of domestic action plans requires broad support, coordination, and collaboration among agencies, academia, local government, Indigenous communities, private industry, and citizens. All source and sector groups have a role to play in contributing to our success.

Key actions under this strategy include:

- Engage stakeholders on local and regional scales to increase the understanding of water quality condition and management challenges, nearshore and beach health, and best management practices and policies.

4

Tracking and communicating progress towards the targets

The U.S. and Canada are working together to develop an adaptive management framework for tracking the progress towards the achievement of targets and LEOs.

4.1 Adaptive Management

The ongoing management of phosphorus loadings to Lake Erie and the actions required to control them requires a robust science program. Through the GLWQA, the U.S. and Canada (in cooperation with others) have committed to undertake the necessary research, monitoring and modeling required to establish, report on and assess phosphorus load reduction targets and allocations (apportioned by country) for the management of phosphorus and other nutrients and to improve the understanding of relevant issues associated with nutrients and excessive algal blooms in the Lake.

Canada and the U.S. are committed to developing and implementing a binational adaptive management approach that will identify the science needed to track progress in terms of achieving the phosphorus reduction targets; reducing harmful and nuisance algal blooms; and reducing the extent of hypoxia in Lake Erie. Progress will

be evaluated systematically and on a periodic basis. Recommendations to adjust phosphorus management strategies or targets will be developed if necessary. As part of this process, emerging issues and stressors will be evaluated to ensure the targets and management actions are relevant and effective in reducing eutrophication issues in Lake Erie.

Tracking and reporting seasonal and annual phosphorus loads is critical for assessing progress. Initial efforts have been focused on two immediate priorities:

1. Developing a coordinated monitoring strategy and network for collecting compatible tributary data to evaluate progress towards meeting the phosphorus targets; and
2. Developing a system to routinely and reliably track and report loads.

Each jurisdiction is committed to developing suites of performance measures to track progress on the implementation of their individual domestic action plans. As part of the adaptive management process, these actions will be regularly reviewed. In addition, each domestic action plan will be revised as necessary (at a minimum of every 5 years starting in 2023).

4.2 Reporting

Canada and the U.S. are committed to report on progress every three years through the Progress Report of the Parties. Each report will contain an assessment of the Lake Ecosystem Objectives, progress on implementation of the domestic action plans and the achievement in phosphorus loadings targets and loading allocations by country. In addition, the GLWQA Nutrients Annex Subcommittee will report on progress via binational webinars and the Lake Erie Lakewide Action and Management

Plan reports. In addition, individual jurisdictions may report their progress towards achieving targets through various means such as updates on agency websites, and the ErieStat pilot program (www.eriestat.org). The table below presents a summary of public reporting where information on algal blooms, hypoxia, and phosphorus loadings can be found. For the latest information, visit <https://binational.net/>.

TABLE 3: Lake Erie Nutrients – Summary of Public Reporting

Annual or seasonal	Lake Erie Lakewide Management Annual Report
	Great Lakes Executive Committee semi-annual meetings
	Nutrients Annex Annual Webinar
	ErieStat
	Factsheets and other watershed or jurisdiction-specific reports
	NOAA's Harmful Algal Bloom Forecast
Every 3 years	Great Lakes Public Forum
	Progress Report of the Parties
	State of Great Lakes Indicators Report
Every 5 Years	Domestic Action Plan Updates
	Canada/US Binational Nutrient Strategy
	Lake Erie Lakewide Action and Management Plan

4.3 Expected Outcomes

In summary, the targets would achieve the following outcomes for Lake Erie:

- **A 40% reduction in spring loads (TP and SRP) from the Maumee River** – This target will significantly reduce the risk of harmful algal blooms in the western basin by limiting cyanobacteria biomass to “mild” levels (for example, similar to the levels observed in 2012), in most years. Blooms may still occur, but will be drastically reduced in spatial extent and biomass density. Significant blooms may still occur occasionally in extremely wet years.
- **A 40% reduction in spring phosphorus loads for the nearshore priority tributaries** – This target would limit cyanobacterial growth in nearshore areas (see map/list).
- **Reducing the annual total phosphorus (TP) load to the central basin to 6,000 MT** – This target would raise the average summer hypolimnetic dissolved oxygen concentration to 2.0 mg/L or higher. This is the threshold for hypoxia and should result in improvements to the central basin bottom habitat by reducing the release of previously sequestered phosphorus from anoxic bottom sediments.

In addition, the reductions needed to address harmful algal blooms and hypoxia in the western and central basins are expected to lower the open lake phosphorus concentrations in the eastern basin, helping to address *Cladophora* issues there.

It is difficult to predict when the expected outcomes in the Lake will be achieved. The short residence time (2.7 years) and the fact that algal blooms in Lake Erie dissipated in response to phosphorus reductions in the 1980s, indicates that the lake should respond quickly to phosphorus reductions, once implemented. The drought conditions of 2012, which were associated with a small bloom, provided a ‘natural experiment’, which showed that the lake could respond very quickly to reductions in tributary phosphorus loads. However, given the magnitude of the problem and inherent challenges in controlling non-point source runoff and accounting for impacts of climate change, invasive dreissenid mussels, and sediment-bound legacy phosphorus, there will likely be a significant period of time before the benefits of our implementation efforts are measurable at a regional scale.

4.4 Conclusion

Significant actions are needed to reduce nutrient loads from agriculture, urban, suburban, and rural non-farm areas of the Lake Erie watershed. All partners need to work together to seek long term solutions for phosphorus control that are impactful and cost effective. Partnerships with the agricultural and municipal sectors, watershed and non-government organizations, Indigenous communities and the general public are essential to achieving the goals of this Strategy. Governments cannot do this alone – addressing the issue in its myriad of forms will require sustained action, by many partners, on both sides of the border.

Glossary

Adaptive management	An iterative process through which management objectives, approaches and policies can be adjusted over time for continuous improvement based on monitoring, performance measures, and evolving science and information.
Anoxia	An area with complete absence of oxygen.
Bioavailable	Readily assimilated by plants and algae and used for growth.
Biomass	The total mass of organisms in a given area or volume.
Best/beneficial management practices	Proven, practical and affordable approaches to conserving or protecting soil, water and other natural resources in urban and rural areas.
Cladophora	An attached algae species that can cause dense mats in standing water, clogging intake pipes as well as fouling shorelines and fishing equipment. <i>Cladophora</i> is the primary cause of nuisance algal blooms in Lake Erie's eastern basin.
Concentration	The mass of a substance present in a given volume of water expressed in units such as milligrams per litre.
Cyanobacteria	Also called blue-green algae, a type of bacteria that undergoes photosynthesis and thus can be influenced by excessive phosphorus concentrations. An example is <i>Microcystis</i> . Cyanobacteria can produce toxic substances — called cyanotoxins — with the potential to harm humans and other organisms.
Cyanotoxins	Toxic biological compounds produced by cyanobacteria such as <i>Microcystis</i> , which produce the toxin microcystin. Cyanotoxins have potentially significant human health consequences if ingested or through skin exposure and may also be toxic to other organisms.
Dissolved phosphorus	See soluble reactive phosphorus.
Dreissenid mussels	A collective term used for zebra and quagga mussels, which are non-native, invasive species in the Great Lakes basin.
Effluent	Discharge from municipal or industrial wastewater treatment plants following treatment.
Epilimnion	The oxygen-rich upper layer of water in a stratified lake; see stratification.
Eutrophication	Excess nutrient enrichment causing nuisance and harmful algal blooms that in turn can cause low dissolved oxygen levels and associated fish kills.
Green infrastructure	Natural and human-made elements that provide ecological and hydrological functions and processes. Green infrastructure can include components such as natural heritage features and systems, parklands, stormwater management systems, street trees, urban forests, natural channels, engineered wetlands, bioswales, permeable surfaces and green roofs.

Harmful algal blooms	See cyanobacteria.
Huron-Erie corridor	The flows from Lake Huron through the St. Clair River, Lake St. Clair and the Detroit River. Flows from the Huron-Erie corridor discharge into Lake Erie's western basin.
Hypolimnion	The bottom layer of water in a stratified lake. In the summer, the hypolimnion is colder than surface waters. In the winter, surface waters are frozen or close to freezing, while the hypolimnion is somewhat warmer — typically a few degrees above freezing. The hypolimnion can experience low levels of dissolved oxygen under certain conditions; see stratification.
Hypoxia	An area with low levels of oxygen. Late summer hypoxia — the reduction of oxygen to less than two parts per million — occurs naturally in Lake Erie's central basin due to the stratification of layers by temperature, with the warmer layers on top.
Lakewide Action and Management Plan	Established under the Canada–U.S. <i>Great Lakes Water Quality Agreement</i> , 2012, these are lake-specific binational action plans for restoring and protecting Great Lakes ecosystems.
Load	The total mass of a substance delivered to a water body over time expressed in units of mass per unit time, such as tonnes per year. Load is the product of concentration (mass per unit volume) and flow rate (water volume per unit time).
Mesotrophic	Body of water with a moderate level of biological productivity and moderate concentrations of phosphorus and/or other nutrients.
Microcystis	A genus of cyanobacteria, known to produce the toxin microcystin.
Microcystin	Toxins produced by cyanobacteria.
Non-point source	Sources of pollution that are many and diffuse, in contrast to point source pollution, which results from a single source. Non-point source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrological modification where tracing the pollution back to a single source is difficult.
Nuisance algal blooms	Blooms of algae such as <i>Cladophora</i> that can cause fish kills (see eutrophication), degrade fish and wildlife habitat, clog water intake pipes, and foul shorelines and fishing equipment but which do not produce toxins.
Nutrient cycling	The natural movement and transformation of nutrients such as phosphorus through soil, water and air, and in different chemical forms.
Oligotrophic	A body of water with a low level of biological productivity and low levels of phosphorus and/or other nutrients.
Point source	Sources of pollution that enter a water body through a pipe or similar outlet, such as a municipal or industrial wastewater treatment plant discharge. Point sources have usually undergone some level of treatment before discharge; an exception is most combined sewer overflows.

Riparian zone	The area of land adjacent to tributaries and the lake where vegetation may be influenced by flooding or elevated water tables. A healthy riparian zone provides habitat for a variety of aquatic and terrestrial species. Its complex vegetative structure protects against erosion and can control the runoff of sediment, phosphorus and other pollutants, reducing impacts on water quality under certain conditions.
Runoff	The flow of water that occurs when excess stormwater, meltwater or other sources flow over the Earth's surface. This might occur because soil is saturated to full capacity, rain arrives more quickly than soil can absorb it or impervious areas send their runoff to surrounding soil that cannot absorb all of it. Surface runoff is a major component of the water cycle and the primary agent in soil erosion by water.
Soluble reactive phosphorus	Phosphorus in dissolved form. The term "reactive" refers to the reaction of phosphorus with a colour agent during the analysis of phosphate concentrations in a laboratory.
Stormwater	Water that originates during precipitation events and snow or ice melt. Stormwater can soak into the soil, be held on the surface and evaporate, or run off and end up in nearby streams, rivers and other water bodies.
Total phosphorus	The combined total of dissolved and particulate phosphorus in a body of water.
Wetlands	Lands that are seasonally or permanently covered by shallow water, as well as lands where the water table is close to or at the surface. In either case, the presence of abundant water has caused the formation of hydric soils and has favoured the dominance of either hydrophytic plants or water-tolerant plants. The four major types of wetlands are swamps, marshes, bogs and fens.

