Lake Erie Ecosystem Priority I Scientific Findings and Policy Recommendations to Reduce Nutrient Loadings and Harmful Algal Blooms

Draft Summary Report
August 2013

INTERNATIONAL JOINT COMMISSION

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Foreword

The problem of excess nutrients in Lake Erie and resulting algal blooms has vexed scientists and the public for more than a half century. Stirred by public concern, governments responded with vigor to the problem in the 1960s and 1970s, resulting in measurable reductions in phosphorous inputs and a steep reduction in algal blooms. The rapid recovery of Lake Erie became a globally known success story.

Lake Erie is once again severely threatened. It is the shallowest of the Great Lakes, the warmest and the most susceptible to eutrophication and the effects of climate change. The recent accelerating decline of this lake, manifest as impaired water quality, massive, summer-long algal blooms, hypoxia and fish kills, has focused attention on the need for rapid actions to reduce external inputs of total phosphorous and the rising proportion of dissolved phosphorous seen as the primary cause of this decline.

The return of severe Lake Erie algal blooms in the 2000s has again galvanized public concern and a governmental response. The worst algal bloom occurred in 2011, prompting the Commission to prioritize binational investigation into the science and opportunities for action by governments to reduce algal bloom causing pollution.

In carrying out its Lake Erie Ecosystem Priority (LEEP), the Commission recognizes the commitment of the U.S. and Canadian governments to restoring the lake's health. The U.S. Great Lakes Restoration Initiative is providing substantial funding to Lake Erie Basin restoration. The Canadian Great Lakes Nutrient Initiative is also contributing substantially to understanding the sources of excess nutrients and measures to reduce them. However, the Commission believes more needs to be done.

The Commission offers its analysis and recommendations in a spirit of cooperation, recognizing that today's challenges to Lake Erie's health are formidable and require the leadership and guidance of the U.S. and Canadian governments and collaboration by all sectors of society to again make the recovery of Lake Erie a globally known success story.

Acknowledgements

The International Joint Commission sincerely appreciates the contributions of dozens of researchers in Canada and the United States to this draft report. In particular, thanks go to the Great Lakes Science Advisory Board's Taking Action on Lake Erie (TAcLE) work group, the authors of science papers that served as the underpinning of this report, and the researchers who attended the Lake Erie Ecosystem Priority Science Synthesis Workshop in February 2013 (see Appendix A) and the workshop's moderator, G. Tracy Mehan. The scientific work that was presented and the lively debate and discussion that followed assured that this draft report reflected a diversity of views from a variety of disciplines.

We thank the following TAcLE members: Sue Watson, David Carpenter, John Casselman, Carol Miller, Mike Murray, George Arhonditsis, Nate Bosch, Greg Boyer, Murray Charlton, Remegio Confesor Jr, Dave Depew, Dave Dolan, Joe DePinto, Scott Higgins, Tomas Hook, Todd Howell, Stu Ludsin, Shawn P. McElmurry, Chitra Gowda, Peter Richards, Don Scavia, Ralph Smith, Morgan Steffen, Steve Wilhelm, and Weitao Zhang.

For their contributions to this draft report and for all the advice they provide to the Commission, we are grateful to the members of the Great Lakes Science Advisory Board (co-chaired by Bill Bowerman and Bill Taylor), the Great Lakes Water Quality Board (co-chaired by Susan Hedman and Michael Goffin) and the Council of Great Lakes Research Managers (co-chaired by Norm Granneman and John Lawrence). We note, however, that the findings and recommendations in this report are solely the responsibility of the Commission.

The Commission also acknowledges and thanks members of the public who attended and made comments on Lake Erie's problems and potential solutions at LEEP outreach meetings in 2012 and the many interested organizations who provided initial thoughts on the scope and direction of the Commission's LEEP work. The Commission welcomes and invites public input on this draft report.

Finally, the Commission would like to highlight the contributions of co-op students Rachael Schulhauser, Natalie Ognibene, Melanie Goodfellow, Caitlin Drouillard, Vanessa Fiorido, and Cole Dortmans.

The authors of this report were Raj Bejankiwar, Glenn Benoy, Matthew Child, Dave Dempsey and John Nevin. Vic Serveiss of IJC staff reviewed a previous draft of this report.

We dedicate this draft report to the memory of Dave Dolan, with thanks for a lifetime of work improving our understanding of the Great Lakes. Dave contributed significantly to the TAcLE Workgroup.

Executive Summary

In 2011, Lake Erie experienced its largest algal bloom in history. In 2012, the International Joint Commission (Commission) established the Lake Erie Ecosystem Priority (LEEP) in response to a growing challenge: lake-wide changes in Lake Erie related to problems of phosphorous enrichment from both rural and urban sources, compounded by the influence of climate change and aquatic invasive species. These changes have resulted in impaired water quality, with impacts on ecosystem health, drinking water supplies, fisheries, recreation and tourism, and property values. This **Summary Report** presents the Commission's key findings and recommendations from the LEEP study.

The Commission is an independent binational organization created by Canada and the United States under the *Boundary Waters Treaty of 1909*. Under the Treaty, the two countries cooperate to prevent and resolve disputes relating to the use and quality of the many lakes and rivers along their shared border. The *Great Lakes Water Quality Agreement* (the Agreement) assigns the Commission a role in assessing progress, engaging the public and providing scientific advice to help the two countries restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes.

Background

The smallest (as measured by volume), shallowest and, with 11.6 million people living in its basin, the most densely populated of the five Great Lakes, Lake Erie has long experienced changes as a result of human activities and natural forces. With a watershed dotted by big cities, with sprawling farmland and little forest cover, Lake Erie is severely threatened by human activities.

Loadings of nutrients, particularly phosphorous from municipal sewage treatment plants and other anthropogenic sources, visibly degraded Lake Erie in the decades leading up to the 1970s. This excessive nutrient enrichment, known as eutrophication, resulted in severe algal fouling of the lake, which in turn created severe aesthetic, taste and odour problems, reduced available oxygen and led to fish die-offs. Eutrophication was particularly evident in Lake Erie and also appeared in other locations in the Great Lakes, including Saginaw Bay (Michigan) and Green Bay (Wisconsin). Great Lakes eutrophication prompted the governments of Canada and the United States to sign the Agreement in 1972, establishing a binational commitment to reduce nutrient loadings and clean up the lakes.

Following the signing, governments on both sides of the international border made significant investments to upgrade and expand municipal sewage treatment plants. In addition, governments took action to reduce phosphorous concentrations in household detergents. By the mid-1980s, Lake Erie phosphorous loadings were reduced by more than half from 1970s levels, and many of the problems associated with eutrophication were reduced or eliminated, confirming that reducing phosphorous loadings led to improved water quality. Lake Erie's recovery was a globally recognized success story.

However, by the early 2000s, problems with excess nutrient enrichment appeared again in Lake Erie, and have since continued to worsen. In recent years, the problem of harmful and nuisance algal blooms has become widespread. In 2011, heavy spring rains flushed a large amount of phosphorous into western Lake Erie. This was soon followed by warm temperatures, creating a mass of algae that extended more than 5,000 km^2 (about 1,930 mi^2), three times larger than the next largest bloom previously recorded.

Although eutrophication is again a serious threat to Lake Erie water quality, the sources and remedies are different from those of the 1960s and 1970s. While sewage plants still contribute some phosphorous to Lake Erie, diffuse runoff from rural and urban lands is a leading factor in eutrophication. Of particular concern is runoff of dissolved reactive phosphorous (DRP), which is highly bioavailable and thus a primary cause of renewed algae blooms. Addressing runoff requires strategies tailored to particular land uses, rather than controls on sewage plants alone.

The LEEP Study

The core objective of LEEP is to provide advice to federal, state, provincial and local governments to develop policy and implement management approaches to help restore the health of the lake's ecosystem by reducing nutrient loads and resulting algal blooms.

To reach this objective, the Commission established study teams of independent experts, who have spent much of the last year developing a better scientific understanding of the causes and controls of phosphorous loading into Lake Erie. The LEEP work plan addressed *science*, *socio-economic* and *regulatory* themes as part of a comprehensive approach. Each theme was addressed by a series of binational working groups led by various Commission advisory boards and councils or by Commission staff.

Early and frequent engagement of the public, public officials and scientists is integral to the LEEP project. The Commission hosted roundtables and public meetings in communities in the Lake Erie basin in both Canada and the United States in 2012 to gather public thoughts on the initial direction of the study. In addition, this draft summary report is now available for public review and comment. The Commission will consider all comments, revise the report, and deliver a final report to the United States and Canadian governments.

Phosphorous Loading to Lake Erie

Phosphorous is the key nutrient limiting the amount of phytoplankton and attached algae in Lake Erie. The primary sources of phosphorous loadings to Lake Erie in the decades leading up to the 1972 Agreement were municipal sewage plants. Today, however, external phosphorous loads occur largely as runoff from diffuse land uses such as fertilized farm fields, lawns and impervious surfaces including streets and parking lots.

Of the 2011 loadings, it is estimated that more than one-half came from tributaries into Lake Erie that are monitored, for example, larger agricultural areas and rural communities. Unmonitored areas, typically coastal communities and smaller agricultural areas adjacent to shorelines, and direct point sources were estimated to each account for about 16 %, while Lake Huron and atmospheric sources each accounted for between 4-6 % of external loadings.

Agricultural operations are a major source of phosphorous loadings into Lake Erie. These loadings result primarily from fertilizer application and animal wastes. The bulk of this input occurs during spring snowmelt and heavy rainstorms, when significant amounts of phosphorous can be transported by runoff water.

Phosphorous from urban areas is associated with construction activities, stormwater runoff, combined sewer overflow discharges, lawn and garden activities, leaves from deciduous trees and pet waste. Due to the multitude of land uses within urban watersheds, pinpointing exact amounts of phosphorous loadings from specific urban land uses is often difficult.

The air is another source of phosphorous loading. Atmospheric deposition to lakes is difficult to quantify and measure but represented six % of the total external load in 2011. Phosphorous can find its way from the airshed into lake ecosystems through inputs to the watershed from rain or snowfall and by wind-transported particles.

Data-driven models show "hot spot" sources exist in sub-basins within the major watersheds and contribute a disproportionate share of the total amount of dissolved reactive phosphorous (DRP, the portion of total phosphorous that is readily available to support algae growth) entering Lake Erie. The single biggest load of bioavailable phosphorous to Lake Erie is derived from the Maumee River watershed in Ohio.

A Lake Experiencing Profound Changes

Lake Erie continues to experience serious changes as a result of phosphorous loading, compounded by the growing influence of climate change. Precipitation patterns in the Lake Erie basin under climate change are characterized by less frequent, but more intense, storms. Such intense events lead to high nutrient runoff from agricultural and urban lands, and increased overall nutrient loads to Lake Erie. Depending on the timing of runoff, future nutrient loading, coupled with warmer water temperatures, could lead to increased severity and frequency of algal blooms.

Algal Blooms

Some species of algae and cyanobacteria ('blue-green algae') in Lake Erie can constitute harmful and nuisance algal blooms. Free-floating mats of cyanobacteria *Microcystis* and *Anabaena* predominate in the lake's western basin and have the potential to produce toxins that pose a significant risk to fish, wildlife and human health. Some areas of the western basin are also affected by dense bottom mats of *Lyngbya*, which is a non-toxic but odourous cyanobacteria that has been reported in the Maumee Basin and other areas. In the eastern basin, large shoreline blooms of the attached filamentous green algae *Cladophora* foul recreational beaches, clog municipal and industrial water intakes, impair water quality and pose potential microbial health risks to wildlife and humans.

Hypoxia

Hypoxia refers to a condition where the dissolved oxygen content of water is reduced to zero or very low levels. This can occur during the summer months in deeper lake basins such as the central basin of Lake Erie, where the water column stratifies in layers and the warmer oxygenated waters at the surface are separated from the colder, denser bottom water. High external nutrient inputs stimulate the production of excessive organic material (algae and other organisms) in the sunlit surface layers, and the subsequent decay of this material in the bottom waters rapidly depletes the supply of oxygen, creating "dead zones," where dissolved oxygen levels are so low that fish and other aquatic life cannot survive. Hypoxic conditions also lead to the release of phosphorous from sediments, known as 'internal loading', which may also contribute to the development of algal blooms.

Climate change could exacerbate the magnitude, duration and frequency of hypoxia in Lake Erie. Warmer future conditions are expected to facilitate an earlier and longer period of stratification (or layering) during summer, causing algal growth and hypoxic conditions to begin sooner and persist over an extended time period.

Fish

Lake Erie fisheries have important ecological, recreational and commercial value. Each species of fish has preferred food choices and temperature ranges, and all fish depend upon adequate dissolved oxygen.

The decomposition process of algal blooms can significantly reduce dissolved oxygen supplies, undermining native fish populations. When algae die, the decomposition process uses much of the dissolved oxygen in the bottom waters. A changing climate – warmer temperatures, less ice cover and increased frequency of intense precipitation events – will enhance these algal blooms, reduce water clarity and exacerbate future hypoxia.

Over the longer term, phosphorous loading together with future climatic conditions could alter Lake Erie's rich and diverse fish community. Cold-water species and species sensitive to low oxygen and reduced water clarity would be expected to decline, while species more tolerant to warm water likely will thrive.

Socio-Economic Conditions

Limited data constrains efforts to estimate the economic effects of Lake Erie algal blooms throughout the entire lake basin. Using Ohio data as a proxy for the broader Lake Erie basin, the LEEP study identified important economic costs associated with effects on human health, regional tourism, property values, beach tourism and recreational fishing.

Regulation and Policy

The Commission reviewed nutrient management statutes and programs among all eight Great Lakes states, Ontario and Quebec, formulating recommendations in part from the most effective initiatives found.

Improving the Health of Lake Erie: Opportunities for Action

Best Management Practices[1]: Controlling Phosphorous From Fields and Streets

The LEEP study involved a comprehensive review of more than 240 sources of information on the implementation and effectiveness of *best management practices* (BMPs) that could be considered for implementation within the Lake Erie basin to reduce phosphorous loads.

The control of phosphorous in agricultural operations needs to be directed towards changes in agricultural practices that have been implemented in recent decades. The goal is to increase the efficiency of phosphorous use at the farm scale. One promising approach involves improvements in the management of soil, manure, and mineral fertilizer and agricultural and conservation practices that balance inputs and outputs of phosphorous within watersheds across the Lake Erie basin. However, the effectiveness of BMPs in agricultural operations can be confounded by extreme weather events.

There are many diffuse sources of phosphorous within urban areas. Therefore, BMPs will need to be highly varied and targeted for implementation in a wide range of urban activities.

New Loading Targets

The LEEP study developed response curves to predict levels of algal blooms and hypoxia as a function of phosphorous loading. These load-response curves should, in turn, be used to establish new loading targets, as part of a comprehensive management plan to address these issues in Lake Erie.

The LEEP study concluded that to reduce algal blooms and areas of hypoxia significantly would require substantial reductions in phosphorous loads below current levels, and that the focus should be on reducing dissolved reactive phosphorous (DRP) loads. Furthermore, in setting future targets, it will be important to recognize that harmful algal blooms and hypoxia targets likely will require separate considerations – solving one problem will not necessarily solve the other. Greater DRP reductions will be needed to solve the hypoxia problem.

Knowledge Gaps

Accurate monitoring of phosphorous loadings, identifying the most important sources, allows for effective priority-setting of actions to restore the health of Lake Erie. The LEEP study identified gaps with respect to monitoring of phosphorous loading and its effects. These include an uneven

[1] In Canada, Best Management Practices are typically referred to as Beneficial Management Practices; they will be referred to as BMPs throughout this report.

distribution of tributary monitoring across the Lake Erie basin, very patchy monitoring of the lake's nearshore zone, and a bias towards routine monitoring programs that may miss critical wet weather events – an issue of increasing importance under climate change.

Knowledge gaps with respect to research include how different physical, chemical, and biological factors interact to create the conditions that can trigger harmful and nuisance algal blooms, how different fish communities of the lake may respond under the warming trends and altered precipitation patterns associated with continued climate change, how much various BMPs actually reduce phosphorous loading and how much they cost. In addition, there is a timely need for economic data that would allow for a better understanding of the economic impacts of algal blooms across the Lake Erie basin.

Commission Recommendations

The Commission believes that current knowledge is sufficient to justify immediate additional effort to reduce external loading of nutrients to Lake Erie. Phosphorous, especially the bioavailable dissolved reactive fraction, is a primary concern. Efforts must deal with both agriculture and urban sources. The highest priority for remedial action should be the Maumee River watershed.

Based on the LEEP study's analysis and key findings, the Commission recommends:

1. **The following targets should be set for phosphorous loadings:**
   - *To reduce the frequency and severity of harmful algal blooms in the western Lake Erie basin to an acceptable level, the total phosphorous (TP) load target for the Maumee River for the spring (March-June) period is 800 MT, a 37% reduction from the 2007-2012 average. For dissolved reactive phosphorous (DRP), the target for the spring period is 150 MT, a 41% decrease from the 2007-2012 average. Extended over the course of a full year, the TP target is 1600 MT, a 39% decrease from the 2007-2012 average.*

   - *When the rest of the watersheds in the western Lake Erie basin are included, the TP load target for the spring is 1600 MT and the DRP target is 300 MT. Extended over the course of a full year, the TP target is 3200 MT.*

   - *To decrease the central Lake Erie basin hypoxic area by 50% to about 2000 km^2 and 10 hypoxic days a year, the target TP load for the western basin and central basin is 4300 MT, a 46% reduction from the 2003-2011 observed average load and 56% below the current target.*

   - *When expressed as annual DRP load, the target for achieving the same hypoxic area (2000 km^2) and number of hypoxic days (10) in the central Lake Erie basin is 550 MT. This new level represents a 78% reduction from the 2005-2011 average DRP load.*

2. **To help attain these targets, the governments of Michigan, Ohio and Ontario, supported by U.S. EPA and Environment Canada, should develop a phosphorous cleanup plan for the western and central basins of Lake Erie, using a framework analogous to the U.S. Clean Water Act Total Maximum Daily Load (TMDL) process. Such a plan will take into account all significant phosphorous sources, and allocate reductions of total phosphorous and DRP according to relative loadings.**

3. **Existing and planned incentive-based programs should immediately shift to a preference for BMPs that are most likely to reduce DRP by reducing the amount of phosphorous applied to fields, slowing the movement of water to the field drainage system, and detaining flows at field drainage outlets.**

4. **Future management efforts should focus on reducing the load delivered during the spring period (March 1 to June 30) and be focused primarily on those subwatersheds that are delivering the most phosphorous into the lake.**

5. **Federal, state and provincial governments should accelerate outreach/extension programs and phase in mandatory certification standards for agrology advisors, retailers and applicators to ensure fertilizer is applied in a manner most likely to prevent nutrient runoff.**

6. **Federal, state and provincial governments and local agencies should increase the level of funding support to 'scale up' agricultural BMP programs, in a manner which considers the other related recommendations in this report.**

7. **The U.S. and Canadian governments should strengthen and increase the use of regulatory mechanisms of conservation farm planning, with nutrient management as a primary emphasis, in balance with the economic viability of the sector.**

8. **U.S. and Canadian federal policy should link the cost and availability of crop insurance purchases or premiums to farm conservation planning and implementation of nutrient management practices.**

9. **All jurisdictions in the Lake Erie basin should ban the application of manure and biosolids from agricultural operations on frozen ground or ground covered by snow.**

10. **The Commission recommends that state, provincial and federal governments work with municipalities to accelerate the promotion and use of "green infrastructure" – green roofs, green walls, filter strips, engineered wetlands, pervious pavement and other measures – in urban stormwater management in the Lake Erie basin. These governments should provide funding and technical support to municipalities and, where feasible and appropriate as an alternative to more expensive stormwater controls, authorize green infrastructure in U.S. municipal water discharge permits and Ontario environmental compliance approvals, and encourage the adoption of local ordinances promoting green infrastructure.**

11. **All jurisdictions in the Great Lakes basin should prohibit the use of phosphorous fertilizers for lawn care with strictly limited exceptions.**

12. **The Lake Erie Basin states should require monitoring of phosphorous in effluent by all major discharging facilities in the lake's watershed.**

13. **Governments should commit sustained funding to enhancing and maintaining monitoring networks for:**

    - *tributaries throughout the Lake Erie basin, including key sub-basins;*
    - *establishment of a water quality monitoring system at the outlet of the Detroit River that measures critical nutrient parameters;*
    - *monitoring during wet weather events to capture seasonal differences from a wider range basin tributaries;*
    - *urban areas to allow for the evaluation of the effectiveness of BMPs; and,*
    - *lake monitoring both at the open-lake and nearshore levels*.

14. **Governments should support research to strengthen understanding of:**

    - *the dynamics of harmful algal blooms through a "systems biology" approach studying entire bloom communities;*
    - *whether and how open lake disposal of dredged sediments from the Toledo navigational channel affects phosphorous loadings in Lake Erie;*
    - *how various factors, such as the interaction of lake water with land-based runoff and tributary discharges, can be used to predict the conditions associated with nuisance blooms under current and future climate change scenarios;*
    - *how Lake Erie's diverse and productive fish communities could respond under the warming trends and altered precipitation patterns associated with continued climate change;*
    - *the effectiveness of current and emerging BMPs designed to prevent or reduce phosphorous loads to the Lake Erie ecosystem; and,*

- *the economic effects of Lake Erie algal blooms throughout the entire lake basin.*

15. **Governments and organizations involved in environmental monitoring and environmental management in the lake improve data management through greater coordination and sharing through, for example, the development of a common data portal, which links to the relevant distributed data and provides an over-all situation assessment of Lake Erie.**

2011 Algae Bloom, Lake Erie, Western Basin. Source: Peter Essick

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Chapter 1: Introduction to the Lake Erie Ecosystem Priority Report

1.1 Purpose of the Report

This report presents the findings and recommendations of the Lake Erie Ecosystem Priority (LEEP) study, which the International Joint Commission (Commission) undertook in 2012 as part of its three-year priority cycle to provide advice to federal, state/provincial and local governments for developing policy and management approaches to address lake-wide challenges with respect to declining water quality, algal blooms and associated ecosystem, human health and economic impacts.

The Commission is an independent binational organization created by Canada and the United States under the *Boundary Waters Treaty of 1909*. Under the Treaty, the two countries cooperate to prevent and resolve disputes relating to the use and quality of the many lakes and rivers along their shared border. At the request of both governments, under the *Great Lakes Water Quality Agreement*[2] (the Agreement), the Commission also has a role in advising the two countries on restoration and maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes.

Intended Audiences

The LEEP study was prepared for the consideration of the Commission to provide advice to the two federal governments to protect and restore Lake Erie. In addition, the analysis and findings of the report will be of direct interest to a broad audience of agencies, residents, organizations and decision-makers with an interest in water quality and the future of Lake Erie.

The report represents a synthesis of extensive scientific analysis. Readers wanting more detailed information are encouraged to review the original scientific and technical papers prepared as part of the study.[3]

1.2 Background for the Report

The Great Lakes basin, from the headwaters of Lake Superior to the outlet of Lake Ontario, is home to more than 45 million people in Canada and the United States. The five Great Lakes, created 10,000 years ago at the end of the last period of continental glaciation, make up the largest surface freshwater system on Earth. These waters support food crop irrigation, electrical power generation and transportation of raw materials and finished goods. They maintain rich wetlands and fisheries. They provide bountiful sources of drinking water and recreational opportunities for millions of people.

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[2] For more information on the Great Lakes Water Quality Agreement, see: www.binational.net or ijc.org
[3] **LEEP** papers are available at: (add website link)

Yet human use of the lakes has not come without impacts to water quality and ecosystems. As the smallest (measured by volume) and shallowest of the five Great Lakes, Lake Erie has long experienced changes as a result of human activities and natural forces.

In the decades leading up to the 1970s, loadings of nutrients, especially phosphorous from municipal sewage treatment plants and other runoff sources, visibly degraded the lake. This excessive nutrient enrichment – also known as eutrophication – resulted in severe algal fouling of the lakes, which in turn created severe aesthetic, taste and odour problems, and fish die-offs. Although eutrophication was apparent at many locations around the Great Lakes, it was particularly evident in Lake Erie. This eutrophication led the governments of Canada and the United States to sign the Agreement in 1972, establishing a binational commitment to clean up the lakes.

Following the signing of the Agreement, governments on both sides of the border made significant investments to upgrade and expand municipal sewage treatment plants. In addition, governments took action to reduce phosphorous concentrations in household detergents. By the mid-1980s, Lake Erie phosphorous loadings were reduced by more than half from 1970s levels, and many of the problems associated with eutrophication were reduced or eliminated (Lake Erie Nutrient Science Task Group, 2009).

These improvements did not persist. By the early 2000s, problems with nutrient enrichment appeared again, and have since continued to worsen. In recent years, the problem of harmful and nuisance algal blooms[4] has once again become widespread. In 2011, heavy rains in the spring flushed a large amount of phosphorous, including large proportions of DRP from agricultural runoff, into western Lake Erie. Warm temperatures, soon followed, creating a mass of algae that extended more than 5,000 km^2 (about 1,930 mi^2). The 2011 algae bloom was the largest in the lake’s history, three times larger than the next largest bloom previously recorded. Trends in agricultural practices and meteorological conditions, including heavy spring rainfall and warm and quiescent summer weather, contributed to the bloom (Michalak *et al.*, 2013).

The problems of nutrient enrichment in Lake Erie are compounded by the influence of climate change and ecosystem changes caused by aquatic invasive species (Lake Erie Nutrient Science Task Group, 2009). As a result of these influences, Lake Erie has experienced a decline in water quality over the past decade, with impacts on ecosystem health, drinking water supplies, recreation and tourism, and property values.

[4] Excessive and relatively rapid growth of algae on or near the surface of water. Blooms can occur naturally as the result of a change in water temperature and current or as a result of an excess of nutrients in the water.

Great Lakes Water Quality Agreement and the IJC

The Agreement is widely regarded as one of the world's most successful binational environmental agreements. Originally signed by Canada and the United States in 1972, the agreement has been revised four times, with each revision responding to evolving priorities.

- The original 1972 Agreement set general and specific water quality objectives and mandated programs to meet them. It gave priority to point-source pollution from sewage treatment plants and industrial sources, as well as changes to allowable levels of phosphorous in household detergents. Point-source pollution was dramatically reduced and many visible and noxious pollution problems were alleviated, including harmful algal blooms in Lake Erie.
- The1978 version of the Agreement adopted an ecosystem approach (one which considers the interaction of air, land, water and living things, including humans) and called for a broad range of pollution-reduction programs, including virtual elimination of the input of persistent toxic substances.
- The Agreement was amended in 1983 to enhance efforts to reduce phosphorous inputs to the Great Lakes. Scientists from both countries worked together to set the target loads for each lake that would need to be met to achieve the water quality objectives of the Agreement. Detailed plans to reduce phosphorous loading to receiving waters were developed and adopted by each jurisdiction in the basin.
- A 1987 amendment called for programs to restore both the quality of open waters and beneficial water uses in 43 of the most contaminated local areas in the basin. Conditions have improved significantly in a number of these 'Areas of Concern', though only five have been restored and removed from the list.
- The 2012 amendment contains several new Annexes responding to current and emerging challenges, including aquatic invasive species, climate change, habitat and species, and groundwater. It also shifts greater emphasis back to nutrients by requiring the development of specific lake objectives for water quality including nutrients (specifying interim targets), and the development of programs to accomplish those objectives.

The Commission continues to play an important role in implementing the Agreement. In addition to engaging and informing the public, it analyzes information provided by the governments, assesses the effectiveness of programs in both countries, advises the governments on ways to meet the objectives, and reports on progress.

1.3 Establishment of the Lake Erie Ecosystem Priority

In 2012, recognizing the urgency and importance of Lake Erie's faltering health, and the potential cost of further delay, the Commission established the Lake Erie ecosystem as a priority area for binational study and action. The Commission also established a three-year objective for the Lake Erie ecosystem to guide research and future cooperative action:

> *"In three years, we will have measurably reduced dissolved reactive phosphorous loads and algae. We will have a better understanding of causes and controls and an adequate monitoring system in place."* [5]

[5] International Joint Commission Retreat in Montreal, QC, Canada (Winter 2012)

To attain this objective, the Commission has spent much of the last year developing a better scientific understanding of the causes and controls of phosphorous in Lake Erie. This report is the outcome of the initial phase of LEEP.

LEEP is intended to complement several important initiatives to reduce nutrient loadings into the Great Lakes already underway at the federal, state, provincial levels and municipal levels. These initiatives include Environment Canada's Great Lakes Nutrient Initiative, the U.S. Great Lakes Restoration Initiative (coordinated by the United States Environmental Protection Agency), and Ohio's Lake Erie Phosphorous Task Force.

1.4 Study Approach

Key Themes

The LEEP work plan addressed science, socio-economic and regulatory themes as part of a comprehensive approach, with the themes addressed by a series of binational working groups led by the Commission's Science Advisory Board (SAB), Council of Great Lakes Research Managers (CGLRM), and Commission staff

The *science* theme addressed five interrelated questions regarding Lake Erie algae outbreaks:

- current external and internal phosphorous loading;
- effects of climate change on phosphorous loading, algal blooms, wetlands and fish;
- effectiveness of agricultural and urban BMPs;
- phosphorous and harmful algal blooms management models and targets; and
- adequacy of phosphorous monitoring programs within the Lake Erie Basin.

The SAB was tasked with the first four of these issues and convened a science working group to author review papers on each issue, under the framework of *Taking Action on Lake Erie* (TAcLE) by four teams, composed of advisory board members and experts in the field. The TAcLE teams carried out extensive literature reviews, conducted independent analyses and modelling, and prepared papers summarizing their findings and conclusions. The fifth science issue, the adequacy of phosphorous monitoring programs within the Lake Erie basin, was addressed by the Council of Great Lakes Research Managers. Draft science papers were reviewed at an experts' workshop in February 2013, after which the report authors revised the papers and presented them to Commission staff.

Under the *socio-economic* theme, the study commissioned an expert paper on the economic impact of excessive algal blooms and the costs and benefits of solutions.

Finally, under the *regulatory* theme, Commission staff prepared a paper on the legislative and regulatory framework affecting sources of nutrients entering Lake Erie, including policies in place at the United States and Canadian federal levels and in the Great Lakes states and the province of Ontario.

Public Engagement

From the beginning of LEEP, the Commission was committed to engaging the views of the public as well as scientists and public officials. In March 2012, the Commission organized a Lake Erie roundtable, attended by more than 60 people, in Ann Arbor, Michigan. The purpose of the roundtable was to enhance the Commission's understanding of the science and policy implications of remedying Lake Erie's algal outbreaks. Scheduled speakers made presentations, which were followed by open discussion among all participants.

Public Concerns about the Lake Erie Ecosystem

Citizens who attended the series of LEEP public meetings raised a wide range of concerns and questions, covering issues relating to agriculture, health and economics. These included:

- the record 2011 algal bloom and current conditions affecting their properties and use of Lake Erie;
- the sources of phosphorous pollution to Lake Erie, including the Detroit wastewater treatment plant, the Maumee River and thermal discharges from power plants to western Lake Erie;
- the role of farm practices in causing phosphorous pollution, focusing on fertilizer use, manure application and tile drainage;
- the role of nitrogen and aquatic invasive species in creating Lake Erie algal blooms;
- the safety of public drinking water as affected by toxic bacteria;
- cutbacks in government research and monitoring; and,
- suggestions that the Commission and governments consider the economic impacts of the impact of algal blooms.

Representatives of agriculture agencies also attended the meetings to provide an overview of cooperative initiatives to promote voluntary practices by farmers to reduce phosphorous runoff, including changes in fertilizer use and application.

Several attendees commended the Commission for reaching out to the public and requested a second round of public meetings on this draft report.

The Commission also hosted eight LEEP public meetings in communities on both sides of the international boundary. Meetings took place in Leamington, Port Stanley, Dunnville and Windsor, ON, in Monroe and Grosse Pointe Farms, MI, and in Port Clinton and Cleveland, OH. At these sessions, Commission staff explained the LEEP process, provided a presentation on Lake Erie and algal blooms, and invited public perspectives.[6] Approximately 300 citizens attended the meetings, offering insights on sources of excess nutrients, algal blooms, and remedies. The observations offered by lakeside residents, anglers, boaters, and other concerned citizens were important contributions to LEEP's analysis and recommendations.

This draft summary report is now available for public review and comment. The first public review session takes place at the first Great Lakes Triennial Meeting under the revised Agreement, to be held in September 2013 in Milwaukee, WI. Part of Great Lakes Week, this limited version of a Triennial Meeting focuses on LEEP while future Triennial Meetings will highlight the Commission's assessment of the Progress Report of the Parties.

[6] A copy of the IJC presentation offered at these meetings is available at http://ijc.org/boards/leep/files/2012/09/LEEP-Presentation-en.pdf.

Schedule of Public Consultation Meetings Summer 2013		
Date	**Location**	**Address**
Monday September 16	Detroit, MI*	Wayne County Community College 1001 W Fort Street Detroit, MI 48226
Wednesday September 18	Sandusky Area	Erie County Conservation League 815 E. Mason Rd Milan, OH, 44846
Thursday September 19	Toledo Area	Maumee Bay Lodge 1750 State Park Road #2 Oregon, OH, 43616
Tuesday September 24	Walpole Island First Nation, ON	Cultural Community Centre 2185 River Road Wallaceburg, ON, N8A 4K9
Wednesday September 25	Port Stanley, ON	Port Stanley Arena 332 Carlow Road, N5L 1B6
Thursday September 26	Leamington, ON	Seacliff Inn 388 Erie Street South, N8H 3E5
Wednesday October 2	Cleveland, OH	Rocky River Nature Center 24000 Valley Pkwy, North Olmsted, OH, 44070
Each open house will have a poster display session from 6:00-7:00pm followed by a time for public comment from 7:00-9:00pm. Detroit's open house will have the poster display from 6:00-6:30pm with the public comment time from 6:30-8:30pm.		

1.5 Organization of the Report

The balance of this summary report is organized into the following three chapters:

Chapter 2 summarizes the effects of phosphorous loading, compounded by the influence of climate change and aquatic invasive species, on the Lake Erie ecosystem, human health and socio-economic conditions.

Chapter 3 reviews existing and possible initiatives to address the impacts on the Lake Erie ecosystem from phosphorous loading. It discusses modelling efforts to identify new phosphorous loading targets that could be established to reduce the loadings into Lake Erie, and identifies BMPs to reduce phosphorous runoff from agricultural operations and urban development. It also identifies important gaps in monitoring and research.

Chapter 4 presents a summary of the study's recommendations for addressing the challenges facing Lake Erie.
An **Annex** provides: acknowledgements/list of contributors; a list of references, by chapter; a list of common acronyms used in the report; a glossary; and a conversion table for comparing metric and U.S. customary units.

2011 Algae Bloom, Lake Erie, Western Basin. Source: MERIS/NASA

Chapter 2: Understanding the Changing Lake Erie Ecosystem

2.1 Introduction

As outlined in Chapter 1, the science component of the Lake Erie Ecosystem Priority (LEEP) focused on improving understanding of how phosphorous loadings are affecting water quality in Lake Erie. The socio-economic and regulatory components of the study, meanwhile, considered the economic impacts and regulatory implications of these changes.

Chapter 2 presents the results of these efforts to better understand why and how Lake Erie is changing. The chapter:

- provides a brief overview of the physical and socio-economic setting of Lake Erie;
- describes trends in phosphorous loading to the lake, as well as the contributions from various sources; and,
- describes the effects of phosphorous loading, compounded by the influence of climate change and aquatic invasive species, on water quality in Lake Erie and on human health and socio-economic conditions in the basin.

2.2 Overview of the Lake Erie Ecosystem

Lake Erie is the smallest[7] and shallowest of all the Great Lakes, with a total surface area of 25,700 km^2 (about 9,900 mi^2) and an average depth of only 19 m (62 ft) (LaMP, 2012; GLIN). The lake is naturally divided into three distinct basins with different average depths: the western basin (7.4 m or 24.1 ft); the central basin (18.5 m or 60.1 ft); and, the eastern basin (24.4 m or 79.3 ft) (GLFC, 2003; Lake Erie LaMP, 2011). As a result, the lake waters warm rapidly in the spring and summer, and can freeze over in winter.

About 80 % of Lake Erie's total inflow comes from the Detroit River, which conveys flows from the upper lakes of Superior, Michigan and Huron into the lake's shallow western basin. About 11 % of the inflow is from rain and snow, and the balance comes from tributaries, the largest of which is the Maumee River (LaMP, 2011). Other major tributaries are the Sandusky, Cuyahoga, Grand, Raisin and Huron rivers. The lake drains into Lake Ontario via the Niagara River.

Lake Erie's shoreline of 1,402 km (871 mi) and land basin of 58,800 km^2 (about 22,700 mi^2) include parts of Indiana, Michigan, Ohio, Pennsylvania, New York and Ontario (CCGLHHD, 1977) (Figure 2-1). The Lake Erie basin is the most densely populated of the five Great Lake basins, with 17 metropolitan areas with populations over 50,000 and a total population of 11.6 million (Lake Erie LaMP 2011).

Key Lake Erie stakeholders include: domestic, municipal and industrial water users; commercial navigation; coastal zone residents and commercial interests; agricultural interests; recreational

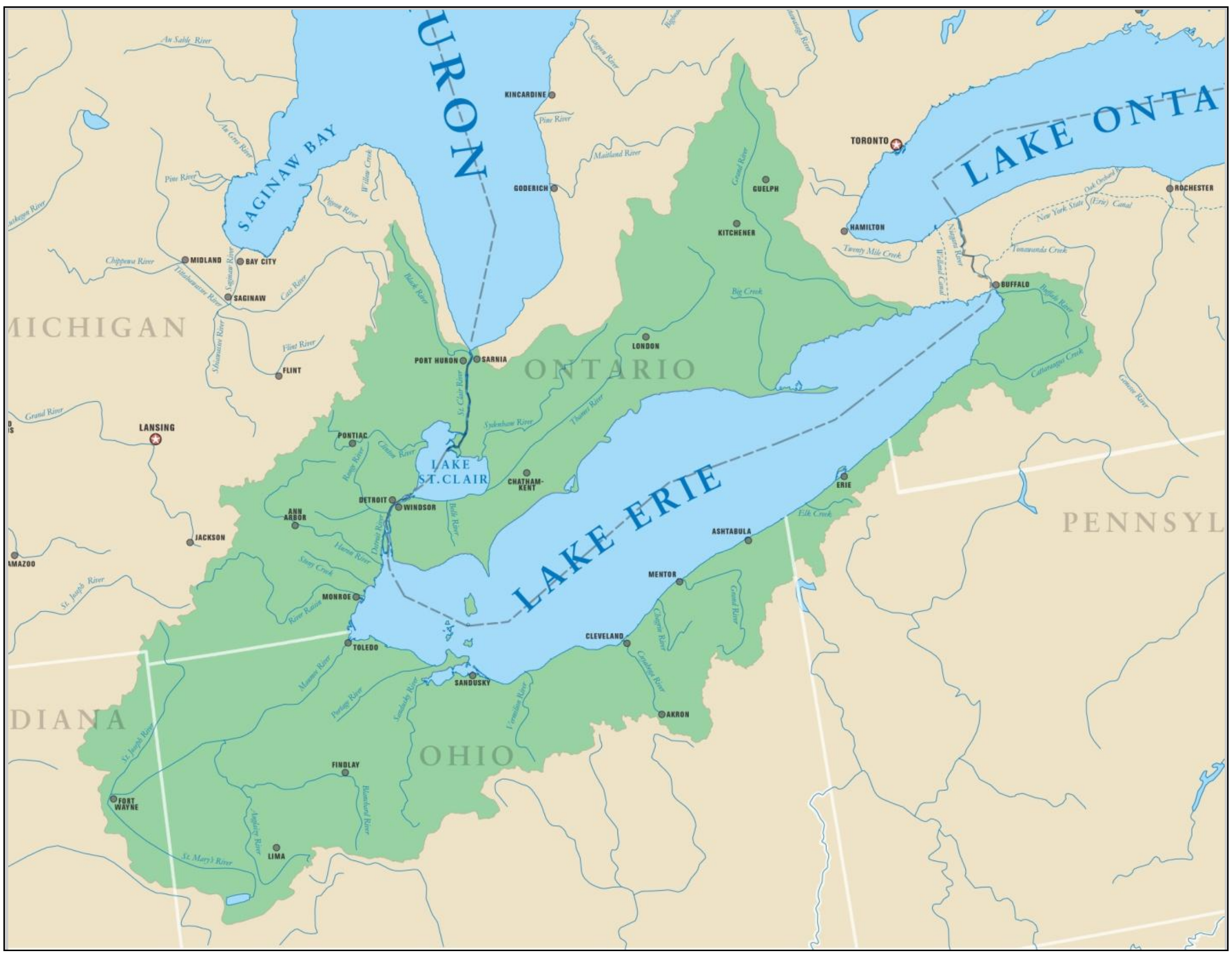
[7] As measured by volume. Lake Ontario has a smaller surface area (about 19,000 km^2 or 7,340 mi^2) but is much deeper than Lake Erie.

boating and tourism; sport fishing and commercial fishing; and First Nations and Native Americans.

With its fertile soils, the Lake Erie basin is intensively farmed, with about 63 % of the lake's watershed used for agriculture. Land use along the shoreline is dominated by: residential uses (39 % in Canada and 45 % in the United States); agriculture (21 and 14 %, respectively) and commercial uses (10 and 12 %, respectively) (USEPA-Government of Canada, 1995).

The shallowness of the lake and its warm temperatures makes it the most biologically productive of all the Great Lakes. It supports a species-rich and diverse fish community, with more than 130 species documented. In addition to their important ecological roles, several species also support large recreational and commercial fisheries. For example, walleye (*Sander vitreus*) supports the lake's most valued recreational fishery and yellow perch (*Perca flavescens*), walleye and several other species support large commercial fisheries(ODNR Lake Erie Strategy Plan).

Figure 2-1: The Lake Erie Basin



(Credit: Michigan Sea Grant)

2.3 Phosphorous

2.3.1 Objectives

Phosphorous has long been recognized as the primary cause of nutrient enrichment (eutrophication) problems in Lake Erie. Microscopic plants - the smallest forms of algae – comprise the base of the food web in any lake. Algae grow by converting available nutrients in the presence of sunlight to new plant material. The dominant forms of nutrients in Lake Erie are made up of nitrogen and phosphorous. However, phosphorous is considered the limiting nutrient (that is, the nutrient that limits the growth of algae) because there is sufficient nitrogen available to algae (Lake Erie Nutrient Science Task Group, 2009).

Phosphorous is a chemical element that occurs both naturally in the environment and in many common human-made products. The major commercial application of phosphorous compounds is the production of fertilizers, used to replace the phosphorous that plants remove from the soil. In the past, it also has been used as a major ingredient in detergents, pesticides and other products.

Loadings vs. Concentrations

The amount of phosphorous in Lake Erie is generally described in one of two ways loadings or concentrations. Loading is the total mass of phosphorous entering the lake from all sources. It is expressed as the mass of phosphorous per given period of time (e.g. kg/day or tonnes/year), and typically used to quantify inputs, such as from streams and rivers. Concentration is the mass of phosphorous in a given volume of water, generally expressed as milligrams or micrograms of phosphorous per litre, and is often used to characterize lakes and their trophic status.

For tributaries entering Lake Erie, loadings are calculated as the product of concentration (e.g. mg/L) and water discharge or flow rate (e.g. cfs or L/day). Loadings and concentrations are not necessarily related. For example, during the spring freshet, there tends to be large quantities of runoff and streamflow and high concentrations of phosphorous. Later in the summer, during the growing season, there can still be storms that generate large quantities of streamflow, but concentrations of phosphorous are often much lower. It is this combination of water volume and phosphorous concentration that differentially impact receiving waters, such as nearshore zones and embayments in western Lake Erie.

The algae issues in the Lake Erie – including free floating Microcystis in the western basin, and attached Cladophora at various locations along the shoreline – occur primarily due to high concentrations of dissolved phosphorous coming from tributary discharges. Deep water hypoxia in the central basin is strongly influenced by phosphorous loads to the west basin. Therefore, reducing phosphorous impacts on the lake must focus on both high concentrations and high load inputs, which primarily come from a few key tributaries including the Maumee River in northwest Ohio. Reducing loads from low concentration sources like the Detroit River may have only a modest influence on algal blooms in the western basin of the lake, though circulation patterns may transfer the influence elsewhere, such as the central basin.

To support the development of effective policy and management approaches to addressing lake-wide challenges in Lake Erie, LEEP sought to:

- provide the best available updated estimates of the total phosphorous load and bioavailable phosphorous (commonly referred to as dissolved reactive phosphorous, or DRP) for Lake Erie through to 2011, by tributary/watershed; and
- evaluate the relative contributions from various sources to total loading.

Key Terms

1. Total Phosphorous (TP) and Dissolved Reactive Phosphorous (DRP)

- **total phosphorous** (TP) refers to all forms of phosphorous in a given quantity of water, including particulate and dissolved forms.
- however, not all of the phosphorous entering a lake from its tributaries is readily available to support algal growth. That portion of the total phosphorous that stimulates algal growth is the dissolved portion, technically referred to as either **bioavailable phosphorous, dissolved reactive phosphorous** (DRP) or soluble reactive phosphorous (SRP).

2. Point and Non-point Sources of Phosphorous

- **point sources:** associated with a specific location, such as an industrial discharge or sewage treatment plant;
- **non-point sources (or diffuse sources)**: associated with many diffuse locations and origins, typically transported by rainfall and snowmelt runoff over land; examples include excess sediments, fertilizers, and pesticides from agricultural lands, built-up districts and residential areas.

3. External and Internal Loading

Phosphorous can enter the water body of a lake in two ways:

- **external loading**: runoff from various point sources and non-point sources in the watershed; from upstream lakes and rivers; and from the atmosphere;
- **internal loading**: from sources within the lake, such as from bottom sediments.

2.3.2 Trends in Phosphorous Loading into Lake Erie

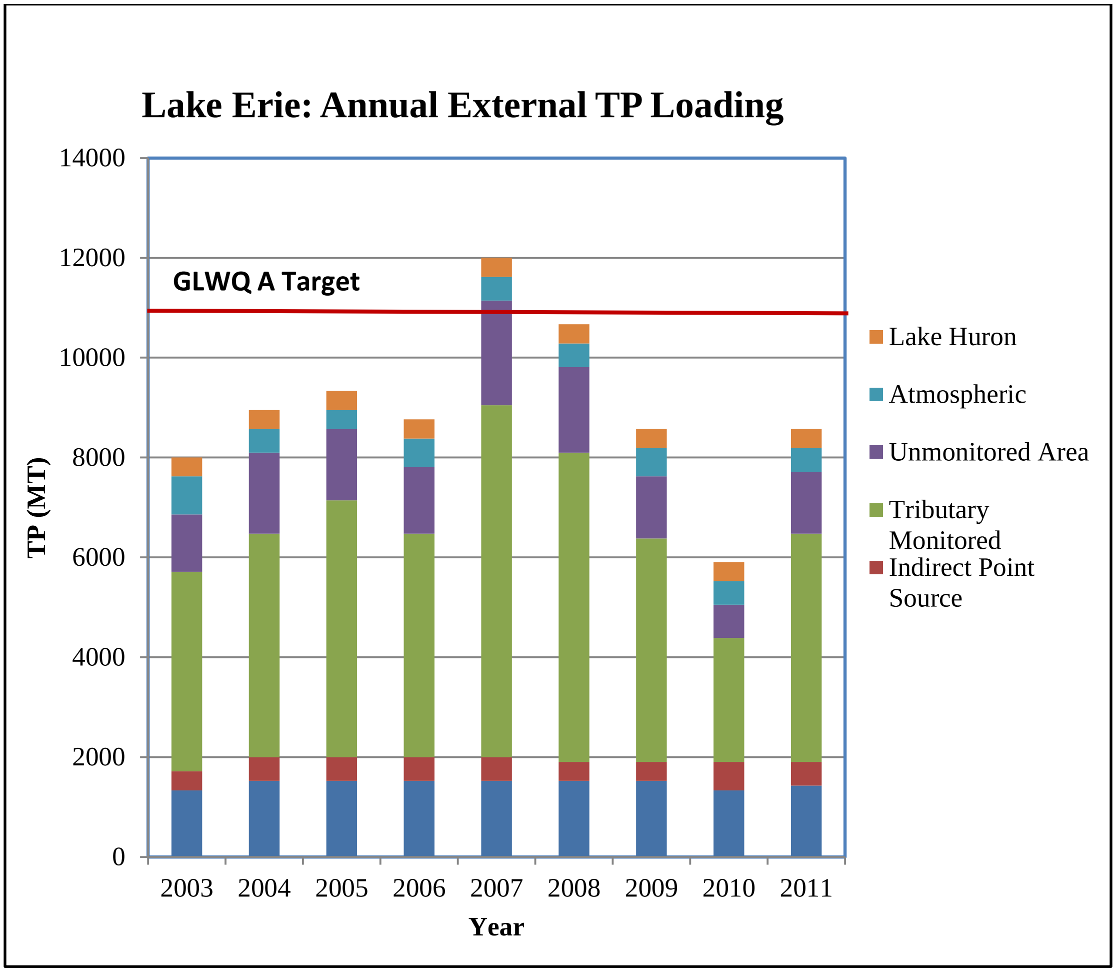
External Loading into Lake Erie

Researchers have updated total phosphorous loads for all of the Great Lakes, including from municipal and industrial point sources, monitored and estimated non-point sources, atmospheric deposition, and inter-lake transfers for 1994 to 2008 (Dolan and Chapra, 2012). LEEP updated these estimates for Lake Erie loads through 2011 using the same methods.

Figure 2-2 illustrates total external loadings of phosphorous into Lake Erie, from various sources. The study found that in most years, total phosphorous loadings into Lake Erie have been below the 11,000 metric tonnes (MT) a year target established under the Agreement. Over the past 10 years, external loadings rose to a peak of nearly 12,000 MT a year in 2007, declined for three years and then again increased in 2011, to more than 8,500 MT.

Figure 2-2: Estimated Annual External Total Phosphorous Loads to Lake Erie

(Metric Tonnes)



The study concluded that the most dramatic reduction in loads into Lake Erie between the late 1960s and the early 1980s came from decreases in point sources of phosphorous, such that current loads are largely from non-point sources. Of the 2011 loadings, more than one-half came from tributaries into Lake Erie that are monitored (for example, larger agricultural and rural communities). Unmonitored areas (typically coastal communities and smaller agricultural areas adjacent to shorelines) and direct point sources each accounted for about 16 %, while other sources each accounted for between four and six % of external loadings. No long-term trends were identified over the period examined. Rather, annual variability in total external loading is driven largely by variability in loadings from the monitored tributaries.

Phosphorous loads to Lake Erie are not distributed equally across the basin. The western basin received 64 % of the 2003-2011 average loads, while the central and eastern basins received 26 and 11 %, respectively (Dolan and Chapra, 2012). Loads within each basin also vary among tributaries for both total phosphorous and DRP, with the largest contributions coming from the Maumee, Detroit, Sandusky, and Cuyahoga rivers.

In general, phosphorous concentrations decrease from west to east, and from nearshore to offshore. The northern waters of the western basin are strongly influenced by flows from Lake Huron via the Detroit River, which tends to have comparatively low concentrations of phosphorous due to the large volume of water. Meanwhile, the lake's southern waters are influenced by the Maumee River and other Ohio watershed inputs, which have very high concentrations of phosphorous in a much smaller volume of water.

Establishment of load targets for Lake Erie, or targets for any other aquatic system, is predicated on measurements of flow (or deposition) rates and nutrient concentrations from rivers throughout the watershed. Numerous water quality monitoring programs are in operation in the Lake Erie watershed, including Heidelberg University's National Center for Water Quality Research in Ohio, U.S. state agencies and the U.S. Geological Survey, the province of Ontario's Provincial Water Quality Monitoring Network, and Environment Canada's Great Lakes Nutrient Initiative, among others. These programs are mainly focused on tributaries that discharge directly into Lake Erie.

A critical influence on nutrient dynamics in Lake Erie is assumed to be the Detroit River as it is thought to contribute 90% of the discharge and about 50% of the phosphorous to the western basin. By the time the river discharges into the northwest corner of Lake Erie, it has integrated nutrient sources from the Upper Great Lakes via the St Clair River, tributaries of Lake St Clair, including the Thames River in southwestern Ontario, and the cities of Windsor and Detroit (location of the largest single wastewater treatment plant in the United States). However, the only monitoring data available for the connecting river system between the Upper Great Lakes and Lake Erie is from the northern section of the St Clair River, just after water exits Lake Huron. At this point, the average annual (2005-2010) load of phosphorous is 326 MT (Chapra and Dolan, 2012). While no comparable monitoring data exists for the Detroit River outlet, research conducted in 2007 estimated that the annual phosphorous load from the river to Lake Erie was 3500-4300 MT, suggesting at least a 10-fold increase between Lake Huron and Lake Erie (Bruxer et al., 2011). An important conclusion stemming from this research was that future monitoring of the lower reaches of the Detroit River requires a series of monitoring stations to account for complexities associated with multiple channels and islands.

Agricultural Sources

Agricultural operations are a major source of non-point loadings of phosphorous, and other contaminants such as nitrogen and sediments, into Lake Erie. These loadings can arise particularly from fertilizer application and animal wastes. During spring snowmelt and heavy rainstorms, phosphorous is transported by runoff. Agricultural non-point sources of phosphorous have increased significantly in the last 15 years, especially the fraction of total phosphorous that is bioavailable (i.e., DRP).

Urban Sources

Phosphorous from urban areas is associated with discharges from wastewater treatment plants, construction activities, stormwater runoff, lawn and garden activities, leaves from deciduous trees and pet waste. However, due to the multitude of land uses within urban watersheds, it is often difficult to pinpoint phosphorous loads from specific urban land covers. Although urban non-point sources of phosphorous can be significant, discharges from urban areas are often closely associated with point sources. Over the last 40 years, point sources have declined significantly.

Detroit Wastewater Treatment Plant

The Detroit wastewater treatment plant is the largest single sewage plant in the United States, serving over 3 million people in 76 communities. The plant discharges into the Rouge River and subsequently the Detroit River upstream of Lake Erie. Cleanup of the facility's discharges in the 1970s was one of the biggest factors in the reversal of Lake Erie eutrophication.

In 1970, the facility began removing phosphorous from its effluent using pickle liquor and polymer to meet a 1 mg/L phosphorous standard for all major plants (3.8 million liters; one million gallons per day or greater). State policy changes affecting household laundry detergents also contributed to the cleanup. Michigan's 1977 phosphorous detergent ban restricted the phosphorous content of household laundry detergents to no greater than 0.5% by weight.

The combined result was a greater than 90% reduction in phosphorous concentration and loading from the plant. Because of the Detroit plant's 2,600 million liter (700 million gallon) per day flow, the impact on Lake Erie was substantial.

Work remains to further reduce phosphorous from the Detroit plant. Combined sewage overflows, which result from major storms that force the bypass of untreated or partially treated sewage from the plant into the river, can be a significant source of phosphorous. A capital improvement program that began in 2000 included over $1 billion for controlling combined sewer overflows. Still, in 2012, the plant was responsible for the release of over 7.8 billion gallons of untreated or partially treated sewage into the Detroit River.

Atmospheric Deposition

Atmospheric deposition to lakes is difficult to quantify and measure but contributed about six % of the total external phosphorous load in 2011. Phosphorous can find its way from the airshed into lake ecosystems via inputs to the watershed from rain or snowfall (known as wet deposition) and wind transported particles (dry deposition) (Anderson & Downing, 2006; Zhai *et al.*, 2009). Wet and dry nutrient loadings to aquatic ecosystems, particularly phosphorous, have increased over the years as a direct result of human activities (Herut *et al.*, 1999; Zhai *et al.*, 2009). Important potential sources of atmospheric deposition of phosphorous into Lake Erie include: microbial decomposition of sewage sludge, landfill and compost heaps; coal combustion; burning of biomass; dust from quarries, agricultural fields and unpaved roads; and automobile emissions.

Dissolved Reactive Phosphorous (DRP)

The Agreement originally focused on total phosphorous as the water quality parameter by which Lake Erie eutrophication was to be managed, and those load targets have generally been met. However, recent research has turned to DRP, a form of phosphorous that is highly bioavailable, as a potential issue of concern (Vanderploeg *et al*., 2009; Richards, 2006). Therefore, the LEEP study sought to identify the highest contributors of DRP as well. This analysis was carried out for 1998-2005, using models to estimate the sub-basin contributions of total phosphorous and DRP for the Detroit River and six major watersheds in the United States draining into the western basin of Lake Erie: the Maumee, Sandusky, Grand, Raisin, Cuyahoga and Vermillion rivers. These watersheds collectively account for the majority of total loads of phosphorous to the lake. Analysis conducted for the LEEP study of loads from the Maumee, Sandusky, Honey Creek, and Rock Creek watersheds reveal that while DRP loads declined in the early 1990s, they have increased since the mid-1990s, in contrast to the relatively stable total phosphorous and particulate phosphorous loads (Figure 2-3). The results of this modelling suggest that there are "hot spot" sources of DRP in sub-basins within the major watersheds that contribute a large proportion of the total phosphorous inputs.

It was also found that *average concentrations* of total phosphorous and DRP in the Detroit River are low compared to those measured in other major tributaries. In contrast, the phosphorous concentrations in the rivers draining the agricultural areas of the western basin, particularly the Maumee, are generally much higher and may have a more direct influence on the development of harmful algal blooms. Nevertheless, the Detroit River represents the largest hydrological loading to Lake Erie and by virtue of its flow, contributes significantly to the total loading (estimated 40-50 %), which may be a significant factor in the annual development of hypoxic conditions in the lake (see section 2.4.1).

Figure 2-3: Annual unit area loads of dissolved reactive phosphorous (DRP) at four Lake Erie watersheds. NCWQR, Heidelberg University, unpublished data.

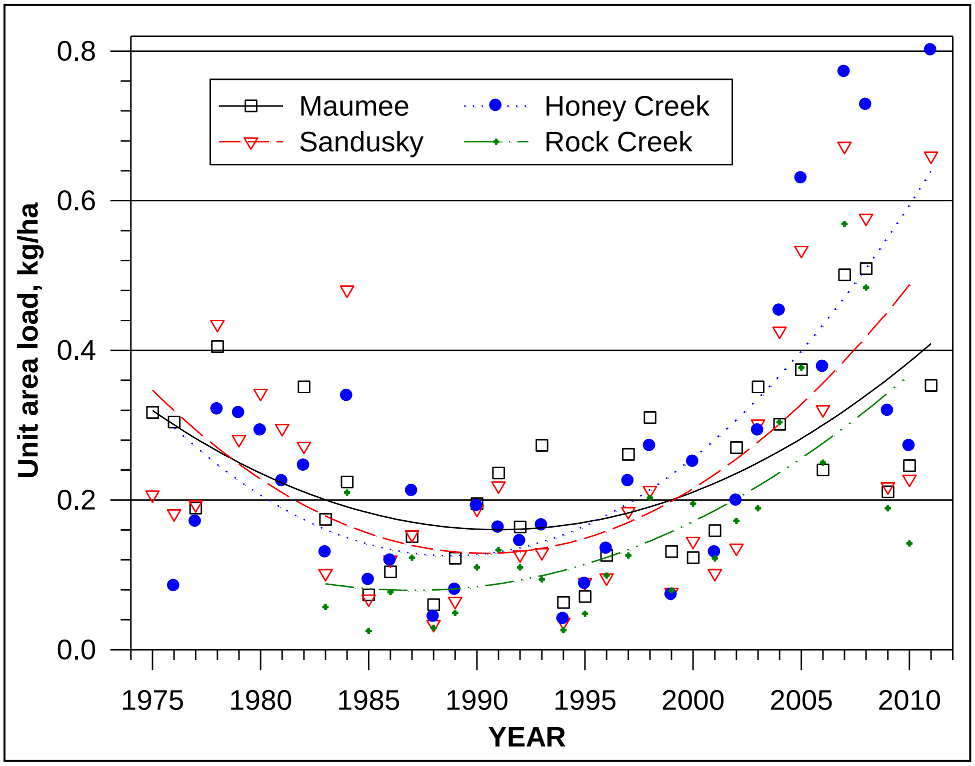
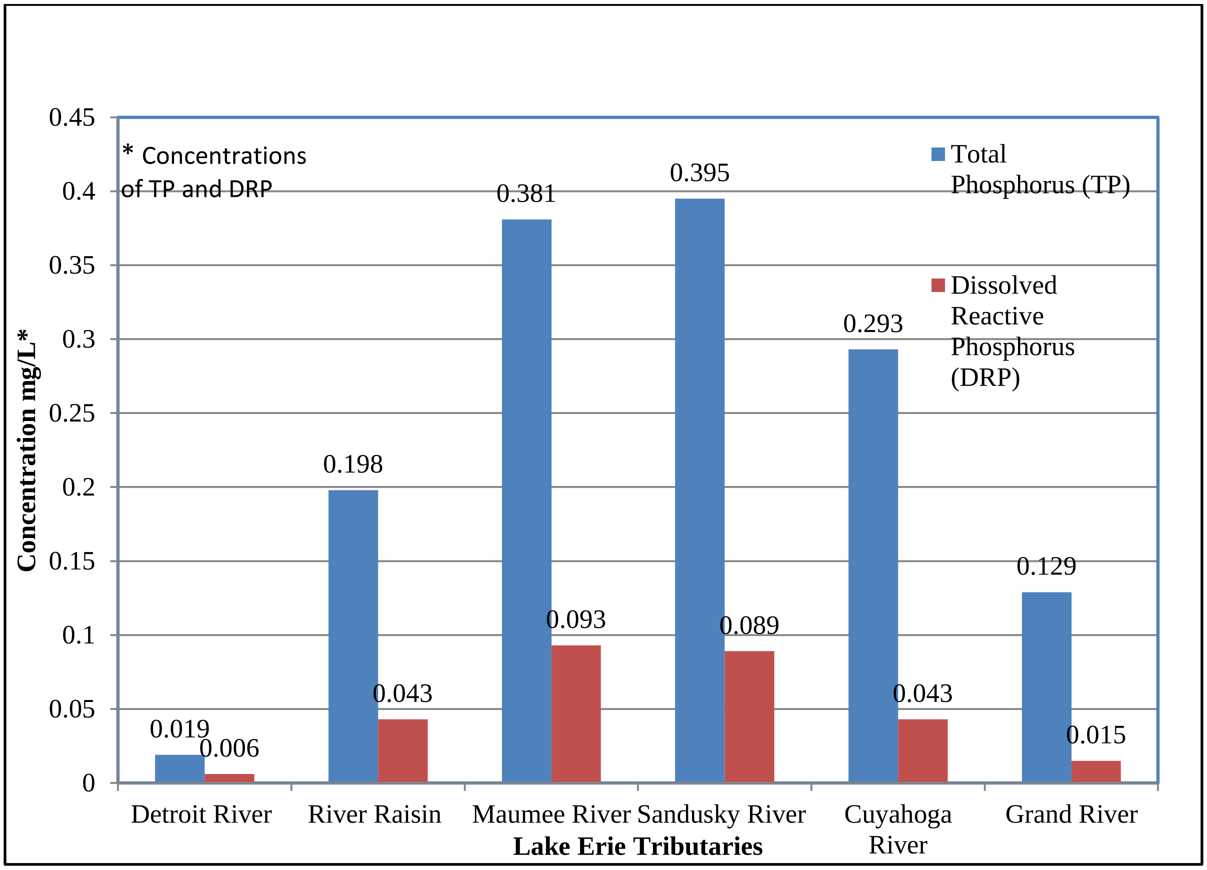


Figure 2-4: Data Comparison of Total P and DRP Concentrations among Lake Erie Tributaries.



Large-scale Modelling of Nutrients in the Great Lakes Basin

To help address eutrophication problems in the Great Lakes, including the sources of nutrients leading to harmful algal blooms, SPARROW (SPAtially Referenced Regression On Watershed attributes) models were recently developed to simulate phosphorous (P) and nitrogen (N) loading in streams throughout the Upper Midwest part of the United States. Results from these SPARROW models were used to: 1) estimate P and N loads to each Great Lake from U.S drainages; 2) rank all U.S. tributaries with drainage areas greater than 150 km^2, based on total loads and relative yields; and 3) determine the relative magnitude of P and N inputs from major sources (atmospheric, point sources, fertilizers, manure, fixation, and forested and urban lands).

A binational modeling effort is now underway between the United States and Canada to develop SPARROW models for P and N for the entire Great Lakes Basin, including the complete Lake Erie watershed. These models are being developed using smaller catchments to enable improved spatial descriptions of where and from what sources the P and N originate and calibrated using more accurate loads, including more data from smaller watersheds, than used in previous models. A new model that links SPARROW with outputs from water-quantity models, called HydroSPARROW, has been developed and is being used to forecast changes in nutrient loads associated with various future climate and land-use change scenarios projected to occur by about 2050 and 2090.

For more information on the SPARROW model, visit the USGS homepage:
http://water.usgs.gov/nawqa/sparrow/

Internal Loading in Lake Erie

Internal loading of phosphorous is essentially a recycling of external loading over some period of time in response to in-lake processes. As a result of this internal cycling, lakes can potentially exhibit a slow response to any reduced external loading (Sondergaard *et al*., 2003). So while internal loading is not "new" phosphorous and cannot be controlled directly, it is important to understand and quantify recycling processes to better anticipate system response times.

There are three types of internal phosphorous cycling in Lake Erie:

- *inter-basin transfers*, involving a transfer of phosphorous entering the western basin (most of the Lake Erie load) to the lake's central basin;
- *water column recycling*, involving a complex mixture of phosphorous uptake and excretion by algae, bacteria, zooplankton, fish, birds, macro benthos, and micro benthos, as well as death, decay, sedimentation; and
- *release of phosphorous from sediment* through decomposition of sedimentary organic matter, (particularly under anaerobic conditions) from iron-rich particulates, and re-suspension of sediment into the water column.

The role of internal loads in delaying responses to external load reductions has been considered by researchers (*e.g*., Sondergaard *et al*., 2003). However, it is important to recognize that in response to the 1972 Agreement, reduced phosphorous loads into Lake Eerie decreased western basin phosphorous concentrations from 40µg/L to 20µg/L by the mid-1980s despite internal recycling. A recent review of responses in small, shallow European lakes showed that most reached equilibrium with reduced phosphorous loads in 10 to 15 years (Jeppesen *et al*., 2007).

This information suggests that there could be a delay in the response of the Lake Erie ecosystem to external load reductions of at least several years and possibly longer, due to this internal load cycling.

2.4 Trends in Effects on the Lake Erie Ecosystem

This section briefly summarizes trends in the effects of phosphorous loading on the Lake Erie ecosystem.

2.4.1 Harmful and Nuisance Algal Blooms

Planktonic Harmful Cyanobacterial Blooms

Beginning in the mid-1990s, increases in highly bioavailable DRP loading to Lake Erie have coincided with a resurgence of planktonic cyanobacterial harmful algae blooms (cHABs). Blooms of *Microcystis aeruginosa* and other cyanobacteria have formed annually in the western basin, and now are appearing elsewhere along the coast. In the last decade, the blooms have developed earlier and extended later than in the past. For example, the 2011 Lake Erie bloom was the worst on record (Michalak et al, 2013), and was visible from satellites until mid-October.

Blooms of *Microcystis* have generally been reported from the western basin, but have recently been developing along the shorelines of the central and eastern basins. Potentially toxic species of *Planktothrix* and *Anabaena* have also been observed with increasing frequency (Davis *et al*., 2012; Saxton *et al*., 2012). While cyanobacteria are known to produce a number of toxins, microcystins are of particular concern.

Early detection of cHAB formation is critical to formation of a proper response, and available detection methods, including remote-sensing, have greatly improved response times in recent years. Molecular methods have tracked historical existence of *Microcystis* dating to the 1970s in Lake Erie, and show that at specific sites the current population is genetically indistinguishable from the historical population (Rinta-Kanto et al, 2009). This finding suggests that environmental or anthropogenic influences have resulted in a surge in the *Microcystis* population in recent years, rather than an invasion of a distinct population.

There is strong evidence that dissolved reactive phosphorous is a key factor driving cyanobacterial biomass and dominance in many freshwater systems, including Lake Erie. However, recent work suggests an important role for other nutrients, in particular, nitrogen, as well as other trace elements, (DeBruyn *et al*., 2004; Dolman *et al*., 2012).

An understanding of the collective effects of these factors will lead to more accurate mathematical modelling and prediction of future cHABs. In addition, climate models predict temperature increases that would favour cyanobacterial dominance in freshwaters and may contribute to an extension of annual bloom duration.

Nuisance Algal Blooms in Lake Erie: Benthic Algae

Over the past 10 to 15 years, study of benthic algae in Lake Erie has been largely limited to two species that form annual nuisance blooms: *Cladophora* in the eastern basin; and, more recently, *Lyngbya* in the western basin. These blooms foul recreational beaches, clog municipal and industrial water intakes, impair water quality and pose potential microbial health risks to wildlife and humans.

Although the ecology of *Cladophora* is generally well documented in Lake Erie, far less information is available for *Lyngbya.* Recent applications of remote-sensing technology and mobile survey technology have successfully documented spatial patterns in the coverage and attached biomass of *Cladophora* and offer new approaches to expand the spatial scope of future research. Differences in substrate availability and light appear to be major determinants of *Lyngbya* and *Cladophora* abundance in Lake Erie. For example, in the more turbid western basin, *Lyngbya* is often found in turbid shallow water, associated with sand and crushed and live dreissenids (small, freshwater mussels) over a limited depth range (1.5 – 3.5 m). *Cladophora*, meanwhile, is found in the more transparent eastern basin attached to dreissenids, rocks and other hard substrate at depths between 0.5 – 10 m.

The arrival of dreissenid mussel populations in Lake Erie has likely contributed to nuisance blooms of *Cladophora* by improving water clarity, supplying nutrients, and providing substrate for filament attachment. The degree of influence of dreissenid mussels on *Lyngbya* is less clear and merits further exploration (Higgins et al, 2007).

The problem of nuisance algal blooms is particularly evident in the nearshore (shoreline and shallow waters adjacent to the shoreline). Nutrient-related problems in the nearshore are worsening, with increasing incidents of algal fouling in many of the Great Lakes including Erie (OMOE, 2013).

It is important to note that much of the information regarding nuisance benthic algal blooms in the Great Lakes in the past (and in more recent years) has been limited to site-specific assessments, supplemented with experimentation and simulation modelling. Researchers now know that there are a number of important factors that influence the dynamics of benthic algal blooms in nearshore waters of the Great Lakes. Hydrodynamics and circulation of water masses shape the interaction of lake water with land-based runoff and tributary discharges, and strongly influence the nutrient, light, temperature and disturbance regimes in the nearshore. In addition, there is improved awareness of the ability of filter-feeding organisms such as dreissenid mussels to reduce or exacerbate conditions suitable for the growth of benthic algae.

Finally, climate change has the potential to greatly influence these interrelationships, as a result of changes in precipitation and temperature. Such changes will significantly alter seasonal growth patterns of algae.

What is lacking is a comprehensive understanding of how these various factors work together to create the conditions associated with nuisance blooms of *Cladophora* and *Lyngbya*. Such understanding is crucial for the sound development of management activity.

2.4.2 Hypoxia

Hypoxia refers to a condition where the dissolved oxygen content of water is reduced to zero or very low levels. This can occur during the summer months in deeper lake basins such as the central basin of Lake Erie, where the water column stratifies in layers and the warmer oxygenated waters at the surface are separated from the colder, denser bottom water. High external nutrient inputs stimulate the production of excessive organic material (algae and other organisms) in the sunlit surface layers, and the subsequent decay of this material in the bottom waters rapidly depletes the supply of oxygen, creating "dead zones," where dissolved oxygen levels are so low that fish and other aquatic life cannot survive. Hypoxic conditions also lead to the release of phosphorous from sediments, known as internal loading, which may also contribute to the development of algal blooms.

Hypoxia, especially in the Lake Erie's central basin, is an annual and natural event and one that probably preceded current urban and agricultural development (Delorme, 1982). In fact, the recurrence of seasonal hypoxic events in the central basin subsequent to the nutrient reductions set out in the Agreement suggests that these events are not due solely to human-induced eutrophication (Charlton *et al*., 1993).

The dissolved oxygen depletion rate and areal extent of hypoxia, however, can be modified by human activities (Rosa and Burns, 1987; Bertram, 1993). For example, owing to excessive phosphorous inputs that stimulated algae production, dissolved oxygen depletion rates during summer increased during the mid-1900s, producing a hypoxic area as large as 11,000 km^2 (about 4,247 mi^2) (Beeton, 1963). During the height of eutrophication, even the shallow western basin of Lake Erie could become hypoxic during windless periods in summer (Hartman, 1972). In fact, by 1963, even a five-day period of hot, calm weather could cause 50 % of the western basin to become hypoxic (Hartman, 1972).

Phosphorous abatement programs initiated as part of the 1972 Agreement are credited with contributing to a decline in bottom hypoxia in both western and central Lake Erie through the early 1990s (Charlton *et al*., 1993). However, since the late 1990s, the extent of bottom hypoxia has increased to levels on par with those observed during the previous era of eutrophication prior to the Agreement (Hawley *et al.*, 2006). The causal mechanisms for this increase are not fully understood, though the shift does coincide with altered precipitation patterns, warmer water temperatures, increased non-point nutrient inputs and extensive algal blooms

Climate Change and Hypoxia

Climate change is predicted to influence hypoxia formation in the Lake Erie ecosystem in several ways. Predictions made for other temperate freshwater ecosystems indicate that continued climate change will exacerbate the magnitude, duration and frequency of hypoxia (Kling *et al*., 2003; Ficke *et al*., 2007; Fang and Stefan, 2009; Jiang *et al*., 2012). Most directly, warmer future conditions are expected to facilitate a longer stratified period during summer, with earlier establishment of thermal stratification and turnover occurring later in the year. Bottom dissolved oxygen depletion, therefore, will begin earlier and hypoxic conditions are likely to persist over an extended time period (Fang and Stefan, 2009). Reductions in water levels could further exacerbate bottom hypoxia.

While uncertainty surrounding future regional precipitation patterns is greater than future regional temperatures, it is plausible that precipitation patterns will be characterized by less frequent, but more intense, precipitation events (Kling *et al*., 2003; Kunkel *et al*., 1999). Such intense events could lead to high nutrient runoff from agricultural and urban lands, and in the absence of dramatic changes in land use, lead to increased overall nutrient loads to Lake Erie. Depending on the timing of runoff, future nutrient loading, coupled with warmer water temperatures, could lead to greater overall phytoplankton production and ultimately exacerbate decomposition and oxygen depletion rates.

Potential changes to future wind patterns have not received the same amount of attention as temperature and precipitation (Kling *et al*., 2003). But by affecting thermal stratification, wind pattern changes also have the potential to alter hypoxia patterns. Specifically, intense wind events could contribute to mass movement of water, including seiches (caused by high sustained winds from one direction that push the water level up at one end of the lake and make the level drop by a corresponding amount at the opposite end) and the potential influx of hypoxic bottom waters into nearshore zones. Moreover, strong wind events could facilitate vertical mixing and both delay stratification in the late spring and bring about earlier turnover in the fall, decreasing the period of oxygen depletion. In short, while future wind patterns will likely affect hypoxia patterns, the magnitude (and even direction) of such effects is unclear.

The effects of hypoxia on food webs (particularly invertebrate and fish communities), and how this may be influenced with climate change, are addressed below.

2.4.3 Effects on Fish

Lake Erie fisheries have important ecological, recreational and commercial value. Each species of fish has preferred food choices and temperature ranges, and all depend upon adequate oxygen. In general the shallow, warm and productive western basin is currently dominated by species that are tolerant of high turbidity and warm temperatures. The eastern basin, the deepest, coldest and least productive, is dominated by deepwater fish, such as lake trout, that prefer cold temperatures, high dissolved oxygen and non-turbid waters. The central basin is dominated by cold water species, including yellow perch and walleye.

Algal blooms in Lake Erie indirectly reduce the integrity of native fish populations through loss of aquatic habitat. When algae die, the decomposition process uses much of the available oxygen dissolved in the water column. This effect is variable in combination with other factors, and is most pronounced in the deeper waters of the central basin where a hypoxic ‘dead zone’ forms. Additionally, decomposing algae on the lake bottom may play a role in the *Type E* botulism outbreaks which cause significant numbers of deaths of fish-eating birds (Lake Erie Committee, 2003).

As described above, warmer temperatures, lower lake levels and increased frequency of intense precipitation events all have the potential to enhance phytoplankton blooms, reduce water clarity and exacerbate future hypoxia. Changes in lake temperature may dramatically alter the existing distribution of fish species, even to the loss of cold water species from the lake. Further, organisms that can readily avoid hypoxic regions (through vertical or horizontal migrations) may be forced to occupy inferior thermal and optical habitats, immediately constraining growth. Such behavioural migrations may alter the overlap, efficiencies, and vulnerabilities of predators and prey, leading to long-term changes to food-web structure and energy flow. Coincident shifts in invertebrate/fish community composition would be expected.

In general, the interactive effects of climate change and nutrient loading are expected to promote a fish community unlike that of the 1960s and 1970s, more tolerant of eutrophic conditions (that is, relatively high concentrations of nutrients). Visual feeding, cold-water and hypoxia-sensitive fish will decline while species more tolerant to warm water will increase. However, the complex interactions between hypoxia, reduced water clarity, harmful algal blooms and altered prey base have the potential to directly and indirectly mediate population patterns in ways not yet fully understood.

In addition, the impacts of climate change on lower trophic levels of Lake Erie will likely not be straightforward. Future climatic conditions will undoubtedly interact with nutrient loading and aquatic invasive species in structuring lower trophic level communities. These expected responses would favor eutrophic-tolerant invertebrate taxa. That is, zooplankton and benthic invertebrate taxa would likely increase in abundance if they are able to: tolerate relatively warm temperatures; effectively consume cyanobacteria; feed under low light conditions; and, utilize a low oxygen zone as a refuge from predation. On their own, expected climate change impacts could lead to invertebrate assemblages trending towards patterns observed during the 1950s and 1960s, at the height of eutrophication.

2.5 Effects on Human Health and Socio-Economic Conditions

Lack of data severely limited efforts to estimate the economic effects of Lake Erie algal blooms throughout the entire lake basin. For example, the LEEP study was unable to quantify impacts related to harmful algal blooms on coastal property values, commercial fishing, boating, and the tourism industry. As a result, the study chose to limit its analysis of economic costs and benefits to the state of Ohio, which has more recent and available relevant information than other jurisdictions in the Lake Erie basin. The Ohio data, therefore, can serve as a proxy, providing illustrative order-of-magnitude data on economic costs and benefits that could be expected at the broader regional level.

2.5.1 Human Health

Drinking Water Supply Protection

In cases where harmful algal blooms appear, municipal water treatment facilities drawing water supplies from Lake Erie may need to carry out additional treatment before the water is safe for human consumption. A 2009 survey of 15 public water systems in Ohio using lake water found that ten reported having used additional treatments in response to algal bloom events that year (OEPA 2010). These treatments included the application of powdered activated carbon, chlorine dioxide, and potassium permanganate. Additional control costs totaled $417,200 for the ten water utilities, ranging from individual plant costs of $400 to $240,000.

It is important to note that algal bloom events of 2009 were less severe than in 2011, and as such, these costs can be seen as a conservative estimate. In addition, since 2009, at least one public water system on Lake Erie has had to upgrade its facilities to include algal bloom-specific treatment capabilities.

Public Health

Individuals enjoying swimming, waterskiing, or boating in contaminated water can be exposed to microcystins. If people drink water contaminated by microcystin, symptoms of exposure include nausea, vomiting and, in very rare but severe cases, acute liver failure. Reported health effects from cyanobacteria in humans are highly uncommon in the United States and Canada. Although the likelihood of people being seriously affected by a *Microcystis* bloom is low, minor skin irritation can occur with contact, and gastrointestinal discomfort can also occur if water from a bloom is ingested. People recreationally exposed to microcystin (for example, personal watercraft operators) also have reported minor skin irritation.

The one reported case of illness in Ohio in 2011 related to harmful algal blooms had an economic value of $2,128 and the estimated ten unreported cases had a combined economic value of $16,720. To understand some of the variability in annual economic impacts from harmful algal blooms, it is worth noting that in 2010, nine total cases of such illness were reported in Ohio for Lake Erie, while only one case was reported in 2012 (Clifton, 2013).

2.5.2 Socio-Economic Conditions

Property Values

Harmful algal blooms are known to diminish aesthetic qualities of shoreline and near-shore properties. While there are examples from the literature about how changes in water quality can impact property values, the magnitude of impacts of these blooms on nearby property values is not clear.

However, the LEEP study estimated that between 24,000 and 210,000 properties could be affected by harmful algal blooms if effects to properties extend between 1.6 and 16 km (1 to 10 mi) inland from the Lake Erie coastline. This estimate, coupled with previous findings from other study sites linking changes in water quality to decreases in property values, suggests that future research to examine changes in housing values along Lake Erie that can be attributable to the presence of harmful algal blooms is warranted. Increased property values could represent a large share of the benefits of future efforts to reduce these harmful blooms.

Regional Tourism

The presence of harmful algal blooms can have immediate economic impacts on a region's tourism industry. Blooms can detract from enjoyment of water-based or near-water activities by spoiling aesthetics or producing unpleasant odors. Public health advisories or site closures issued due to the presence of the blooms can keep visitors from participating in activities and keep prospective visitors from making trips. Foregone or shortened trips translate into losses in tourist spending in the region, which in turn have implications on incomes, employment, and tax revenues.

However, the LEEP study concluded that despite the historically severe algal event in the summer of 2011, Ohio's tourism industry statewide and in the Lake Erie region experienced growth over recent years. This finding suggests that a wide range of factors affects annual tourism expenditures, including employment and general economic conditions and summer weather.

Although available data do not point to an immediate economic impact to the tourism industry caused by harmful algal blooms, there may still be longer-term or delayed impacts in the future. Tourism supports a substantial amount of regional and statewide employment, as well as contributing to local, state, and federal tax revenues. Therefore, it will be important to continue efforts to better understand how potential effects of such blooms on the tourism industry.

Beach Recreation

Ohio's Lake Erie shoreline provides vast and varied beach recreation choices, with 62 public beaches along its approximately 502 km (312 m) coast (Ohio Department of Health, 2010 and 2011). During the serious outbreak of harmful algal blooms in 2011, the Ohio Department of Health issued advisories at four beaches in Lake Erie's western basin. The advisories were issued in late August and extended into October.

Combining an estimate of the per trip benefit of reducing one beach advisory obtained from a previous economic study of Lake Erie beaches ($3.65), the number of beach trips taken to Maumee Bay State Park (178,500), and the assumed equivalence factor between the HAB-related advisory and a typical advisory, the LEEP study estimated the economic value of damages to beach recreation caused by HABs in 2011 to be approximately $1.3 million for Maumee Bay State Park.

Recreational Fishing

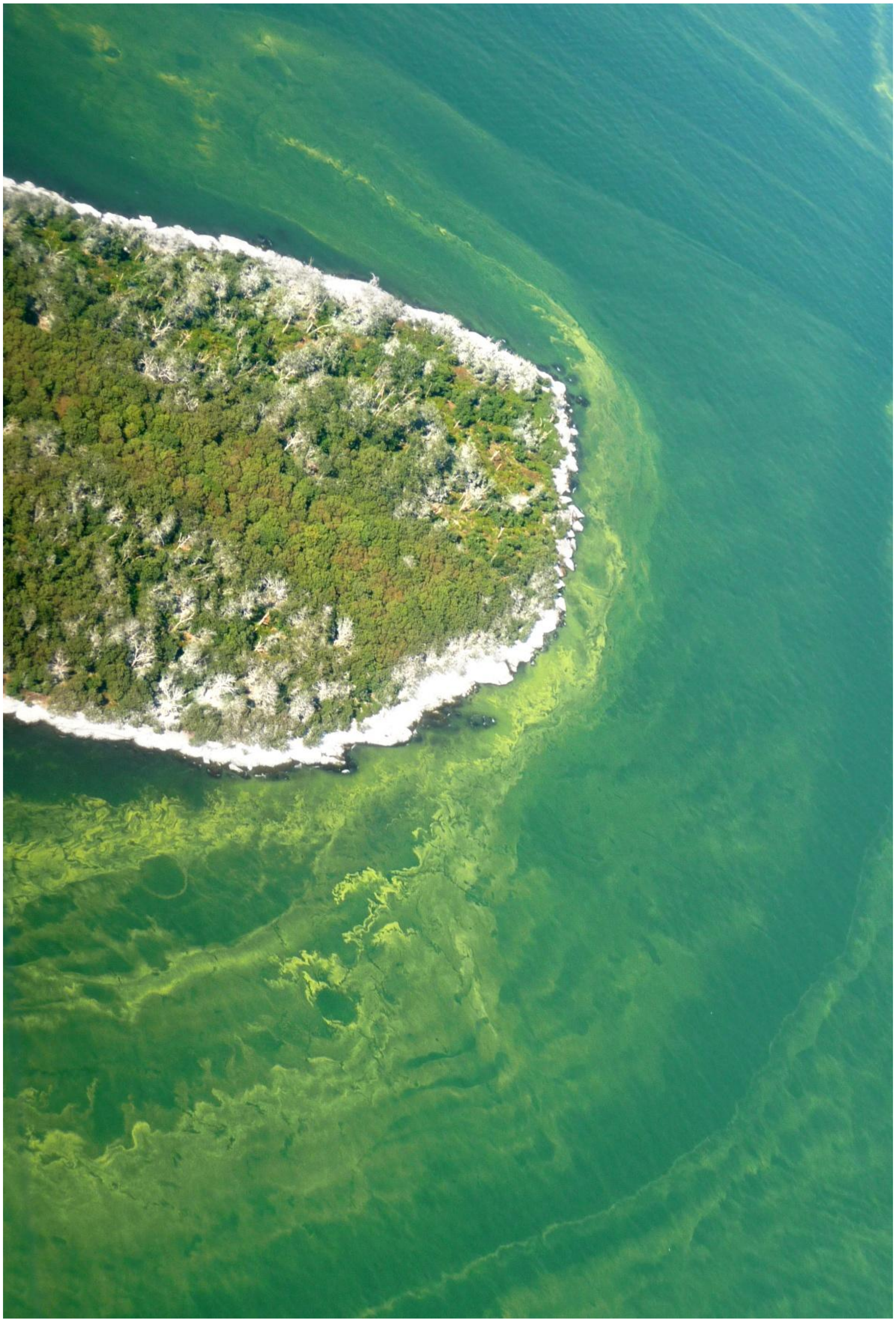
Lake Erie is considered to have world class walleye and small mouth bass fisheries, attracting anglers from across Canada and the United States. In 2011, anglers in Ohio took more than 550,000 fishing trips on Lake Erie by private or charter boat, spending on average more than five hours a trip. Recreational anglers on Lake Erie also support a substantial charter boat industry which totaled an estimated $9.9 million in revenue in the state in 2010 (Lucente *et al*., 2012).

As discussed earlier in this chapter, harmful algal blooms pose a threat to the health of the fishery of Lake Erie in several ways. If these effects on Lake Erie's fishery continue to the extent that fish populations decrease, then sport fishing catch and effort also could decline, contributing to economic losses across the recreational fishing sector. In addition, if algal toxins affect the safety of consuming fish or if taste and odor issues arise frequently enough among sport-caught fish intended for consumption, then recreational anglers may react by taking fewer trips or by taking trips to sites other than Lake Erie.

Applying an accepted economic value per recreational fishing trip, the LEEP study estimated the economic value of impacts to recreational fishing from the severe 2011 harmful algal bloom event on Lake Erie at approximately $2.4 million in Ohio.

Commercial Fishing

The LEEP study was not able to identify any decline in the value of commercial fishing as a result of the 2011 harmful algal blooms. Rather, the weight and value of the 2011 harvest were above typical values, particularly compared to harvests in the early 2000s. Any economic impacts to the commercial fishery as a result of the linkages among harmful algal blooms, hypoxia and fish kills may only become evident over a number of years.



Middle Island, 2011. Lake Erie, Western Basin. Source: Michigan Sea Grant

Chapter 3:

Improving the Health of the Lake Erie Ecosystem

3.1 Introduction

The core objective of the Lake Erie Ecosystem Priority (LEEP) undertaken by the Commission is to provide advice to federal, state and provincial, and local governments for developing policy and management approaches to address lake-wide challenges with respect to declining water quality, algal blooms and associated ecosystem, human health and economic impacts.

Chapter 3 reviews *existing and possible initiatives to address the impacts on the Lake Erie ecosystem* from phosphorous loading. The chapter:

- describes the role that BMPs in urban areas and agricultural operations can play in reducing phosphorous loading;
- describes modelling efforts to identify new phosphorous loading targets that could be established to reduce the loadings into Lake Erie; and,
- identifies important gaps in monitoring and research.

The chapter also highlights examples of efforts underway by various governments and organizations to address phosphorous loads in Lake Erie.

3.2 Implementing Best Management Practices (BMPs)[8]

This section presents an overview of BMPs in both agricultural and urban settings that could be considered for implementation within the Lake Erie basin to reduce phosphorous loads.

BMP is a term used in the United States and Canada to describe a range of proven, practical methods, techniques and other actions that allow individuals or organizations to prevent or reduce the risks of water pollution resulting from their activities. BMPs typically evolve over time, as new approaches (for example, based on new information or new technology) are introduced, proven to be effective and adopted.

LEEP undertook a comprehensive review of more than 240 primary sources of information on the implementation and effectiveness of BMPs in Canada and the United States. The study focused on BMPs that have been evaluated using scientific methods for phosphorous reduction. A secondary focus was to highlight BMPs that have been implemented within the Lake Erie watershed, or more generally, in the Great Lakes region.

[8] BMPs are termed beneficial management practices in Canada.

3.2.1 BMPs in Agricultural Operations

As noted in Chapter 2, agriculture is a major source of non-point inputs of phosphorous in the Lake Erie basin. Agricultural systems have evolved from being net phosphorous sinks, where crop production is phosphorous-limited, to being phosphorous sources, where there is net phosphorous export from most farms (McElmurry et al, 2013).

The control of agricultural phosphorous losses should be directed towards the long-term goal of increasing the efficiency of phosphorous use on farms (and therefore, farm profitability). This goal can be achieved through practices that balance inputs and outputs of phosphorous within a watershed and improve the management of soil, manure, and mineral fertilizer at the farm, watershed, or regional scales, while preserving or improving crop and livestock yields.

BMPs in agricultural operations can be divided according to *source* and *transport*:

- *source* BMPs minimize the potential of phosphorous as pollution at the origin, before it is transported from the soil by water movement; and,
- *transport* BMPs are mostly structures and methods that reduce the transport of phosphorous.

Phosphorous Source BMPs

Table 3-1 summarizes the major BMPs associated with addressing the sources of phosphorous in agricultural operations. Key activities associated with source BMPs include nutrient management, which includes fertilizer and manure management, and animal feed management.

Nutrient management is designed to budget, supply, and conserve nutrients for plant production; minimize agricultural non-point source pollution of surface and groundwater resources; properly utilize manure or organic by-products as a plant nutrient source; protect air quality by reducing odours, nitrogen emissions (ammonia, oxides of nitrogen), and the formation of atmospheric particulates; and, maintain or improve the physical, chemical, and biological condition of soil (USDA-NRCS 2012).

The LEEP study found that nutrient management and related practices (for example, soil and tissue testing, fertilizer rates calculation, variable rate application, precision agriculture) in crop-based agriculture were primarily geared towards efficient agronomic output but not necessarily environmental quality. Concern with the latter seems to be more prevalent in animal-based agricultural production and not well-studied in purely crop-based production agriculture. The effect of fertilizer application rate on phosphorous loss at a farm scale is directly related to application method, the hydrologic soil group, and crop type. Nutrient management in combination with tillage and erosion practices may reduce total phosphorous loads by more than 80 % but in some cases may increase the loads (Cestti *et al*., 2003).

Table 3-1: BMPs Associated with Phosphorous (P) Sources in Agricultural Operations

1.	Balance P inputs with outputs at farm or watershed scale
2.	Minimize P in livestock feed
3.	Test soil and manure to maximize P management
4.	Physically treat manure to separate solids from liquid
5.	Chemically treat manure to reduce P solubility (*i.e.*, alum, fly ash, and water treatment residuals)
6.	Biologically treat manure (*i.e.*, microbial enhancement)
7.	Calibrate fertilizer and manure spreaders
8.	Apply proper application rates of P
9.	Use proper method for P application (*i.e.*, broadcast, plowed in, injected, subsurface placement, or banding)
10.	Carefully time P application to avoid imminent heavy rainfalls
11.	Implement remedial management of excess P areas (spray fields and disposal sites)
12.	Compost or pelletize manures and waste products to provide alternate use
13.	"Mine" P from high-P soils with certain crops and grasses

(Sharpley *et al.,* 2006: Best Management Practices to Minimize Agricultural Phosphorous Impacts on Water Quality)

Manure export from the farm generally is not a viable management option because of hauling costs and off-farm land application options are generally restricted to the nearest neighbours (Sharpley *et. al.*, 2006). In most areas, waste storage, composting, and land applications are the most viable options for manure management.

The "4R" stewardship framework is a major initiative in nutrient stewardship, jointly promoted by The Fertilizer Institute, International Plant Nutrition Institute, the International Fertilizer Industry Association, and the Canadian Fertilizer Institute (see text box).

In animal-based agriculture, feed mass balance has become an evolving and important BMP. Animal farms have decreased in numbers but their capacity has increased in terms of herd size and farm densities. As a result, net nutrient influxes and net nutrient excess occur in most of these farms (Sims, 1977). Decreasing phosphorous in feeds is the best method to mitigate phosphorous loss from feces. Manure total phosphorous reductions with feed management range from 16 to 33 %.

The *"4R" Stewardship Framework* is based on:

1. *Right Fertilizer Source:* matching appropriate fertilizer source & product with soil properties & crop needs. Nutrient interactions should be accounted & nutrients should be balanced according to crop needs & soil tests.

2. *Right Rate:* matching application rates with crop requirements. Excessive fertilizer application may lead to nutrient loss to the environment with no additional gain crop yield & quality.

3. *Right Time:* making the nutrient available when the crops need them; influenced by pre-plant or split application timing, controlled release technologies, stabilizers, & inhibitors.

4. *Right Place:* placing & keeping nutrients where the crop can efficiently use them. The method of fertilizer application is critical. The most appropriate placement method is determined by the crop, cropping systems, & soil properties. Injection or incorporation is the preferred method but soil disturbance needs to be balanced with erosion-control BMPs such as conservation tillage, buffer strips, cover crops, & irrigation management.

Phosphorous Transport BMPs

Transport BMPs are aimed at erosion control and total phosphorous reduction.

Residue and Tillage Management (Conservation Tillage)

These are management practices that leave at least 30 % of the soil surface covered with crop residue following tillage and planting to reduce soil erosion (Galloway *et al*., 1981). In general, conservation tillage reduces total phosphorous loads up to 60 to 80 % when undertaken in conjunction with other nutrient management practices. Results varied widely for reductions in DRP loads.

Conservation Cropping

This BMP includes crop rotation, conservation cover and strip cropping. Bosch *et al.* (2009) observed that post-BMP loading of DRP decreased by 74 % and nitrate by 73 to 88 %.

Conservation Buffers

These buffers are designed to create or improve habitat, reduce sediment, organic material, nutrients and pesticides in surface runoff and shallow ground water flow. They include contour buffer strips (narrow strips of permanent, herbaceous vegetative cover around landscape contours, riparian forest buffers (areas dominated by trees or shrubs adjacent to and up-slope of watercourses or water bodies) and filter strips or areas of herbaceous vegetation.

Wetlands

Constructed wetlands are designed to treat wastewater and runoff primarily from agricultural processing, livestock, and aquaculture facilities and also used to improve storm runoff quality or other water flows. Hoffmann *et al*. (2012) observed a high reduction in nitrogen but a net phosphorous release in two restored riparian wetlands. Rogers *et al*. (2009) observed that a disturbed wetland exported 50 % more sediment and 30 % more total phosphorous than what entered the wetland.

Protection and restoration of natural wetlands can be a method of nutrient control or reduction. Wetlands have many other values, but also potential to help reduce nutrient loadings to Lake Erie. Historic wetland losses in the basin have been significant, including over 90 % of coastal wetlands in much of western Lake Erie and the Huron-Erie Corridor (Maynard and Wilcox, 1997). Research has been undertaken over the past several decades to assess the nutrient behavior in existing wetland complexes, including in Old Woman Creek National Estuarine Research Reserve in western Lake Erie, where shorter term high phosphorous removal rates were on occasion observed (e.g. Heath, 1992; Krieger, 2003). Earlier estimates indicated that with significant wetland restoration in western Lake Erie, phosphorous load reductions of up to 1/3 could be attained (Mitsch et al., 1989). Key factors that affect the nutrient reduction potential of a wetlands complex in the basin include the geomorphic setting in the landscape, hydrology (including seasonal and annual changes in water flows, nature of connection to riverine or lacustrine water bodies, and hydraulic residence time in wetland), biogeochemistry within the wetland, and nutrient loading patterns (including forms and magnitude). Several issues to be considered in wetland restoration as an approach to reduce nutrient loadings include the potential for initial increased nutrient export early in the restoration phase, nutrient "saturation" of the wetland, the potential for climate change to alter wetland structure and functions (or otherwise challenge nutrient objectives), and the need to consider nutrient reduction goals amongst the broader suite of wetland services and values of interest in the basin (*e.g.* Mitsch and Gosselink, 2007; Euliss *et al.* 2008).

Drainage Water Management

This BMP manages the discharge water from surface and/or subsurface agricultural drainage systems to avoid impacts on downstream receiving waters.

Emerging Technologies

LEEP identified several current and emerging technologies for the reduction of phosphorous loadings from agricultural areas that deserve further research. These include: two-stage ditches (Powell *et al*., 2007); controlled drainage (Kroger *et al*., 2011; Nistor and Lowenberg-DeBoer, 2007); hydrologic attenuation; treatment of tile outlets with, for example, bioreactors and filters (McDowell *et al*., 2008).

Encouraging BMPs on Ohio Farms:
Ohio's Healthy Lake Erie Fund

Less than a year after it was implemented, the $3 million Healthy Lake Erie Fund has enabled farmers to apply agricultural nutrient reduction practices on more than 14,000 ha (35,000 acres) of farmland in the western Lake Erie basin watershed.

The Healthy Lake Erie Fund is administered by the Ohio Department of Natural Resources (ODNR) in cooperation with local soil and water conservation districts through the Ohio Clean Lakes Initiative. The main goal of the Ohio Clean Lakes Initiative is to reduce harmful algal blooms in the western Lake Erie basin by implementing and installing BMPs to reduce nutrient runoff into the lake.

Under the Healthy Lake Erie Fund, farmers have adopted a range of agronomic practices, including cover crops, variable rate fertilizer applications, nutrient incorporation and controlled drainage structures. Participating farmers are required to conduct soil tests to determine the nutrient levels and follow recommendations to determine the appropriate amount of fertilizer to apply to their fields. The ODNR plans to designate some of these farmers as "ambassadors" so they can share their experiences and help expand the adoption of additional practices by other farmers throughout the western Lake Erie basin and the rest of Ohio.

Source: http://www2.ohiodnr.com/cleanlakes/healthy-lake-erie-fund

Managing Total Phosphorous vs. DRP

As noted in Chapter 2, the management of the bioavailable DRP has become an increasingly important issue. This question is of particular importance in considering BMPs for agricultural practices.

Traditionally, total phosphorous was considered as 23 to 33 % bioavailable (Baker 2010). However, Seo *et al*. (2005) measured DRP (most of which is bioavailable) as 70 % of total phosphorous in runoff from a no-tilled and broadcast fertilizer field.

The recurrence of severe algal blooms in Lake Erie in the mid-1990s coincided with an increase in DRP loads. A combination of several factors may have caused the increase in DRP export from agricultural lands (OH-NRCS 2012):

- conservation practices (for example, reduced- and no-till cropping systems) implemented since the early 1990s across the basin focused on reducing sediment and total phosphorous, but these practices are less useful for controlling DRP;
- farming equipment has become larger and producers now typically broadcast fertilizer onto the soil surface, rather than banding, where fertilizer is placed adjacent to the crop;
- large-equipment traffic may have caused soil compaction, resulting in decreased infiltration and increased runoff;
- increasingly, fertilizer is applied in the fall instead of spring;
- the application of two years' worth of fertilizer in one year for a corn-corn or corn-soybean crop sequence saves money, time, and labour for the producers but results in higher rates and amounts of fertilizer available for export out of the cropland into the streams; and,

- the maximization of crop yields through fertilizer application and the use of conservation tillage may have also increased soil phosphorous levels, particularly at the soil surface (soil stratification) over a long period of time.

Finally, it is important to note that the effectiveness of BMPs in agricultural operations is likely to be challenged by a changing climate. For example, recent data indicate that large phosphorous loads – including DRP – are exported into Lake Erie during major storms. Under climate change, such storms likely will become more frequent and more intense. However, current BMPs are targeted primarily to reducing particulate phosphorous, not DRP. Therefore, there will need to be a shift in focus for BMPs in agricultural operations to take into account this climate change effect.

3.2.2 Urban BMPs

Given the significant loading of phosphorous into Lake Erie from urban areas, there is clear need to evaluate the effectiveness of urban-focused BMPs. Moreover, because there are many diffuse sources of phosphorous within urban areas, so, too, the relevant BMPs will need to be highly varied and targeted for implementation in a wide range of urban activities.

Non-Point Source BMPs

The LEEP study reviewed two types of non-point source BMPs in the urban setting:

- alternative behavior/management BMPs (known as non-structural BMPs); and,
- structural (or engineered) BMPs.

Alternative Behaviour/Management) BMPs

Educational campaigns focused on changing behaviour of urban residents typically result in only modest changes, with some BMP practices adopted more readily than others. A common non-structural BMP often considered by communities facing phosphorous related problems in surface waters is reducing phosphorous loads from lawn fertilizers. Loadings are reduced considerably if fertilization is based on soil tests rather than routine practice (Erickson *et al*., 2005).

Scotts Phosphorous Free Lawn Fertilizers

In 2006, recognizing the link between nutrient runoff and algal blooms, the Scotts Miracle-Gro Company made a commitment to the Chesapeake Bay area that phosphorous in their lawn foods would be reduced by 50%. In 2011, Scotts expanded this commitment and pledged to remove phosphorous entirely from their Turf-Builder® lawn food maintenance products across the United States. In May 2013, Scotts announced that this goal has been achieved. All Scotts lawn maintenance products are now phosphorous-free; this will reduce the amount of nutrient runoff that is able to enter waterways and promote the growth of potentially harmful algae.

Alternatively, composted manure used as a source of slow-release phosphorous reduces total phosphorous loadings to urban streams compared to conventional commercial turf-grass sod imported and maintained with inorganic phosphorous fertilizer (Richards *et al*., 2008). In Ann

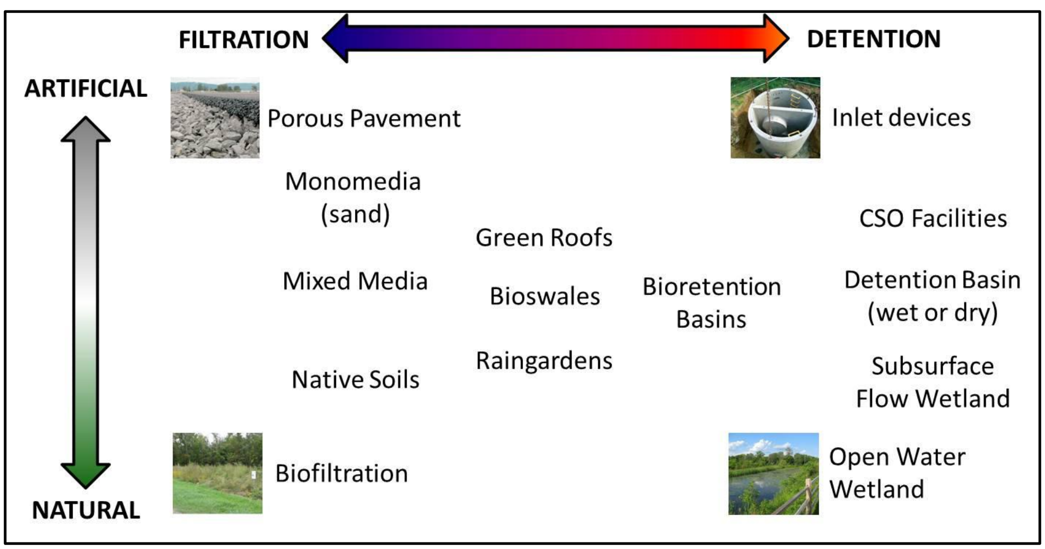
Arbor, MI, significant reductions in total phosphorous and a trend of DRP reduction followed a municipal ordinance limiting the application of lawn fertilizers containing phosphorous (Lehman *et al*., 2008). In the same city, Dietz *et al*. (2004) found 82 % of residents began to leave lawn clippings in place, while only 11 % applied fertilizer after soil tests. However, these changes were not found to result in a significant change in phosphorous loadings.

Other non-structural changes include better management of leaves, pet waste, street sweeping and the use of native plants. One study found that nearly three times more phosphorous was released when leaves were cut (for example, when mulched) (Cowen and Lee, 1973). In another study, pet waste accounted for 84 % of phosphorous inputs in the Minneapolis-Saint Paul, MN metropolitan area (Fissore *et al*., 2012). In northern Virginia, regular street sweeping was reported to result in 40-70 % removal of total phosphorous (NVPDC and ESI, 1992). Finally, the use of low maintenance plants that are indigenous to the eco-region are expected to reduce the transport of phosphorous through stormwater runoff (Hipp *et al*., 1993).

Non-Point Source Structural BMPs

Urban structural BMPs consist of a spectrum of approaches (Figure 3-1). Engineered systems typically employ filtration, detention which allows for settling of phosphorous that is adsorbed (attached) to soil particles or a combination of both. They can be designed as artificial systems or to apply natural processes.

Figure 3-1: Spectrum of Urban Structural BMPs



(Source: TACLE WG Summary Report 2013)

Traditionally, stormwater infrastructure was designed to mitigate flooding and move water as rapidly as possible to nearby water bodies. More recently, this infrastructure sought to reduce peak flows, sediment loads, and turbidity during runoff events. However, both of these objectives ignore other factors such as nutrient loads that play a significant role in water quality impairments (USEPA, 2009). As a result, BMPs are evolving to be more holistic and sustainable with the aim of reducing pollutant loads (Batroney *et al*., 2010). The following BMPs appear to be promising structural BMPs in urban settings:

- *porous pavements*: total phosphorous removal rates of 60-71 % have been reported through the use of porous pavements, though reports are inconclusive;
- *media filters:* sub-surface sand filters are reported to remove 43-82 % total phosphorous (Maniquiz *et al*., 2010; Leisenring *et al*., 2010);
- *filter strips/bio-swales*: level-spreader-grassed filter strips along highways appear to result in significant reductions (48 %) in phosphorous loadings in stormwater runoff (Horner *et al*., 1994; MMS, 1992; Reeves, 1994);
- *green roofs:* these can reduce the peak flow generated from urban roof tops; however, they may contribute more P than they absorb as a result of leaching from material used to construct the green roof. Limited data suggest differences in performance in the short- versus long-term, suggesting a need for more rigorous long-term study and monitoring (Berndtsson, 2010);
- *bio-retention basins:* include rain gardens, filter boxes and all other vegetative basins designed to increase infiltration and evapotranspiration. Removal efficiencies of phosphorous by bioretention basins are reported to be as high as 97 % depending on the composition of soils used (Carpenter and Hallam, 2010);
- *detention and retention basins:* treatment efficiencies vary considerably, ranging from 20 to 90 % removal, depending on their design (City of Austin 1995);
- *constructed wetlands:* removal efficiencies of constructed wetlands vary widely, ranging from 30 to 70 % of total phosphorous loads, with some evidence of reduced DRP loads, as well. However, removal in both sub-surface flow and open surface wetlands is hampered by low oxygen conditions that can result in the release of previously sequestered phosphorous (Van de Moortel *et al*., 2009); and,
- *commercial devices:* oil and grit separators have been found to be relatively ineffective (less than 10 % removal efficiency) in reducing total phosphorous loads. Another type of commercial device, a subterranean concrete detention basin designed to remove settled solids, similar to septic systems, was found to remove approximately 50 % (Zhang *et al*., 2010).

In reviewing the treatment efficiency of these various structural BMPs, the LEEP study reviewed more than 6,000 records from the International Stormwater BMP Database (www.bmpdatabase.org). Based on this review, the study concluded that:

- only 43 % of the samples demonstrated phosphorous removal;
- bio-retention ponds and wetland basins were the most effective urban BMPs, with about 82 and 75 %, respectively, showing some removal.

The review of treatment efficiency also highlighted the importance of understanding the different forms of phosphorous – total and DRP. For example, detention basins, bio-filters and wetland channels were all found to have clearly different removal efficiencies for *total* versus *dissolved* phosphorous.

There are limited reliable data available on the cost of structural urban BMPs. In general, the LEEP study found that engineered infiltration basins are the most expensive, detention basins and infiltration trenches the cheapest. However, these cost estimates are based on a small sample size and a diversity of specific BMPs included within broad categories. Moreover, the estimates do not account for size of watersheds and facilities.

Examples of Structural BMPs in the Lake Erie Basin:

Some recent structural BMPs applied in the Lake Erie basin include:

- *Bio-retention* - Detroit's storm-sewer-shed, Southfield, MI
- *Openwater Wetland* – Swift Run Wetland, Huron River Watershed, Ann Arbor, MI
- *Detention Basin* – Traver Creek Detention Basin, Huron River Watershed, Ann Arbor, MI
- *Retention Basin* – Pittsfield Retention Basin, Huron River Watershed, Ann Arbor, MI
    - *Bio-retention Basins and Surface Wetlands* – Lake St. Clair Metropark, MT. Clements, MI
- *Multiple BMPs* – Laurel Creek, Grand River in southern Ontario

Urban Point Sources

Lake Erie receives the largest municipal load of phosphorous of the Great Lakes, but large-scale waste water treatment plants have been nearly 100 % compliant with their discharge permits since the 1990s.

However, combined sewer overflows allowed under U.S. permits, in which treatment is bypassed during intense rain or snowmelt, deliver about 90.4 metric tonnes a year in total phosphorous to the lake from Ohio alone (Ohio EPA, 2010). Nineteen combined sewer overflows discharge untreated sewage directly into Lake Erie and 107 others discharge to receiving waters that empty into Lake Erie, including Mill Creek, the Cuyahoga River, Rocky River, and Big Creek (Gomberg, 2007).

Measuring the Performance of Urban BMPs

The LEEP study's analysis indicated that BMP performance can vary dramatically depending on the metric used (Lenhart and Hunt, 2011). Evaluating BMPs based on concentrations alone can be misleading, because performance varies during and between stormwater runoff events. Particularly problematic is the simple *%age removal* metric, because it is dependent on the initial concentration of pollutant (Zhang *et al*., 2010) and does not account for background water quality, eco-region differentiation, and background, or "irreducible," concentrations. Additionally, it inherently assumes an association between influent (incoming) and effluent pollutant concentrations (McNett *et al*., 2011).

Regardless of the type of BMP, three main mechanisms are responsible for phosphorous removal in stormwater: bio-uptake; sorption; and precipitation. Ultimately, phosphorous is retained through physical processes, either by attaching to material within BMPs (*e.g.*, sorption to wetland plants) or by settling out directly as a precipitate or indirectly while associated with biological material or suspended solids. Of these mechanisms, sorption reactions are the most common mechanism employed by most BMPs. However, because phosphorous partitioning between particulate and dissolved forms can vary widely depending on amount and type of solids present and can convert rapidly, improving BMP performance "will also likely need to address dissolved P in order to achieve high and/or consistent pollutant removal" (Leisenring *et al.*, 2010). This need for more advanced analysis of phosphorous is a common theme throughout urban and agricultural BMPs.

Encouraging Changes by Shoreline Residents:
The Rondeau Bay Community-Based Social Marketing Project

In 2010, responding to algal blooms, excessive weed growth and murky waters in Lake Erie's Rondeau Bay, Ontario's Ministry of Natural Resources (MNR) launched a community-based social marketing campaign to encourage shoreline residents to adopt land use and household practices to reduce discharges of nutrients to the lake. The campaign identified three key behaviours to encourage: the proper maintenance of septic systems: the use of phosphorous-free detergents; and, the use of phosphorous-free fertilizers.

A survey of the shoreline residents found that 90 % of respondents valued water quality as a community resource. Three significant barriers were identified: lack of awareness of the impacts of algal growth on water quality; lack of awareness of how residents were contributing to the issue; and, a lack of understanding of the relationship between nutrient enrichment and algae blooms.

The provincial ministry concluded that the shoreline residents did not have adequate information to make environmentally-minded decisions regarding their personal activities and the resulting inputs of phosphorous into Rondeau Bay. Based on this finding, the MNR:

- committed to a communication campaign about nutrient enrichment and algae;
- hosted a swap program in which residents could trade conventional fertilizers for phosphorous-free ones;
- provided a list of phosphorous-free detergents and ensured their availability; and
- began to use regular mailings from the municipality as opportunities to remind home owners to have their septic systems inspected and maintained.

Source: Ontario Ministry of Natural Resources, 2010

3.3 Response Curves and Establishment of New Loading Targets

Response curves show relationships between variables and were developed to predict levels of harmful algal blooms (HABs) and hypoxia as a function of phosphorous loading. These load-response curves, in turn, can be used to establish new loading targets, as part of a comprehensive management plan to restore the ecological integrity of Lake Erie. Owing to the bathymetry of the lake, the outlet of the Detroit River and the relative importance of different watersheds as sources of phosphorous, the western basin is prone to HABs and the central basin is prone to hypoxia.

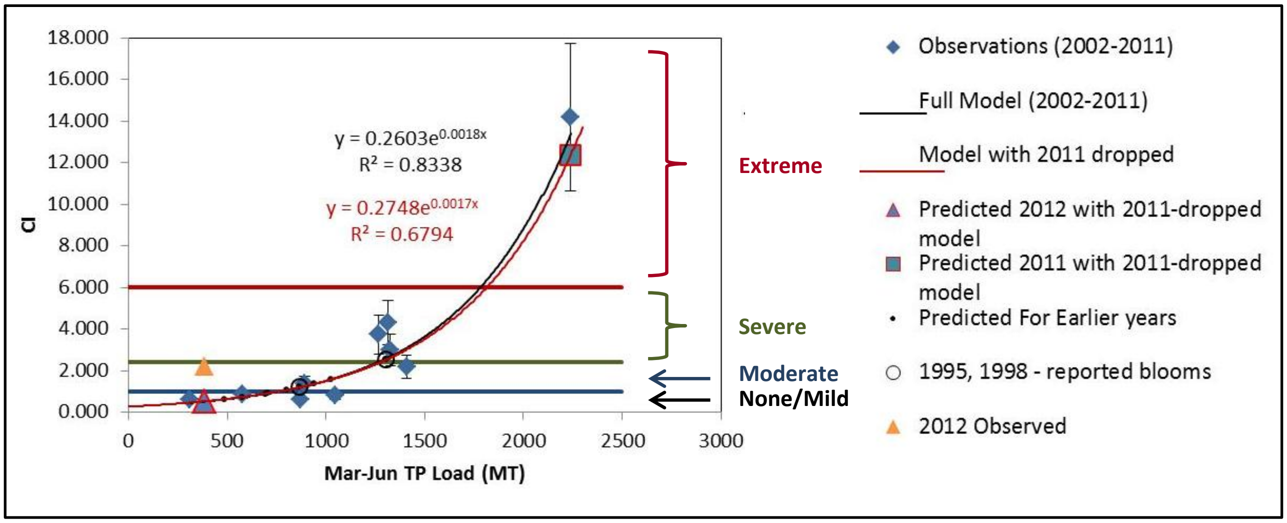
3.3.1 Harmful Algal Blooms in the Western Basin

Recent advances in satellite imagery have been used to quantify the spatial extent and severity of HABs in Lake Erie. Stumpf *et al.* (2012) developed a Cyanobacterial Index (CI) for the years 2002 to 2011 and related it to phosphorous loads. CI and area are linearly related, with a CI of 1.0 being approximately equivalent to 300 km^2 of bloom. The CI-total phosphorous (TP) loading model was calibrated using phosphorous data from Heidelberg University and discharge data from the USGS. Stumpf *et al.* (2012) found that spring discharge and TP loads from the Maumee River during the March-June period were strongly correlated with the CI.

Spring phosphorous loading from the Maumee River is considered a primary driver of HABs in western Lake Erie as the watershed is the dominant nonpoint source of nutrient loading to the western basin. It contributes about 5 % of the discharge to the western basin, but nearly 50 % of the phosphorous loading, making it a good surrogate for all western basin nonpoint sources. The other major source of loading to the western basin is the Detroit River, which also contributes almost 50 % of the phosphorous load, but more than 90 % of the discharge. Detroit River concentrations are considered too low to make a significant contribution to major cyanobacterial blooms in the western basin of Lake Erie, although loadings from the Detroit River may have a larger influence on central basin hypoxia and the overall trophic status of the lake.

The relationship between the March-June TP load and the CI is exponential (Fig. 3-2) and uncertainty around predictions of bloom severity tends to increase with higher loads. Rather than use this statistical model to calculate specific numerical CI values or annual forecasts, bloom categories were devised to capture the variability in observed blooms from 2002 to 2011 (http://epa.ohio.gov/Portals/35/lakeerie/ptaskforce2/P_Load_ConcRecs.pdf). Using these categories, severe or extreme blooms have been recorded in 4 of the 12 years and during another two years, borderline moderate/severe blooms have been recorded. Of the remaining six years, two fall into the moderate category and four fall into the none/mild category.

Figure 3-2: The Cyanobacterial Index (CI) plotted in relation to the spring (March-June) total phosphorous (TP) load for the Maumee River (modified from Stumpf *et al.* 2012).



To achieve an average annual bloom of "None/Mild" for western Lake Erie, the provisional TP load target for the Maumee River for the spring (March-June) period is 800 MT (Table 3-2). Dissolved (or dissolved) reactive phosphorous (DRP) is considered the most bioavailable fraction of TP and the fraction that triggers and sustains algal blooms. With the understanding that DRP comprises approximately 20 % of TP in western Lake Erie tributaries, a provisional DRP target for the spring period can be set at 150 MT. In addition, annual (12-month) load targets for the Maumee River can be estimated following conversion factor. Approximately 50 % of the annual TP load from the Maumee River enters the western basin during the spring, meaning the provisional annual TP load target for the Maumee River is 1600 MT.

The Maumee River watershed covers about 50 % of the western Lake Erie basin, not including contributing upper Great Lakes watersheds upstream of the outlet of the Detroit River. Other important watersheds that drain into the western basin include Sandusky, Raisin, Huron, Ottawa-Stony, Cedar-Portage, and the Huron-Vermillion, among other smaller watersheds. All have approximately the same level of agricultural land use (Han *et al.* 2012). Therefore, the provisional TP load targets for the western basin for the spring period is 1600 MT and for the entire year is 3200 MT. The provisional DRP load target for the spring period is 300 MT.

Table 3-2: Spring (March-June) TP and DRP targets and annual TP targets for the Maumee River watershed and the Western Lake Erie Basin using the Stumpf *et al.* (2012) Cyanobacterial Index (CI). Mar-Jun is March 1 through June 30 (50 % of the annual load discharged during this 4 month period); DRP is estimated at 20 % of TP; the Maumee River watershed is 50 % of the Western Basin (Maumee, Sandusky, Raisin, Huron, Ottawa-Stony, Cedar-Portage, Huron-Vermillion).

Cyano Index (CI)	**Bloom condition (year, 20xx)**	**Mar-Jun TP load (MT)**	**Mar-Jun DRP load (MT)**	**Annual TP load (MT)**
Maumee River				
<1	None/Mild (02, 05, 06, 07, 12)	<800	<150	<1600
1-2.4	Moderate (03, 04)	800-1250	150-225	1600-2500
2.4-6	Severe (08, 09, 10)	1250-1750	225-315	2500-3500
>6	Extreme (11)	>1750	>315	>3500
Western Lake Erie				
<1	None/Mild (02, 05, 06, 07, 12)	<1600	<300	<3200
1-2.4	Moderate (03, 04, 12)	1600-2500	300-450	3200-5000
2.4-6	Severe (08, 09, 10)	2500-3500	450-630	5000-7000
>6	Extreme (11)	>3500	>630	>7000

For the 2005 to 2011 period of record (7 years), the average March-June TP load from the Maumee River was 1160 MT, the average March-June DRP load was 240 MT, and the average annual TP load was 2580 MT (National Centre for Water Quality Research, Heidelberg University, http://www.heidelberg.edu/academiclife/distinctive/ncwqr/data). To achieve their respective targets, the March-June TP load reduction factor is 31 %, the March-June DRP load reduction factor is 37 %, and the annual TP load reduction factor is 38 %.

Selection of a baseline period of record for calculation of average annual loads can have a direct influence on load reduction factors. If the 2007 to 2012 period of record (6 years) from the same Heidelberg University NCWQR database is used to calculate annual loads, the average March-June TP load for the Maumee River is 1275 MT. Against the same target of 800 MT, the load reduction factor increases to 37 %. For the average March-June DRP load (255 MT), the load reduction factor increases to 41 % and, for the average annual TP load (2630 MT), the load reduction factor increases marginally to 39 %.

In comparing observed average loads against target loads, two additional factors should be taken into consideration. First, the recent trend towards more frequent and larger algal blooms in western Lake Erie means that more recent periods of record yield relatively higher phosphorous load reduction factors than longer periods of record that stretch back into the 1990s. Second, if the current trend of DRP displacing particulate phosphorous in TP loads continues, load reduction factors for DRP will increase.

These provisional targets should be phased in over a nine year-period (2013-2022) and interim targets should be established to coincide with the 2012 GLWQA triennial cycle. Given the scale of the HAB and hypoxia issues in Lake Erie and the attendant scale of nutrient abatement and management measures considered necessary to meet targets, significant lag times in phosphorous levels and overall ecological condition are to be anticipated.

The 2012 GLWQA includes an interim phosphorous (TP) load target for Lake Erie as a whole of 11000 MT per year. Most of the phosphorous entering Lake Erie does so into the western basin. The response curve relationships reported here suggest that this interim target should be revised; on average, phosphorous loads at this level will not have the net benefit of reducing the size and severity of HABs in western Lake Erie.

3.3.2 Central Basin Hypoxia

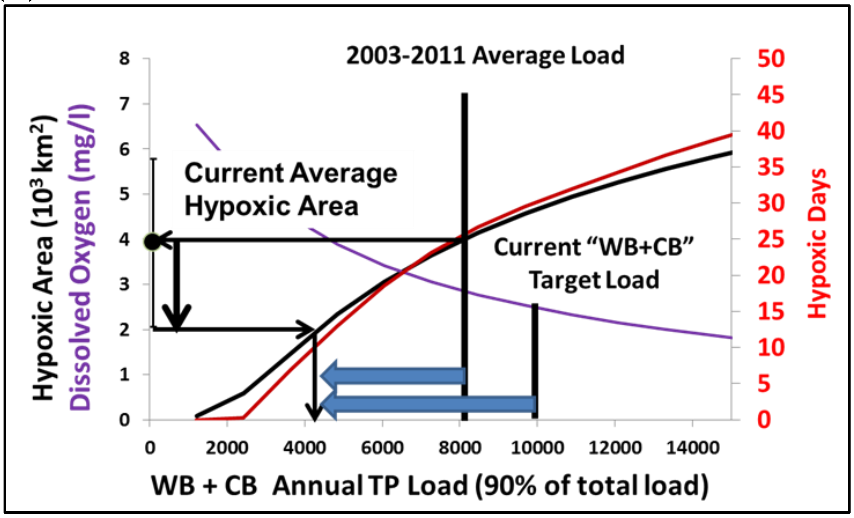
Response curves relating hypoxia to phosphorous loads were developed for the central basin of Lake Erie through application of hydrodynamic and eutrophication models (Rucinski et al. 2010, Rucinski et al. In revision) and geostatistical relationships observed between hypoxic area or hypoxic days and bottom-water dissolved oxygen concentrations (Zhou et al. 2013). In general, higher phosphorous loads are inversely related to dissolved oxygen levels, which, in turn, result in larger hypoxic areas and a greater number of hypoxic days.

For the years 2003 to 2011, the average TP load to the western (WB) and central (CB) basins of Lake Eire was about 8000 MT (Fig. 3-3). This translates into an average hypoxic area of 4000 km^2 and 25 hypoxic days. To decrease the hypoxic area by 50 % to 2000 km^2 and to about 10 hypoxic days a year, the target TP load for the WB and CB is 4300 MT, a 46 % reduction from the 2003-2011 observed average load and a 56 % below the current target.

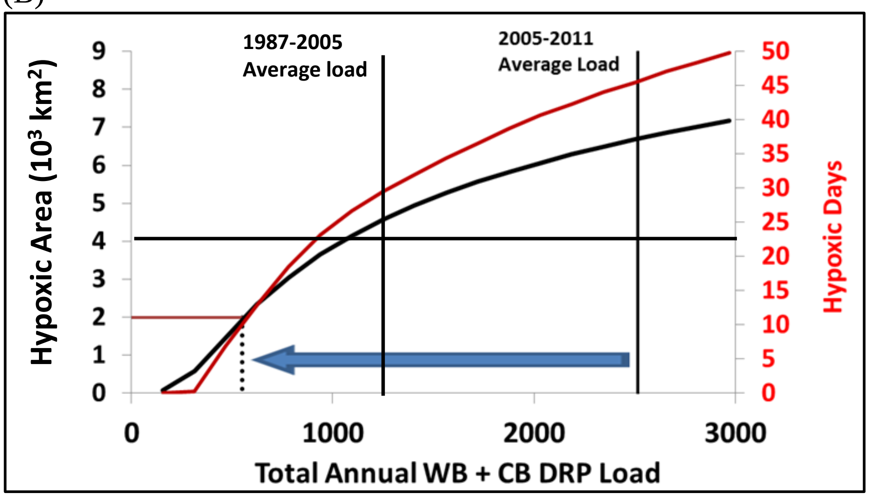
When expressed as annual DRP load, the target for achieving the same hypoxic area (2000 km^2) and number of hypoxic days (10) is 600 MT. This value is slightly lower than the average estimated for the early 1990s; however, since there has been a significant increase in DRP load over the past two decades, this new level represents a 78 % reduction from the 2005-2011 average DRP load.

Fig 3-3: (A) Relationships between total phosphorous (TP) load for the western (WB) and central (CB) basins of Lake Erie and dissolved oxygen concentrations, and two measures of hypoxia, hypoxic area and hypoxic days. (B) Relationships between dissolved reactive phosphorous (DRP) loads and hypoxic area and hypoxic days.

(A)



(B)



When the ecological issues of HABs and hypoxia are considered together, comparisons can be made between recommended targets between the two sets of responses curves. For the long-term elimination of HABs, the March-June TP target recommended by the IJC for the Maumee River is 800 MT, a 31 % reduction from 2005-2011 period of record or a 37 % reduction from the 2007-2012 period of record. If all western and central basin non-point sources were reduced by the same % and applied across the full year, then the resulting annual TP load would be reduced from 8000 MT to 6275 MT, which clearly exceeds that estimated for achievement of an average hypoxic area of 2000 km^2 (4300 MT). Therefore, in setting future targets, it is critical that HAB and hypoxia endpoints are developed separately.

3.4 Knowledge Gaps

The LEEP study undertook an extensive review of the knowledge gaps in the areas of monitoring and research for addressing lake-wide challenges in Lake Erie.

3.4.1 Monitoring

An appropriate targeted monitoring program is an important element of an effective and coordinated management plan for addressing declining water quality, increasing frequency and severity of algal blooms and associated ecosystem impacts. Monitoring data can provide input for the models used to establish new target loads and feedback on the results of management actions.

Status

The LEEP study conducted an inventory of federal, provincial and state government sampling programs in Lake Erie, as well as programs conducted by academic institutions. The analysis identified a wide variety of monitoring efforts, depending on the purpose of the monitoring.

Sampling programs aimed at the open waters of Lake Erie, such as the U.S. EPA Great Lakes National Program Office's monitoring and Environment Canada's Great Lakes Surveillance Program are undertaken on an annual or bi-annual basis. Other programs, including the Lake Erie Index Station Monitoring (near shore tributaries and open water), the U.S. National Coastal Assessment (nearshore and open water), the Ontario Broad Scale Monitoring Program (inland lakes), and the New York LCI program (inland lakes), operate on a rotational basis every three to five years. These programs are focused on detecting long-term trends. By contrast, the majority of tributary monitoring programs aim to detect nutrient samples on a monthly basis during the ice free season.

While the long-term annual or monthly monitoring efforts may give a reasonable picture of the status of nutrients in tributaries and Lake Erie over time, they may not fully capture the complexities of nutrient loading, such as those that occur during wet weather events. This limitation may make it more difficult to calculate nutrient loadings in the long run. The LEEP study found that only a few monitoring programs sample more frequently, on either a bi-weekly, weekly or daily basis. These programs can capture the effects of wet weather events and can be used to calculate nutrient loading more accurately. Heidelberg University has a sampling program that samples on a daily basis and three times daily during wet weather events. The U.S. Geological Survey recently installed automated tributary monitoring gauges that monitor on a daily basis and include special sampling during storm events. The Great Lakes Intakes Program (Ontario Ministry of Environment) and the Great Lakes Nutrient Initiative (Environment Canada) both sample tributaries and the nearshore on a weekly basis.

These findings highlight the importance of seasonality, frequency and coordination of programs to meet the different needs of program managers, whether they are focused on loading analysis, modelling, long-term trends or unique wet weather events that can cause a rapid influx of nutrients.

In general, there are frequent sampling programs for DRP and total phosphorous in all of the major tributaries to Lake Erie. However, many of the monthly programs do not perform specific sampling during wet weather. There are also consistent efforts to assess the nutrient concentrations in Lake Erie on a less frequent basis. However, many smaller tributaries are not monitored on a regular basis.

Most programs monitor for total phosphorous as well as DRP, among a wide variety of other water quality parameters, though several programs have indicated that they do not have the capacity to monitor for DRP. Most but not all of the major water quality sampling programs collect flow data or have nearby gauges that collect flow data. Several programs do not have flow gauges directly associated with the phosphorous water quality monitoring.

Key Gaps in Monitoring

Based on the review of current monitoring in Lake Erie, the LEEP study identified a number of important gaps with respect to monitoring. In general, there are limited detailed data on seasonal in-lake ecosystem dynamics, including nearshore-offshore connections, and on higher spatial-resolution watershed monitoring, with an emphasis on dissolved and particulate forms of phosphorous. Specific gaps include the following:

Detroit River Near the Outlet to Lake Erie

Lack of accurate Detroit River phosphorous loading measurements creates a sizable uncertainty in the phosphorous budget for Lake Erie. Without current information on the hydrology and chemistry of the Detroit River, it is difficult to estimate flow and phosphorous loads to Lake Erie, disentangle upstream sources of phosphorous, and a challenge to modernize load targets for Lake Erie as a whole and for its western, central and eastern basins.

Tributary Monitoring and Loading Measurements

There is limited monitoring of phosphorous loading to Lake Erie from key sub-basins, outside of the Heidelberg program. To track changes over targeted time frames, including during the critical snowmelt period and rainfall events and develop, refine, and calibrate watershed models, it is important to establish robust monitoring networks. This kind of information can enable evaluation of BMP effectiveness and facilitate transfers and scaling of edge-of-field results to other basins and at larger spatial scales.

Wet Weather Monitoring

There is a need to obtain nutrient loading data during wet weather events at a wider range of seasons in all major tributaries. This need will only increase as a changing climate brings more frequent and intense storm events.

Nearshore Monitoring

Current monitoring efforts in Lake Erie's nearshore are limited, particularly at higher resolution time and space scales. This gap inhibits a better understanding of nutrient dynamics in the ecologically important nearshore, and the exchange of water and nutrients between nearshore and offshore areas.

Lake Erie Charter Boat Association and the Ohio EPA Nearshore Monitoring Partnership

In 2011, the Ohio Environmental Protection Agency gained a partner in its water monitoring program in Lake Erie. With the help of the Lake Erie Charter Boat Association, an increased amount of nearshore data is being collected in the western basin of Lake Erie. Prior to this partnership, Ohio EPA staff monitored 13 nearshore water stations monthly, from March through October. The new partnership enables charter boat captains to help monitor water quality related to HABs between Toledo and Sandusky. The cooperative agreement provides researchers with more data on water quality, the effects of improved watershed management practices, and nutrient loading information in the western basin of Lake Erie from tributary streams.

Source: http://www.epa.state.oh.us/newsbycategory/tabid/5980/vw/1/itemid/19/ohio-epa,-lake-erie-charter-boat-association-partner-to-monitor-lake-erie.aspx

3.4.2 Research

LEEP identified several key gaps in current understanding of critical relationships in the Lake Erie ecosystem.

Harmful Algal Blooms

To date, most of the research on harmful algal blooms has addressed single model organisms. There are gaps in understanding the dynamics of entire bloom communities, including the interactions of the different physical, chemical and biological factors that influence freshwater blooms. This broader view could provide a more comprehensive picture of harmful bloom dynamics, and thus support better modelling efforts and lead to innovative management practices in the field.

One important example of the limited understanding of harmful algal blooms is the potential impacts of the disposal of dredge spoils in the open waters of Lake Erie. The Toledo Navigational Port, located in the shallowest portion of Lake Erie, is dredged on an annual basis to maintain a clear navigational route, with the spoils relocated for disposal farther out in the lake. However, open-lake disposal may contribute to the occurrence of harmful algal blooms through resuspension of nutrient-rich sediments that support algal growth. It is expected a field assessment during 2013, funded by the United States Army Corps of Engineers, which is responsible for the dredging, will help scientists assess the relative contribution of dredged material disposal to algal blooms in the basin.

Nuisance Algae Blooms

Much of the information regarding nuisance blooms in the Great Lakes in the past has been limited to site-specific assessments, sometimes supplemented with experimentation and simulation modelling. Lacking is a comprehensive understanding of how various factors, such as the interaction of lake water with land-based runoff and tributary discharges can be used to predict the conditions associated with nuisance blooms.

Fish and Fisheries

As noted in Chapter 2, harmful algal blooms, interacting with climate change, can affect Lake Erie fishes both directly (for example, by altering fish reproduction) and indirectly (for example, by altering food web interactions and the use of particular habitat). It will be critically important to better understand how the rich and diverse fish communities of the lake could respond under the warming trends and altered precipitation patterns associated with continued climate change.

BMPs

There are substantial gaps in the understanding of the effectiveness of current and emerging BMPs designed to prevent or reduce the risks of phosphorous loads to the Lake Erie ecosystem. For example, few studies have quantified phosphorous load reductions by urban or agricultural BMPs within the Lake Erie watershed. Reports of BMP effectiveness are variable and often contradictory.

Model Development

There is an important gap with respect to the development of models that can support the development of future target loads for Lake Erie. For example, the response curves in the LEEP study's assessment of target loads were based on a limited set of models related to algal blooms and a single set of models related to hypoxia. As was the case when the original target loads were established for Lake Erie under the Agreement, it is important to develop, test, and deploy a suite of models to decrease the uncertainty in the forecasts.

Watershed-based models are useful for quantifying sources of phosphorous from Lake Erie watersheds, evaluating BMPs, and forecasting the influence of climate change on phosphorous loads to stream and river networks.

Environment Canada's Great Lakes Nutrient Initiative

Focusing on Lake Erie, Environment Canada's $16 million Great Lakes Nutrient Initiative is helping address the complex problems of recurrent toxic and nuisance algae, nearshore water quality and ecosystem health in the Great Lakes. The Initiative targets five priority areas:

- establishing current nutrient loadings from selected Canadian tributaries;
- enhancing knowledge of the factors that impact tributary and nearshore water quality, ecosystem health, and algae growth;
- establishing binational lake ecosystem objectives, phosphorous objectives, and phosphorous load reduction targets;
- developing policy options and strategies to meet phosphorous reduction targets; and,
- developing a binational nearshore assessment and management framework.

The Initiative will help Canada to deliver on key commitments under the recently amended *Canada–United States Great Lakes Water Quality Agreement.*

Source: Environment Canada website: www.ec.gc.ca

U.S. Great Lakes Restoration Initiative

The U.S. government's Great Lakes Restoration Initiative is funded at approximately $285 million in 2013. Led by the U.S. EPA, the Initiative has funded multiple projects to restore and protect Lake Erie. One of the Initiative's objectives is to promote nearshore health by protecting watersheds from polluted runoff. Examples of projects designed to reduce nutrient runoff into Lake Erie and tributaries:

- A $194,000 project to increase nutrient management plan expertise in the Blanchard River watershed;
- A $497,000 grant to promote best management practices in the Maumee River Basin; and
- A $527,000 grant to promote nutrient reduction in Powell Creek.

(Source: Great Lakes Restoration Initiative website http://greatlakesrestoration.us/)

Dead Fish, Lake Erie 2011, Western Basin. Source: Michigan Sea Grant

Chapter 4:
Lake Erie Ecosystem Priority: Recommendations

4.1 The Challenge

The Lake Erie Ecosystem Priority (LEEP) study was established by the International Joint Commission (IJC) in 2012 in response to a growing challenge: lake-wide changes in Lake Erie related to problems of nutrient enrichment, compounded by the influence of climate change and aquatic invasive species. As a result of these changes, Lake Erie has experienced a decline in water quality over the past decade, with impacts on ecosystem health, drinking water supplies, recreation and tourism, and property values. LEEP's core objective was to provide advice to federal, state/provincial and local governments for developing policy and management approaches to address this challenge and help restore the health of the Lake Erie ecosystem.

LEEP was guided by a set of three-year goals established by the Commission for the Lake Erie ecosystem:

> *"In three years, we will have measurably reduced dissolved reactive* phosphorous loads *and algae. We will have a better understanding of causes and controls and an adequate monitoring system in place."*

To accomplish this goal, the Commission has spent much of the last year developing a better scientific understanding of the causes and controls of phosphorous loading into Lake Erie. This summary report has presented the key findings of the study in terms of:

- the key factors contributing to changes in the Lake Erie ecosystem, and the important effects of these changes on the Lake Erie ecosystem, human health and socio-economic conditions (Chapter 2); and,
- existing and possible initiatives to address the impacts on the Lake Erie ecosystem from phosphorous loading (Chapter 3).

4.2 Recommendations

Recommendations are grouped into four major categories:

- setting phosphorous reduction targets for Lake Erie;
- reducing phosphorous loading into Lake Erie from agricultural sources;
- reducing phosphorous loading into Lake Erie from urban sources, and
- strengthening research and monitoring in the Lake Erie basin.

4.2.1 Setting Phosphorous Reduction Targets

The 2012 Agreement provides an interim total phosphorous concentration substance objective for western Lake Erie of 15 parts per billion, and an interim phosphorous load target for the entire lake of 11,000 metric tonnes (MT) annually. The Parties have agreed to develop revised phosphorous concentration objective targets and phosphorous loading targets for Lake Erie within three years of the Agreement's entry into force in 2016. The response curve relationships developed for this report suggest that the interim target of 11,000 MT should be revised; on average, phosphorous loads at this level will not have the net benefit of reducing the size and severity of HABs in western Lake Erie.

The Commission believes that sufficient science exists to propose loading targets for phosphorous and dissolved reactive phosphorous for Lake Erie that will reduce harmful algae blooms in the western basin and reduce the hypoxic area in the central basin by half. The Commission believes that phased targets for reduction should also be set for three-year intervals, leading to attainment of the targets within nine years. Such an approach can be nested within an adaptive management framework whereby nutrient management policies and practices can be evaluated and prioritized.

The Commission recommends the following targets for phosphorous loadings:

- *To reduce the frequency and severity of harmful algal blooms in the western Lake Erie basin to an acceptable level, the total phosphorous (TP) load target for the Maumee River for the spring (March-June) period is 800 MT, a 37 % reduction from the 2007-2012 average. For dissolved reactive phosphorous (DRP), the target for the spring period is 150 MT, a 41 % decrease from the 2007-2012 average. Extended over the course of a full year, the TP target is 1600 MT, a 39 % decrease from the 2007-2012 average.*

- *When the rest of the watersheds in the western Lake Erie basin are included, the TP load target for the spring is 1600 MT and the DRP target is 300 MT. Extended over the course of a full year, the TP target is 3200 MT.*

- *To decrease the central Lake Erie basin hypoxic area by 50 % to about 2000 km^2 and 10 hypoxic days a year, the target TP load for the western basin and central basin is 4300 MT, a 46 % reduction from the 2003-2011 observed average load and 56 % below the current target.*

- *When expressed as annual DRP load, the target for achieving the same hypoxic area (2000 km^2) and number of hypoxic days (10) in the central Lake Erie basin is 550 MT. This new level represents a 78 % reduction from the 2005-2011 average DRP load.*

As noted in the Commission's 16th *Biennial Report*, most pollution reduction under the U.S. Clean Water Act has been accomplished through pollution discharge limits imposed via permits for individual facilities or "point sources" such as factories and wastewater treatment plants. While effective in reducing a significant proportion of pollution to Great Lakes tributaries and open lakes, this approach does not address most nonpoint sources such as pollution runoff from land, including agricultural land.

In the United States, the Clean Water Act provides a mechanism for addressing both point and nonpoint sources of pollution for a given water body. The total maximum daily load (TMDL) process entails development of an inventory of sources of a given pollutant for an individual water body, an allocation of the contribution of that pollutant from point and nonpoint sources to the water body, and an enforceable plan to reduce pollution from these sources in order to meet Clean Water Act water quality standards.

An analogous framework, respecting international differences in law and procedure and adopted voluntarily by appropriate jurisdictions, would enable the states of Michigan and Ohio and the Province of Ontario to develop a phosphorous cleanup plan for the western and central basins of Lake Erie. The plan would take into account all significant sources of phosphorous loadings to the western and central basins and allocate reductions according to the relative loadings of the sources. This would provide for both fairness and efficiency in reducing phosphorous loadings over time.

To help attain the Commission's proposed targets, the governments of Michigan, Ohio and Ontario, supported by U.S. EPA and Environment Canada, should develop a phosphorous cleanup plan for the western and central basins of Lake Erie, using a framework analogous to the U.S. Clean Water Act TMDL process. Such a plan will take into account all significant phosphorous sources, and allocate reductions of total phosphorous and DRP according to relative loadings.

4.2.2 Reducing Phosphorous Loading into Lake Erie from Agricultural Sources

The Commission concludes that the major sources of phosphorous to Lake Erie now are from non-point sources, especially agricultural operations. Reducing non-point source loads into Lake Erie poses a special challenge. There are many such sources across the area, mostly small in scale and widely distributed. Furthermore, reducing nutrient runoff from these sources require changes in practices that have until now typically been voluntary and incentive-based, and may now in some cases need to be enforceable through statute and/or regulation. Even if such practices are adopted, the results might appear only after a number of years and thus it can be difficult to measure their success.

The Commission also concludes that although total phosphorous loads have remained fairly constant since the late 1990s, the dissolved fraction of the total load has increased significantly. There is increasingly clear scientific consensus based on available research and prevailing expert opinion that reducing eutrophication problems in Lake Erie will require significant reductions in phosphorous loadings from agricultural operations.

Federal, state and provincial governments, with sometimes considerable involvement from local agencies and agricultural organizations, have developed a very complex suite of agri-environmental programming in the Great Lakes basin. The governments should accelerate their pursuit of a blend of activities to reduce nutrient loadings to Lake Erie by fully incorporating the following five principles:

Focus on Dissolved Reactive Phosphorous

The LEEP study found that the bioavailable form of total phosphorous – dissolved reactive phosphorous (DRP) is mostly responsible for driving the problem of harmful algal blooms in Lake Erie. Yet traditional agricultural best/beneficial management practices (BMPs) are geared towards particulate phosphorous, which has relatively low bioavailability. And to make matters more complicated, the LEEP study confirms that the effectiveness of various BMPs at reducing DRP is poorly understood. Further, the LEEP study found that the influence of subsurface drainage (i.e., agricultural tiles) is both poorly understood and poorly managed in comparison to surface runoff, and so is the role of drains in assimilating nutrients from surrounding farmland.

The Commission recommends that existing and planned incentive-based programs immediately shift to a preference for BMPs that are most likely to reduce DRP by reducing the amount of phosphorous applied to fields, slowing the movement of water to the field drainage system, and detaining flows at field drainage outlets.

Project Targeting

It has long been understood that different locations in the Great Lakes basin have different potential for phosphorous contributions to the lakes based on soil types, climate, gradients, prevailing agricultural practices, and other factors. Research and monitoring have identified the tributaries, and in some cases individual subwatersheds, that release a disproportionate share of the total amount of DRP entering Lake Erie. The Maumee River in Ohio contributes about five % of discharge, but nearly 50 % of phosphorous loading to the western basin, and should be the primary focus of phosphorous reduction efforts from non-point sources in the Lake Erie basin. Although project targeting in priority areas is underway – for example, the U.S. Great Lakes Restoration Initiative Action Plan (USEPA, 2010) and Ohio's Nutrient Reduction Strategy (2013) identify priority watersheds, as do efforts in Ontario to target the Lake Simcoe watershed – greater emphasis on priority watersheds and subwatersheds throughout the Lake Erie basin is required. The need to target phosphorous reduction also responds to the reality that there will probably always be limited resources available to address the sources of agricultural non-point source runoff.

Research conducted in the Maumee River watershed confirms that the spring load (March 1 to June 30) is highly predictive of subsequent harmful algal bloom size. Thus, management actions that target the timing of delivery of phosphorous to the lake are also critically important.

The Commission recommends that future management efforts focus on reducing the load delivered during the spring period (March 1 to June 30) and be focused primarily on those subwatersheds that are delivering the most phosphorous into the lake.

Apply Nutrients Based on Agronomic Need

This report earlier briefly described the 4Rs right fertilizer source, right rate, right time and right place which provides a useful framework for guiding fertilizer application in the Lake Erie basin and beyond. The 4Rs can be effective in reducing nutrient export from fields, while meeting plant nutrition needs and therefore maximizing crop yields.

The Commission's analysis determined that there are some good examples of voluntary 4R nutrient stewardship in the Lake Erie watershed. In fact, almost all of the jurisdictions in the Lake Erie watershed have voluntary certification programs, the *4R Nutrient Stewardship Certification Standard* in Indiana, Michigan and Ohio noteworthy among them. However, a review of ongoing efforts to reduce nutrient loadings to Lake Erie revealed that more progress is required to characterize fertilizer use. For example, Ohio EPA's Ohio Nutrient Reduction Strategy (OEPA, 2013) describes how current procedures by fertilizer retailers and applicators do not allow for farm-specific tracking of applications. Reporting procedures in other Lake Erie jurisdictions also make tracking fertilizer application difficult. It is also widely accepted throughout the agricultural community that while most farmers routinely sample soil fertility, only a smaller proportion apply fertilizer at variable rates within a field based on those results. Thus, nutrients are routinely applied at rates that do not reflect site specific soil fertility needs and exceed the agronomic need of the crops being grown.

The Commission recommends that federal, state and provincial governments accelerate both 4R outreach/extension programs, and phase in mandatory certification standards for agrology advisors, retailers and applicators to ensure fertilizer is applied based on the 4Rs.

Canada –Ontario Environmental Farm Plan (EFP)

The Environmental Farm Plans (EFP) program began in Ontario in 1993 and is internationally recognized for its success in assisting Ontario farmers to implement more environmentally sustainable practices. To date over 35,000 Ontario farmers have participated in the program.

An EFP is a voluntary assessment prepared by farm families to increase their environmental awareness in up to 23 different areas related to their farming operation. Through EFP local workshops, farmers and experts work together to identify each farm's unique environmental strengths and areas of concern. The farmers then set realistic action plans to address the areas of concern, as well as appropriate time tables to improve environmental conditions. Cost-share programs are available to help implement projects and improve environmental weaknesses. Farms with EFPs in Ontario can easily be identified by the 'our farm has an environmental farm plan' sign.

Source: http://www.omafra.gov.on.ca/english/environment/efp/efp.htm

Michigan Agriculture Environmental Assurance Program (MAEAP)

MAEAP was created in 1998 with the input of a coalition of agricultural, environmental, and conservation groups, who had a common goal in mind, the prevention of agricultural pollution. The program is innovative, proactive, and voluntary to help all farmers, in the state of Michigan, prevent or minimize the risk of agricultural pollution while keeping their farming operations sustainable. MAEAP is a three stage process designed to reduce farmers' legal and environmental risks. The program teaches effective land stewardship practices that meet both state and federal regulations, while allowing farmers to identify and prevent agricultural pollution risks from their farming operations. After the requirements are met, the farmer becomes certified and can display a MAEAP sign, which easily recognises that the farm is environmentally assured.

To date, 1,400 MAEAP verifications have been completed, over 10,000 Michigan farmers have started the process, and annually, an average of 5,000 Michigan farmers attend an educational session. Each year, MAEAP is credited with reducing soil erosion by more than 300,000 tons and phosphorous by more than 500,000 pounds. In addition, nearly 10,000 acres have been taken out of agricultural production and restored in the form of filter strips and almost 1,900 gullies have been stabilized to protect water quality.

Sources: *http://www.michigan.gov/mdard/0,4610,7-125-1599-12819--,00.html*
http://osceolalakecd.org/maeap/

Incentive-based programs

The Commission found that all Lake Erie jurisdictions offer some form of agricultural outreach and extension services, including technical advice and financial assistance for completing agricultural BMPs. As described elsewhere in the Commission's recommendations, the effectiveness of BMPs in reducing the impact of phosphorous on Lake Erie would be improved by targeting management actions to the spring runoff period, high delivery potential subwatersheds, and selecting BMPs that are effective at reducing the dissolved fraction of total phosphorous.

Despite the widespread implementation of BMPs, the LEEP study found that the overall proportion of total phosphorous loadings to the lake attributable to non-point sources has been increasing, especially from agriculture. Modeling has confirmed that while agricultural BMPs are having some effect in reducing the export of total phosphorous from watersheds to the lake, BMPs need to be much more widely implemented to substantially reduce nutrient yields.

Education and awareness-building are essential tools to promote greater adoption of BMPs. Research suggests that initiatives using a one-on-one interaction and on-farm visits are the most successful at encouraging adoption of specific nutrient management practices. Several jurisdictions have developed special stewardship outreach programs with these features. There is now an opportunity to build on the success of these initiatives throughout the Lake Erie basin.

The Commission recommends that federal, state and provincial governments and local agencies increase the level of funding support to 'scale up' agricultural BMP programs, in a manner which considers the other related recommendations in this report.

Regulatory programs

The Commission's analysis confirms that for most agricultural operations management of nutrients relies mostly on incentive-based programs, and influence-based models. Our study found that several decades of this approach has not been adequate in reducing agricultural non-point sources of nutrients to Lake Erie – total phosphorous loads have not declined appreciably in many watercourses draining agricultural areas, and the bioavailable fraction of total loads has been steadily increasing. The Commission also found that some regulatory controls are used to supplement traditional incentive and education based programming.

The Commission recommends that the Parties strengthen and increase the use of regulatory mechanisms of conservation farm planning, with nutrient management as a primary emphasis, in balance with the economic viability of the sector. As described earlier in this section, the Commission recommends that governments phase in mandatory 4R certification standards for agrology advisors, retailers and applicators to ensure commercial fertilizer applications meet plant nutrition requirements while minimizing impacts on downstream environments. Through a mandatory process that requires training for fertilizer industry actors, well-considered and science-based prescriptions for nutrient amendments at the field level, application practices that minimize runoff, and appropriate record keeping and reporting, nutrient loading to receiving waters can be minimized without compromising crop yields.

Regulatory controls should include those that link agricultural program benefits to environmental performance. In both the U.S. and Canada, crop insurance (also known as production insurance) is a key risk management program available to most producers. Crop insurance is the largest farm-related expenditure in U.S. federal agricultural policy, budgeted at about $90 billion over a 10-year period. In Ontario, roughly five million acres of farmland is insured through production insurance each year. Both U.S. and Canadian programs are taxpayer supported – for example, in Ontario, producers pay 40 % of the premium cost while the federal and provincial governments pay the balance of the premium cost and all of the administration costs. The insurance guarantees farmers a certain price for more than 100 crops, including those commonly grown in the Lake Erie basin. The security provided to farmers by crop insurance is valuable, but there is no linkage between the insurance and environmental stewardship. Without conservation compliance incentives, increased pressure from the marketplace puts marginal acres at risk, resulting, among other things, in tiling and draining of marginal lands, as has happened in the Lake Erie watershed. **The Commission recommends that U.S. and Canadian federal policy link the cost and availability of crop insurance purchases or premiums to farm conservation planning and implementation of nutrient management practices.**

Regulatory controls include legislated requirements on the handling and application of nutrients at a national or state/provincial level. The Commission's analysis confirms that there is unevenness across Lake Erie jurisdictions – for example, New York State prohibits manure application on frozen ground, Indiana prohibits it except in emergencies, while Ontario, Michigan, Ohio and Pennsylvania allow manure application on frozen ground under certain conditions. Liquid or semi-liquid manure, which contains phosphorous, cannot easily permeate frozen ground and is much more likely to run off into nearby water bodies, particularly if the region also has snow cover that melts during the winter. Our analysis showed different jurisdictional regulatory responses to application of other sources of phosphorous, including biosolids application on frozen ground and restrictions on manure application rates, and it is likely that other areas of difference exist that were not considered as part of our analysis. **The Commission recommends that all jurisdictions in the Great Lakes basin ban the application of manure and biosolids from agricultural operations on frozen ground or ground covered by snow.**

4.2.3 Urban Sources of Phosphorous Loading into Lake Erie

The LEEP study concluded that there are immediate opportunities to reduce nutrient runoff into Lake Erie from point and non-point sources in urban areas.

Urban stormwater can be an important source of nutrients. Construction projects in urban areas can cause significant soil disturbance. Eliminating sod cover and forested areas to make way for development removes water filtration and soil stabilization systems that contribute to the removal of nutrients from stormwater. Stormwater accumulates nutrients from a variety of sources including lawn fertilizers, cleaning agents and other urban residues. Impervious surfaces such as pavement and roofs that occur in urban areas are responsible for increases in volume of stormwater and the distance that it travels to the nearest water-body. "Green infrastructure" – including green walls, filter strips, rain gardens, bio-swales, engineered wetlands and stormwater ponds, among others – can help reduce nutrient runoff in urban stormwater. Federal, state and provincial incentives, including financial and technical assistance, are needed to support municipalities in the adoption of green infrastructure. As an alternative to requirements for more expensive stormwater controls, the Lake Erie basin states and Ontario can also authorize green infrastructure as a condition of permits or environmental compliance approvals.

The Commission recommends that state, provincial and federal governments work with municipalities to accelerate the promotion and use of "green infrastructure" – such as green walls, filter strips, engineered wetlands, pervious pavement and other measures – in urban stormwater management in the Lake Erie basin. These governments should provide funding and technical support to municipalities and, where feasible and appropriate as an alternative to more expensive stormwater controls, authorize green infrastructure in U.S. municipal water discharge permits and Ontario environmental compliance approvals, and encourage the adoption of local ordinances promoting green infrastructure.

The application of fertilizer to turf or gardens in urban areas can contribute to eutrophication, as fertilizer often runs off directly into surface water bodies or into storm sewers that may discharge into the environment without treatment. At the same time, sufficient phosphorous is present in most turf to support healthy lawns without phosphorous fertilizer. Several Great Lakes states have implemented limitations on the use of phosphorous fertilizer and require phosphorous-free fertilizer for most residential lawns. The Minnesota Department of Agriculture reports that since the implementation of lawn fertilizer restrictions in the state there has been no difficulty for homeowners in finding phosphorous free fertilizers. The law has substantially reduced phosphorous lawn fertilizer use without increasing consumer costs (Minnesota Department of

Agriculture, 2007). Implementing this type of regulation has reduced the amount of phosphorous found in nearby rivers in some cases. This may be significant because similar reductions were not observed in nearby areas that did not have similar regulation in place (Lehman et. al., 2009). Neither Ontario nor Quebec has province-wide laws that restrict the use of phosphorous for lawn care, but municipalities may pass by-laws that restrict the use of fertilizers in urban settings.

The Commission recommends that all jurisdictions in the Lake Erie basin prohibit the use of phosphorous fertilizers for lawn care with strictly limited exceptions.

Finally, a widely used approach to reducing nutrient runoff from urban sources is a permitting system requiring treatment to limit the amount of nutrients that can be discharged in effluent from municipal or industrial sources. All jurisdictions have implemented a permitting system for industrial and municipal discharges and Ontario regulations provide that each major municipal wastewater environmental compliance approval requires monitoring of nutrients. But among the Lake Erie Basin states, the percentage of major discharging facilities that do not monitor for phosphorous is 12 % in Michigan, 21 % in Ohio, 44 % in Pennsylvania and 53 % in New York. Approximately 32 % of major discharging facilities (municipal and industrial) in the Great Lake States do not monitor for phosphorous (U.S. EPA, 2012), although this does not include information for facilities with permit limits and monitoring requirements for other nitrogen species or phosphorous species (i.e., phosphate).

The Commission recommends that the Lake Erie Basin states require monitoring of phosphorous in effluent by all major discharging facilities in the lake's watershed.

Milwaukee, Wisconsin Leading the Green Infrastructure Movement

The city of Milwaukee, like many cities in the Midwest, lacked the capacity to contain high flow water events and discharged pollutants directly into its rivers and Lake Michigan. Milwaukee's greatest problem was outdated infrastructure, which combined stormwater with sewage in the sewer systems. The Milwaukee Metropolitan Sewerage District (MMSD) decided to take the initiative to begin investing in infrastructure solutions and urban BMPs. To solve the issues of high flow events and the combined sewers, a deep tunnel project was undertaken. The Deep Tunnel project is a 31.2 km (19.4mi) inline stormwater storage system and has reduced the likelihood of overflow events from over 50 to less than three times per year.

The MMSD has also implemented a number of urban BMPs to help reduce the amount of runoff entering the sewage system. A commitment to reduce runoff by 15 % is being achieved through green infrastructure, native plantings, and low-tech devices. The efforts made by the city are in line with LEED; in fact, Milwaukee is considering making LEED a requirement for all city-funded development projects. A stormwater fee, based off of the % of on-site impervious surface area, has also been implemented city wide. The fee can be challenged by the owner, if they implement one or more urban BMP practices on their property. The city of Milwaukee is now a leader in green infrastructure. The city represents a great case study of the effectiveness of urban BMPs and provides valuable insight into the implementation of these initiatives.

4.2.4 Monitoring and Research in the Lake Erie Basin

The LEEP study concluded that an improved understanding of critical relationships in the Lake Erie ecosystem and the ability to model them are core tasks for addressing challenges of nutrient enrichment and the associated environmental and socio-economic impacts. Strengthened monitoring and research are needed to support management initiatives, evaluate the effectiveness of BMPs, and develop models used in establishing new target loads for phosphorous and other nutrients.

The Commission recommends that governments commit sustained funding to enhancing and maintaining monitoring networks for:

- *tributaries throughout the Lake Erie basin, including key sub-basins;*
- *establishment of a water quality monitoring system at the outlet of the Detroit River that measures critical nutrient parameters;*
- *monitoring during wet weather events to capture seasonal differences from a wider range basin tributaries;*
- *urban areas to allow for the evaluation of the effectiveness of BMPs; and,*
- *lake monitoring both at the open-lake and nearshore levels.*

The Commission recommends that governments support research to strengthen understanding of:

- *the dynamics of harmful algal blooms through a "systems biology " approach studying entire bloom communities;*
- *whether and how open lake disposal of dredged sediments from the Toledo navigational channel affects phosphorous loadings in Lake Erie;*
- *how various factors, such as the interaction of lake water with land-based runoff and tributary discharges, can be used to predict the conditions associated with nuisance blooms under current and future climate change scenarios;*
- *how Lake Erie's diverse and productive fish communities could respond under the warming trends and altered precipitation patterns associated with continued climate change;*
- *the effectiveness of current and emerging BMPs designed to prevent or reduce the risks of phosphorous loads to the Lake Erie ecosystem; and,*
- *the economic effects of Lake Erie algal blooms throughout the entire lake basin.*

The Commission recommends that governments and organizations involved in water management in the lake improve data management through greater coordination and sharing through, for example, the development of a common data portal, which links to the relevant distributed data and provides an over-all situation assessment of Lake Erie.

Other Recommendations

The Commission also reaffirms recommendations from its *16th Biennial Report*:

- **Governments should support and encourage development and use of technologies such as using manure digesters and transporting manure to areas needing fertilizer.**
- **Governments should develop improved models to more accurately estimate phosphorous loadings to western Lake Erie and to other basins experiencing problems associated with excess phosphorous.**
- **Governments should collaborate to develop, maintain and share an inventory of effective management actions that are used to better retain nutrients and sediments on the land, especially in watersheds yielding high phosphorous loadings. Examples of management actions include: 1) implementing outreach to waterfront residents on better construction and maintenance of septic systems and 2) establishing requirements that septic systems be inspected at time of house sale and upgraded when necessary.**

Conclusion

The Commission fully appreciates the formidable challenges ahead in restoring the health of Lake Erie. Harmful algae blooms and an expanded hypoxic area developed over a 10 to 15-year period, and remedying these problems will take a comparable amount of time.

History shows, however, that the degradation of Lake Erie by human activities can be reversed by human effort. Fifty years ago, some declared Lake Erie dead and suggested that it was beyond remedy. Instead, with the collaboration of governments at all levels, an informed and active citizenry, and strong science underpinning, ambitious goals for Lake Erie's recovery were established and attained.

The Commission commends the governments of Canada and the U.S. for renewing their commitment to restore Lake Erie in the 2012 Agreement, and for investing in new initiatives that hold promise in furthering understanding and cleanup of the lake. This report is intended to support and inform this work. The Commission is optimistic that the same combination of government, public and scientific collaboration that reversed the degradation of Lake Erie in the 1970s and 1980s will do so again in the years immediately ahead.

Partnerships are Critically Important to Protecting Lake Erie

Many organizations and agencies on both sides of the border play an active role in working to protect and improve the health of Lake Erie. Partnerships both across the border and between public and private groups are critical to achieving the goals of reducing phosphorous loads and harmful algal blooms.

Lake Erie Waterkeeper: The Lake Erie Waterkeeper acts as an advocate for the health of Lake Erie and its tributaries like the Maumee and Cuyahoga Rivers. The Lake Erie Waterkeeper website provides the opportunity for members of the public to report pollution and algal blooms. It also provides recommendations for simple measures that people can take to reduce the phosphorous runoff from their homes and neighbourhoods as well as ideas for lobbying government officials to improve wastewater management and best management practices.

Conservation Ontario: Conservation Ontario has been a key player in the *Source Protection Program* that aims to protect water quality by reducing runoff and erosion. This program helps farmers and landowners to recognize when runoff and erosion may be occurring on their land, and provides recommendations for eliminating those problems. Recommendations include riparian area management like establishing buffer zones and restoring native plant ranges, and nutrient management like improving manure storage and handling or treating manure.

National Wildlife Federation: The NWF released a report in April, 2013 called *Taken by Storm: How Heavy Rain is Worsening Algal Blooms in Lake Erie*. This report examines link between spring rainfall and Lake Erie algal blooms and notes that heavy rains flush farm fertilizers and manure into local waters, which in turn drain into Lake Erie. This causes a build-up of phosphorous in the lake and, ultimately, toxic algal blooms. The report focuses on the Maumee River and provides a number of solutions to help implement strong conservation practices; restore the natural landscape and wetlands to reduce runoff; and reduce carbon pollution that causes global warming.

Ecojustice: In its 2013 *Great Lakes Sewage Report Card* Ecojustice analyzes 12 Ontario municipalities and ranks each one based on how they deal with sewage treatment. This report was then provided to mayors and city councillors in each of the 12 municipalities along with Ecojustice's recommendations for improving sewage management. These recommendations include prioritizing sewage infrastructure investment, investing in green infrastructure, and reporting whenever inadequately treated sewage is released.

Ducks Unlimited Canada: DUC works with public and private landowners to restore and retain wetlands. Natural wetlands play a critical role in the filtering out of nutrients like phosphorous before they reach rivers and lakes. By ensuring that wetlands are restored to health and by protecting currently healthy wetlands, DUC hopes to reduce the amount of nutrient runoff that reaches Lake Erie, thereby reducing the size and severity of nuisance algal blooms.

Lake Erie Lakewide Management Plan (LaMP): LaMP was a strategic response from Canada and the United States that outlines nutrient management actions to reduce excessive phosphorous loading and the eutrophication of Lake Erie. The report establishes nutrient targets for Lake Erie and its basins and provides goals for nutrient management, research and monitoring. The report also provides recommendations for how government, academia, conservation authorities, NGOs, community groups, industry, and the general public can do to reduce nutrient runoff to Lake Erie.

Appendix A

Lake Erie Ecosystem Priority Science Synthesis Workshop, Hilton Windsor, Windsor, ON (Canada) February 25-26, 2013 List of Attendees		
George Arhonditsis University of Toronto	Raj Bejankiwar International Joint Commission	Glenn Benoy International Joint Commission
Elin Betanzo Northeast-Midwest Institute	Jennifer Boehme International Joint Commission	William Bowerman University of Maryland
Greg Boyer University of New York	George Bullerjahn Bowling Green State University	Mark Burrows International Joint Commission
David Carpenter University of Albany	Hunter Carrick Central Michigan University	John Casselman Queen's University
Matthew Child International Joint Commission	Jan Ciborowski University of Windsor	Rem Confesor Heidelberg University
Tim Davis NSERC Research Fellow	Dave Dempsey International Joint Commission	Joe DePinto LimnoTech
David Dolan University of Wisconsin	Patrick Doran The Nature Conservancy	John Downing Iowa State
Sandy George Environment Canada	Chitra Gowda ERCA	Don Jackson University of Toronto
Saad Jasim International Joint Commission	Laura Johnson Heidelberg University	Donna Kashian Wayne State University
Gary Klecka Dow Chemical (Retired)	Brent Lofgren GLERL	Jill Mailloux International Joint Commission
Alex Mayer Michigan Technological University	Tracy Mehan The Cadmus Group, Inc.	Carol Miller Wayne State University
Lewis Molot York University	Michael Murray NWF	John Nevin International Joint Commission
Gertrud Nurnberg Freshwater Research	Natalie Ognibene International Joint Commission	Lana Pollack International Joint Commission
Jeff Reuter Ohio State University	R. Peter Richards Heidelberg University	Jeffrey Ridal St. Lawrence River Institute
Don Scavia University of Michigan	Scott Sowa The Nature Conservancy	Katie Stammler University of Waterloo
Craig Stow NOAA	Deborah Swackhamer University of Minnesota	William Taylor University of Waterloo
Lizhu Wang International Joint Commission	Sue Watson Environment Canada	Richard Whitman USGS
John Wilson International Joint Commission	Shawn McElmurry Wayne State University	Dereth Glance International Joint Commission

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Glossary

ADAPTIVE MANAGEMENT -- A planning process that can provide a structured, iterative approach for improving actions through long-term monitoring, modelling and assessment. Through adaptive management, decisions can be reviewed, adjusted and revised as new information and knowledge becomes available or as conditions change.

ALGAE – Aquatic organisms that survive through photosynthesis; they can range in size from microscopic organisms to large seaweed and giant kelp.

ALGAL BLOOMS – An excessive and relatively rapid growth of algae on or near the surface of water. It can occur naturally as the result of a change in water temperature and current or as a result of an excess of nutrients in the water.

BASIN – All land and water within the confines of a drainage basin. Similar term: **Watershed.**

BEST MANAGEMENT PRACTICES (BMP) – A term used in the United States and Canada to describe a range of proven, practical methods, techniques and other actions that allow individuals or organizations to prevent or reduce the risks of water pollution resulting from their activities. Best practices typically evolve over time, as new approaches are introduced, proven to be effective and adopted. Also known as beneficial management practices.

BIOAVAILABLE PHOSPHOROUS - That portion of the total phosphorous that is available to support algal growth (also known as dissolved reactive phosphorous [DRP] and dissolved reactive phosphorous [SRP].

BOUNDARY WATERS TREATY OF 1909 – The agreement between the United States and Canada that established principles and mechanisms for the resolution of disputes related to boundary waters shared by the two countries. The International Joint Commission was created as a result of this treaty.

CLIMATE CHANGE – A change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable time periods.

EUTROPHICATION – The process by which a body of water becomes rich in dissolved nutrients, such as phosphorous, thereby encouraging the growth and decomposition of oxygen-depleting plant life and resulting in harm to other organisms; also known as nutrient enrichment.

EXTERNAL LOADING – Runoff of a pollutant from various point sources and non-point sources in the watershed, from upstream lakes and rivers, and from the atmosphere.

GREAT LAKES WATER QUALITY AGREEMENT (THE AGREEMENT) – First signed in 1972, the Agreement expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem.

HYPOXIA – A condition where excessive nutrients contribute to algal growth and subsequently high oxygen consumption during decomposition of the algae. This process creates “dead zones”, typically near the lake bottom, where dissolved oxygen levels are so low that fish and other aquatic life cannot survive.

INTERNAL LOADING – Transport of a pollutant from sources within the lake, such as from bottom sediments.

INTERNATIONAL JOINT COMMISSION (IJC) – International independent agency formed in 1909 by the United States and Canada under the *Boundary Waters Treaty* to prevent and resolve boundary waters disputes between the two countries. The IJC makes decisions on applications for projects such as dams in boundary waters, issues Orders of Approval and regulates the operations of many of those projects. It also has a permanent reference under the Great Lakes Water Quality Agreement to help the two national governments restore and maintain the chemical, physical, and biological integrity of those waters.

LOADING – Entry of a pollutant, such as phosphorous, into a water body.

NON-POINT SOURCES – Sources of pollutants associated with many diffuse locations and origins, typically transported by rainfall and snowmelt runoff over land; for example, excess fertilizers, herbicides and insecticides from agricultural lands and residential areas.

NUTRIENT – A food, or any nourishing substance assimilated by an organism, and required for growth, repair, and normal metabolism. For example, phosphorous and nitrogen are nutrients for algae.

PHOSPHOROUS – An element used in a wide range of agricultural, industrial and domestic products; the key nutrient limiting the amount of phytoplankton and attached algae in Lake Erie.

POINT SOURCES – Sources of pollutants, such as phosphorous, associated with a specific location; for example, an industrial or sewage treatment plant.

TOTAL PHOSPHOROUS – Refers to all forms of phosphorous in a given volume of water, including particulate and dissolved forms.

Metric System – United States Customary System Units

(with abbreviations)

Length

1 metre (m) = 3.2808 feet (ft)
1 ft = 0.3048 m
1 kilometre (km) = 0.6214 mile (mi)
1 mi = 1.6093 km

Area

1 square kilometre (km^2) = 0.3861 square mile (mi^2)
1 mi^2 = 2.59 km^2
1 hectare (ha) = 2.47 acres
1 acre = 0.405 ha

Weight

1 metric tonne (MT) = 1.1 short tons (2,200 pounds)