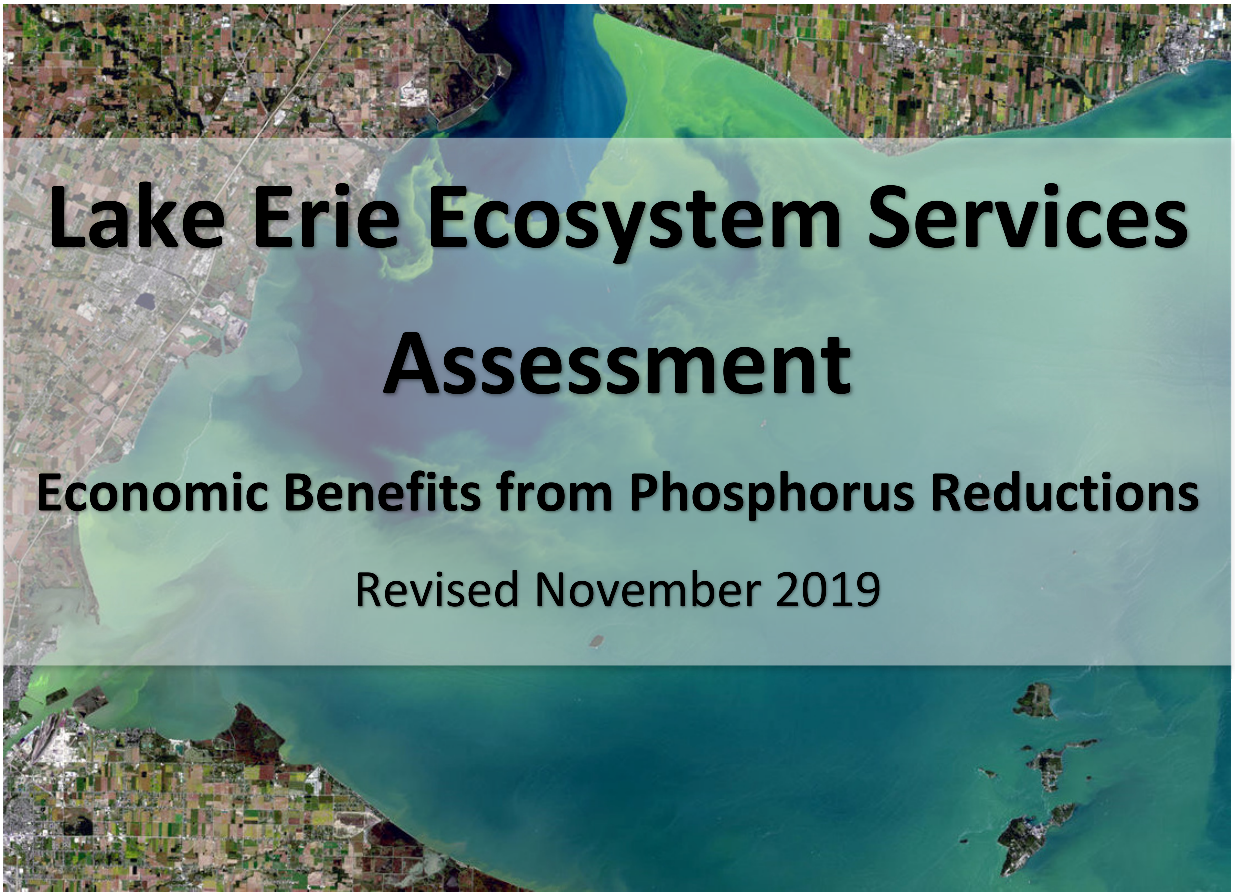

Lake Erie Ecosystem Services Assessment

Economic Benefits from Phosphorus Reductions

Revised November 2019

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Table of Contents

Cover Photo: Satellite Image of the 2017 Harmful Algal Bloom

Photo Credit: USGS, 2017

Abbreviations

Consumer Surplus is the value of a good or service to the consumer, over and above what the consumer pays for that good or service.

Ecosystem Services (ES) are, simply and in the terms chosen by the U.S. Forest Service, "the benefits people obtain from ecosystems" (USDA Forest Service, 2012). We prefer a definition with a little more power to guide analyses of ecosystem services:

"Ecosystem services are the effects on human well-being of the flow of benefits from *ecosystems to people* over given extents of space and time" (Johnson, Bagstad, Snapp, & Villa, 2010).

The italics are to emphasize that ecosystem services are about human welfare, not nature for its own sake. They are about flows of benefits (as opposed to states of nature). Ecosystem services also flow from one place to another at one time or another (they are not static). This definition is an important component of the lens through which we have viewed and evaluated the existing literature.

Ecosystem Service Value (ESV) is the translation of a flow of benefits into dollar terms. So, we can say that a flow of a million gallons of water per day in a watershed is an ecosystem service. And if each gallon is worth a penny, we could say that the ecosystem service value of that daily flow would be $10,000.

Benefit Transfer Method (BTM) is a means of establishing the value of ecosystem service flows in one setting by transferring values derived through primary research in another setting. For example, if a study of the ecosystem service values of a wetland forest in one place has determined that each acre of such forest generates $1,000 per acre per year in recreational value (because it is good songbird habitat and therefore supports birdwatching, say), we might transfer that value to an acre of wetland forest in another location. This is an example of the sub-genre of BTM known as "unit value transfer", in which a single number or set of numbers is transferred from the earlier study.

Harmful Algal Blooms (HABs) are overgrowths of algae in water, of which some produce toxins that are often fueled by sunlight, slow-moving water, and nutrient loading, and can kill or sicken animals and people, create dead zones in water, and raise treatment costs for drinking water.

Willingness to Pay is the maximum price a consumer is willing to pay for a good or service.

Table List

Figure List

Executive Summary

Project Findings

In the Lake Erie subregion, an ecosystem assessment framework allows us to connect biophysical processes to economic outcomes. This creates a more complete picture of environmental interventions that could result in the greatest change in benefits to communities and the general public over space and time by quantifying the value that we receive from those affected ecosystem services.

Specifically, we quantify benefits gained and costs avoided for achieving the GLWQA target 40% phosphorus reduction goal for spring total phosphorus (TP) and soluble reactive phosphorus (SRP) loads as well as other general phosphorus reductions. Following the model allows us to:

- Measure how changes in ecosystem outcomes (and indicators) will occur by achieving the target, specifically changes in the frequency, severity, and toxicity of HAB events,
- Estimate changes in the established target ecosystem services for evaluation - recreation, aesthetics, food/nutrition, raw materials, waste assimilation, and water supply, and
- Quantify the benefits (or avoided losses) people in the Lake Erie subregion would gain if phosphorus reductions are achieved.

The Economic Benefits of Reducing Harmful Algal Blooms

This analysis estimates that achieving the GLWQA 40% phosphorus reduction goal would result in gains of $1 million (2018$ USD) and $31.3 to $123.4 million (2018$ USD) for Lake Erie's beach-goers and recreational anglers, respectively. These are the first estimates that directly quantify economic benefits that all (Canadian and U.S.) beach-goers and recreational anglers visiting Lake Erie would receive if the GLWQA 40% reduction target is achieved.

General reductions in phosphorus loads could also reduce the frequency and intensity of HABs, which could have positive impacts on recreationists and spur additional benefits. Findings from analyses of other levels of phosphorus reduction include:

- A 20% reduction in spring SRP loads from the Maumee River which would result in an annual consumer surplus gain for all of Lake Erie's recreational anglers of $11.7 to $37 million (2018$ USD).
- A 20% reduction in the number of water quality advisories and beach closure days for Lake Erie's beaches which would result in benefits ranging from $23.8 to $26.7 million (2018$ USD).
- A 30% reduction in the number of water quality advisories and beach closure days for Lake Erie's beaches which would result in benefits ranging from $36.2 to $41 million (2018$ USD).
- An annual reduction in the incremental operating costs associated with the treatment and monitoring of algae of up to $2.6 million a year (2018$ USD) for water treatment plants sourcing water from Lake Erie.

On the other hand, if there is no reduction in phosphorus loads and HABs continue to occur annually, there could be residential property value declines for U.S. and Canadian households next to and near the lake as well as increased costs to public water suppliers. If HABs continue to create conditions in which microcystin drinking water standards are exceeded, households next to and near the lake could experience property value losses of $685.9 million to $1.1 billion (2018$ USD), respectively. This analysis also provides the first estimate, to our knowledge, of potential algae-related costs for the 43 public water suppliers (31 U.S. and 12 Canadian) sourcing water directly from the lake. Capital expenditures for algae-related projects from 10 plants surveyed and from three Canadian plants total over $84.7 million to date.

Background

Lake Erie is the most biologically productive of all the Great Lakes and the main drinking water source for over 11 million people. The Great Lakes provide drinking water for 40 million people and represent one-third of the U.S. economy. Because Lake Erie is shallow and highly productive, the lake serves as an indicator for the deeper lakes that take longer to respond to threats. Determining the economic threats to Lake Erie provides a warning of the economic damage from Harmful Algal Blooms (HABs) that could come to other Great Lakes.

Put-In-Bay
Photo Credit: Lake Erie Shores & Islands

Lake Erie's waters support a critical $12.9 billion tourism industry, is home to world-class walleye and smallmouth bass fisheries, and provides a multitude of recreational opportunities such as bird watching, boating, and recreational fishing (U.S. EPA, 2019). In the past decade, harmful algal blooms (HABs) have plagued the lake annually, with some events producing toxic algae that threaten the tourism industry, near lake property values, and local businesses. To address the resurgence of HAB events, Canada and the United States signed the amended Great Lakes Water Quality Agreement (GLWQA) in 2012 with Annex 4 specifically addressing HABs in Lake Erie and other Great Lakes. Annex 4 required domestic action plans for both the U.S. and Canada be completed, with a specific focus on the western and central basins of Lake Erie. The domestic action plans were completed in 2018 and the plans established nutrient reduction objectives for the western and central basins positioned to reduce the frequency and intensity of HABs. This analysis focuses on the western basin objective—a 40% reduction in the total and soluble reactive phosphorus entering Lake Erie.

Project Overview

Lucas County, the City of Oregon, and the City of Toledo, provided support for this study to better understand how economic benefits (or avoided costs) would accrue through connecting potential land and resource management actions with the maintenance and improvement of key ecosystem service values. The framework for this ecosystem service assessment is provided through:

- Participatory research techniques with key regional stakeholders to refine and gain consensus around a targeted subset of ecosystem services for detailed analysis;
- Analyzing existing relationships between stressors and the supply of those key services and using the results to estimate impacts of management changes on ecosystem service supply; and
- Assessing the economic and environmental impacts of degradation of water quality in the Lake Erie subregion.

The first phase of this study[1] included an extensive literature review of the economic value of ecosystem services related to water quality in Lake Erie which provided a foundation for this analysis. Results from Phase I indicated that the majority of existing research and funding has been directed to either the Great Lakes region as a whole, or to the presence of HABs in the western basin.

To our knowledge, this analysis is the first ecosystem service assessment that quantifies the economic benefits (or avoided losses) of achieving the GLWQA 40% phosphorus reduction target goal and other phosphorus reductions for **all** of Lake Erie's recreational anglers and beach-goers in Canada and the United States. This analysis also quantifies the potential property value losses for households along the Lake Erie lakefront if toxic algae continue to be prevalent, and potential annual operating costs associated with the monitoring and treatment of algae for all public water suppliers sourcing water directly from Lake Erie.

Scope of Project: Lake Erie Subregion Ecosystem Service Assessment

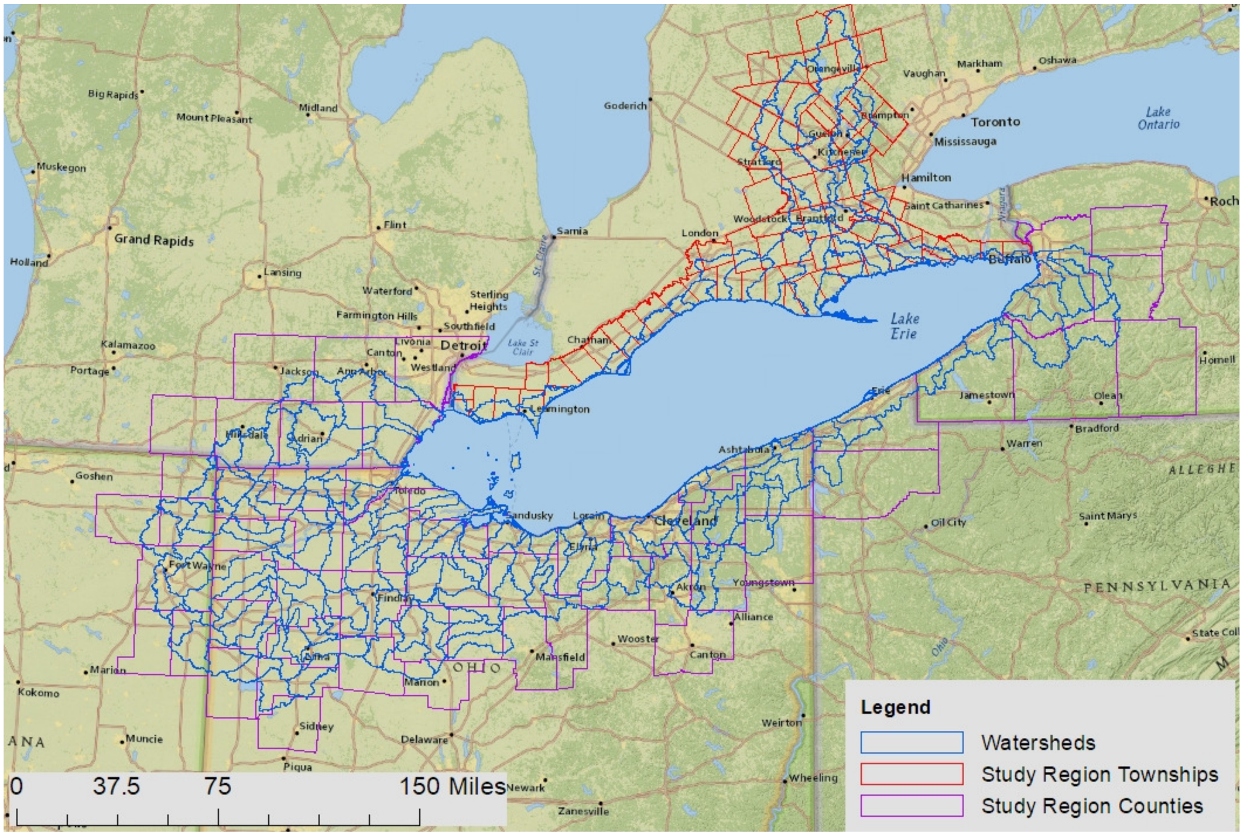
This project uses a baseline ecosystem service assessment to understand how management scenarios result in changes in the supply of ecosystem services and understand what the natural and recreational assets in the subregion are worth. These changes in supply have a monetary value, and by incorporating ecosystem service values into funding prioritization, policy-making, and management planning, we can better understand how management scenarios trigger downstream benefits to society and understand what costs (or foregone benefits) would accrue with the maintenance of the status quo.

[1] Sponsored by the Lake Erie Foundation and the National Fish and Wildlife Foundation.

Geographic Scope

This assessment defines the Lake Erie subregion as the 160 watersheds (HUC 10/Quaternary-U.S. and Canada classifications, respectively) which drain directly into the western, central, and eastern basins of Lake Erie (Figure ES-1).[2]

Figure ES-1. Study Region-Lake Erie Watersheds



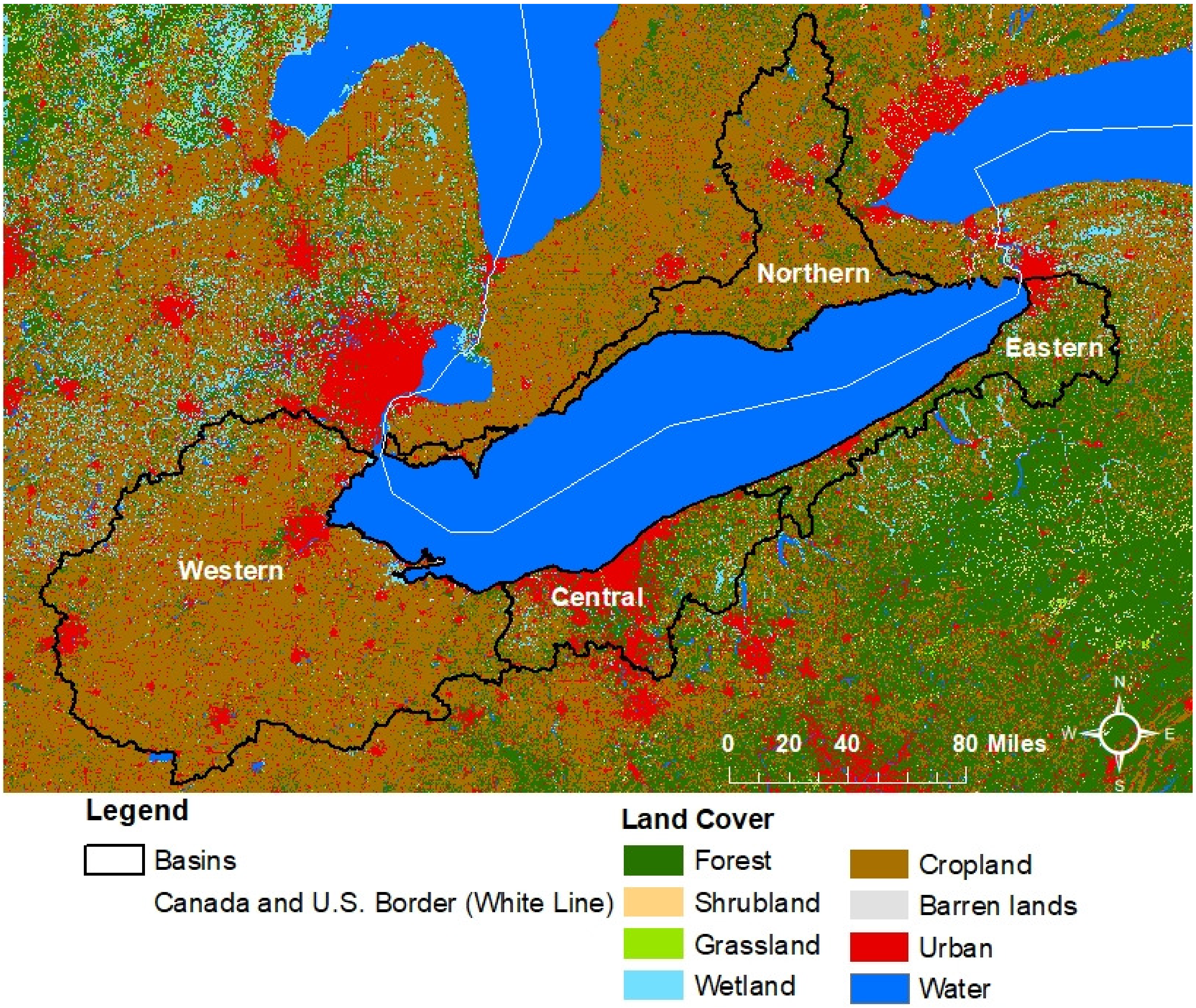
Value of the Lake Erie Subregion's Natural Capital

The dominant land cover type across the subregion is cropland, followed by water, temperate subpolar needleleaf forest, and urban land (Figure ES-2).

The land cover in the subregion provides over $443.0 billion (2018$ USD) in ecosystem service benefits annually, with water contributing the most at over $326.9 billion (2018$ USD) and cropland adding another $101.5 billion (2018$ USD). By ecosystem service, waste assimilation, or the improvement of soil and water quality through the breakdown and/or the immobilization of pollution, supplies an annual benefit of over $112.4 billion (2018$ USD). Recreation contributes another $108.4 billion (2018$ USD) in annual ecosystem service value while food/nutrition contributes to $79.2 billion (2018$ USD)

[2] The lake itself has three distinct basins, the western, central, and eastern. The Northern "basin", or the Ontario portion of the subregion, does not refer to the lake's three basins, rather the tertiary (Canadian watershed classification equivalent to U.S. HUC 8 watersheds) watersheds that comprise the secondary (Canadian watershed classification equivalent to U.S. HUC 6 watersheds) watershed. See Table 1 for more details on the watershed classification levels for U.S. and Canada.

Figure ES-2. Land Cover in the Study Region
Source: Commission for Environmental Cooperation, 2018



Methods for Analysis

This assessment is completed through three elements:

1) Evaluating Means-Ends Using the National Ecosystem Service Partnership Guidebook
    a) The first element develops a means-end diagram that lays out the most important pathways by which our predefined stressor connects to biophysical and economic quantities. Once an action and pathways between the action and ecosystem services are established, we then can measure how changes in ecosystem service provision in the Lake Erie subregion translates into economic benefits.
    b) An important step in this process is gaining a better understanding of what ecosystem services are important for people living in, or visiting, the Lake Erie subregion. To further refine and prioritize the baseline ecosystem services, we incorporated

stakeholder input, in the form of an online survey and two online webinars, to get a better account of how people in the subregion value and use the lake.

2) Spatial Analysis Connecting Sources, Sinks, and Benefit Areas
    a) After identifying key ecosystem services and societal benefits or outputs in the Lake Erie subregion using means-ends diagramming, we connect actions and ecosystem processes to geographically specific areas where ecological and/or economic outcomes could occur.
3) Estimating Key-Ecological and Economic Outcomes
    a) Our last step employs the production function method to estimate the value of key individual ecosystem services produced and enjoyed in the region using the results from the survey and webinars, relevant data, and previous studies of ecosystem service provision in other areas reasonably similar to the Lake Erie subregion.

Next Steps

This assessment, like other ecosystem service assessments, relies on applying estimates developed from existing literature to a focus area. HABs and algae have wide-ranging impacts on a number of critical economic industries and activities in the subregion, however, we were unable to quantify economic outcomes due to the lack of literature connecting how reducing harmful algae would produce specific benefit outcomes. This analysis is an important first step in understanding how reducing the intensity, severity, and frequency of HABs can translate into positive economic and environmental benefits across the subregion and the methods established should serve to guide future analysis on other important industries and activities in the region.

Overview of Lake Erie's Ecosystem and Harmful Algal Blooms

About the Lake

One-third of the total population of the Great Lakes Basin resides within the Lake Erie subregion, making it the most populated Great Lakes watershed (U.S. Environmental Protection Agency [U.S. EPA], 2019). Lake Erie provides drinking water for roughly 11 million people, including 17 metropolitan areas with populations of over 50,000 (U.S. EPA, 2019). Within the Great Lakes Region, Lake Erie faces the greatest environmental stress from urbanization, industrialization, and agriculture.

Lake Erie boasts 872 miles of shoreline and the entire subregion encompasses five states: Ohio, Michigan, Pennsylvania, New York, Indiana, and Ontario, Canada. Lake Erie is the smallest (by volume), shallowest, and southernmost Great Lake. The lake has an average depth of about 62 ft, warms rapidly in the summer, and has a retention time[3] of only 2.6 years (U.S. EPA, 2019). Due to its shallowness and warmer waters, Lake Erie is the most biologically productive Great Lake, supporting a $244 million commercial fishing industry (U.S. EPA, 2019).

The lake itself has three very distinct basins — the western, central, and eastern — that function nearly separately due to their different depths. The western basin is the shallowest, with an average depth of 24 ft and a maximum depth of 62 ft (U.S. EPA, 2019). The central basin has an average depth of 60 ft and a maximum depth of 82 ft and the eastern basin is the deepest, with an average depth of 80 ft and a maximum depth of 210 ft (U.S. EPA, 2019).

Maumee Bay State Park
Photo Credit: Rachel Tippett

[3] Retention time is the length of time it takes for water in a lake to be completely replaced (Center for Great Lakes Literacy, n.d.).

The Resurgence of Algal Blooms in Lake Erie

Algal bloom in Maumee Bay State Park
Photo Credit: Pamela Struffolino, University of Toledo (USGS, 2018b)

During the 1960s, the lake was perceived as dying and in dire need of restoration efforts due to excessive nutrients, eutrophication, and increasing algal blooms. Throughout the '70s and '80s, binational collaborations between the U.S. and Canada aimed to improve water quality by controlling nutrient and toxic pollution from point sources such as wastewater treatment plants and eliminating phosphorus from laundry detergents. The success and adoption of phosphorus control programs virtually eliminated algal blooms by the late '80s; however, in the mid-1990s algal blooms returned to the lake's western basin and water quality again declined.

The "re-eutrophication" of Lake Erie is different from the blooms experienced in the 1960s, as there is a different conglomeration of toxic blue-green and green algae (predominantly the cyanobacteria, *Microcystis*) and shoreline algal problems are more localized (Strickland, Fisher, & Korleski, 2010). Given that **total** phosphorus loading has remained relatively constant since the 1980s, scientists now suggest that some of the new causes of re-eutrophication are (Strickland, Fisher, & Korleski, 2010):

- Increased internal loadings of phosphorus,[4]
- An underestimation of phosphorus inputs from sources like stormwater,
- Changes in overall nutrient balances in the lake and related adaptations of nutrient uptake mechanisms by algae and bacteria,
- Changes in **bioavailable**[1] (dissolved) phosphorus loadings that do not parallel changes in total phosphorus loading, and
- Changes in climate conditions that affect the physical conditions in the lake, such as lake levels, rising temperatures, and wind events.

[4] Internal loading is the "result from phosphorus from organic sources (feces, decomposition of dead matter, etc.) and the release of phosphorus that is already stored in lake sediments" (Bingham, Sinha, Lupi, & Environmental Consulting & Technology Inc., 2015). External loading "includes nonpoint sources, point sources, and atmospheric deposition of phosphorus" (Bingham, Sinha, Lupi, & Environmental Consulting & Technology Inc., 2015).

Total phosphorus *is the combination of dissolved and particulate forms*

Dissolved phosphorus, also known as soluble reactive or bioavailable phosphorus, is highly bioavailable and easily taken up by plants

Particulate phosphorus binds to soil particles and is easily transported by wind and water erosion

(Environment and Climate Change Canada & Ontario Ministry of the Environment and Climate Change, 2018 & U.S. EPA, 2018)

Other conditions that compound the problem include changes in the ecosystem brought on by the spread of invasive zebra and quagga mussels. The mussels filter the water column by selectively consuming algae they like, however, the algae they do not consume happens to be the cyanobacteria that causes harmful algal blooms (HABs) (Sielski, 2017). The increased water clarity allows for "greater penetration of solar energy for chlorophyll production and warming of the water column, allowing algae to grow at greater depths" (U.S. EPA, 2018, p. 5).

The harmful algal blooms Lake Erie recently experiences have profound impacts on the communities surrounding the lake. In 2011, Lake Erie experienced the largest algal bloom recorded in history (at the time), spanning roughly 2,000 square miles and measuring at a peak toxicity level 224 times greater than World Health Organization (WHO) guidelines (Erickson, 2013). Just a few years later, the toxicity of the 2014 HAB event caused the City of Toledo to issue a "do not drink" warning, leaving half a million people in the Toledo area without drinking water for three days.

Zebra Mussels
Photo Credit: USGS, n.d

The same HAB event triggered a "do not swim" and "do not drink" warning on Pelee Island, of which about 90% of residents rely on the lake for drinking water (City Desk, 2014). The warning lasted roughly 2 weeks and the mayor noted that the island lost $500,000 a week in tourism dollars (Medeiros, 2017). One year later, the 2015 HAB event broke the 2011 record and became the largest bloom ever recorded, keeping boats out of the lake for six to seven weeks (Patel & Parshina-Kottas, 2017).

Policy Context: Addressing HABs

To address the recent resurgence of HAB events, Canada and the United States signed the amended Great Lakes Water Quality Agreement (GLWQA) in 2012.[5] The two nations committed to re-evaluating phosphorus loading targets by 2016 and producing domestic action plans ("action plans") that would achieve nearshore and open-water objectives by 2018 (Environment and Climate Change Canada & Ontario Ministry of the Environment and Climate Change, 2018 & U.S. EPA, 2018). In contrast to the management actions of the 1970s that targeted phosphorus loadings from point-sources, the two national action plans now emphasize reducing phosphorus loadings from nonpoint sources, including urban, agricultural, and rural runoff.

On average, runoff from non-point sources contributes to 72% of total phosphorus loads entering the lake annually (U.S. EPA, 2018). The majority of nonpoint source runoff is from agricultural fertilizer and manure and depends on weather conditions, which leads to variability season-to-season and from year-to-year (Environment and Climate Change Canada & Ontario Ministry of the Environment and Climate Change, 2018). Phosphorus loads are generally highest in late winter and spring and in years with more rain and storm events (Environment and Climate Change Canada & Ontario Ministry of the Environment and Climate Change, 2018).

Each basin of the lake has its own suite of issues related to excessive algal growth. The direction of flow through Lake Erie is west to east, meaning that phosphorus loads entering the western basin of the lake can have lingering impacts in the central and eastern basins and ultimately

NO-TILL FARMING: MIXED RESULTS IN CONTROLLING PHOSPHORUS

Starting in the mid-1990s, no-till farming became a widely adopted best management practice adopted by farmers in the Lake Erie region. There is no plowing in no-till farming; instead, crops are planted by inserting seeds into small holes (Erickson, 2013).

On one hand this technique keeps particulate phosphorus bound to soils and reduces the amount of erosion leaving the field, which makes the practice very important for reducing total phosphorus levels. However, on the other hand, some research suggests that the practice is contributing to the movement of dissolved phosphorus into the Lake.

If soils are not plowed, phosphorus is generally confined to the top 2 to 4 inches of soil, where it is easily dissolved in rainwater and can be washed away during storm events (Sielski, 2017). Once phosphorus saturation reaches a certain point in the top layers of soil, it does not attach and moves freely through the soil profile in a dissolved form (Sielski, 2017). By leaving the bottom layers of soil undisturbed, no-till farming removes a critical natural filtration process.

[5] The agreement also includes 10 annexes which focus on specific issues such as nutrients, lake wide management, and aquatic invasive species (U.S. EPA, 2015).

Lake Ontario (Environment and Climate Change Canada & Ontario Ministry of the Environment and Climate Change, 2018).

Maumee River
Photo Credit: USDA, 2014

In the western basin of the lake, where harmful algal blooms dominate, the GLWQA objective is to reduce algae to non-severe levels 90% of the time. Cropland is the dominant land cover type in the basin, and warmer water temperatures coupled with surface water runoff containing high levels of phosphorus from agricultural lands create ideal growing conditions for algae. It is estimated that 89% of total phosphorus loads entering the western basin of Lake Erie come from nonpoint sources, largely by way of the Maumee and Detroit Rivers, with the largest phosphorus discharges after heavy rains (U.S. EPA, 2018). The EPA determined that phosphorus levels in the Maumee River are the single best predictor of the severity of HAB events. Therefore, in order to achieve the GLWQA objective, a 40 percent reduction (from 2008 levels) in the spring total and dissolved phosphorus loads from the Maumee River is needed (U.S. EPA, 2018).

As water moves west to east, the overgrowth of algae in the western basin dies and decomposes in the central basin, creating large areas of low-oxygen dead zones. Since 2000, the hypoxic (low oxygen) area in the central basin has increased to an average of 4,500 km^2, peaking at 8,800 km^2 in 2012 following the significant HAB event in 2011 (U.S. EPA, 2018). The hypoxic conditions in 2012 have been linked to tens of thousands of fish deaths in Ontario and can affect the growth and survival of many aquatic organisms (U.S. EPA, 2018). In order to minimize hypoxia in the central basin during the summer months, the GLWQA objective is to limit total phosphorus loads entering the lake to 6,000 metric tons per year (MTA) annually, which would result in a dissolved oxygen concentration of 2mg/L in the bottom waters of the central basin.

Dead fish surrounded by algae in Pelee Island, Ontario
Photo Credit: Tom Archer, 2011 (NOAA, 2019b)

The predominant problem in the eastern basin, and mostly on the Canadian side of Lake Erie, is the accumulation of the algae *Cladophora* on the lakebed, in the water, and along the shoreline (Environment and Climate Change Canada & Ontario Ministry of the Environment and Climate Change, 2018). *Cladophora* fouls nearshore aesthetic conditions, may promote the growth or retention of pathogens, clogs water intakes, decreases recreational opportunities, and may negatively impact lakefront property values (Bootsma, Jensen, Young, & Berges, 2004). Currently, an insufficient scientific consensus exists regarding the exact relationship between phosphorus loads and *Cladophora* levels. In the absence of scientific certainty, and until concrete targets can be identified, the GLWQA goal in the eastern basin is to maintain levels of algae below nuisance levels[6] by reducing phosphorus to create conditions that promote healthy algal biomass and retain algal species consistent with healthy aquatic ecosystems (U.S. EPA, 2018).

GLWQA Phosphorus Reduction Targets for Lake Erie

1) To maintain cyanobacteria biomass at levels that do not produce concentrations of toxins that pose a threat to human or ecosystem health in the waters of the western basin of Lake Erie: a 40 percent reduction in spring total phosphorus (TP) and soluble reactive phosphorus (SRP) loads from the Maumee River in the United States. Using 2008 as the baseline, this equates to a spring (March-July) load of 860 metric tons TP and 186 metric tons SRP.

2) To minimize the extent of hypoxic zones in the waters of the central basin of Lake Erie: a 40 percent reduction in TP entering the western and central basins of Lake Erie—from the United States and from Canada—to achieve an annual load of 6,000 metric tons to the central basin. This amounts to a reduction from the United States and Canada of 3,316 metric tons and 212 metric tons respectively.

3) To maintain algal species consistent with healthy aquatic ecosystems in the nearshore waters of the western and central basins of Lake Erie: a 40 percent reduction in spring TP and SRP loads from the following watersheds where algae is a localized problem: in Canada, Thames River, and Leamington tributaries; and in the United States, Maumee River, River Raisin, Portage River, Toussaint Creek, Sandusky River and Huron River (Ohio).

[6] *Cladophora* is considered a "nuisance algae" because the algae does not pose a direct threat to human health or produce toxins similar to the blue-green algae in the western basin. However, as the algae accumulates, excess levels of *Cladophora* rotting and decaying on a beach promotes bacterial growth that can pose a risk to human health (Wisconsin Department of Natural Resources, 2013).

Ecosystem Service Assessment of Lake Erie's Natural Capital

This assessment of ecosystem services was completed in two phases. In the first phase, with input from the National Wildlife Foundation, we conducted an extensive review of existing literature on the economic value of ecosystem services related to water quality in Lake Erie which this analysis is predicated on. This includes all of Lake Erie, which Michigan, Ohio, Pennsylvania, New York, and Ontario border. Most existing research and funding have been directed either to the Great Lakes Region as a whole or to the presence of HABs in the lake's western basin.

With input from Lucas County, the City of Oregon, the City of Toledo, and Lake Erie Waterkeeper, this ecosystem service assessment aims to connect potential land and resource management actions (achieving the GLWQA 40% phosphorus reduction goal) with the maintenance and improvement of key ecosystem service values by:

- Using participatory research techniques with key regional stakeholders to refine and gain consensus around a targeted subset of key ecosystem services for detailed analysis,
- Analyzing existing relationships between stressors and the supply of those key services and using the results to estimate impacts of management changes on ecosystem service supply, and
- Shedding light on the economic and environmental impacts of degradation on water quality.

What are Ecosystem Services?

Ecosystem services (ES) are the values of the goods and services provided by healthy and functional ecosystems that people would otherwise need to provide for themselves (Phillips, Silverman, & Gore, 2008). Ecosystem services are divided into four general categories:

- Provisioning services: The ecosystem services that detail the material or energy outputs ecosystems provide, including food, water, and raw materials (The Economics of Ecosystems and Biodiversity, n.d.).
- Regulating services: Critical services ecosystems provide by functioning as "regulators" for certain events. Examples include forests providing carbon sequestration and wetlands providing natural moderation from extreme events (The Economics of Ecosystems and Biodiversity, n.d.).
- Habitat or supporting services: Refer to the fact that intact ecosystems provide critical habitat for species and the maintenance of genetic diversity (The Economics of Ecosystems and Biodiversity, n.d.).
- Cultural services: non-material benefits people obtain from ecosystems, including recreation, tourism, aesthetics, and spiritual experiences (The Economics of Ecosystems and Biodiversity, n.d.).

Put-In-Bay
Source: Rachel Tippett

Aesthetic Value: Benefits people receive from an attractive landscape

Farm in the Western Basin, Ohio
Source: Dianne Johnson, NRCS, 2014

Food/Nutrition: Benefits people receive from functioning ecosystems that provide conditions for growing food

Different land cover types provide different rates of services; for example, an acre of wetland provides a much higher value of natural water treatment ability compared to an acre of urban land. Examples of ecosystem services in the Lake Erie subregion include, but are not limited to, aesthetics, local climate regulation, recreation, food/nutrition, and water supply.[7]

Stressors on the ecosystem, such as high levels of nutrient run-off, can reduce or disrupt the supply of ecosystem services and this disruption results in economic costs to society. If service supplies are diminished to the point where people need to replace services through man-made means, there will be a material cost to society. For example, when a clean water supply—an ecosystem service—is degraded by HABs, people might pay more in water treatment costs and can suffer from sickness and lost recreational opportunities. These losses can be quantified in dollar terms and help us understand the benefit of clean water in economic terms.

Baseline Ecosystem Service Assessment

Published studies and research pertaining to ecosystem services in Lake Erie in the past decade are of three general types. Systematic reviews of ecosystem service value (ESV) in Lake Erie provide a broad, general picture of the natural benefits provided by the lake. Spatial distribution analyses focus on identifying where ESVs and/or underlying environmental conditions occur, often for the purpose of focusing on land conservation efforts on areas where ESVs are either most abundant or most imperiled. Finally, ecosystem-service-specific valuations take a narrower approach and use more detailed methods to evaluate conditions or actions affecting one or a small group of ecosystem benefits, such as drinking water or recreation.

A baseline ecosystem service assessment allows us to understand how management scenarios result in changes in the supply of ecosystem services. These changes in supply have a monetary value, and by incorporating ecosystem service values into funding prioritization, policy-making, and management

[7] For a complete list of ecosystem services in the Lake Erie subregion, see the section “Ecosystem Services in the Lake Erie Subregion” and Appendix C: Baseline Ecosystem Service Value in the Lake Erie Subregion.

planning, we can better understand how management scenarios trigger downstream benefits to society and understand what costs (or foregone benefits) would accrue with the maintenance of the status quo.

Economists have developed widely accepted methods to estimate the monetary value of ecosystem services and/or natural capital. One of the most common methods is the Benefit Transfer Method (BTM), which establishes values for ecosystem services produced by a particular region. According to the Organization for Economic Cooperation and Development (OECD), BTM is the "bedrock of practical policy analysis," particularly when collecting new primary data is not feasible (OECD, 2006).

BTM takes a rate of ecosystem benefit delivery calculated for one or more "source areas" and applies that rate to conditions in the "study area." Typically, rates are drawn from previous studies that estimate the value of various ecosystem services from similar land cover/biome types. Benefits (in dollars per unit area for each land cover type) from the source areas are then applied to the study area. For example, data from the source area may include the per acre value of recreation in forestlands. The per acre value of recreation from the source area can be applied to the number of acres of forestland in the study area. Multiplying the per acre value of recreation in the source area's forest land by the number of acres of forestland in the study area produces an estimate of the recreational value of the study area's forests.

It is important to use source studies from regions with underlying economic, social, and other conditions similar to the study area. This ensures that estimated values are more reliable given the study area's specific demographics and socio-economic characteristics.

Estimation of ecosystem service values in the Lake Erie subregion requires two general steps:

1. Identify the total number of acres for each land cover classification[8].
2. Multiply the total acres in each land cover type by the ESV (per acre per year) for each individual ecosystem service, where applicable, to arrive at final ecosystem service values in dollars per year for each land cover type.
    a. Some land covers, such as shrubland, only have one ecosystem service with a quantified value(s) that are appropriate for benefit-transfer valuation while others have none. Other land cover types, particularly wetlands and forests, have a handful of measured ESV's, ranging from air quality to recreation. For land cover types that have more than one estimate for a single service, we use the average value of the estimates.
    b. The variety in ESV's and the number of studies for each land cover type is a result of both the existence of primary studies for each land cover and service, and by the suitability of those values in application to Lake Erie's subregion. We identified 310 values that apply to Great Lakes land cover types and to land cover types in the U.S. and Canada (See Appendix C: Baseline Ecosystem Service Value in the Lake Erie Subregion).

[8] Land cover data is from the North America Land Change Monitoring System (NALCMS) (Commission for Environmental Cooperation, 2018). See Appendix A: NALCMS Land Cover, for the different types of NALCMS land cover classifications.

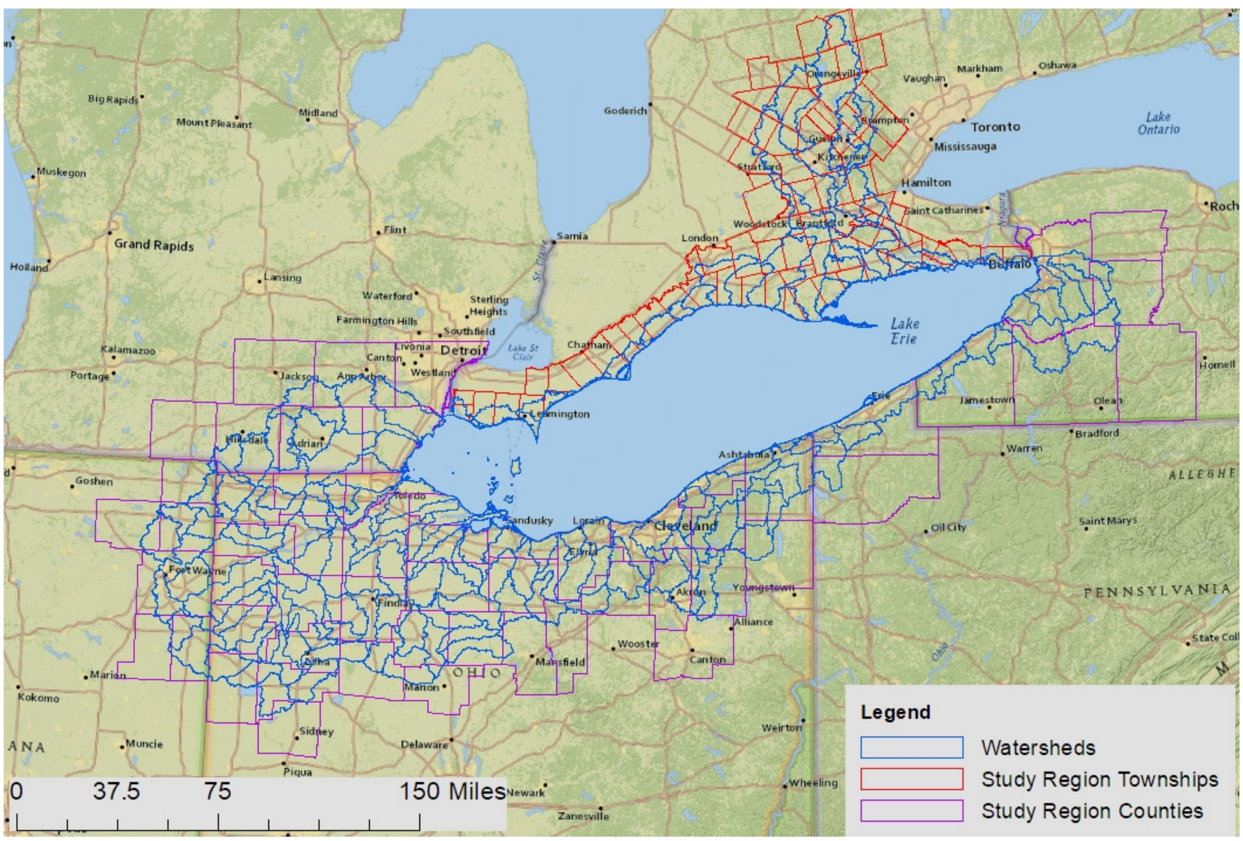
The result is a three-dimensional dataset with dollar-value estimates of ecosystem services in each acre of the study region based on land cover type.

Geographic Scope

This analysis defines the Lake Erie subregion ("study region") as the lake and the watersheds (HUC 10/Quaternary) that drain directly into the western, central, and eastern basins of Lake Erie (Figure 1).[9] We use the United States Geological Survey's (USGS) hierarchical system for classifying watersheds to determine the boundaries for the western, central, and eastern basins (HUC 6) (U.S. Geological Survey, 2018). The boundary for the Canadian portion of the subregion (named Northern Lake Erie by the Canadian watershed classification system) was determined by using secondary watershed layers from the Government of Ontario (2015). Table 1 shows an example of the USGS hydrological classifications as well as the Canadian equivalent watershed classifications.

Figure 1. Study Region-Lake Erie Watersheds

Sources: Base map from National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, Increment P Corp; U.S. Watershed Boundaries from U.S. Geological Survey, 2018; Canadian Watershed Boundaries from Government of Ontario, 2015; Study Region Townships from Municipal Affairs and Housing, 2015; Study Region Counties from U.S. Census Bureau, 2016



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[9] On the U.S. side, this includes the three HUC 6 basins, the western, central, and eastern, that drain into the western, central, and eastern basins of the lake, respectively. The Canadian portion of the subregion includes the secondary watershed, the U.S. equivalent to a HUC 6 basin, named Northern Lake Erie and drains into all three basins of the lake.

Table 1. Example of U.S. and Canadian Watershed Classifications

U.S.					Canada			
Name	**Level**	**Code**	**Example Name**	**Numeric Code**	**Name**	**Level**	**Name**	**Code**
Region	1	HUC2	Great Lakes Region	04	Primary	1	Great Lakes - St. Lawrence	02
Subregion	2	HUC4	Western Lake Erie	0410				
Basin	3	HUC6	Western Lake Erie	041000	Secondary	2	Northern Lake Erie	02G
Subbasin	4	HUC8	Huron-Vermillion	04100012	Tertiary	3	Cedar	02GH
Watershed	5	HUC10	Huron River	0410001206	Quaternary	4	Point Pelee	02GH-08
Subwatershed	6	HUC12	Mud Brook	041000120606				

The USGS classifies the Niagara subbasin (HUC 8) as part of the U.S. eastern basin, however, the subbasin drains north into Lake Ontario and was excluded subbasin from the analysis. Similarly, the Lake St. Clair drainage basin and the Thames River watersheds were not included as part of the Canadian portion of the subregion, or any watersheds that drain to Lake Erie by way of the Detroit River.

While these areas have important value for the subregion and have been classified by the GLWQA as part of the Lake Erie watershed, this baseline ecosystem service assessment only focuses on watersheds that drain directly to Lake Erie. In total, we analyze 160 watersheds, including the 83 watersheds of the western basin, the 24 of the central basin, the 18 of the eastern basin, and the 35 watersheds in Canada (See Appendix B: Watersheds used in the Baseline Ecosystem Service Assessment).

Land Cover in the Lake Erie Subregion

The most prevalent land cover type is cropland, covering roughly 44% of the study region. Water covers another 32% (Table 2, Figure 2, Figure 3a&b).[10] Excluding the area of the study region covered by the lake itself, cropland still covers the majority of the land cover at 64%, followed by temperate or sub-polar forests (17%), and urban land (15%) (Figure 3b & Table 2).

[10] The land cover classifications reported in the body of the report are reclassified based on the NALCMS classification system (See Appendix A: NALCMS Land Cover for the NALCMS classifications and the reclassifications used in the body of the report). See Table A-2 in Appendix A for acres of land cover by NALCMS classification.

Table 2. Land Cover in the Lake Erie Study Region

Land Cover	Basin (HUC 6/Tertiary)					
	U.S. Western (acres)	U.S. Central (acres)	U.S. Eastern (acres)	Northern-Canadian (acres)	Lake Erie (acres)	Total (acres)
Forest	608,374	630,506	614,867	470,333	22,308	**2,346,387**
Shrubland	4,258	12,383	21,058	6,623	3,347	**47,668**
Grassland	44,135	42,984	11,808	937	2,130	**101,994**
Wetland	203,204	74,404	62,838	12,773	11,174	**364,394**
Cropland	5,716,887	505,327	452,680	2,121,661	44,706	**8,841,261**
Barren	20,791	2,072	2,318	24,927	4,793	**54,901**
Urban	938,338	654,021	190,061	255,969	33,886	**2,072,275**
Water	66,998	21,923	4,287	30,060	6,357,285	**6,480,553**
Total	**7,602,985**	**1,943,620**	**1,359,917**	**2,923,283**	**6,479,629**	**20,309,434**

Figure 2. Land Cover in the Study Region
Source: Commission for Environmental Cooperation, 2018

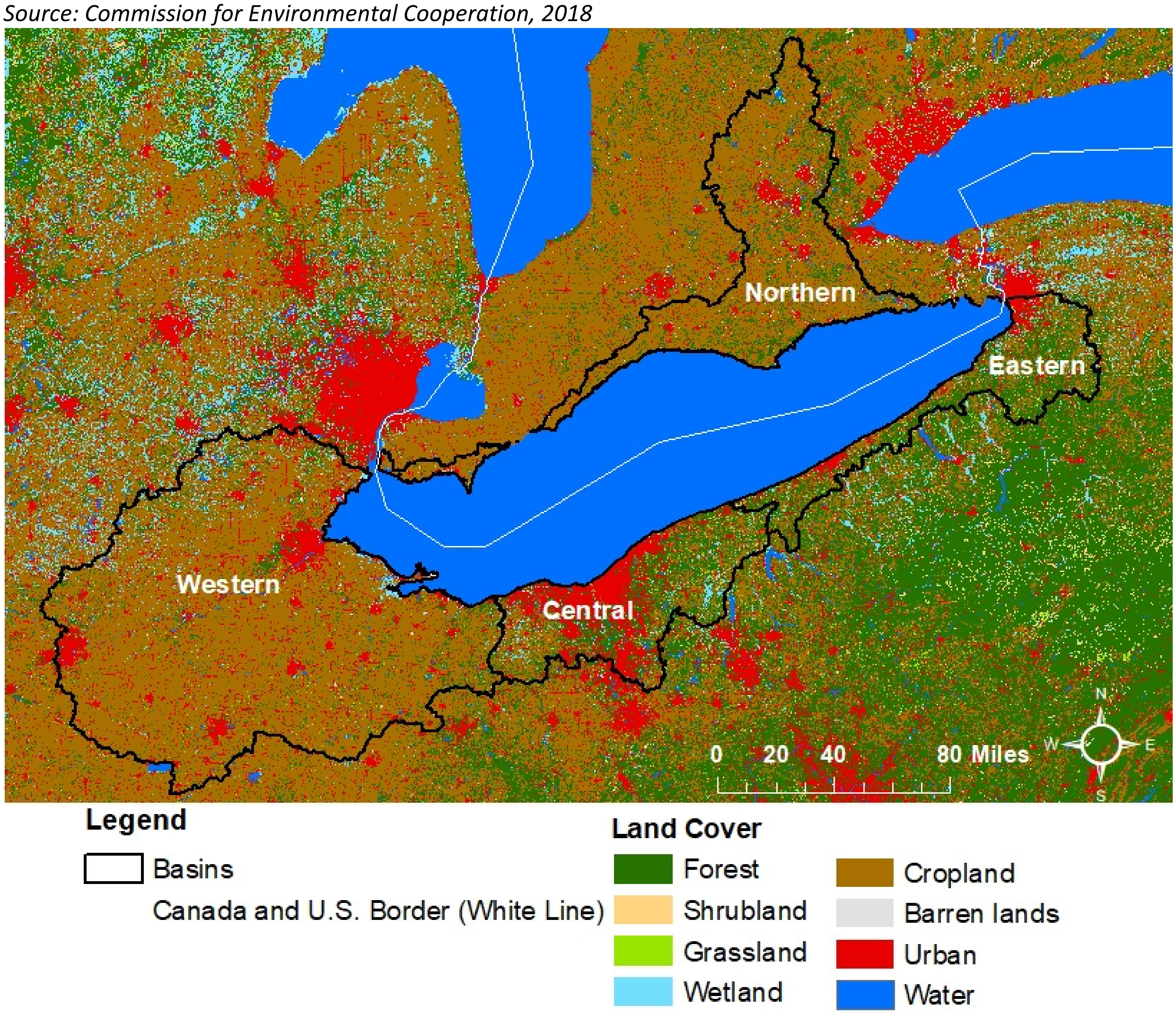
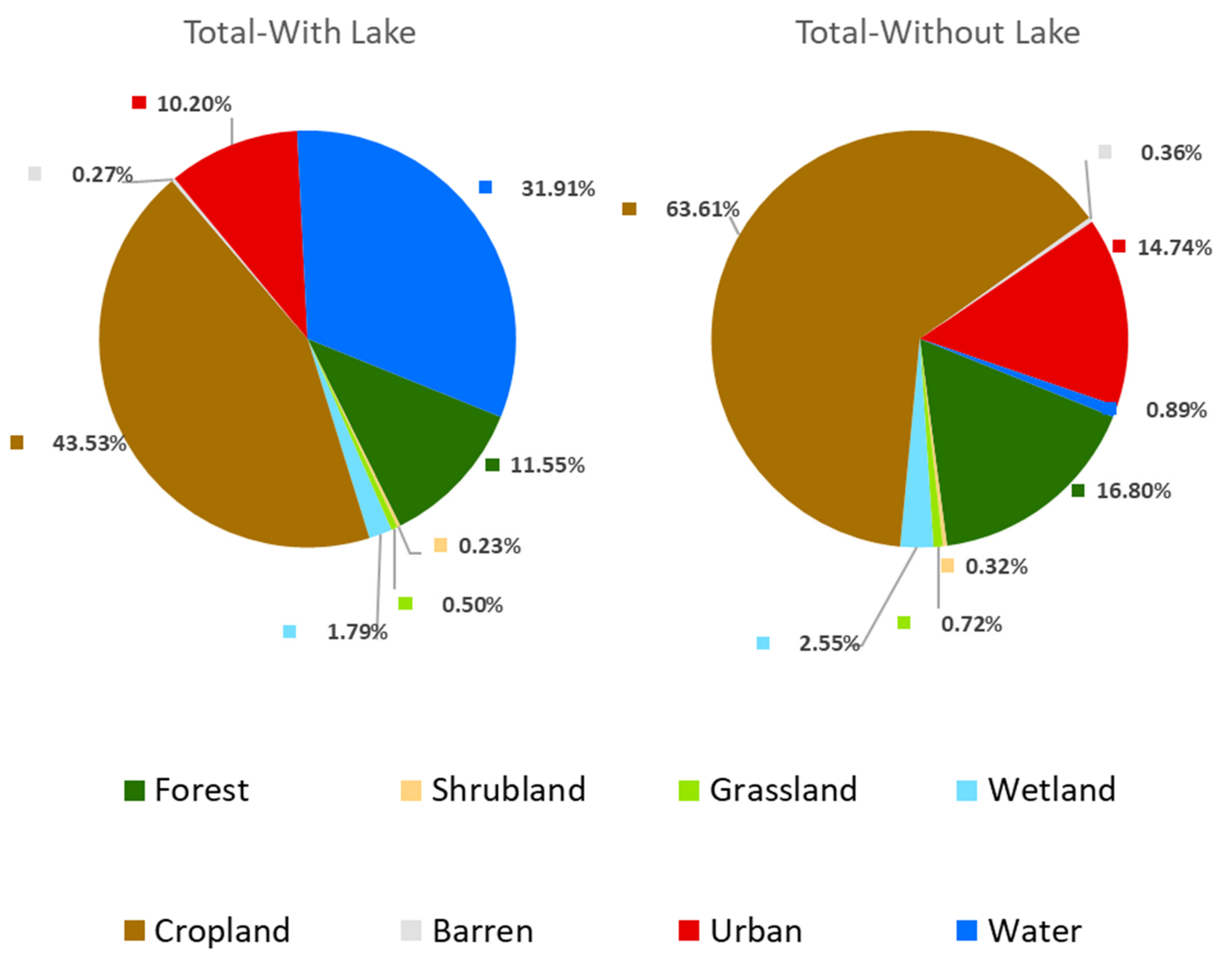


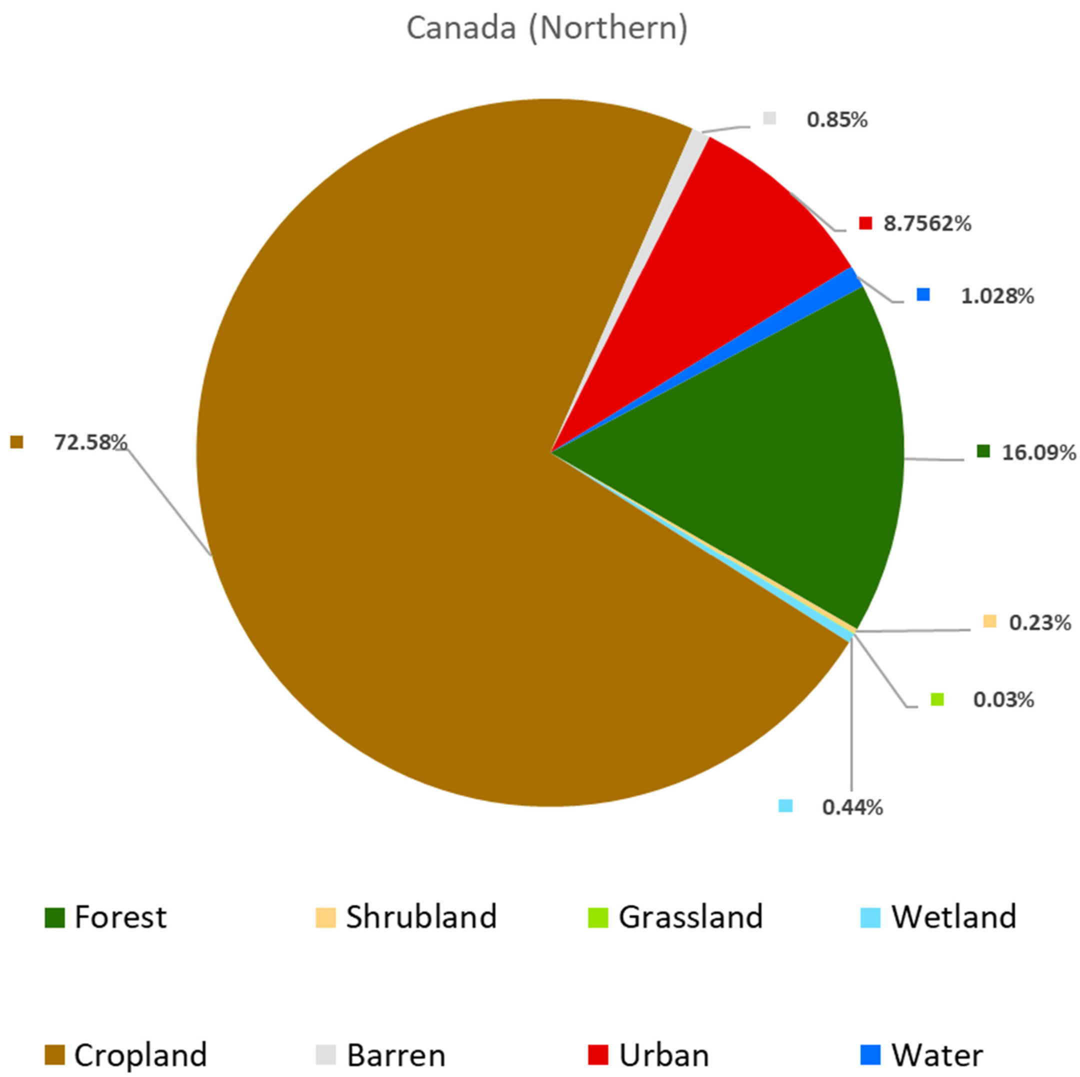
Figure 3a & 3b. Land Cover Distribution in the Study Region—With Lake (U.S. and Canada) and Without Lake (U.S. and Canada)

3a **3b**



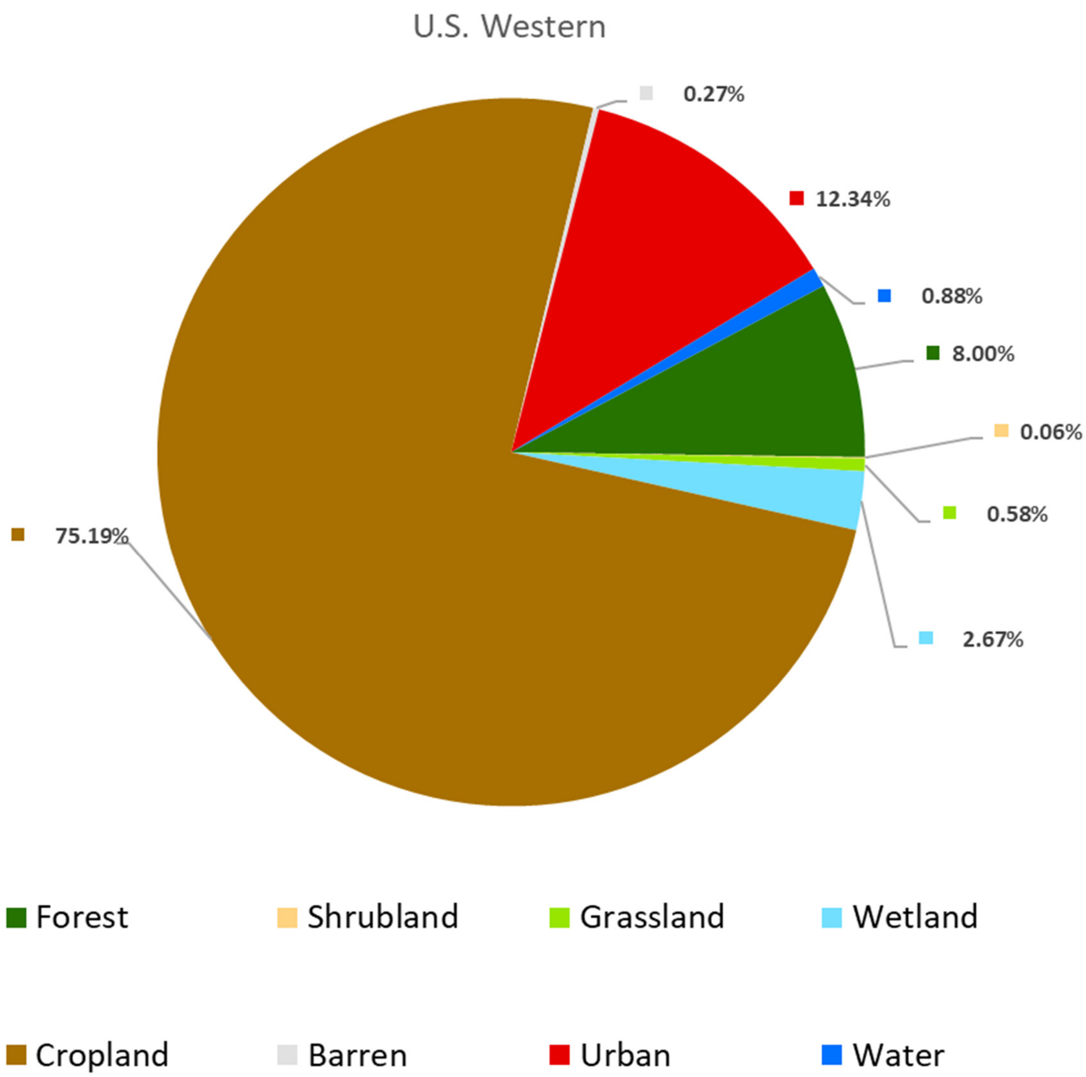
Cropland covers 72.6% of the Canadian (northern) portion of the subregion (Figure 4). Forest lands comprise roughly 16.0% of the area and urban lands cover another 8.8%.

Figure 4. Land Cover Distribution in the Canadian Portion of the Study Region



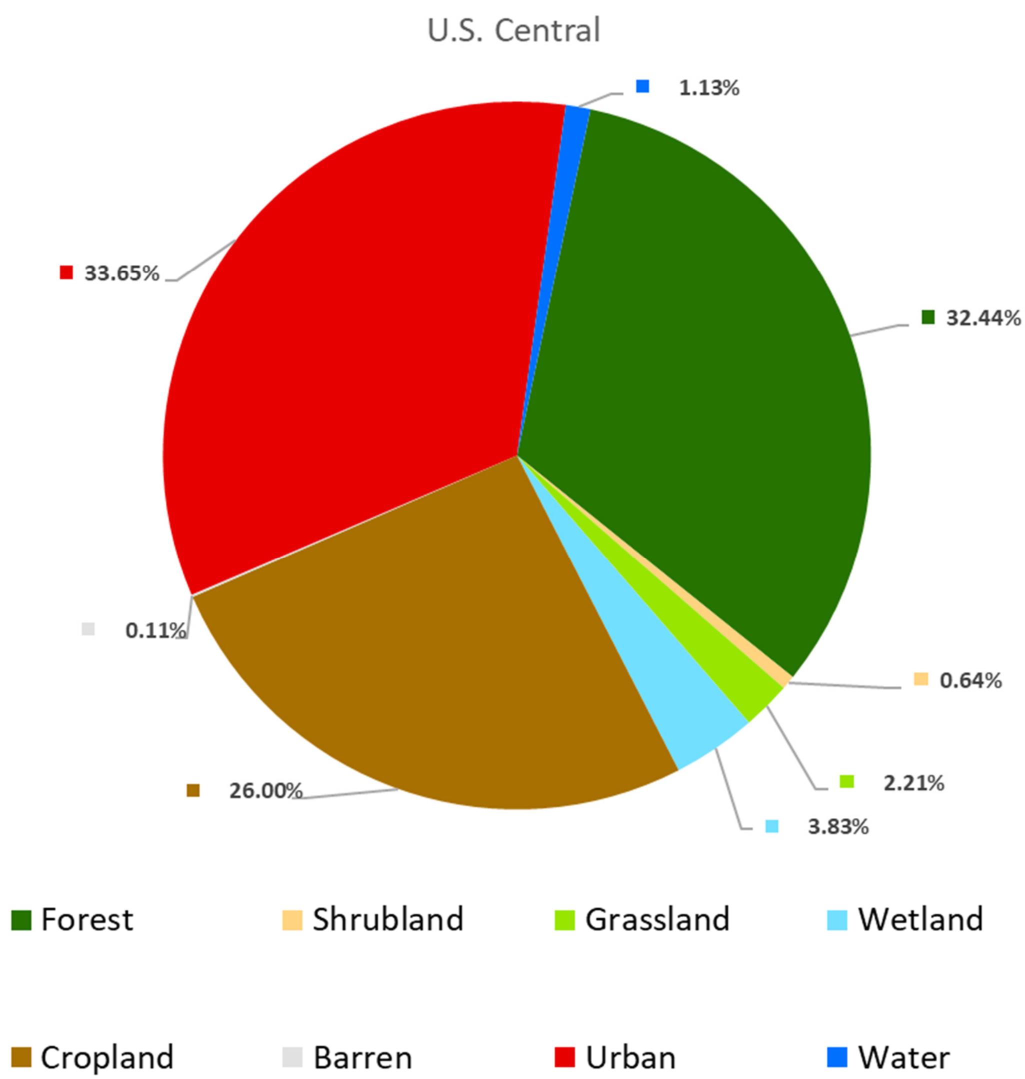
In the U.S. western basin, cropland covers roughly 75.2% of the basin (Figure 5). Another 12.3% percent of the basin is classified as urban land and roughly 8% of the basin is covered by forests.

Figure 5. Land Cover Distribution in the U.S. Western Basin



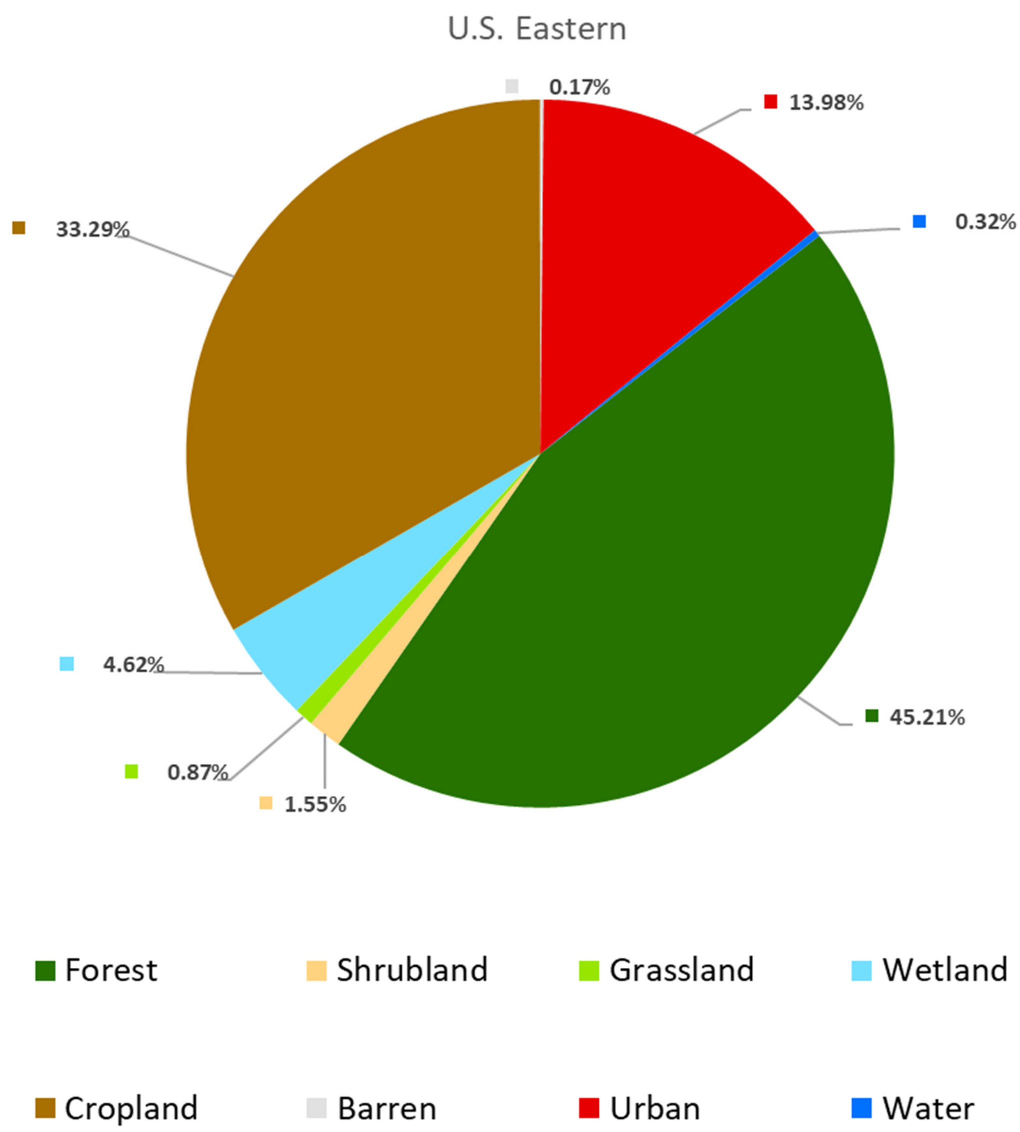
Land cover in the U.S. central basin differs from the U.S. western and Canadian areas; cropland covers only 26% of the basin, over 30% of the basin is forested, and over 30% of the basin is covered by urban land (Figure 6).

Figure 6. Land Cover Distribution in the U.S. Central Basin



The eastern basin has the largest proportion of forest cover compared to the rest of the subregion, with roughly 45% of the basin covered by forests (Figure 7). Cropland comprises 33.3% of the land cover while urban land covers 14%.

Figure 7. Land Cover Distribution in the U.S. Eastern Basin



Ecosystem Services in the Lake Erie Subregion

Establishing a baseline ecosystem service value allows us to better understand what the natural and recreational assets in the subregion are worth. The land cover in the subregion provides ecosystem service benefits worth over $443.0 billion annually (Table 3). By land cover, water provides the most benefits, contributing to over $326.9 billion (2018$ USD) a year in ecosystem service value such as waste assimilation, recreation, and water supply. (See Appendix C: Baseline Ecosystem Service Value in the Lake Erie Subregion for additional information on ecosystem service values broken out by basin, by NALCMS classification, as well as descriptions of the ecosystem services.)

Table 3. Ecosystem Services Values in the Lake Erie Study Region by Land Cover Type

Land Cover	Average Value (2018$ USD/year)
Forest	$3,726,893,689
Shrubland	$14,487,524
Grassland	$4,097,885,995
Wetland	$6,737,426,680
Cropland	$101,482,005,964
Barren Lands	$29,095,012
Urban	$6,871,010
Water	$326,902,992,994
Total	**$442,997,658,869**

By service, waste assimilation provides $112.4 billion (2018$ USD) in annual benefits and recreation provides $108.4 billion (2018$ USD) (Table 4). Food/Nutrition provides another $79.2 billion (2018$ USD) in benefits while aesthetics provides $59.0 billion in the region (2018$ USD) (Table 4).

Table 4. Ecosystem Service Values in the Lake Erie Study Region

Ecosystem Service	Average Value (2018$ USD/year)
Aesthetic	$59,009,947,423
Air Quality	$8,174,438
Biodiversity	$26,884,970,087
Climate Regulation	$555,770,337
Cultural, Other	$1,267,467,224
Erosion Control	$1,247,272,767
Food/Nutrition	$79,212,916,438
Pollination	$6,413,187,896
Protection from Extreme Events	$1,137,520,806
Raw Materials	$169,219,632
Recreation	$108,419,286,473
Renewable Energy	$549,679,574
Soil Formation	$783,192,920
Waste Assimilation	$112,437,726,677
Water Supply	$44,901,326,177
Total	**$442,997,658,869**

Methods for Analysis Framework

Within our Lake Erie study region, the value of ecosystem goods and services are estimated using the "production function approach". This approach has been used to estimate agricultural relationships and connect the amount of a commodity produced to units of inputs. For example, if one considers that gallons of clean water, days spent recreating on a beach, or trips taken by recreational anglers, are commodities, then the value of those goods and services are the number of gallons, days, or trips (respectively) multiplied by the value per unit. The advantages of this approach include that it provides estimates of the biophysical and economic quantities associated with ecosystem outputs.

The production function approach is similar to the benefit function transfer method in that it uses relevant variables and established relationships to estimate the quantity of an ecosystem good or service. The production function approach differs by starting a step back in the value chain in order to consider the biophysical quantities of ecosystem services involved as distinct from the economic value of those services. Instead of only considering the economic value of ecosystem services for a specific land cover type within a region, the production function approach also quantifies the biophysical units delivered. For example, the economic value ascribed at the end of a calculation of beach value would be the dollar value of a day's beach-going. This value would then be multiplied by the number of beach-going days our ecological production function tells us Lake Erie shorelines can support, based on water quality, quantity, and other factors.

We implement the production function approach through three elements in this analysis:

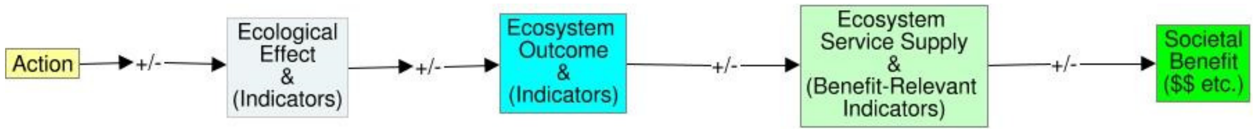
- Evaluating Means-Ends Using the National Ecosystem Service Partnership Guidebook
- Spatial Analysis Connecting Sources, Sinks, and Benefit Areas
- Estimating Key-Ecological and Economic Outcomes

These three elements are further described below.

Element One: Evaluating Means-Ends Using the National Ecosystem Service Partnership Guidebook

The first element lays out the most important pathways by which our predefined stressor connects to biophysical and economic quantities. Once an action and pathways between the action and ecosystem services are established, we then can measure how changes in ecosystem service provision in the subregion translates into economic benefits. We use the technique established by the National Ecosystem Service Partnership Guidebook (NESP) known as Means-Ends Diagramming to link changes in land/resource management to outcomes, including the market and non-market benefits conveyed by recreational use, property values, and passive use value of cleaner water.

Figure 8. Means-Ends Diagram Framework



An important step in this process is gaining a better understanding of what ecosystem services are important for people living in, or visiting, the Lake Erie subregion. Based on our baseline ecosystem service assessment, we know what ecosystem services are provided by the land cover, and given ample opportunities for recreation and that the lake provides drinking water for 11 million people, we have a general understanding as to which ecosystem services are important in the region (See Section: Ecosystem Services in the Lake Erie Subregion). To further refine and prioritize this list, we incorporated stakeholder input, in the form of an online survey[11] and two online webinars, to get a better account of how people in the subregion value and use the lake.

The survey was sent out to a variety of stakeholders in the U.S. and Canada and the results represent a diversity of interests within the region; respondents included business owners, recreators, residents, academia, local governments, and nonprofits. Survey participants were asked to identify, for the basin they were answering for[12], key sectors (or industries and activities) in their basin, stressors and environmental issues, key ecosystem benefits provided by the land and water, and actions that could be completed to protect or enhance those ecosystem benefits.[13]

We also held two webinars, one for central and eastern basin stakeholders and one for the western basin, which allowed us to discuss the survey results and hear what ecosystem services and benefits participants prioritize. This became the basis for our analysis of potential changes in the delivery of ecosystem services and their respective societal benefits (See Table 5). The webinars provided opportunities for more direct interaction with stakeholders and more qualitative and quantitative information regarding the key sectors, issues, benefits, and potential actions within the basins.

SURVEY RESULTS

We received 136 responses, with most respondents indicating they were answering for the lake's western and central basins. A large majority (85%) of the respondents listed recreation and tourism as a key sector. Other key sectors identified as priorities by the survey respondents include boating/charter boats (54%), recreational fishing (52%), and farming (52%). For issues, 75% of respondents indicated that nearshore algal blooms are a key environmental issue, followed by drinking water quality (54%), runoff from commercial fertilizer (54%), and aquatic invasive species (53%).

People in the region also value the drinking water, both quantity and quality, provided by the lake and surrounding land, with an overwhelming 93% of respondents listing the benefit as one of the top five. Other benefits frequently listed include habitat for species of all kinds (68%), boating/sailing (62%), and other recreation (60%). To protect these ecosystem benefits, the majority of respondents indicated that actions need to address run-off from a majority of sources, including improving commercial fertilizer management (82%), improving manure management on farmlands (77%), reducing sewage overflows (69%), and improving septic system management (69%).

[11] Stakeholders were identified by the Advisory Committee to this report.

[12]We asked participants to answer for the basin of the lake (western, central, or eastern) they were most familiar with. Because the lake itself has no northern basin, Canadian respondents answered based on which basin their water drains into.

[13] A copy of the survey can be found in Appendix D: Lake Erie Ecosystem Services Survey.

Webinar Results

The key economic and/or environmental stressors identified by participants in the central and eastern basin webinar include nearshore algae blooms, aquatic invasive species, open lake algae blooms, plastics (micro and macro), and runoff from commercial fertilizer. These stressors impact key sectors of the two basins, including recreation and tourism (beach-goers, surfers, triathlon participants, stand up paddleboarders, to name a few identified by the participants), boating and charter boats, recreational fishing, shipping, and businesses dependent on the Lake (breweries, wineries, food manufacturers such as Nabisco, etc.). The webinar participants also noted that there is a negative perception regarding Lake Erie's water quality which can have a big impact on recreation, boating, businesses, and general visitation.

We asked central and eastern basin participants what management actions need to be completed in order to address the stressors. The top actions mentioned were reducing sewage overflows, improving commercial fertilizer management, improving manure management on farmlands, reducing phosphorus in wastewater plants, and better stormwater management across the subregion. Addressing the stressors, either through the actions talked about during the webinar or through other means, would improve the key ecosystem benefits identified by the participants, including water for drinking (quantity and quantity), boating and/or sailing, other recreation activities (hiking, kayaking, paddle boarding, festivals, etc.), habitat for species of all kinds, and recreational/sport fishing.

In the western basin webinar, participants cited nearshore algae blooms, poor drinking water quality, runoff from commercial fertilizer, manure runoff from large animal feeding operations, aquatic invasive species, loss of buffer zones, and inadequate sewage systems as key economic and/or environmental stressors. Key sectors identified by the webinar participants include recreation and tourism (birding, kayaking, sailing, amusement parks, hunting clubs, land preserves, and camping), recreational fishing, agriculture (row crops, concentrated animal feeding operations, other animal agriculture, forestry, and wineries), boating/charter boats, manufacturing (breweries, microbreweries), commercial fishing, and urban development.

In order to address the environmental and economic stressors, participants indicated there needs to be improvements in how commercial fertilizer is managed, improvements in manure management on farmlands, reductions in sewage overflows, better treatment of sewage treatment plant sludge, improvements in septic system management, state tax incentives for cover crops and other conservation practices, and more wetland construction. Addressing the stressors would improve the key ecosystem benefits identified by participants, including water for drinking (quantity and quantity), habitat for species of all kinds, recreation, aesthetics, and boating/sailing.

Participants from both webinars identified harmful algal blooms as the largest stressor impacting key sectors and ecosystem benefits. Much of the discussion in both webinars centered around the challenges of addressing HABs and how they impact recreation and businesses.

Element Two: Spatial Analysis Connecting Sources, Sinks, and Benefit Areas

After identifying key ecosystem services and societal benefits or outputs in the Lake Erie subregion using means-ends diagramming (See Figure 9. Means-Ends Diagram for Reducing HABs), we connect actions and ecosystem processes to geographically specific areas where ecological and/or economic outcomes could occur. This is particularly important because differences in the biophysical characteristics (temperature, depth, species mix and utilization, rate of turnover) of the west, central, and east portions of Lake Erie will translate into different ecological impacts and different economic outcomes—even for the same ecosystem service—depending on where in the basin the effects occur. HABs in the western portion, for example, may have large effects on water treatment costs, property values, and beach-going days in the west, while going all but unnoticed in the eastern portion.

Element Three: Estimate Key Ecological and Economic Outcomes

Our last step employs the production function methods to estimate the value of key individual ecosystem services produced and enjoyed in the region, using the results from the survey and webinars, relevant data, and previous studies of ecosystem service provision in other areas reasonably similar to the Lake Erie subregion.

The Economic Benefits from Reducing Harmful Algal Blooms

As funders, developers, and other decision-makers involved in the management of natural resources become more interested in the value of benefits we receive from nature, a model for assessing how decisions or policies impact these benefits becomes increasingly important. The use of ecosystem service conceptual models, like means-end diagramming, can help simplify complex relationships between humans and their environment while providing a common and credible framework for any place or any intervention.

In the Lake Erie subregion, the framework described above allows us to connect biophysical processes to economic outcomes, which will create a more complete picture of environmental interventions that could result in the greatest change in benefits to communities and the general public over space and time by quantifying the value that we receive from those affected ecosystem services. Figure 9 lays out the means-end diagram pathways developed for this analysis and Table 5 lists the target ecosystem services for priority analysis, how the services are impacted by HAB events, and the potential economic benefits and costs avoided if the severity of HABs is reduced.

Figure 9. Means-Ends Diagram for Reducing HABs

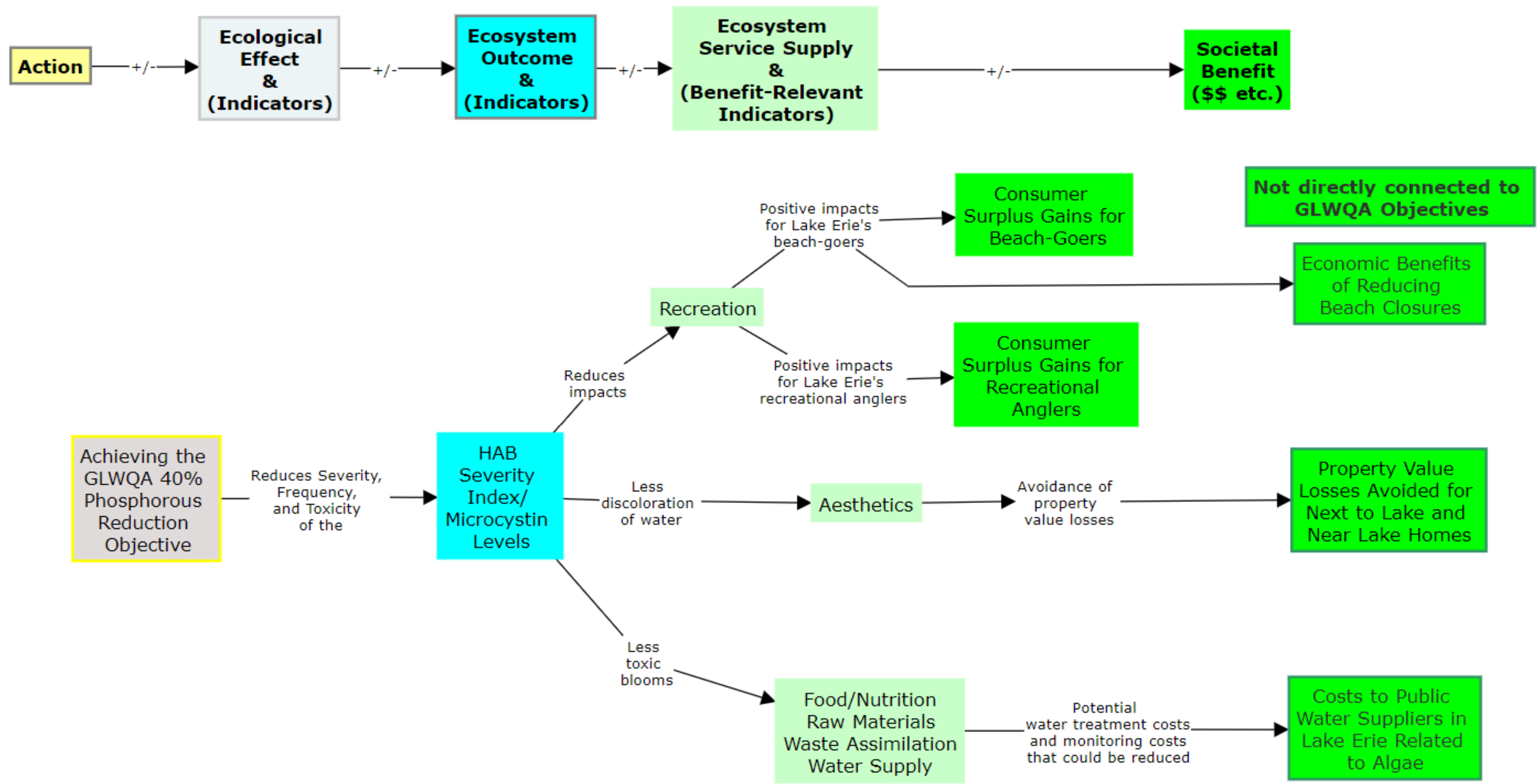
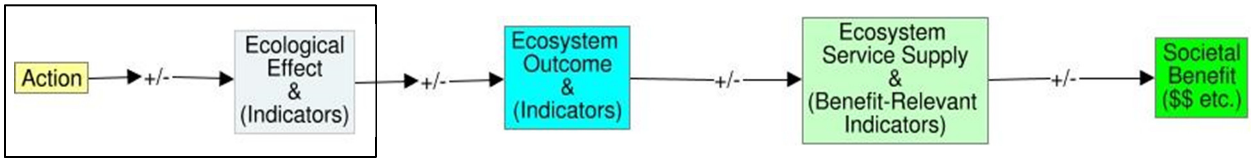


Table 5. Priority Ecosystem Services for Analysis as Determined by Stakeholder Input

Target Ecosystem Services	Type of Ecosystem Service	Ecosystem Services Provided by Lake Erie	Entities Affected by HABs	What We Measure
Recreation	Cultural	Bird watching, recreational hunting and fishing, boating, beach recreation, hiking, and kayaking	Individuals engaging in recreation on or around the lake Businesses engaged in services related to recreation or tourism	1) Consumer surplus gained by Lake Erie recreational anglers if the GLWQA target is achieved or a 20% reduction in phosphorus is achieved 2) Benefits gained by Lake Erie's beach-goers if the GLWQA target is achieved 3) Benefits for Lake Erie's beach-goers if there are 20% or 30% reductions in the number of beach advisories and closures
Aesthetics	Cultural	Lake views, forests, and agricultural landscapes	Households living along or near the lakeshore	1) Property value capitalization losses for lakefront and near lake homes
Food/Nutrition Raw Materials Waste Assimilation Water Supply	Provisioning	Water for drinking (freshwater), food from agriculture, and raw materials	Households drawing from Lake Erie for residential water supply Water treatment plants	1) Costs to water treatment plants associated with the monitoring, treatment, and capital expenditures from HABs

The following sections detail what each element of the means-end diagram represents, and the specific measures and indicators related to the Lake Erie subregion used in this ecosystem service assessment.

Actions and Ecological Effects (& Indicators)



"Actions", the yellow box, are interventions, policy scenarios, etc., and can have both positive and negative effects when their implications cascade through the ecosystem. "Ecological effects", the grey box, represent the direct impacts to the ecosystem we might expect from an action. Using the GLWQA target phosphorus reductions for springtime TP and SRP loads as defined by the two national action plans as our action, we examine how achieving the 40% reduction will translate into positive societal benefits (or avoided losses) for those living in and visiting the Lake Erie subregion. In this analysis, our action is also an ecological effect; we premise the analysis on the assumption that some combination of management actions will lead to the ecological effect of a 40% decrease in TP and SRP springtime loads.

The national action plans were completed in 2018 and many of the recommended management actions (e.g., agricultural best management practices, wastewater treatment plant upgrades, restoration projects, etc.) are underway. The efficiency of how individual actions reduce phosphorus is being studied, but many programs do not require reporting of phosphorus reductions. Management actions targeting the reduction of SRP run-off from agricultural lands rely on farmers to change existing practices and have not yet been applied or mandated across basins, making the extent to which these practices contribute to SRP reductions on a regional scale unascertained.[14]

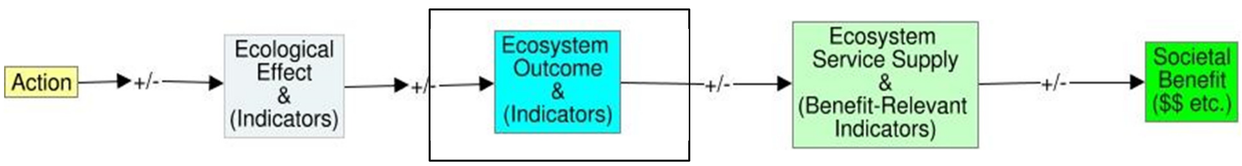
Example of edge of field monitoring equipment in Black Creek Watershed
Photo Credit: USGS, 2016

[14] There have been studies documenting the effectiveness of agricultural BMPs, including Gildow (2015), which evaluated fertilizer application practices for reducing phosphorus discharges from the Maumee River. Tomer et al. (2015) also developed multipractice watershed planning scenarios and assessed the nutrient reduction potential of different BMP's, which may be incorporated into Lake Erie watershed planning. In conversations with staff

Because the data and conclusions drawn from monitoring efforts are still in development, to our knowledge there is currently no consensus that can point to which management actions for reducing phosphorus are the "best". We define "best", in this case, as actions that are cost-effective in reducing phosphorus loads, and also have high feasibility of being implemented **across the subregion**. Management actions, especially relating to agricultural practices, often come with a high price tag and unless funding, grants, or other financial incentives are provided, may not be easily feasible to implement on a region-wide scale.

Due to the apparent lack of region-wide consensus regarding which management actions are the "best/most cost effective" to implement across basins and given that each management action requires a different set of collaborators, stakeholders, and decisionmakers (further complicating how feasible a potential management action can be), we did not model benefit estimates for specific management actions. Instead, by using the GLWQA goal as the action for modeling and analysis, we presume that some combination of management actions and policy decisions will get the lake to the GLWQA goal.

Ecosystem Outcome (& Indicators)



The blue box contains ecosystem outcomes and indicators of the ecological effects of the action and are impacts that we can measure. The action, reducing lake-wide phosphorus loads, would diminish the frequency, severity, and toxicity of HAB events. We use the HAB severity index as the ecosystem outcome that will change if the GLWQA target is achieved by this action. Changes in the HAB severity index will then drive the changes in economic benefits received by users of the Lake Erie subregion.

HAB Severity Index

At the beginning of the summer, NOAA and its research partners release a forecast predicting the severity of the season's HAB given factors such as winter and spring rainfall amounts and modeled phosphorus loading predictions. Between July and October, during peak HAB season, NOAA provides analyses on the location of blooms as well as 3-day forecasts of where the bloom is heading based on satellite images, transport, mixing, scum formation, and bloom decline. The severity index provides the public, government, recreators, and others with near real-time information about HAB events so that users of the lake can avoid the negative impacts associated with these events.

At the end of summer, NOAA releases the seasonal severity index, which indicates what the bloom severity actually was compared to forecasts made earlier in the season. The index is based on the amount of bloom biomass over the peak 30 days of the bloom (National Oceanic and Atmospheric Administration, 2018). In Figure 10, the severity index for 2002 to 2019 is provided as well as the thresholds for mild years and severe years.

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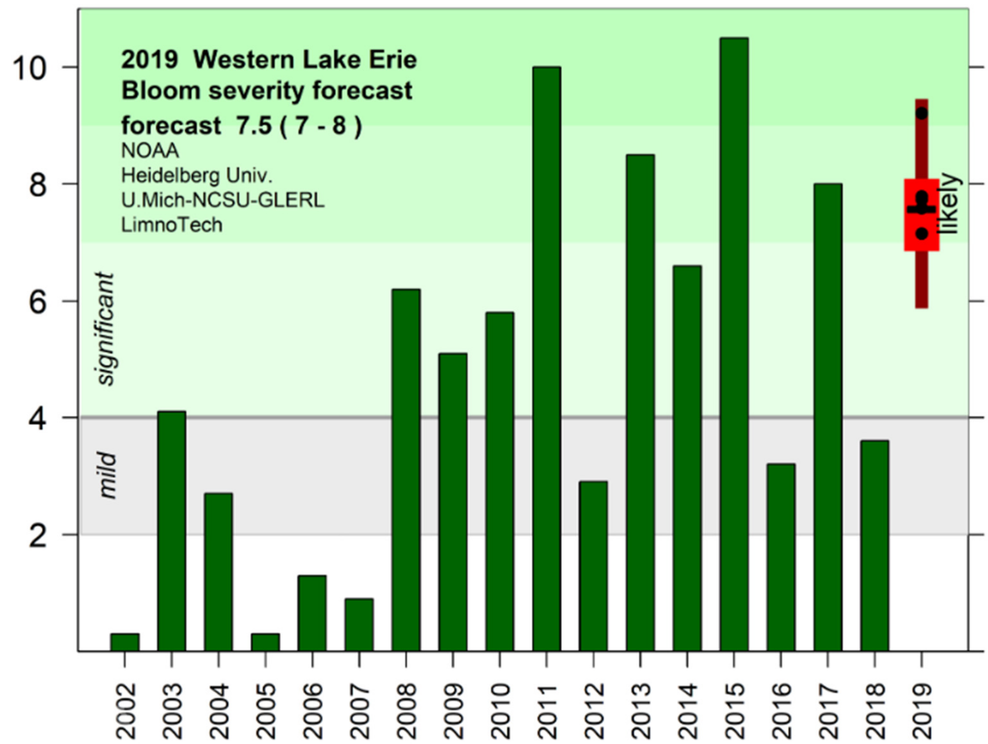
members at the Environmental Working Group, they pointed out that there is a lack of accountability in implementing BMP practices and knowing which practices work better than others.

Figure 10. HAB Severity Index for 2002 to 2019
Source: (National Oceanic and Atmospheric Administration, 2019c)



A 40% reduction in spring phosphorus loads is posited to significantly reduce the risk of HABs in the western basin by limiting bloom biomass to mild levels or between 2 and 4 on the severity index (U.S. EPA, 2018). We use the annual HAB severity index in our model as a proxy for ecosystem outcomes that would occur from reductions in phosphorus by comparing impacts in years where the HAB severity index was significant with years where the index was mild. While mild blooms still have the potential to impact shoreline areas, such effects are generally minimal. Therefore, we assume in the analysis that recorded impacts in years with mild HABs are similar to the impacts that could occur in future years when the GLWQA target is achieved.

Microcystin

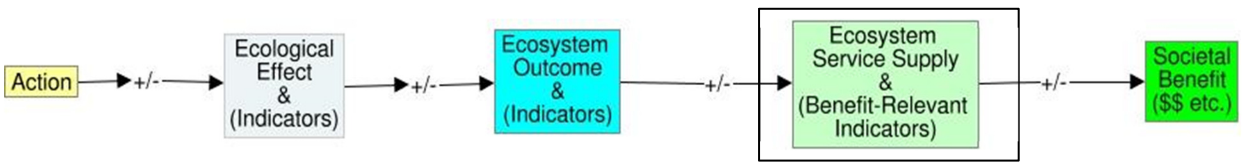
Cyanobacteria such as *Microcystis* produce cyanotoxins (microcystin) that can have significant health effects on humans and animals. Exposure to high levels of microcystin, through ingestion or skin exposure, is associated with dermal effects including skin rashes, ear and eye infections, and gastrointestinal diseases (Environmental Protection Agency, 2017). There have also been documented acute and lethal poisonings from cyanobacteria in animals and wildlife in Lake Erie (Gatz, 2013). While there is not a clear consensus regarding how consumption of fish from Lake Erie poses threats to human health, studies show that increased toxic blooms could lead to unsafe levels of microcystin concentrations in fish (Wituszynski, Hu, Zhang, & Chaffin, 2017).

In addition to health effects, the toxicity of HAB events can have significant economic impacts on recreation industries, water treatment plants, and other industries relying on the lake. Exposure guidelines for drinking water and recreation vary state by state, with several following the guidelines put forth by the World Health Organization (U.S. EPA, 2014). (See Table 6 for WHO recreation guidelines and page 50 for microcystin drinking water guidelines from the EPA and states in the subregion).

Table 6. World Health Organization Recreational Guidance (2003) for Microcystin
Source: Adapted from U.S. EPA, 2014

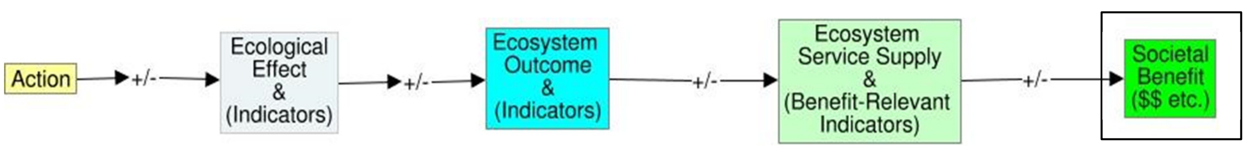
Relative Probability of Acute Health Effects	Cyanobacteria (cells/mL)	Chlorophyll-a (µg/L)	Estimated Microcystin Levels (µg/L)
Low	< 20,000	< 10	< 10
Moderate	20,000-100,000	10-50	10-20
High	> 100,000-10,000,000	50-5,000	20-2,000
Very High	> 10,000,000	> 5,000	> 2,000

Ecosystem Service Supply (& Benefit-Relevant Indicators)



The light green box contains ecosystem services-services we value and receive from nature- such as drinking water, clean air, recreational fishing days, raw materials, etc. Through interaction with regional stakeholders, we determined that key target ecosystem services supplies impacted by HABs include recreation, aesthetics, food/nutrition, raw materials, and water supply (See Table 5- Priority Ecosystem Services for Analysis). The quality of these services is impacted by the ecosystem outcomes and indicators in the blue boxes and can be measured as monetary changes in the societal benefit we receive.

Societal Benefits



The endpoints of the diagram, in the bright green box, represent the estimated benefits, measured in dollars, people in the Lake Erie subregion would gain if the GLWQA target is achieved. From our action, which may have impacts on the quality of drinking water, aesthetics, and downstream recreational fishing catch, we can estimate changes in consumer surplus, water treatment costs, and the change in recreational fishing quality (measured by willingness to pay).

Willingness to Pay and Consumer Surplus

Willingness to Pay (WTP) is the maximum amount a consumer is willing to pay, give up, or exchange for a good or service, or to avoid an undesired outcome, such as pollution. For example, a recreational angler may be willing to pay $20 more per trip if there is no HAB event occurring in Lake Erie.

Consumer Surplus (CS) then, is the value of the good or service to the consumer, over and above what they actually pay for it (their WTP - market price). For example, if a recreational angler is willing to pay $100 dollars for a fishing trip, but only has to pay $50, the total value of the trip is still $100. The difference in the two values—what the angler is willing to pay for the trip and what the angler actually paid for the trip—of $50 is the consumer surplus and represents an increase in the angler's well-being. The $50 consumer surplus is not paid or spent but measures the economic benefit the angler receives from their use and enjoyment of fishing in Lake Erie.

Recreation

Tourism is an important component of the Lake Erie economy that relies on water quality. For counties adjacent to Lake Erie in Ohio alone, 2012 estimates of tourism-related economic impacts include $11.8 billion in sales, $3.2 billion in wages, and over 117,000 jobs (Stratus Consulting, 2015). Recreational opportunities also benefit communities across the greater subregion, as visitors from around the world travel through, spend money, and purchase local goods and services en route to the lake.

Achieving the GLWQA 40% reduction goal would result in benefits of $1 million (2018$ USD) and $31.3 to $123.4 million (2018$ USD) for Lake Erie's beach-goers and recreational anglers, respectively. A 20% reduction in phosphorus would result in an annual consumer surplus benefit for anglers of $11.7 to $37 million. Reducing the frequency and intensity of HABs could also reduce the number of water quality advisories and beach closure days across the lake. A 20% reduction would result in economic benefits ranging from $23.8 to $26.7 million (2018$ USD) while a 30% reduction would result in benefits ranging from $36.2 to $41 million (2018$ USD). More details on the benefit estimates follow below and in Appendix F: Data and Calculations.

Beach-Related Recreation

The beaches along Lake Erie's 872 miles of shoreline are a popular destination for recreators, driving tourism dollars toward local economies. Lake Erie's beach-goers are heavily influenced by the overall beauty, health, clarity, and lack of odor of the lake when deciding where to recreate (Wolf, Chen, Gopalakrishnan, Haab, & Klaiber, 2018). With toxic HABs becoming an annual nuisance, the increasing number of recreational public health advisories issued at beaches can negatively affect beach visitation in Lake Erie if recreators choose another nearby destination or forego their trip altogether. HABs present in Lake Erie may also deter beach-goers from taking future trips simply due to the negative perceptions and stigma associated with the degradation of water quality.

Researchers estimate that the economic value of damages to beach recreation in Maumee Bay State Park caused by the HAB event in 2011 totaled $1.3 million (Bejankiwar, Benoy, Child, Dempsey, & Nevin, 2013). For 14 other beaches in the western basin, there could have been an additional $14.4 million and $11.2 million in benefits if the 2011 and 2014 HAB events did not occur, respectively (Bingham, Sinha, Lupi, & Environmental Consulting & Technology Inc., 2015). Given there are 70 public access beaches in Ohio alone (Glaser, 2017), and that the negative stigma associated with the degradation of water quality can remain long after a HAB event, economic losses from foregone beach trips due to HAB events could be a potentially staggering recurring cost to the region.

While a multitude of literature exists quantifying the value of Lake Erie's beaches and expenditures associated with beach recreation (Murray, Sohngen, & Pendleton, 2001; Sohngen, Lichtkoppler, & Bielen, 1999; Palm-Forster, Lupi, & Chen, 2016; Sohngen, Lichtkoppler, & Bielen, 1999), fewer studies directly link how impacts from HABs change beach recreators' preferences.[15] One study conducted by researchers at the Ohio State University estimates that beach recreators would gain $0.07 (2018$ USD) per trip taken if the GLWQA 40% target reduction of phosphorus loadings is achieved (Wolf, Chen, Gopalakrishnan, Haab, & Klaiber, 2018). Applying this estimate to beach-goers in Lake Erie results in an annual welfare implication of $1 million (2018$ USD) if the GLWQA target is achieved (See Appendix F: Data and Calculations).

Achieving the GLWQA target phosphorus goals would also likely reduce the number of beach closure days and recreational health advisories issued during summer, which would translate into economic benefits. For example, in Lake Michigan reducing beach closures by one day could increase seasonal aggregate welfare values by $12 to $34 million (Song, Lupi, & Kaplowitz, 2010). Estimates of the seasonal

Children playing on a Lake Erie Beach
Photo Credit: Federal Highway Administration, n.d.

[15] We are aware of one study, by Brent Sohngen at The Ohio State University, which is expected to be released in early 2020. The study will contribute "to further understanding of the value of public access to the Lake Erie Coastline, as well as the impacts of HABs and other water quality problems on visitation and the economy" (Snow, 2018).

aggregate loss of closing any one beach range from $130,000 to $24 million and closing all beaches on Lake Michigan could result in losses as high as $2.7 billion (Song, Lupi, & Kaplowitz, 2010).

Researchers estimate that Lake Erie beach-goers value a 20% reduction in the average number of water quality advisories and beach closures at $28.66 (2018$ USD) per visitor per year, or $1.87 (2018$ USD) per visit (Austin, Anderson, Courant, & Litan, 2007). A 30% reduction is valued at $43.61 (2018$ USD) per visitor per year, or $2.87 (2018$ USD) per visit (Austin, Anderson, Courant, & Litan, 2007). Applying these estimates to the total number of beach-goers visiting Lake Erie a year, we find a 20% reduction in the number of beach advisories and beach closures would result in an annual economic benefit ranging from $23.8 to $26.7 million (2018$ USD), and a 30% reduction results in economic benefits of $36.2 to $41 million (2018$ USD) (See Appendix F: Data and Calculations).

Beach-Related Recreation Benefits

- Achieving the GLWQA target phosphorus goals would result in **$1 million** in additional consumer surplus benefits for beach-goers in Lake Erie.
- A 20% reduction in the number of water quality advisories and beach closure days for Lake Erie's beaches would result in economic benefits ranging from **$23.8 to $26.7 million.**
- A 30% reduction in the number of water quality advisories and beach closure days for Lake Erie's beaches would result in economic benefits ranging **from $36.2 to $41 million.**

Recreational Fishing

Lake Erie is the most biologically productive of the Great Lakes in terms of angler yield and supports a well-established recreational fishing industry that attracts anglers from all around the world (Graefe, Mowen, Ferguson, & Dorata, 2018). Commonly known as the "Walleye Capital of the World", the lake supports a healthy walleye population and world-class small bass fisheries (Zhang & Sohngen, 2017). Lake Erie also boasts the largest diversity of fish species of all the Great Lakes with over 100 native fish species inhabiting its waters (Graefe, Mowen, Ferguson, & Dorata, 2018).

Walleye hatches in 2018 ranked the second highest in history and yellow perch hatches were well above long-term averages (Ohio Department of Natural Resources, 2018). The Ohio Department of Natural Resources also estimated that fishing in 2018 for smallmouth bass, black bass, steelhead, and white bass would be excellent (Ohio Department of Natural Resources, 2018).

Although the current state of Lake Erie's fisheries suggests healthy and abundant fisheries, toxic HAB events and fish deaths linked to hypoxic zones could pose a threat to the future of the lake's fisheries and has already affected how recreational anglers use the lake (Ohio Sea Grant, 2019). One study found that more toxic blooms could increase microcystin levels in Lake Erie's fish that would then pose a greater risk to public health if the fish were consumed (Wituszynski et al., 2017). From 2001 to 2016, the U.S. Fish & Wildlife Service (2002;2018b) documented 255,000 fewer recreational anglers visiting

Lake Erie in the 15-year span. A survey sent to Ohio Lake Erie anglers found that 96% of respondents were aware of HAB events and over 50% of anglers changed their behavior due to HABs either by changing fishing locations, not taking fishing trips, or spending less time fishing (Sohngen, Zhang, Bruskotter, & Sheldon, 2014). Lake Erie anglers tend to avoid HABs for aesthetic reasons and perceptions of the impact of HABs on personal and fish health (Gill, Rowe, & Joshi, 2018).

Fishing for yellow perch on the dock near Marblehead Lighthouse
Photo Credit: Melissa Hathaway/Ohio Division of Wildlife (Federal Highway Administration, n.d.)

In another study estimating the impact of HABs on the lake's recreational fishing industry, researchers found counties in Ohio adjacent to Lake Erie experiencing a summer-long moderate WHO advisory can expect to lose an average of 8.2 fishing license sales a month (Wolf, Georgic, & Klaiber, 2017). This translates into a total loss of roughly 3,600 fishing licenses and lost trip expenditures ranging between $2.2 and $5.6 million per fishing season (Wolf, Georgic, & Klaiber, 2017).

One measure that is particularly useful in representing an angler's heterogeneous preference for reducing water quality degradation associated with HABs is an angler's willingness to pay for different fishing activities. An angler's WTP for reducing water quality degradation from HAB events is the maximum amount that an angler will pay for water quality improvements above their total fishing rip cost (travel, food, bait, tackle, gas, boat rental, etc.), or what they already pay for a fishing trip. There have been a number of estimates, mainly focused on Ohio anglers, that quantify WTP measures related to reducing impacts from HABs (Table 7).

Table 7. Willingness to Pay Values for Recreational Fishing
Source: Zhang & Sohngen, 2018

WTP Measure	Low Estimate (2018$ USD)	High Estimate (2018$ USD)
Ohio Lake Erie Anglers-Per trip value for a 40% reduction in spring SRP loads from the Maumee River	$43.12	$64.68
Ohio Lake Erie Anglers-Per trip value for a 20% reduction in spring SRP loads from the Maumee River	$16.17	$19.40

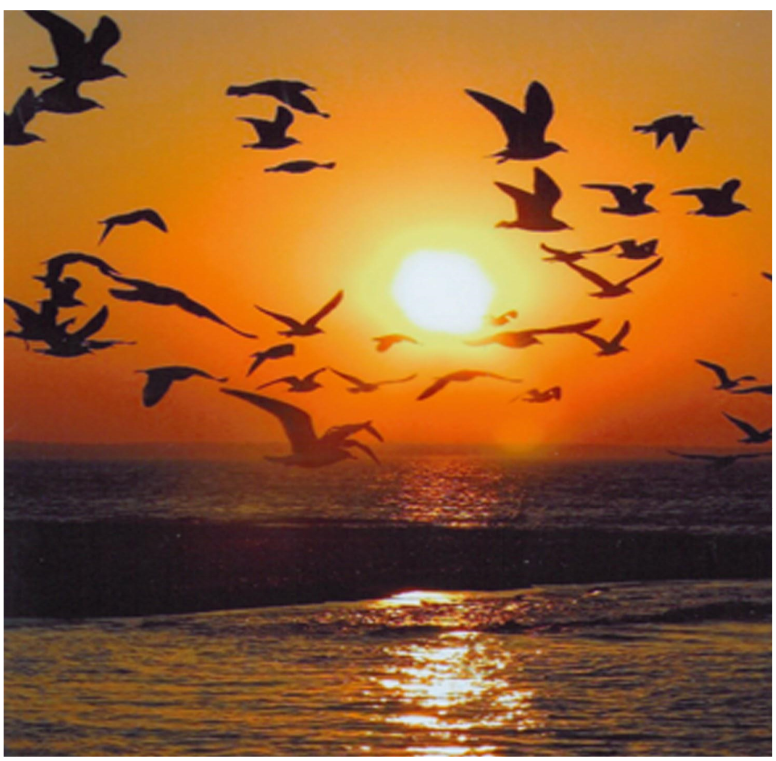
The results from Zhang & Sohngen (2018) indicate that Ohio Lake Erie anglers are willing to pay $43.12 to $64.68 (2018$ USD) more per trip if the GLWQA 40% target reduction is achieved and $16.17 to $19.40 (2018$ USD) more per trip for a 20% reduction. Achieving the GLWQA target would result in an annual consumer surplus gain of $31.3 to $123.4 million (2018$ USD) for impacted recreational angling trips in Lake Erie and achieving a 20% reduction would result in gains of $11.7 to $37 million (2018$ USD) (See Appendix F: Data and Calculations).

Benefits to Recreational Anglers

- Achieving the 40% GLWQA phosphorus reduction target would result in an annual consumer surplus gain of **$31.3 to $123.4 million**
- Achieving a 20% reduction in phosphorus loads would result in an annual consumer surplus gain of **$11.7 to $37 million**

Property Values

Across the nation, waterfront homes are some of the most valuable and desirable properties (Krause, 2014). Water bodies like Lake Erie provide residents with a multitude of environmental amenities, including spectacular lake-views and ample recreational opportunities. These benefits, however, are under increasing threat from HAB events. Lakeshore residents in nearby Grand Lake St. Marys State Park have reported anecdotal evidence of declining property values due to HABs, with some declines as high as 50% (Arenschield, 2015). In addition, eutrophication events have been known to negatively affect those living in lakeshore communities by decreasing recreational opportunities and contributing to losses in aesthetic benefits from the discoloration of water by algae (Bejranonda, Hitzhusen, & Hite, 1999).



Sunset on Lake Erie
Photo Credit: Rona Proudfoot (Federal Highway Administration, n.d.)

General literature on the topic indicates that water quality improvements correspond to increases in property value (Ara, Irwin, & Haab, 2016; Baron, Zhang, & Irwin, 2016; Krysel, Boyer, Parson, & Welle, 2003; Liu, Opaluch, & Uchida, 2017). For example, researchers have found that in Lake Erie, a 1 meter change in water clarity causes a 1.93 percent change in housing value and a 1 µg/L reduction of chlorophyll-a (which can be used as a proxy measurement for microcystin concentration) yields a 2% increase in home prices (Ara, Irwin, & Haab, 2016; Baron, Zhang, & Irwin, 2016). However, less literature exists directly valuing the impact of toxic algae on property values, which is of most concern for those residing near Lake Erie.

Emerging research, particularly for the Great Lakes and other water bodies close to Lake Erie, quantifies the effects of HABs on property values. For example, surpassing the 1 µg/L WHO threshold for microcystin contributes to declines in housing values in near-lake homes[16] of 11%, with 32% in property value losses for lake-adjacent homes (Wolf & Klaiber, 2016).

We use the results of the Wolf & Klaiber (2016) study to estimate potential property value losses along the entire lakeshore of Lake Erie if HABs continue to create conditions in which the WHO drinking water standards are exceeded. While these estimates of potential property value losses do not directly connect to the GLWQA objective, decreases in phosphorus loads entering the lake are posited to reduce the toxicity of HAB events, which could translate into avoided property value losses.

There are 14,025 U.S. households and 1,068 Canadian households within 66 ft (20 m) of the lakeshore with a total property value of $2.1 billion (2018$ USD). If the WHO drinking water standard is exceeded, the average household within 66 ft (20 m) of the lakeshore can expect to lose 32% in property value (Wolf & Klaiber, 2016). For these Lake Erie households, that translates to potential property value losses of $685.9 million (2018$ USD) (See Appendix F: Data and Calculations).

Between 66 ft (20 m) and 820 ft (250 m) from the lakeshore, 67,680 U.S. and Canadian households have a total property value of $9.6 billion (2018$ USD). This set of households can expect to lose 11% of property value when the WHO drinking water standard is exceeded, which translates to potential property value losses of $1.1 billion (2018$ USD) (Wolf & Klaiber, 2016). Table 8 provides more information about property value losses by basin, state, and for Ontario and Appendix F: Data and Calculations provides more information on methods.

Potential Property Value Declines

- Households within 66 ft (20 m) of Lake Erie could experience property value declines of **$685.9 million.**
- Households within 66 ft (20 m) to 820 ft (250 m) of Lake Erie could experience property value declines of **$1.1 billion.**

[16] Capitalization losses were estimated for six inland counties in Ohio between 2009 and 2014.

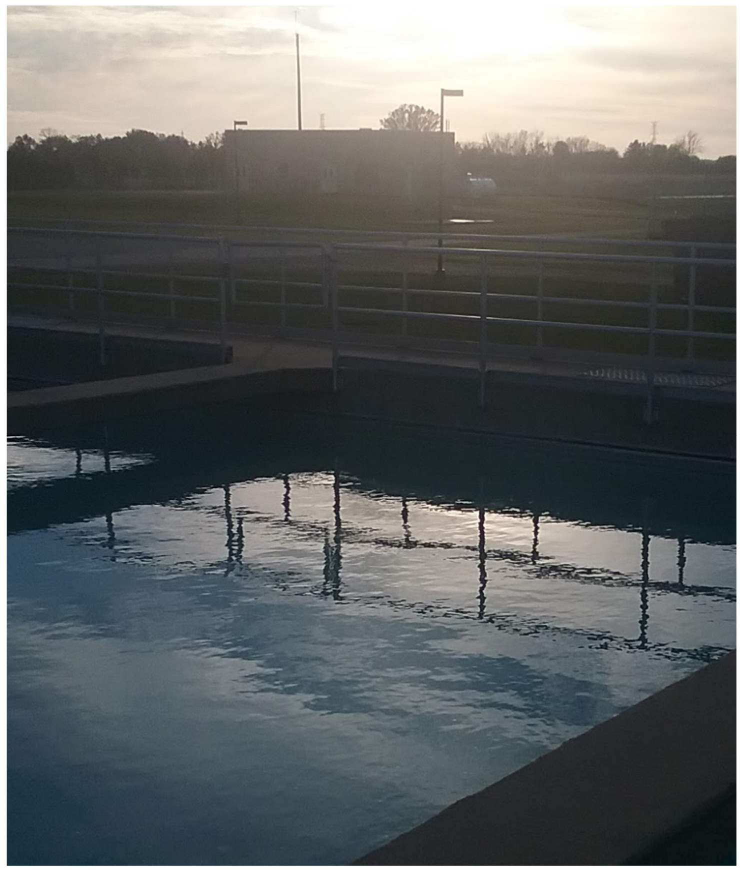
Table 8. Potential Property Value Losses in the Study Region

Zone of Influence	Total Property Value of Households (2018$ USD)	Number of Households	Potential Property Value Losses (2018$ USD)
Total (U.S. and Canada)			
Lakeside (66 ft)	$2,143,423,475	15,093	$685,895,512
Near Lake (66-820 ft)	$9,609,637,643	67,680	$1,057,060,141
By Basin (U.S.)			
U.S Western Basin Lakeside (66 ft)	$836,914,468	5,640	$267,812,630
U.S. Central Basin Lakeside (66 ft)	$721,552,062	5,479	$230,896,660
U.S Eastern Basin Lakeside (66 ft)	$391,380,379	2,907	$125,241,721
U.S Western Basin Near Lake (66-820 ft)	$2,441,717,736	16,560	$268,588,951
U.S Central Basin Near Lake (66-820 ft)	$4,277,138,037	31,581	$470,485,184
U.S Eastern Basin Near Lake (66-820 ft)	$1,906,166,785	14,646	$209,678,346
By State (U.S.)			
Ohio Lakeside (66 ft)	$1,522,185,514	10,842	$487,099,364
Michigan Lakeside (66 ft)	$58,839,198	505	$18,828,543
New York Lakeside (66 ft)	$217,767,337	1,489	$69,685,548
Pennsylvania Lakeside (66 ft)	$151,054,860	1,189	$48,337,555
Ohio Near Lake (66-820 ft)	$6,579,925,256	47,022	$723,791,778
Michigan Near Lake (66-820 ft)	$243,469,588	2,166	$26,781,655
New York Near Lake (66-820 ft)	$1,001,151,310	7,083	$110,126,644
Pennsylvania Near Lake (66-820 ft)	$800,476,404	6,517	$88,052,404
Canada (Ontario)			
Ontario Lakeside (66 ft)	$193,576,566	1,068	$61,944,501
Ontario Near Lake (66-820 ft)	$984,615,085	4,892	$108,307,659

Water Treatment Costs

Excess levels of phosphorus and toxic concentrations of cyanobacteria like microcystin can result in higher water treatment costs for municipalities, causing higher water bills for residents (U.S. EPA, 2015). HABs can taint water with a foul taste and odor, which often requires that water treatment plants implement additional treatment measures, such as adding granular or powdered activated carbon above normal levels. The high toxicity of HAB events have also caused water treatment plants to shut down altogether, leaving residents without access to public drinking water.

In 2013, the toxin levels in the raw intakes at the Carroll Water and Sewer Department in Carroll Township measured 17 times the state recommended drinking water standard, overwhelming the system's treatment ability and knocking the plant offline (Hunt, 2013). The now infamous Toledo water shutdown of 2014 brought HAB water treatment issues to the national forefront after half a million residents were left without access to public drinking water due to microcystin levels measuring three times higher than the WHO recommended limit. Voluntary reports from Toledo businesses indicate up to $30 million in economic impacts from the shutdown, and the city's finance director estimates that the shutdown cost the city over $200,000 alone in overtime costs (Sanchez, n.d.; Henry, 2014).



City of Oregon Water Treatment Plant
Photo Credit: Melissa Hopfer

The U.S. EPA released guidance on health advisories for microcystin in 2015 which solidified the first nationwide microcystin concentrations standards for other states to follow (Table 9) (U.S. EPA, 2014). The EPA guidance values are non-regulatory (not mandated) and quantify concentrations of microcystin at which adverse health effects are expected to occur based on a 10-day exposure. Canada also has nationwide microcystin guidelines for drinking water and recreation which are less stringent than the U.S. EPA's guidance (Table 9) (Government of Canada, 2018).

Table 9. Microcystin Health Guidelines
Sources: U.S. EPA, 2014; Government of Canada, 2018; Windsor-Essex County Health Unit, 2019

Microcystin Level (µg/L)	Advisory
WHO	
<10	Recreational Guidance
10-20	Recreational Guidance
20-2,000	Recreational Guidance
>2,000	Recreational Guidance
U.S. EPA	
0.3	Drinking Water Health Advisory: For Bottle-fed infants and pre-school children
1.6	Drinking Water Health Advisory: For school-age children and adults
Canada	
>0.3	Drinking Water Health Advisory: For Bottle-fed infants and pre-school children
>1.5	Do Not Drink
1.5-10	Drinking Water Health Advisory: For the general population, including young children Swim with caution
10-20	Recreational Guidance (Do not swim)
Ohio	
0.3	Do Not Drink: Children under 6 and sensitive populations (pregnant women, nursing mothers, those receiving dialysis treatment, the elderly and immune-compromised individuals)
1.6	Do Not Drink: Children 6 and older and adults
6	Recreational Public Health Advisory
20	Do Not Use: Based on the recreational no contact advisory thresholds

There are no federal regulations in the United States or in Canada[17] mandating that public water systems test for microcystin. States and provinces in the region differ in how they test and treat microcystin:

- Ohio is the only state in the Lake Erie subregion that has developed their own microcystin standards (Table 9), and as of 2016, requires that the 21 public water suppliers (Table 10) directly sourcing surface water from Lake Erie routinely test and report for microcystin.
- Pennsylvania has adopted the U.S. EPA's drinking water advisory standards, Ohio EPA's recreational use standards, and the State of Oregon's cyanotoxin guidance thresholds for pet exposure (0.2 µg/L) (Table 9) (Pennsylvania Department of Environmental Protection, Pennsylvania Department of Conservation and Natural Resources, & Erie County Department of Health, 2017). Routine sampling at the two public water suppliers (Table 10) in Pennsylvania is conducted during the peak summer recreational months (Memorial Day through Labor Day) on a case-by-case basis, with more frequent testing occurring during times with confirmed HABs (Pennsylvania Department of Environmental Protection, Pennsylvania Department of Conservation and Natural Resources, & Erie County Department of Health, 2017).
- In Michigan, out of the three public water suppliers sourcing from Lake Erie (Table 10), the City of Monroe's water treatment plant is the only one that voluntarily follows microcystin testing protocols as established by the Ohio EPA[18] (Michigan Department of Environmental Quality, 2014).
- The frequency of microcystin testing at the five New York systems is unknown, but the State does maintain an active online HAB reporting program, suggesting that testing is usually confined to periods in which there is a visible bloom (New York State Department of Health and Environmental Conservation, 2014).
- In Canada, Ontario's municipal water systems are required to test for microcystin whenever cyanobacteria are a concern in water intakes (McFadyen. 2019). Microcystin testing is not required year-round, and the frequency of testing increases when there is a confirmed HAB event. Monitoring activities in Ontario over the past several years indicate that microcystin has not been detected in treated drinking water (McFadyen, 2019).

Table 10 provides information on the number of public water systems by state, the number of customers served, and gallons treated daily. For a complete list of public water suppliers used in this analysis, see Appendix F: Data and Calculations.

[17] In Canada, the lead authority for regulating drinking water rests with provinces and territories. While there is no national regulation on cyanobacterial toxins, Health Canada works collaboratively with all provinces and territories in establishing the Guidelines for Canadian Drinking Water Quality, which are used as the scientific and technical basis for provincial/territorial drinking water regulations and requirements for drinking water utilities (Health Canada, personal communication, April 5, 2019).
[18] The frequency of microcystin testing at the other two treatment plants (Monroe South County and Frenchtown Township) is unknown.

Table 10. Public Water Systems Sourcing Water from Lake Erie Summary

U.S.			
State	**Number of Public Water Systems**	**Total Number of Customers Served**	**Total Gallons Treated Daily**
Ohio[a]	21	2.6 million	371 million
Pennsylvania	2	224,602	52.5 million
Michigan	3	99,023	13.9 million
New York	5	755,464[b]	141.5 million[b]
Canada			
Number of Public Water Systems		**Total Number of Customers Served**	**Total Gallons Treated Daily**
12		306,051	117,229,495
Total			
Number of Public Water Systems		**Number of Customers Served[b]**	**Total Gallons Treated Daily[a]**
43		4 million	696 million

Notes

a. There are an additional 36 public water suppliers that buy water from the Lake Erie system. The information in this table only reflects the data from public water suppliers that source water directly from Lake Erie.

b. Data for the population served includes all five New York plants. The total gallons treated per day estimate only reflects three of the five public water suppliers in New York. A Chautauqua county representative was unable to provide treatment capacity estimates for the Pines Motel and Bluewater Beach Campground systems (C. James, personal communication, April 17, 2019).

To avoid future plant shutdowns like the Toledo event and to ensure the safety of public water supplies, water treatment plants across the Lake Erie subregion are rapidly investing in additional infrastructure, equipment, and supplies to treat microcystin as well as increasing the frequency of monitoring and testing efforts. Since 2014, the Ohio EPA has distributed over $150 million in loans to water treatment plants for infrastructure projects related to algae (Raymond, 2019). Additional infrastructure upgrades have been completed using other funding sources, indicating an even higher estimate of algae-related costs to treatment plants.

While investments in equipment and increases in the frequency of monitoring efforts are still largely completed on a voluntary basis[19], they still represent a significant cost to the public water suppliers that may be reflected in higher water bills for residents if costs are passed on to consumers. As of October 2010, the City of Celina in nearby Grand Lake Saint Mary estimated that the total costs

[19] With the exception of water treatment plants in Ohio that are mandated to complete surface water testing as of 2016.

incurred associated with algae, including treatment installation, toxic algae testing set-up, and operation and maintenance, was $12.4 million, of which $3.4 million was total operation and maintenance to date (Davenport & Drake, 2011). In 2015, the U.S. EPA provided the City of Toledo with a $5.1 million loan to fund the construction of a powdered carbon-activated filtration system at the Collins Water Park treatment plant which increased the plant's ability to treat water with chemicals fourfold, but costs about $3,000 to $4,000 a day for operation (Samilton, 2018; Henry, 2013; Kaczala, 2015). The plant manager estimates that prior to 2014, the Collins Water Park Plant spent an average of $3 million every summer on chemicals to neutralize algae, with costs reaching $4.7 million and $5 million in 2014 and 2015, respectively (Henry, 2014).

Ohio EPA 2014 Water Treatment Plant Survey Results

In 2014, the Ohio EPA surveyed 20 water treatment plants from the western (4) and central basins (8), the Sandusky subbasin (6), and Lake Erie islands (2) in order to gain a better understanding of treatment, monitoring, and expenditure investments related to algae. At the time of the survey, 75% of the respondents did not test for cyanotoxins, and only the four western basin systems and one system in the Sandusky subbasin reported that they did. Out of the 20 respondents, 12 stated that they use algae control strategies or treatments on raw water before it reaches the plant, with chemical treatments such as potassium permanganate, $KMnO_4$, or other oxidants.

Even prior to the Ohio EPA requirement in 2016 mandating that water suppliers test for cyanotoxins, plants incurred significant costs for algae-related expenses. The survey results indicate that annual expenses associated with algae-related source monitoring (including staff and supply expenses if the analysis was completed by the water system) total $292,940 and annual equipment and training expenses totaled $140,750. Annual costs related to source water algae control expenses and treatment expenses related to reducing algae-related issues totaled over $3.2 million, with average maximum monthly expenses ranging from $275 for the island systems, $1,475 in the central basin, $17,615 in the Sandusky subbasin, and $178,000 in the western basin. Six of the plants had already made capital investments at the time of the survey totaling to date $615,000 and three systems indicated they would be installing or upgrading equipment to deal with algae.

With Ohio public suppliers now required to test for toxins, systems that did not test or sample for cyanotoxins in the past have now inherited a new set of annual operating costs and the higher intensity of frequency for testing can pose an additional cost burden to all plants. Smaller plants may not have the capital to fund large algae treatment projects nor be able to afford more frequent monitoring (Allen, 2016). When Ohio mandated plants begin testing daily rather than weekly during summer months, many smaller treatment plants raised concerns over the lack of grant opportunities and funding for the higher frequency for testing (Allen, 2016).

While the safety of public water supplies is imperative, and at least in the near-future plants must adapt and incur additional operating costs related to algae, reducing the intensity and frequency of HAB events can undoubtedly reduce treatment costs.

Water treatment plant costs related to algae vary from season to season and year to year, and it is becoming increasingly important to understand the range of costs public water suppliers across the basin now incur because of HAB events. To help fill in that information gap, we surveyed water suppliers across the Lake Erie subregion and received feedback on annual treatment costs and capital project costs from 10 plants (See Appendix E: Water Treatment Plant Survey for the template of the survey used and Appendix F: Data and Calculations for the survey results). Using the survey input and results from Smith (2015), which surveyed three Ontario public water suppliers, we are able to obtain average annual algae-related cost estimates for water treatment plants by basin and by plant size (See Appendix F: Data and Calculations for more information on the plants used and cost estimates by basin).

Applying the average cost estimates from three Ontario plants surveyed by Smith (2015) and the eight plants we surveyed[20], the 31 U.S. plants incur total annual incremental operating costs of $1.7 million (2018$ USD) from algae-related impacts. Canadian plants could incur an additional operating cost of $889,778 (2018$ USD) if algae conditions worsen (Smith, 2015). In total, water treatment plants sourcing water directly from Lake Erie incur annual operating costs associated with the treatment (and monitoring) of algae of over $2.6 million (2018$ USD). Our estimate reflects a conservative value and does not include costs to public water supply systems that source water from the main tributaries of Lake Erie or systems that buy water from Lake Erie sourced systems. Two systems surveyed, the Defiance water treatment plant in Ohio (2.9 million gallons per day capacity) and the Windsor Utilities Commission system in Ontario (31.7 million gallons per day capacity) draw water from the Maumee and Detroit Rivers, respectively, and were not included in our calculation of cost estimates.[21] Just these two plants alone incur annual costs related to algae treatment and monitoring of $46,000 and $2.6 million (2018$ USD), respectively. Plants that buy water from Lake Erie systems may encounter higher rates for water purchases if treatment costs at plants sourcing water from Lake Erie increase in the future.

Additional Annual Operating Costs Due to Algae

- The 31 U.S. water treatment plants incur total annual incremental operating costs of **$1.7 million** from algae-related impacts.
- The 12 Canadian plants incur an additional operating cost of **$889,778** (2018$ USD).
- In total, water treatment plants sourcing water directly from Lake Erie incur annual operating costs associated with the treatment (and monitoring) of algae of over **$2.6 million.**

[20] Two of the plants surveyed do not draw water directly from Lake Erie and were not included in the cost estimates. For more information on these plants see Appendix F: Data and Calculations.

[21] Estimates are only for public water suppliers that source water directly from Lake Erie.

Capital projects related to algae from the plants we surveyed and from three Canadian plants surveyed by Smith (2015) total over $84.7 million. To date, the 10 U.S. plants we surveyed have already spent over $81.2 million (2018$ USD) on capital expenditures related to algae (See Appendix F: Data and Calculations). In Canada, planned capital investments, as well as investments already made, total over $3.5 million (2018$ USD), with the three plants surveyed by Smith (2015) already spending $115,166 on capital projects, and two plants noting planned investments of $3.3 million (2018$ USD) if algal conditions worsen.

Capital Expenditures for Algae-Related Projects

Capital expenditures for algae-related projects from the 10 plants we surveyed and from three Canadian plants total over $84.7 million to date.

While public water suppliers have invested substantial capital towards algae-related treatment, achieving the GLWQA 40% target would undoubtedly decrease future water treatment costs. A decrease in the severity of future HAB events would likely translate to reduced expenditures by public water suppliers for the treatment of toxins in drinking water, and in a best-case scenario, savings in monitoring costs if future HABs become mild enough that the frequency of testing and monitoring could be reduced.

Next Steps

This assessment, like other assessments using the production function approach, relies on applying estimates developed from existing literature to the focus area. Given that existing data and literature in the subregion is largely concentrated on near-lake and in-lake impacts, specific benefit outcomes that downstream communities would receive from a healthier Lake Erie may be underrepresented. These communities could see additional economic benefits in the form of:

- Lower water treatment costs for plants that buy from systems sourcing directly from Lake Erie
- Increased tourism and sales revenues (gas, food, accommodation, etc.) from visitors travelling through communities en route to the lake

Algae and HABs also have impacts on many other industries and activities across the lake, but due to the lack of literature connecting reductions in algae to specific benefit outcome estimates, we were not able to quantify economic outcomes. In the following section, we qualitatively detail how other key industries and activities[22] are impacted by HABs and address how the framework established in this analysis can contribute to estimation of economic benefits.

[22] Key industries and activities are those sectors identified in the collaborative stakeholder process that were deemed important for consideration in this analysis.

Other Recreation & Tourism Sectors

Birding

Through our stakeholder interaction process, birdwatching was identified as a key economic sector by numerous participants on the webinars and survey respondents. Lake Erie is a premier global destination for birdwatching for both migratory and native species (The Courier, 2014). Birding is also an important component of tourism. In 2011 birdwatching contributed over $26 million in activity and 283 jobs to Ohio's economy (Koslow, Lillard, & Benka, 2013).

Birding in the Magee Trail National Wildlife Refuge
Photo Credit: (Federal Highway Administration, n.d.)

Bird mortalities have been documented in water bodies with recurring cyanobacteria blooms and the presence of microcystin has been found to propagate through riparian food webs (U.S. EPA, 2013; Moy, Dodson, Tassone, Bukaveckas, & Bulluck, 2016). Scientists are studying the direct effects of microcystin on birds in Lake Erie but there are no published conclusions yet; data and observations from other regions prone to HABs show that the toxin negatively impacts birds, inducing liver lesions in some cases. In the Salton Sea National Wildlife Refuge in California, scientists hypothesize that the cyanobacteria microcystin was the prominent reason for the massive die-off of thousands of water birds migrating through the refuge, and in the Chesapeake Bay, microcystin poisoning has been linked to mortality and illnesses of the Great Blue Heron (Cone, 1995; Koslow, Lillard, & Benka, 2013).

Avian botulism is another growing concern in the Great Lakes, with more than 80,000 birds dying from exposure to the neurotoxin since 1999 (Abbey-Lambertz, 2014). Scientists believe that when the nuisance algae *Cladophora*, the dominant algae in the eastern basin of Lake Erie, decomposes on the lake floor, it creates an ideal environment for the bacterium that produces the toxin to thrive (Abbey-Lambertz, 2014).

There is currently no study in the literature that links the presence and severity of HABs, or algae in general, to changes in recreation demand for birders in Lake Erie. Because birding is a significant tourist attraction, a key next step in regional research includes establishing how, and by how much, birders value reductions in the severity and frequency of HAB events. This can then be applied to the number of birders across Lake Erie to produce an estimate of the economic benefit birders could receive if toxic algae, or other nuisance algae like *Cladophora*, is reduced.

Boating/Charter Boats

Recreational boating and charter boat fishing are another prominent component of tourism in the Lake Erie region. Lake Erie's recreational boating industry supports over 26,000 jobs and has an annual economic impact of over $3.5 billion (City of Cleveland, 2013). The American Sport Fishing Association estimates that expenditures related to sport fishing on charter boats in Lake Erie contribute $1 billion to the regional economy annually and the Ohio Division of Wildlife estimates there are 724 Ohio-licensed charter boat captains and 682,634 private charter, head boat, and personal watercraft fishing trips in 2017 (Lake Erie Foundation, 2019).

In a survey conducted by the Ohio Sea Grant, Lake Erie charter boat captains highlighted that HABs were one of the top critical issues confronting the lake (Lucente, 2010). In Ottawa County, charter boat captains noted that business dropped about 7% from 2017 to 2018 because of HABs, and a poll of the roughly 250 charter boat captains belonging to the Lake Erie Charter Boat Association highlighted that publicity surrounding HABs reduced business by 20-25% due to people canceling trips to avoid green scum (Carson, 2018; Jackson, 2018).

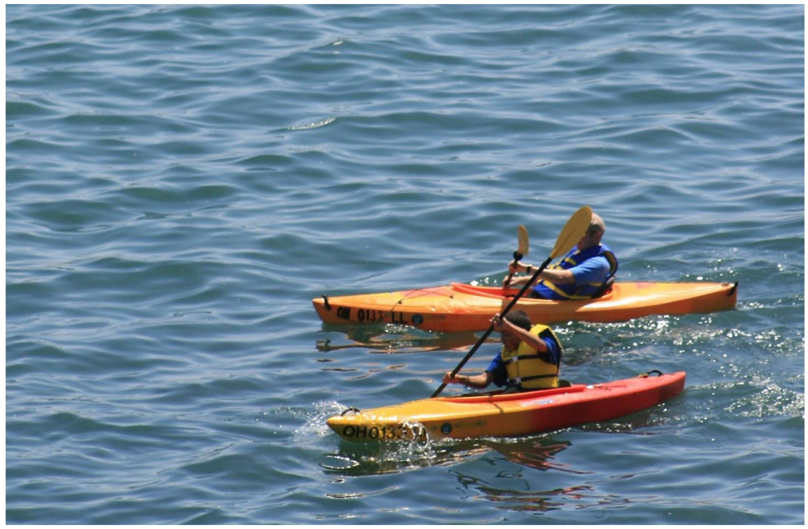
Even though some people fish while out in their boats and others do not, data (number of trips for people only boating, number of recreators only participating in boating, trip expenses, etc.) are typically not reported separately. Future research could identify the relationship between changes in demand preferences of only recreational boaters (i.e., people boating for leisure, cruises, etc.) with reductions in the severity and frequency of HABs. This will help us better understand how recreational boaters' preferences differ from those also partaking in fishing.

For boaters that also fish, Zhang and Sohngen (2017) estimate that anglers are willing to pay $8 to $11 more per trip to boat through one less mile of HABs en route to a fishing site and $6 to $73 more per trip for one less hour spent to catch a walleye. Future analysis could estimate anglers' gains in consumer surplus from reduced HAB interaction by comparing the average area

Sailing on the Lake
Photo Credit: (Federal Highway Administration, n.d.)

covered by a bloom in mild years with severe years and applying WTP measures to the number of recreational anglers that boat en route to a fishing site.

In order to determine how boaters would benefit from less severe and frequent HAB events, there needs to be more research conducted in the preferences of recreational boaters, boaters engaged in recreational fishing, and the charter boat industry.



Kayakers in Lake Erie
Photo Credit: (Federal Highway Administration, n.d.)

Medical Costs

Exposure to microcystin can adversely affect human and animal health, and the effects of microcystin poisoning vary depending on the route of exposure (e.g., ingestion, inhalation, direct content) and the exposure level (Trevino-Garrison et al., 2015). Signs and symptoms of microcystin poisoning can occur within minutes to hours of exposure and often include nausea, vomiting, diarrhea, coughing, sore throat, rash, and liver damage (Trevino-Garrison et al., 2015).

Because symptoms of acute microcystin poisoning mimic more common illnesses such as the flu or food poisoning, many cases go unreported and documented poisonings are generally limited to those that ultimately decide to visit a hospital for treatment. The 2014 HAB event sent at least 60 people from Toledo to the hospital and from 2008 to 2014, 228 documented hospital visits were associated with HABs in the state of New York (Konkel, 2017; Figgatt, Muscatiello, Wilson, & Dziewulski, 2016). Assuming the average cost for a clinical visit at the University of Toledo Medical Center is $205[23], the 60 people hospitalized in Toledo due to the HAB collectively paid an estimated $12,300 (American Hospital Directory, 2019). This total could be greater if some of those impacted needed more intensive care, rather than a simple clinical visit.

Until more accurate statistics on the number of people that needed hospital care are available, the true public health costs of HABs cannot be fully determined. Future analysis on the topic could examine the economic impact of HABs on medical care costs, including the number of people hospitalized per year due to acute microcystin poisonings, estimates of the number of unreported cases, and the cost of treatment for hospital visits and prescriptions, as well as indirect costs (such as time lost from work).

[23] The data was last updated on 2/13/2019, and we assume that this value is current.

Conclusion

Achieving the GLWQA 40% phosphorus reduction goal would create positive economic implications in the form of benefits for recreational anglers and beach-goers, avoided capitalization losses for property owners, and reduced algae-related treatment and monitoring costs for public water suppliers. To our knowledge, this ecosystem service assessment is the first analysis to estimate the benefits of achieving the GLWQA target phosphorus goals for all recreational anglers in Canada and the U.S. fishing in Lake Erie and all beach-goers in Canada and the U.S. visiting Lake Erie. This analysis also estimates potential property value losses along the entire shoreline if microcystin levels continue to surpass drinking water standards, as well as annual operating costs associated with the monitoring and treatment of algae for all public water suppliers sourcing water directly from Lake Erie.

Works Cited

Abbey-Lambertz, K. (2014, August 6). Disturbing Photos Show Why Algae Blooms Are A Growing Global Threat. Retrieved April 23, 2019, from HuffPost website: https://www.huffpost.com/entry/lake-erie-algae-bloom-2014-_n_5647824

Aburto-Oropeza, O., Ezcurra, E., Danemann, G., Valdez, V., Murray, J., & Sala, E. (2008). Mangroves in the Gulf of California increase fishery yields. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(30), 10456–10459. https://doi.org/10.1073/pnas.0804601105

Allen, C. (2016). *Overview of Public Water System Harmful Algal Blooms Rules — Questions and Answers*. 14.

Amacher, G. S., & Brazee, R. J. (1989). Application of wetland valuation techniques: Examples from Great Lakes Coastal Wetlands. *University of Michigan, School of Natural Resources*.

American Hospital Directory. (2019, February 13). American Hospital Directory - The University of Toledo Medical Center (360048) - Free Profile. Retrieved April 24, 2019, from https://www.ahd.com/free_profile/360048/The_University_of_Toledo_Medical_Center/Toledo/Ohio/

Anderson, G. D., & Edwards, S. F. (1986). Protecting Rhode Island coastal salt ponds - an economic-assessment of downzoning. *Coastal Zone Management Journal*, *14*, 67–91.

Anielski, M., & Wilson, S. (2005). *Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems*. Retrieved from Pembina Institute website: http://www.pembina.org/reports/Boreal_FINAL.pdf

Ara, S., Irwin, E., & Haab, T. (2016). The Influence of Water Quality on the Housing Price Around Lake Erie, 20.

Arenschield, L. (2015, August 5). Toxic algae sickens woman at Grand Lake St. Marys, but state won't close beaches. Retrieved March 14, 2019, from https://www.dispatch.com/article/20150804/NEWS/308049786

Armstrong, D., Rooper, C., & Gunderson, D. (2003). Estuarine Production of juvenile Dungeness Crab and Contribution to the Oregon-Washington Coastal Fishery. *Estuaries*, *26*(4), 1174–1188.

Austin, J. C., Anderson, S., Courant, P. N., & Litan, R. E. (2007). *America's North Coast: A Benefit-Cost Analysis of a Program to Protect and Restore the Great Lakes*. 86.

Balmford, A., Fisher, B., Green, R. E., Naidoo, R., Strassburg, B., Kerry Turner, R., & Rodrigues, A. S. L. (2010). Bringing Ecosystem Services into the Real World: An Operational Framework for Assessing the Economic Consequences of Losing Wild Nature. *Environmental and Resource Economics*, *48*(2), 161–175. https://doi.org/10.1007/s10640-010-9413-2

Balmford, A., Rodrigues, A., Walpole, M., Brink, P., Kettunen, M., de Groot, R., & Cambridge, U. (2013). *The Economics of Biodiversity and Ecosystems: Scoping the Science.* Retrieved from http://ec.europa.eu/environment/nature/biodiversity/economics/teeb_en.htm

Baron, A., Zhang, W., & Irwin, E. (2016). Estimating the Capitalization Effects of Harmful Algal Bloom Incidence, Intensity and Duration? A Repeated Sales Model of Lake Erie Lakefront Property Values. Retrieved December 21, 2018, from https://ageconsearch.umn.edu/bitstream/236589/2/Algae%20Lake%20Erie_AAEA.pdf

Barrow, C. J. (1991). *Land degradation: development and breakdown of terrestrial environments.* 305 pp. Retrieved from CABDirect2.

Batie, S. S., & Wilson, J. R. (1978). Economic Values Attributable to Virginia's Coastal Wetlands as Inputs in Oyster Production. *Southern Journal of Agricultural Economics*. Retrieved from http://ageconsearch.umn.edu/bitstream/30270/1/10010111.pdf

Bejranonda, S., Hitzhusen, F. J., & Hite, D. (1999). Agricultural Sedimentation Impacts on Lakeside Property Values. *Agricultural and Resource Economics Review*, *28*(2), 208–218. https://doi.org/10.1017/S1068280500008200

Bell, F. W. (1989). *Application of wetland valuation theory to commercial and recreational fisheries in Florida* (p. 148). Florida Sea Grant Program.

Bell, F. W. (1997). The economic valuation of saltwater marsh supporting marine recreational fishing in the southeastern United States. *Ecological Economics*, *21*(3), 243–254. https://doi.org/10.1016/S0921-8009(96)00105-X

Bergstrom, J. C., Dillman, B. L., & Stoll, J. R. (1985). Public Environmental Amenity Benefits of Private Land: The Case of Prime Agricultural Land. *Southern Journal of Agricultural Economics*, *17*(01). Retrieved from http://ideas.repec.org/a/ags/sojoae/29361.html

Bergstrom, J. C., Stoll, J. R., Titre, J. P., & Wright, V. L. (1990). Economic value of wetlands-based recreation. *Ecological Economics*, *2*(2), 129–147. https://doi.org/10.1016/0921-8009(90)90004-E

Bingham, M., Sinha, S. K., Lupi, F., & Environmental Consulting & Technology Inc. (2015, October). Economic Benefits of Reducing Harmful Algal Blooms in Lake Erie. Retrieved November 20, 2018, from https://legacyfiles.ijc.org/tinymce/uploaded/Publications/Economic-Benefits-Due-to-Reduction-in-HABs-October-2015.pdf

Bishop, K. (1992). Assessing the benefits of community forests: an evaluation of the recreational use benefits of two urban fringe Woodlands. *Journal of Environmental Planning and Management*, *35*(1), 63–76. https://doi.org/10.1080/09640569208711908

Bootsma, H. A., Jensen, E. T., Young, E. B., & Berges, J. A. (2004). *Cladophora Research and Management in the Great Lakes* (p. 111).

Brookshire, D. S., Thayer, M. A., Schulze, W. D., & d'Arge, R. C. (1982). Valuing Public Goods: A Comparison of Survey and Hedonic Approaches. *The American Economic Review*, *72*(1), 165–177.

Bruce, J., Dupont, D., & Renzetti, S. (2010). *Economic value of protecting the Great Lakes*. Marbek Consultants.

Buffalo Water. (2019). 2018 Annual Drinking Water Quality Report. Retrieved April 17, 2019, from http://www.buffalowater.org/Quality/WaterQualityReports/20182019WaterQualityReport

Canada Centre for Remote Sensing. (2015). North American Land Change Monitoring System (NALCMS) Collection. Retrieved May 6, 2019, from https://catalog.data.gov/harvest/object/61179025-e021-4993-a373-30f5dddaa6f3/original

Canada-Ontario Agreement on Great Lakes Water Quality, and Ecosystem Health, & Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health. (2014). *Characterization of Canadian watersheds in the Lake Erie basin*. Retrieved from http://www.farmfoodcareon.org/wp-content/uploads/2016/07/Characterization-of-Watersheds.pdf

Carson, D. (2018, October 5). Charter boat captains feel financial pain from Lake Erie algae. Retrieved December 19, 2018, from https://www.thenews-messenger.com/story/news/local/2018/10/05/charter-boat-captains-feel-financial-pain-lake-erie-algae/1372352002/

Center for Great Lakes Literacy. (n.d.). How long does it take water to flow through the Great Lakes basin? Retrieved May 8, 2019, from https://www.cgll.org/topics/retention-time/

City Desk. (2014, August 27). Algae bloom concerns prompt Pelee Island warning | Windsor Star. Retrieved May 1, 2019, from https://windsorstar.com/news/algae-bloom-contaminates-pelee-island-water

City of Cleveland. (2013). City of Cleveland Economic Development - Water. Retrieved April 23, 2019, from http://rethinkcleveland.org/Strategic-Advantages/Key-Assets/Water.aspx

City of Dunkirk. (2016). Annual Drinking Water Quality Report. Retrieved April 17, 2019, from http://www.dunkirktoday.com/wp-content/uploads/AWQR_2016_Dunkirk.pdf

Cleveland, C. J., Betke, M., Federico, P., Frank, J. D., Hallam, T. G., Horn, J., … Kunz, T. H. (2006). Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. *Frontiers in Ecology and the Environment*, *4*(5), 238–243. https://doi.org/10.1890/1540-9295(2006)004[0238:EVOTPC]2.0.CO;2

Commission for Environmental Cooperation. (2018). North American Land Change Monitoring System. Retrieved April 2, 2019, from http://www.cec.org/tools-and-resources/north-american-environmental-atlas/north-american-land-change-monitoring-system

Cone, M. (1995, March 29). Bird Deaths at Salton Sea Blamed on Toxic Algae. *Los Angeles Times*. Retrieved from https://www.latimes.com/archives/la-xpm-1995-03-29-mn-48397-story.html

Costanza, R., Farber, S. C., & Maxwell, J. (1989). Valuation and management of wetland ecosystems. *Ecological Economics*, *1*(4), 335–361. https://doi.org/10.1016/0921-8009(89)90014-1

Costanza, R., Wilson, M., Troy, A., Voinov, A., Liu, S., & D'Agostino, J. (2006). The value of New Jersey's ecosystem services and natural capital. *Gund Institute for Ecological Economics, University of Vermont and New Jersey Department of Environmental Protection, Trenton, New Jersey*, *13*. Retrieved from http://www.academia.edu/download/30561335/njvaluationpart2.pdf

Costanza, R., d'Arge, R., Farber, S., Grasso, M., deGroot, R., Hannon, B., & van den Belt, M. (1997). The Value of the World's Ecosystem Services and Natural Capital. *Nature*, *387*, 253–260.

Creel, M., & Loomis, J. (1992). Recreation value of water to wetlands in the San Joaquin Valley: Linked multinomial logit and count data trip frequency models. *Water Resources Research*, *28*(10), 2597–2606. https://doi.org/10.1029/92WR01514

Davenport, T., & Drake, W. (2011). Grand Lake St. Marys, Ohio – The Case for Source Water Protection: Nutrients and Algae Blooms. Retrieved March 20, 2019, from https://dnr.mo.gov/env/wpp/rules/rir/docs/davenport-drake-2011.pdf

Earth Economics. (n.d.). Ecosystem Valuation Toolkit. Retrieved May 6, 2019, from https://www.eartheconomics.org/ecosystem-valuation-toolkit

Eitniear, S. (n.d.). Impacts of Microcystin in a Municipal Water Supply, 60.

Environment and Climate Change Canada, & Ontario Ministry of the Environment and Climate Change. (2018, February 22). Canada-Ontario Lake Erie Action Plan Partnering on Achieving phosphorus Loading Reductions to Lake Erie from Canadian Sources. Retrieved November 15, 2018, from https://www.canada.ca/en/environment-climate-change/services/great-lakes-protection/action-plan-reduce-phosphorus-lake-erie.html

Environmental Protection Agency. (2017, June). Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters. Retrieved December 21, 2018, from https://www.epa.gov/sites/production/files/2017-07/documents/08_july_3_monitoring_document_508c_7.5.17.pdf

Erickson, J. (2013, April 1). Record-breaking 2011 Lake Erie algae bloom may be sign of things to come. Retrieved February 18, 2019, from https://news.umich.edu/record-breaking-2011-lake-erie-algae-bloom-may-be-sign-of-things-to-come/

Erie County Water Authority. (2019). Erie County Water Authority Delivered Water Summary. Retrieved April 17, 2019, from https://www.ecwa.org/delwatsum

Everard, M., Great Britain, & Environment Agency. (2009). *Ecosystem services case studies*. Bristol: Environment Agency.

Farber, S. (1996). Welfare Loss of Wetlands Disintegration: A Louisiana Study. *Contemporary Economic Policy*, *14*, 92–106. https://doi.org/10.1111/j.1465-7287.1996.tb00606.x

Farber, S., & Costanza, R. (1987). The economic value of wetlands systems. *Journal of Environmental Management*, *24*, 41–51.

Federal Highway Administration. (n.d.). Lake Erie Coastal Ohio Trail - All Photos | America's Byways. Retrieved June 17, 2019, from https://www.fhwa.dot.gov/byways/byways/59836/photos/all

Flores, L., Harrison-Cox, J., Wilson, S., & Batker, D. (2013). *Nearshore Valuation-Primary Values. Nature's Value in Clallam County: The Economic Benefits of Feeder Bluffs and 12 Other Ecosystems*. Tacoma, WA: Earth Economics.

Gatz, L. (2013). Freshwater Harmful Algal Blooms: Causes, Challenges, and Policy Considerations, 29.

Gibbons, D. C. (1986). *The Economic Value of Water*. Retrieved from Resources for the Future website: https://books.google.com/books/about/The_economic_value_of_water.html?id=5VkXgPwwofAC

Gildow, M. C. (2015). *Evaluating Fertilizer Application Practices to Reduce phosphorus Discharge from the Maumee River*. 81.

Gill, D., Rowe, M., & Joshi, S. J. (2018). Fishing in greener waters: Understanding the impact of harmful algal blooms on Lake Erie anglers and the potential for adoption of a forecast model. *Journal of Environmental Management*, *227*, 248–255. https://doi.org/10.1016/j.jenvman.2018.08.074

Glaser, S. (2017, June 9). Lake Erie beach guide: Where to find the best stretches of sand on Ohio's North Coast. Retrieved March 19, 2019, from https://www.cleveland.com/travel/2017/06/lake_erie_beach_guide_where_to.html

Gosselink, J. G., Odum, E. P., Center, U. of F. U. and R. D., & Pope, R. M. (1974). *The Value of the Tidal Marsh*. Center for Wetland Resources, Louisiana State University.

Government of Canada. (2018, September 7). Profile Page for Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Cyanobacterial Toxins [research;guidance]. Retrieved March 20, 2019, from https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-cyanobacterial-toxins.html

Government of Canada Fisheries and Oceans Statistical Services. (2008, October 6). Survey of Recreational Fishing in Canada 2005: Selected Results for the Great Lakes Fishery | Fisheries and Oceans Canada. Retrieved October 15, 2019, from https://waves-vagues.dfo-mpo.gc.ca/Library/346362.pdf

Government of Canada Fisheries and Oceans Statistical Services. (2007, October 6). 2005 Survey of Recreational Fishing in Canada. Retrieved November 7, 2019, from https://waves-vagues.dfo-mpo.gc.ca/Library/329241.pdf

Government of Ontario. (2015, February 20). Quaternary watershed boundaries. Retrieved April 1, 2019, from Ontario.ca website: https://www.ontario.ca/data/quaternary-watershed-boundaries

Graefe, A. R., Mowen, A. J., Ferguson, M. D., & Dorata, E. J. (2018). *Assessing the Economic Impact and Significance of Recreational Angling on Lake Erie Waters: Final Report*.

Gren, I.-M., & Söderqvist, T. (1994). *Economic valuation of wetlands: a survey*. Beijer International Institute of Ecological Economics, The Royal Swedish Academy of Sciences.

Gupta, T. R., & Foster, J. H. (1975). Economic criteria for freshwater wetland policy in Massachusetts. *American Journal of Agricultural Economics*. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=US19750030691

Haener, M. K., & Adamowicz, W. L. (2000). Regional forest resource accounting: a northern Alberta case study. *Canadian Journal of Forest Research*, *30*(2), 264–273. https://doi.org/10.1139/x99-213

Hall, D. S. (2010). *Applied ecosystem services in working forests: A direct market valuation* (University of Tennessee, Knoxville). Retrieved from http://trace.tennessee.edu/utk_gradthes/804/

Health Canada. (2019, April 5). *Personal Communication Health Canada*.

Henry, T. (2013, September 7). Toxins overwhelm area water plant. Retrieved March 21, 2019, from http://www.toledoblade.com/local/2013/09/07/Toxins-overwhelm-water-plant/stories/20130906238

Henry, T. (2014, August 29). Toledo's water chemical cost up by $1.7M | Toledo Blade. Retrieved March 21, 2019, from https://www.toledoblade.com/local/2014/08/29/City-s-water-chemical-cost-up-by-1-7M.html

Hill, S. (2015, March 25). $244M economic impact shows importance of Lake Erie commercial fishery | Windsor Star. Retrieved January 16, 2019, from https://windsorstar.com/uncategorized/244m-economic-impact-shows-importance-of-lake-erie-commercial-fishery

Hughes, Z. (2006). *Ecological and economics assessment of potential eelgrass expansion Hugheseat Sucia Island* [Term Paper]. University of Washington.

Hunt, S. (2013). Ottawa County residents told drinking water might contain toxic algae. Retrieved March 20, 2019, from https://www.dispatch.com/article/20130907/NEWS/309079770

Jackson, T. (2018, August 27). Action needed for Lake Erie. Retrieved April 23, 2019, from http://www.sanduskyregister.com/story/201808230010

James, C. (2019, April 17). *Personal Communication with Casey James-Chautauqua County*.

Jaworski, E., & Raphael, C. N. (1978). Fish, Wildlife, And Recreational Values of Michigan 's Coastal Wetlands. *Michigan Department of Natural Resources February 1978, 209 p. 25 Fig, 62 Tab, 205 Ref, 1 Append. Wetlands Value Study, Phase 1.* Retrieved from http://search.proquest.com/docview/19192481?pq-origsite=summon&

Jenkins, W. A., Murray, B. C., Kramer, R. A., & Faulkner, S. P. (2010). Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. *Ecological Economics*, *69*(5), 1051–1061. https://doi.org/10.1016/j.ecolecon.2009.11.022

Johnston, R. J., Opaluch, J. J., Grigalunas, T. A., & Mazzotta, M. J. (2001). Estimating Amenity Benefits of Coastal Farmland. *Growth and Change*, *32*(3), 305–325. https://doi.org/10.1111/0017-4815.00161

Kaczala, K. (2015, April 27). Toledo - Ohio EPA loans will fund water plant upgrades. Retrieved March 21, 2019, from http://www.presspublications.com/15813-toledo-ohio-epa-loans-will-fund-water-plant-upgrades

Kahn, J. R., & Buerger, R. B. (1994). Valuation and the Consequences of Multiple Sources of Environmental Deterioration: The Case of the New York Striped Bass Fishery. *Journal of Environmental Management*, *40*(3), 257–273. https://doi.org/10.1006/jema.1994.1019

Kauffman, G., Homsey, A., McVey, E., Mack, S., & Chatterson, S. (2011). *Socioeconomic Value of the Chesapeake Bay Watershed in Delaware* (p. 45). Retrieved from University of Delaware's Institute for Public Administration website: http://www.wra.udel.edu/wp-content/publications/DelChesapeakeWatershed.pdf

Kelch, D., Lichtkoppler, F., Sohngen, B., & Daigneault, A. (2009, February 19). The Value of Steelhead (Onchorhynchus mykiss) Angling in Lake Erie Tributaries. Retrieved November 15, 2018, from http://www.bioone.org/doi/abs/10.3394/0380-1330(2006)32%5B424:TVOSOM%5D2.0.CO%3B2

Kildow, J. T., Colgan, C., Kite-Powell, H., Shivendu, S., & Tindall, R. (2004). *Estimates of water-quality related values and other relevant data for Long Island Sound*. Long Island Sound Study.

Knoche, S., & Lupi, F. (2007). Valuing deer hunting ecosystem services from farm landscapes. *Ecological Economics*, *64*(2), 313–320. https://doi.org/10.1016/j.ecolecon.2007.07.023

Koslow, M., Lillard, E., & Benka, V. (2013). *Taken by Storm: How Heavy Rain is Worsening Algal Blooms in Lake Erie With a Focus on the Maumee River in Ohio*. Retrieved from https://www.nwf.org/~/media/PDFs/Water/Taken_By_Storm_NWF_2013.ashx

Krause, A. (2014, September 11). What is Waterfront Worth? Retrieved March 14, 2019, from https://www.zillow.com/research/what-is-waterfront-worth-7540/

Kreutzwiser, R. (1981). The Economic Significance of the Long Point Marsh, Lake Erie, as a Recreational Resource. *Journal of Great Lakes Research*, *7*(2), 105–110. https://doi.org/10.1016/S0380-1330(81)72034-3

Krysel, C., Boyer, E. M., Parson, C., & Welle, P. (2003). Lakeshore Property Values and Water Quality: Evidence from Property Sales in the Mississippi Headwaters Region. Retrieved March 14, 2019, from http://www.friendscvsf.org/bsu_study.pdf

Lake Erie Foundation. (2019). LAKE ERIE TOURISM ECONOMIC IMPACT IN OHIO. Retrieved April 23, 2019, from https://lakeeriefoundation.org/about-lake-erie/economics/

Lant, C., & Roberts, R. (1990). Greenbelts in the Cornbelt: Riparian Wetlands, Intrinsic Values and Market Failure. *Environment and Planning A*, 1375–1388.

Lipton, D. (2009). Economic Benefits of a Restored Oyster Fishery in Chesapeake Bay. *Journal of Shellfish Research*, (May 2008), 619–623. https://doi.org/10.2983/0730-8000(2008)27[619:EBOARO]2.0.CO;2

Liu, T., Opaluch, J. J., & Uchida, E. (2017). The impact of water quality in Narragansett Bay on housing prices. *Water Resources Research*, *53*(8), 6454–6471. https://doi.org/10.1002/2016WR019606

Loomis, J., & Ekstrand, E. (1998). Alternative approaches for incorporating respondent uncertainty when estimating willingness to pay: the case of the Mexican spotted owl. *Ecological Economics*, *27*(1), 29–41.

Loomis, J., Kent, P., Strange, L., Fausch, K., & Covich, A. (2000). Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics*, 15.

Lucente, J. (2010). Lake Erie and the Ohio Charter Sport Fishing Industry 2010 PowerPoint Presentation. Retrieved April 23, 2019, from http://wsg.washington.edu/wordpress/wp-content/uploads/outreach/nwwws/C2/C2_Lucente.pdf

Lui, Z. (2006). *Water Quality Simulation and Economic Valuation of Riparian Land-use Changes*. University of Cincinnati.

Mazzotta, M. J. (1996). Measuring public values and priorities for natural resources: An application to the Peconic Estuary system. *Dissertations and Master's Theses (Campus Access)*, 1–272.

McFadyen, S. (2019, March 28). *Microcystin Testing in Canada Personal Communication*.

Medeiros, T. (2017, July 17). Pelee Island Mayor Hopes Algae Bloom Predictions Are Wrong. Retrieved February 19, 2019, from http://www.iheartradio.ca/am800/news/pelee-island-mayor-hopes-algae-bloom-predictions-are-wrong-1.2862045

Michigan Department of Environmental Quality. (2014, September). Current State of Harmful Algal Bloom Impacts on Michigan Drinking Water Supplies. Retrieved March 22, 2019, from https://www.michigan.gov/documents/deq/deq-odwma-water-cdw-HAB_Impacts_467739_7.pdf

Michigan Department of Natural Resources. (2019, July). Michigan Creel Data Effort. Retrieved October 1, 2019, from http://gis-midnr.opendata.arcgis.com/datasets/michigan-creel-data-effort

Mitsch, W. J., & Gosselink, J. G. (2000). The value of wetlands: importance of scale and landscape setting. *Ecological Economics*, *35*(1), 25–33. https://doi.org/10.1016/S0921-8009(00)00165-8

Moore, R., Williams, T., Rodriguez, E., & Hepinstall-Cymmerman, J. (2011). *Quantifying the value of non-timber ecosystem services from Georgia's private forests* (p. 44). Retrieved from http://www.warnell.uga.edu/news/wp-content/uploads/2011/02/Final-Report-1-24-11.pdf

Mowen, A. J., Graefe, A. R., Kerstetter, L., & Ferguson, M. D. (2013). *2012-2013 Presque Isle State Park Visitor Survey: Final Report*. 57.

Moy, N. J., Dodson, J., Tassone, S. J., Bukaveckas, P. A., & Bulluck, L. P. (2016). Biotransport of Algal Toxins to Riparian Food Webs. *Environmental Science & Technology*, *50*(18), 10007–10014. https://doi.org/10.1021/acs.est.6b02760

Municipal Affairs and Housing. (2015). Municipal boundaries | Ontario.ca. Retrieved May 8, 2019, from https://www.ontario.ca/data/municipal-boundaries

Murray, C. (2019, Sept 5). *Personal Communication Pennsylvania Fish and Boat Commission*.

Murray, C., Sohngen, B., & Pendleton, L. (2001). Valuing water quality advisories and beach amenities in the Great Lakes. *Water Resources Research*, *37*(10), 2583–2590. https://doi.org/10.1029/2001WR000409

NESP (National Ecosystem Services Partnership). (2016). *Federal Resource Management and Ecosystem Services Guidebook.* (2nd ed.). Duram: National Ecosystem Services Partnership, Duke University. Retrieved from https://nespguidebook.com/

National Centers for Coastal Ocean Science. (2019). HAB Forecasts. Retrieved March 7, 2019, from https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-forecasts/

National Oceanic and Atmospheric Administration. (2019b). Harmful Algal Blooms: Great Lakes Region. Retrieved June 17, 2019, from https://www.regions.noaa.gov/great-lakes/index.php/project/harmful-algal-blooms/

National Oceanic and Atmospheric Administration. (2019c, July). NOAA, partners predict large summer harmful algal bloom for western Lake Erie | National Oceanic and Atmospheric Administration. Retrieved July 12, 2019, from https://www.noaa.gov/media-release/noaa-partners-predict-large-summer-harmful-algal-bloom-for-western-lake-erie

National Oceanic and Atmospheric Administration. (2018, October 26). Experimental Lake Erie Harmful Algal Bloom Bulletin 26 October 2018, Seasonal Assessment. Retrieved March 7, 2019, from https://cdn.coastalscience.noaa.gov/hab-data/bulletins/lake-erie/2018/bulletin_2018-final.pdf

Natural Resources Conservation Service. (2014). Ohio Farmers Show Their Commitment to Protecting Lake Erie. Retrieved June 17, 2019, from https://www.usda.gov/media/blog/2014/08/28/ohio-farmers-show-their-commitment-protecting-lake-erie

New York State Department of Environmental Conservation. (2019). Lake Erie Reports. Retrieved September 20, 2019, from https://www.dec.ny.gov/outdoor/32286.html

New York State Department of Health and Environmental Conservation. (2014, August 8). JOINT STATEMENT BY NEW YORK STATE DEPARTMENTS OF HEALTH AND ENVIRONMENTAL CONSERVATION REGARDING THE AUGUST 2014 LAKE ERIE ALGAL BLOOM AND WATER SUPPLY RESRICTIONS IN TOLEDO OHIO. Retrieved March 22, 2019, from http://www.dec.ny.gov/docs/water_pdf/bga20140808.pdf

Nowak, D. J., Crane, D. E., & Dwyer, J. F. (2002). Compensatory value of urban trees in the United States. *Journal of Arboriculture*, *28*(4), 194–199.

Office of the New York State Comptroller. (2017). *Drinking Water Systems in New York: The Challenges of Aging Infrastructure*. 29.

Ohio Department of Natural Resources. (2018, March 29). 2018 Lake Erie Sport Fishing Outlook Shares Great News for Anglers - News from the Ohio Department of Natural Resources. Retrieved March 8, 2019, from http://ohiodnr.gov/news/post/2018-lake-erie-sport-fishing-outlook-shares-great-news-for-anglers

Ohio Department of Natural Resources Division of Wildlife Lake Erie Fisheries Units. (2019, March). Ohio's Lake Erie Fisheries 2018 Annual Report. Retrieved December 26, 2018, from http://wildlife.ohiodnr.gov/portals/wildlife/pdfs/fishing/LakeErieStatus.pdf

Ohio Department of Natural Resources Division of Wildlife Lake Erie Fisheries Units. (2017, April). Ohio's Lake Erie Fisheries 2016.

Ohio Department of Natural Resources Division of Wildlife Lake Erie Fisheries Units. (2013, March). Ohio's Lake Erie Fisheries 2012.

Ohio EPA, Division of Drinking and Ground Waters. (2016, July 24). Ohio's Drinking Water Source Protection Areas. Retrieved April 19, 2019, from https://oepa.maps.arcgis.com/apps/webappviewer/index.html?id=38d04980a40d41f59d832a50f3fc0b92

Ontario Ministry of Tourism, Culture and Sport. (2017, August 16). Regional Tourism Profiles. Retrieved January 28, 2019, from http://www.mtc.gov.on.ca/en/research/rtp/rtp.shtml

Ohio Sea Grant. (2019). The Dead Zone, Lake Hypoxia and Anoxia. Retrieved May 31, 2019, from Ohio Sea Grant College Program website: https://ohioseagrant.osu.edu/research/issues/deadzone

Opaluch, J. J., Grigalunas, T. A., Diamantedes, J., Mazzotta, M., & Johnston, R. (1999). *Recreational and resource economic values for the Peconic Estuary, prepared for the Peconic Estuary Program*. Peconic Estuary Program.

Organization for Economic Cooperation and Development. (2006). Benefits Transfer. In *Cost-Benefit Analysis and the Environment* (pp. 253–267). Retrieved from http://www.oecd-ilibrary.org/environment/cost-benefit-analysis-and-the-environment/benefits-transfer_9789264010055-18-en

Palm-Forster, L. H., Lupi, F., & Chen, M. (2016). Valuing Lake Erie Beaches Using Value and Function Transfers. *Agricultural and Resource Economics Review*, *45*(02), 270–292. https://doi.org/10.1017/age.2016.15

Pennsylvania Department of Environmental Protection. (2019). Drinking Water Reporting System. Retrieved April 16, 2019, from http://www.drinkingwater.state.pa.us/dwrs/HTM/SelectionCriteria.html

Pennsylvania Fish and Boat Commission Lake Erie Research Unit. (2019). *Lake Erie Status and Trends Report 2018*.

Pennsylvania Fish and Boat Commission Lake Erie Research Unit. (2017). *Lake Erie Status and Trends Report 2016*.

Pennsylvania Fish and Boat Commission Lake Erie Research Unit. (2013). *Lake Erie Status and Trends Report 2012*.

Phillips, S., Silverman, R., & Gore, A. (2008). *Greater Than Zero: Toward the Total Economic Value of Alaska's National Forest Wildlands*. Retrieved from The Wilderness Society website: https://partners.tws.org/wildscience/Publications1/Greater%20than%20Zero.pdf

Pimentel, D. (1998). *Benefits of biological diversity in the state of Maryland*. Ithaca, NY: Cornell University, College of Agricultural and Life Sciences.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, K., McNair, M., … Blair, R. (2003). Environmental and Economic Costs of Soil Erosion and Conservation Benefits. *Science*, *Vol. 267* (No 5201).

Pompe, J. J., & Rinehart, J. R. (1995). Beach Quality and the Enhancement of Recreational Property Values. *Journal of Leisure Research*, *27*(2). Retrieved from http://js.sagamorepub.com/jlr/article/view/866

Prince, R., & Ahmed, E. (1989). Estimating individual recreation benefits under congestion and uncertainty. *Journal of Leisure Research*, *21*, 61–76.

Qiu, Z., Prato, T., & Boehrn, G. (2006). Economic Valuation of Riparian Buffer and Open Space in a Suburban Watershed1. *JAWRA Journal of the American Water Resources Association*, *42*(6), 1583–1596. https://doi.org/10.1111/j.1752-1688.2006.tb06022.x

Rausser, G. C., & Small, A. A. (2000). *Valuing Research Leads: Bioprospecting and the Conservation of Genetic Resources* [Berkeley Olin Program in Law & Economics, Working Paper Series]. Retrieved from Berkeley Olin Program in Law & Economics website: http://econpapers.repec.org/paper/cdloplwec/qt4t56m5b8.htm

Raymond, H. (2019, March 22). HAB Information Personal Communication.

Ready, R. C., Berger, M. C., & Blomquist, G. C. (1997). Measuring Amenity Benefits from Farmland: Hedonic Pricing vs. Contingent Valuation. *Growth and Change*, *28*(4), 438–458.

Reid, Walter V., Assessment Panel, Cropper, A., Capistrano, D., Carpenter, S., Chopra, K., … Zubek, M. (2005). *Millennium Ecosystem Assessment: Ecosystems and Human Well-Being: Synthesis*.

Retrieved from World Resources Institute website: http://www.millenniumassessment.org/documents/document.356.aspx.pdf

Rein, F. A. (1999). An Economic Analysis of Vegetative Buffer Strip Implementation. Case Study: Elkhorn Slough, Monterey Bay, California. *Coastal Management*, *27*(4), 377–390. https://doi.org/10.1080/089207599263785

Robinson, W. S., Nowogrodzki, R., & Morse, R. A. (1989). The value of honeybees as pollinators of US crops. *American Bee Journal*, *129*, 411–423, 477–487.

Rosenberger, R. S., & Walsh, R. G. (1997). Nonmarket Value of Western Valley Ranchland Using Contingent Valuation. *Journal of Agricultural and Resource Economics*, *22*(2), 1–14.

Sala, O. E., & Paruelo, J. M. (1997). Ecosystem services in grasslands. *Nature's Services: Societal Dependence on Natural Ecosystems*, 237–251.

Samilton, T. (2018, September 6). Toledo works to restore trust in its water after 2014 microcystin scare. Retrieved March 21, 2019, from https://www.michiganradio.org/post/toledo-works-restore-trust-its-water-after-2014-microcystin-scare

Shafer, E. L., Carline, R., Guldin, R. W., & Cordell, H. K. (1993). Economic amenity values of wildlife: Six case studies in Pennsylvania. *Environmental Management*, *17*(5), 669–682. https://doi.org/10.1007/BF02393728

Smith, R. (2015). *Algal Blooms: Estimating Costs to the Lake Erie Basin Economy*.

Snow, J. (2018, March 8). What's the True Value of Lake Erie Beaches? Retrieved March 18, 2019, from https://ohioseagrant.osu.edu/news/2018/8iywb/value-lake-erie-beaches

Sohngen, B., Lichtkoppler, F., & Bielen, M. (1999). The Value of Lake Erie Beaches. Retrieved January 28, 2019, from http://ohioseagrant.osu.edu/archive/_documents/publications/FS/FS-078%20Value%20of%20Lake%20Erie%20beaches.pdf

Sohngen, B., Zhang, W., Bruskotter, J., & Sheldon, B. (2014). Results from a 2014 survey of Lake Erie anglers, 31.

Song, F., Lupi, F., & Kaplowitz, M. (2010). *Valuing Great Lakes Beaches*. 31.

Stratus Consulting. (2015, July 2). Phase 1 Study of the Triple Bottom Line Values of Clean Water in Northeast Ohio: Executive Summary. Retrieved September 6, 2018, from http://clevelandwateralliance.org/wp-content/uploads/2017/04/NEOhio_Report_ExecutiveSumm.pdf

Southwest Ontario Tourism Corporation. (2019). *2018-19 Consumer Survey Results*. Retrieved from https://static1.squarespace.com/static/5abbaa98f93fd495aa77b220/t/5d4ddaa396d2fb0001ca004d/1565383336714/V2+-+2018-19+Combined+Consumer+Survey+Presentation.pdf

Strickland, T., Fisher, L., & Korleski, C. (2010). Ohio Lake Erie phosphorus Task Force Final Report, 109.

Stumpf, R. (2019, February 14). Personal Communication.

Stumpf, R. P., Davis, T. W., Wynne, T. T., Graham, J. L., Loftin, K. A., Johengen, T. H., … Burtner, A. (2016). Challenges for mapping cyanotoxin patterns from remote sensing of cyanobacteria. *Harmful Algae*, *54*, 160–173. https://doi.org/10.1016/j.hal.2016.01.005

The Courier. (2014, March 29). Birding is big business along Lake Erie coast. Retrieved April 22, 2019, from https://thecourier.com/opinion/columns/2014/03/29/birding-is-big-business-along-lake-erie-coast/

The Economics of Ecosystems and Biodiversity. (n.d.). Ecosystem Services. Retrieved April 16, 2019, from TEEB website: http://www.teebweb.org/resources/ecosystem-services/

Thibodeau, F. R., & Ostro, B. D. (1981). An economic analysis of wetland protection. *Journal of Environmental Management*, *19*, 72–79.

Tomer, M. D., Porter, S. A., Boomer, K., James, D. E., Kostel, J. A., Helmers, M. A., … Mclellan, E. (2015). Agricultural Conservation Planning Framework: 1. Developing Multipractice Watershed Planning Scenarios and Assessing Nutrient Reduction Potential | Request PDF. *Journal of Environmental Quality*. http://dx.doi.org/10.2134/jeq2014.09.0386

Trevino-Garrison, I., DeMent, J., Ahmed, F. S., Haines-Lieber, P., Langer, T., Ménager, H., … Carney, E. (2015). Human Illnesses and Animal Deaths Associated with Freshwater Harmful Algal Blooms—Kansas. *Toxins*, *7*(2), 353–366. https://doi.org/10.3390/toxins7020353

Troy, A., & Bagstad Ken. (2009). Estimating Ecosystem Services in Southern Ontario. Retrieved April 30, 2019, from https://alus.ca/wp-content/uploads/2016/08/estimation-of-ecosystem.pdf

U.S. Census Bureau. (2018). American FactFinder. Retrieved April 30, 2019, from https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

U.S. Census Bureau. (2016, May 27). U.S. County Boundaries - Data.gov. Retrieved May 8, 2019, from https://catalog.data.gov/dataset/u-s-county-boundaries

U.S. Census Bureau. (2010). 2010 Census. Retrieved March 15, 2019, from Geography website: https://www.census.gov/geo/maps-data/data/tiger-data.html

U.S. Department of Agriculture. (2014, August 21). Working Together to Improve Water Quality Along the Lake Erie Shore. Retrieved June 17, 2019, from https://www.usda.gov/media/blog/2014/08/21/working-together-improve-water-quality-along-lake-erie-shore

U.S. Environmental Protection Agency. (2019, January 29). Lake Erie [Overviews and Factsheets]. Retrieved February 14, 2019, from https://www.epa.gov/greatlakes/lake-erie

U.S. Environmental Protection Agency. (2018, March 1). U.S. Action Plan for Lake Erie [Overviews and Factsheets]. Retrieved November 14, 2018, from https://www.epa.gov/glwqa/us-action-plan-lake-erie

U.S. Environmental Protection Agency. (2015, March 2). GLWQA Annexes [Policies and Guidance]. Retrieved May 31, 2019, from U.S. Environmental Protection Agency website: https://www.epa.gov/glwqa/glwqa-annexes

U.S. Environmental Protection Agency. (2014, June 19). Guidelines and Recommendations [Overviews and Factsheets]. Retrieved November 19, 2018, from https://www.epa.gov/nutrient-policy-data/guidelines-and-recommendations

U.S. Environmental Protection Agency. (2013, December 4). Indicators: Algal Toxins (microcystin) [Overviews and Factsheets]. Retrieved April 22, 2019, from US EPA website: https://www.epa.gov/national-aquatic-resource-surveys/indicators-algal-toxins-microcystin

U.S. Fish & Wildlife Service. (2018a). *2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*. 168.

U.S. Fish & Wildlife Service. (2018b, October). 2016 National Survey of Fishing, Hunting, & Wildlife-Associated Recreation (FHWAR). Retrieved January 25, 2019, from https://www.census.gov/library/publications/2018/demo/fhw-16-nat.html

U.S. Fish & Wildlife Service. (2002). *2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*. 170.

United States Geological Survey. (n.d.). Invasive Mussels. Retrieved May 29, 2019, from https://www.usgs.gov/ecosystems/invasive-species-program/science/invasive-mussels?qt-science_center_objects=0#qt-science_center_objects

U.S. Geological Survey. (2018). U.S. Geological Survey - National Hydrography Dataset. Retrieved March 27, 2018, from https://nhd.usgs.gov/wbd.html

U.S. Geological Survey. (2018b, April). USGS Study Identifies Factors Related to Cyanobacterial Harmful Algal Blooms.

United States Geological Survey. (2017, September). Lake Erie algal bloom. Retrieved May 29, 2019, from https://www.usgs.gov/media/images/lake-erie-algal-bloom

United States Geological Survey. (2016). Edge of Field Monitoring equipment, Black Creek Watershed. Retrieved July 8, 2019, from https://www.usgs.gov/media/images/edge-field-monitoring-equipment-black-creek-watershed

U.S. National Agricultural Statistics Service. (2014). *Land Values and Cash Rents, 2013 Summary*. Retrieved from USDA Economic Research Service, National Agricultural Statistics Service website: http://www.ers.usda.gov/topics/farm-economy/land-use,-land-value-tenure/background.aspx

USDA Forest Service. (2012). National Forest System Land Management Planning. *Federal Register'*, *77*(68), 21162.

Van der Ploeg, S., Wang, Y., Gebre Weldmichael, T., & De Groot, R. S. (2010). *The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services.* [Excel database and accompanying documentation]. Retrieved from Foundation for Sustainable Development website: http://www.es-partnership.org/esp/80763/5/0/50

Walsh, R. G., Loomis, J. B., & Gillman, R. A. (1984). Valuing Option, Existence, and Bequest Demands for Wilderness. *Land Economics*, *60*(1), 14–29. https://doi.org/10.2307/3146089

Weber, T. (2007). *Ecosystem services in Cecil County's green infrastructure: Technical Report for the Cecil County Green Infrastructure Plan* (p. 32) [White Paper]. Retrieved from The Conservation Fund website: http://www.ccgov.org/uploads/PlanningAndZoning/General/CecilCoMD_TechReport%20-%20Ecosystem%20services.pdf

Whitehead, J. C. (1990). Measuring willingness-to-pay for wetlands preservation with the contingent valuation method. *Wetlands*, *10*(2), 187–201. https://doi.org/10.1007/BF03160832

Whitehead, J. C., Groothuis, P. A., Southwick, R., & Foster-Turley, P. (2009). Measuring the economic benefits of Saginaw Bay coastal marsh with revealed and stated preference methods. *Journal of Great Lakes Research*, *35*(3), 430–437. https://doi.org/10.1016/j.jglr.2009.03.005

Windsor-Essex County Health Unit. (2019). Blue-Green Algae Bloom. Retrieved April 16, 2019, from Windsor-Essex County Health Unit website: https://www.wechu.org/drinking-water-small-drinking-water-systems-beaches-pools-and-spas/blue-green-algae-bloom

Winfree, R., Gross, B. J., & Kremen, C. (2011). Valuing pollination services to agriculture. *Ecological Economics*, *71*, 80–88. https://doi.org/10.1016/j.ecolecon.2011.08.001

Wisconsin Department of Natural Resources. (2013, December 17). Nuisance algae (Cladophora) in Lake Michigan - Wisconsin DNR. Retrieved May 10, 2019, from https://dnr.wi.gov/topic/greatlakes/cladophora.html

Wituszynski, D. M., Hu, C., Zhang, F., Chaffin, J. D., Lee, J., Ludsin, S. A., & Martin, J. F. (2017). Microcystin in Lake Erie fish: Risk to human health and relationship to cyanobacterial blooms. *Journal of Great Lakes Research*, *43*(6), 1084–1090. https://doi.org/10.1016/j.jglr.2017.08.006

Wolf, D., & Klaiber, H. A. (2016). Bloom and bust: Toxic algae's impact on nearby property values. *Ecological Economics*, *135*, 209–221. https://doi.org/10.1016/j.ecolecon.2016.12.007

Wolf, D., Chen, W., Gopalakrishnan, S., Haab, T., & Klaiber, H. A. (2018). The Economic Impacts of Harmful Algal Blooms and E. Coli on Recreational Behavior in Lake Erie. Retrieved January 28, 2019, from https://ageconsearch.umn.edu/record/274026/files/Abstracts_18_05_21_14_22_55_44__128_146_189_76_0.pdf

Wolf, D., Georgic, W., & Klaiber, H. A. (2017). Reeling in the damages: Harmful algal blooms' impact on Lake Erie's recreational fishing industry. *Journal of Environmental Management*, *199*, 148–157. https://doi.org/10.1016/j.jenvman.2017.05.031

Woodward, R. T., & Wui, Y.-S. (2001). The economic value of wetland services: a meta-analysis. *Ecological Economics*, *37*(2), 257–270.

Wu, J., & Skelton-Groth, K. (2002). Targeting conservation efforts in the presence of threshold effects and ecosystem linkages. *Ecological Economics*, *42*(1–2), 313–331. https://doi.org/10.1016/S0921-8009(02)00104-0

Young, C. E., & Shortle, J. S. (1989). Benefits and costs of agricultural nonpoint-source pollution controls: The case of St. Albans Bay. *Journal of Soil and Water Conservation*, *44*(1), 64–67.

Zhang, W., & Sohngen, B. (2018). Do U.S. Anglers Care about Harmful Algal Blooms? A Discrete Choice Experiment of Lake Erie Recreational Anglers. *American Journal of Agricultural Economics*, *100*(3), 868–888.

Zhang, W., & Sohngen, B. L. (2017). Heterogeneous Preferences for Water Quality Attributes: A Discrete Choice Experiment of Lake Erie Recreational Anglers, 42.

Zhou, X., Al-Kaisi, M., & Helmers, M. J. (2009). Cost effectiveness of conservation practices in controlling water erosion in Iowa. *Soil and Tillage Research*, *106*(1), 71–78. https://doi.org/10.1016/j.still.2009.09.015

Appendix A: NALCMS Land Cover

The North American Land Change Monitoring System (NALCMS) is a trilateral effort between Canada, the United States, and Mexico to develop a single land cover monitoring approach across North America (Canada Centre for Remote Sensing, 2015). Table A-1 includes the descriptions of the NALCMS land covers that exist in the Lake Erie subregion as defined by the NALCMS classification system as well as the reclassifications used in the body of the report.

Table A-1. NALCMS Land Cover Classification Descriptions in the Lake Erie Subregion
Source: Canada Centre for Remote Sensing, 2015

Land Cover (NALCMS Classification)	Reclassification	Description
Temperate or sub-polar needleleaf forest	Forest	Forests generally taller than three meters and more than 20 percent of total vegetation cover. These occur in the northern United States, Canada and mountainous zones of Mexico. These forests have greater than 75 percent of tree crown cover represented by deciduous species.
Sub-polar taiga needleleaf forest	Forest	Forest and woodlands with trees generally taller than three meters and more than 5 percent of total vegetation cover with shrubs and lichens commonly present in the understory. The tree crown cover contains at least 75 percent of needle-leaved species. This type occurs across Alaska and northern Canada and may consist of treed muskeg or wetlands. Forest canopies are variable and often sparse, with generally greater tree cover in the southern latitude parts of the zone than the north.
Temperate or sub-polar broadleaf deciduous forest	Forest	Forests generally taller than three meters and more than 20 percent of total vegetation cover. These occur in the northern United States, Canada and mountainous zones of Mexico. These forests have greater than 75 percent of tree crown cover represented by deciduous species.
Mixed forest	Forest	Forests generally taller than three meters and more than 20 percent of total vegetation cover. Neither needleleaf nor broadleaf tree species occupy more than 75 percent of total tree cover, but are co-dominant.
Temperate or sub-polar shrubland	Shrubland	Areas dominated by woody perennial plants with persistent woody stems less than three meters tall and typically greater than 20 percent of total vegetation. This class occurs across the northern United States, Canada, and the highlands of Mexico.
Sub-polar or polar shrubland-lichen-moss	Shrubland	Areas dominated by dwarf shrubs with lichen and moss typically accounting for at least 20 percent of total vegetation cover. This class occurs across northern Canada and Alaska.

Table A-1, Continued.

Land Cover (NALCMS Classification)	Reclassification	Description
Temperate or sub-polar grassland	Grassland	Areas dominated by graminoid or herbaceous vegetation, generally accounting for greater than 80 percent of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. This class occurs across Canada, the United States, and the highlands of Mexico.
Sub-polar or polar grassland-lichen-moss	Grassland	Areas dominated by grassland with lichen and moss typically accounting for at least 20 percent of total vegetation cover. This class occurs across northern Canada and Alaska.
Sub-polar or polar barren-lichen-moss	Barren	Areas dominated by a mixture of bare areas with lichen and moss that typically account for at least 20 percent of total vegetation cover. This class occurs across northern Canada and Alaska.
Barren Lands	Barren	Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Generally, vegetation accounts for less than 10 percent of the total cover.
Wetland	Wetland	Areas dominated by perennial herbaceous and woody wetland vegetation which is influenced by the water table at or near surface over extensive periods of time. This includes marshes, swamps, bogs, mangroves, etc., either coastal or inland where water is present for a substantial period annually.
Cropland	Cropland	Areas dominated by intensively managed crops. These areas typically require human activities for their maintenance. This includes areas used for the production of annual crops, such as corn, soybeans, wheat, maize, vegetables, tobacco, cotton, etc.; perennial grasses for grazing; and woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class does not represent natural grasslands used for light to moderate grazing.
Urban	Urban	Areas that contain at least 30 percent or greater urban constructed materials for human activities (cities, towns, transportation, etc.)
Water	Water	Areas of open water, generally with less than 25 percent cover of non-water cover types. This class refers to areas that are consistently covered by water.

Table A-2 provides land cover area estimates, in acres, within the Lake Erie subregion by NALCMS classification. The lake itself has some acreage of land from islands.

Table A-2. Land Cover in the Lake Erie Subregion by NALCMS Classification

Land Cover (NALCMS Classification)	Basin (HUC 6/Tertiary)					
	U.S. Western (acres)	U.S. Central (acres)	U.S. Eastern (acres)	Northern-Canadian (acres)	Lake Erie (acres)	Total (acres)
Temperate or sub-polar needleleaf forest	5,325	8,045	48,130	9,277	600	**71,376**
Sub-polar taiga needleleaf forest	0	0	0	1,225	146	**1,371**
Temperate or sub-polar broadleaf deciduous forest	600,986	622,316	530,254	294,584	16,986	**2,065,127**
Mixed forest	2,063	145	36,482	165,247	4,576	**208,513**
Temperate or sub-polar shrubland	4,258	12,383	21,058	6,596	3,347	**47,641**
Temperate or sub-polar grassland	44,135	42,984	11,808	839	2,101	**101,866**
Sub-polar or polar shrubland-lichen-moss	0	0	0	26	0	**26**
Sub-polar or polar grassland-lichen-moss	0	0	0	98	29	**127**
Sub-polar or polar barren-lichen-moss	0	0	0	21	14	**35**
Wetland	203,204	74,404	62,838	12,773	11,174	**364,394**
Cropland	5,716,887	505,327	452,680	2,121,661	44,706	**8,841,261**
Barren lands	20,791	2,072	2,318	24,906	4,779	**54,867**
Urban	938,338	654,021	190,061	255,969	33,886	**2,072,275**
Water	66,998	21,923	4,287	30,060	6,357,285	**6,480,553**
Total (acres)	**7,602,985**	**1,943,620**	**1,359,917**	**2,923,283**	**6,479,629**	**20,309,434**

Figure A-1a & A-1b shows the land cover distribution in the study region by NALCMS classification for the entire study region and the portion of the study region that excludes the lake itself. Figures A-2 through Figures A-5 show the land cover distribution by NALCMS classification by land basin.

Figure A-1a & A-1b. Land Cover Distribution in the Study Region by NALCMS Classification—With Lake and Without Lake

3a **3b**

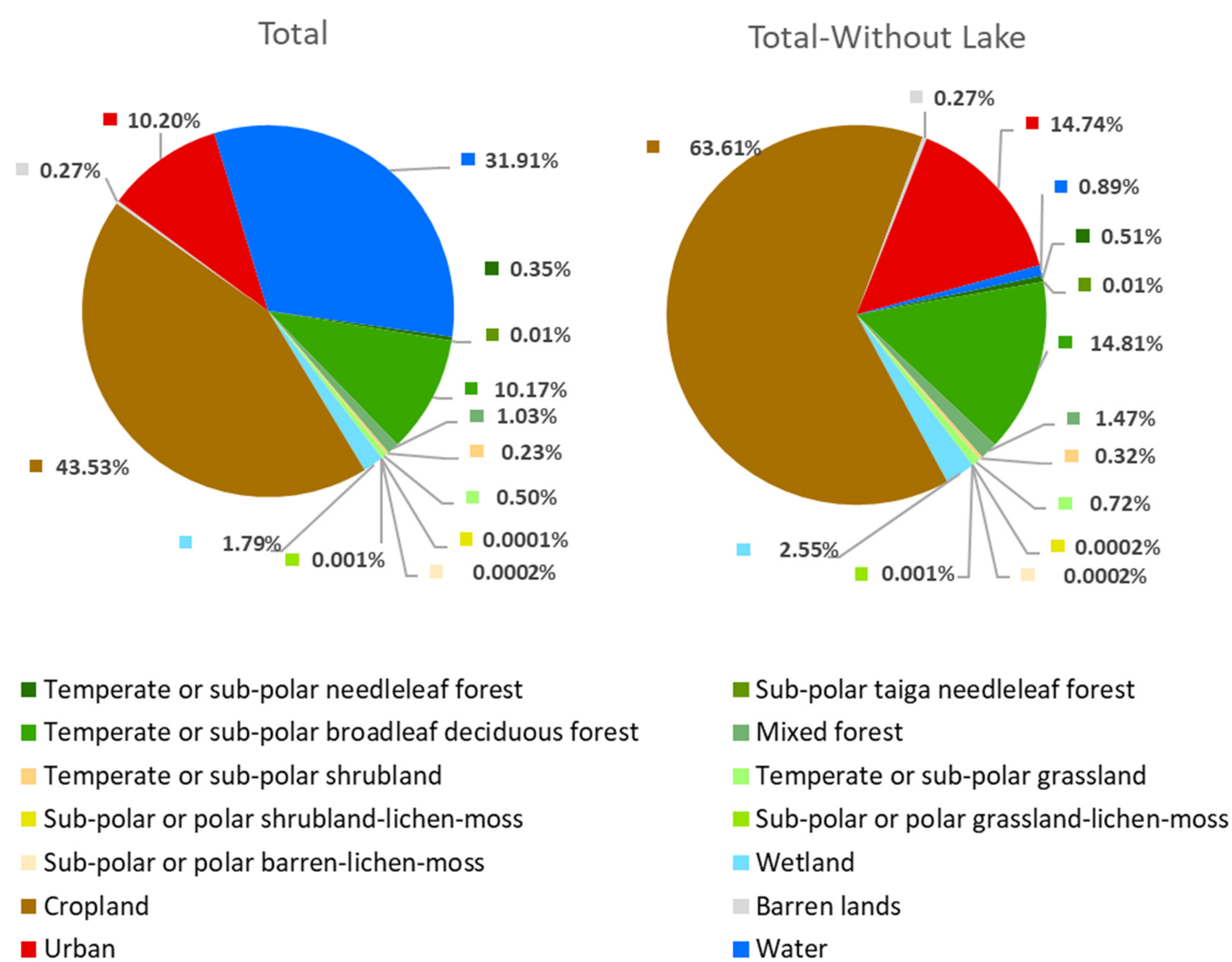


Figure A-2. Land Cover Distribution in the Canadian Portion of the Study Region by NALCMS Classification

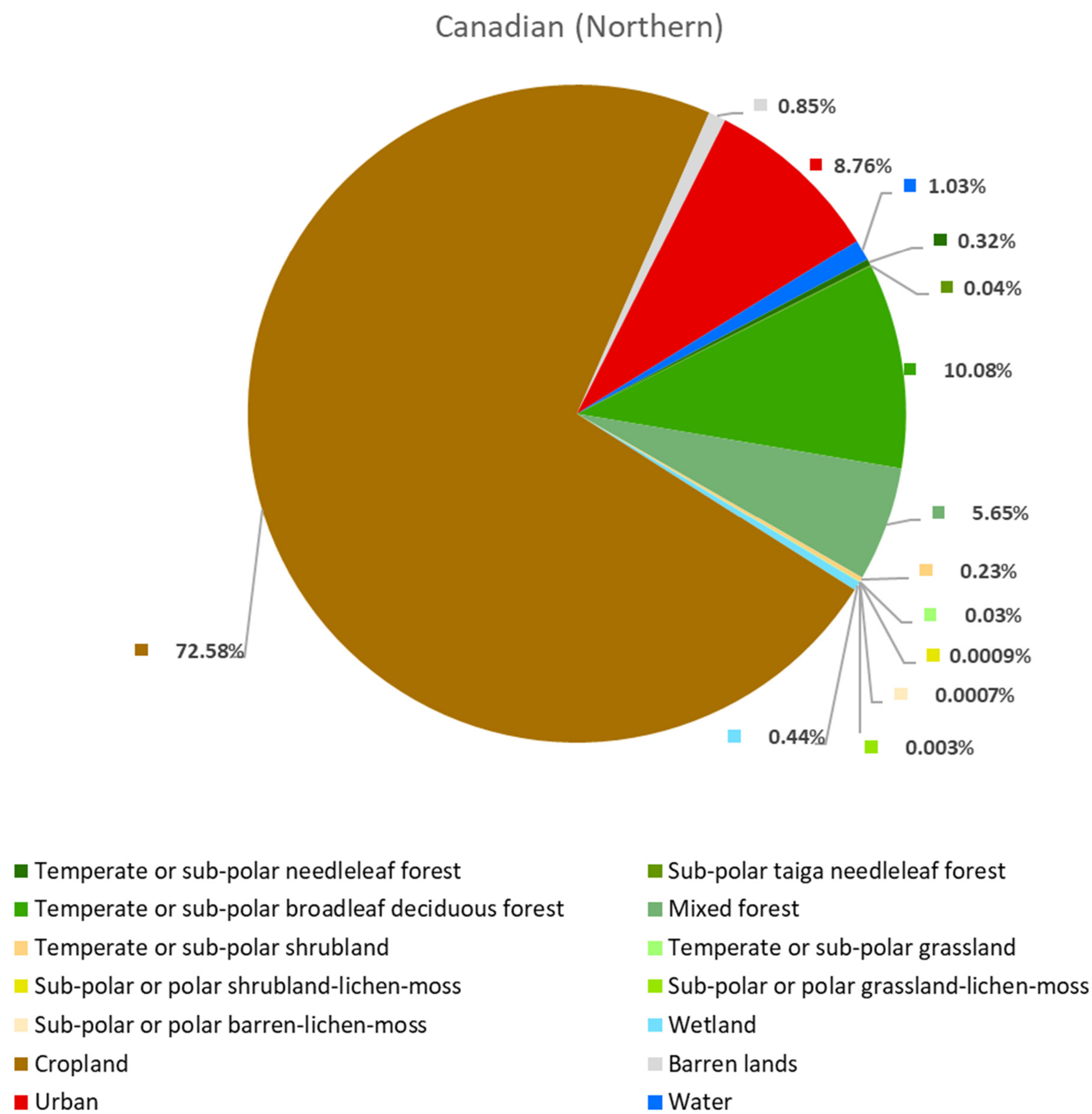


Figure A-3. Land Cover Distribution in the U.S. Western Basin by NALCMS Classification

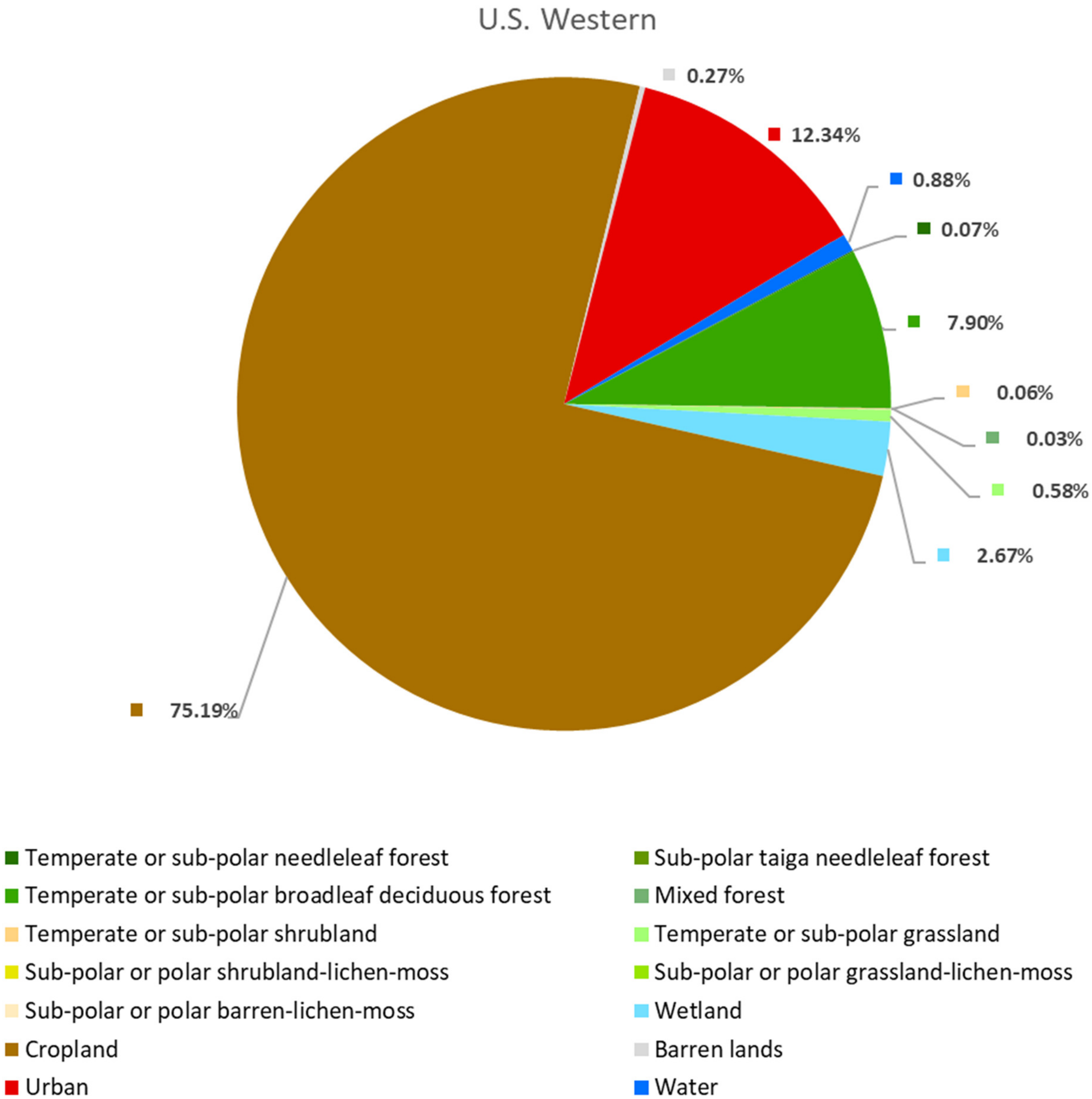


Figure A-4. Land Cover Distribution in the U.S. Central Basin by NALCMS Classification

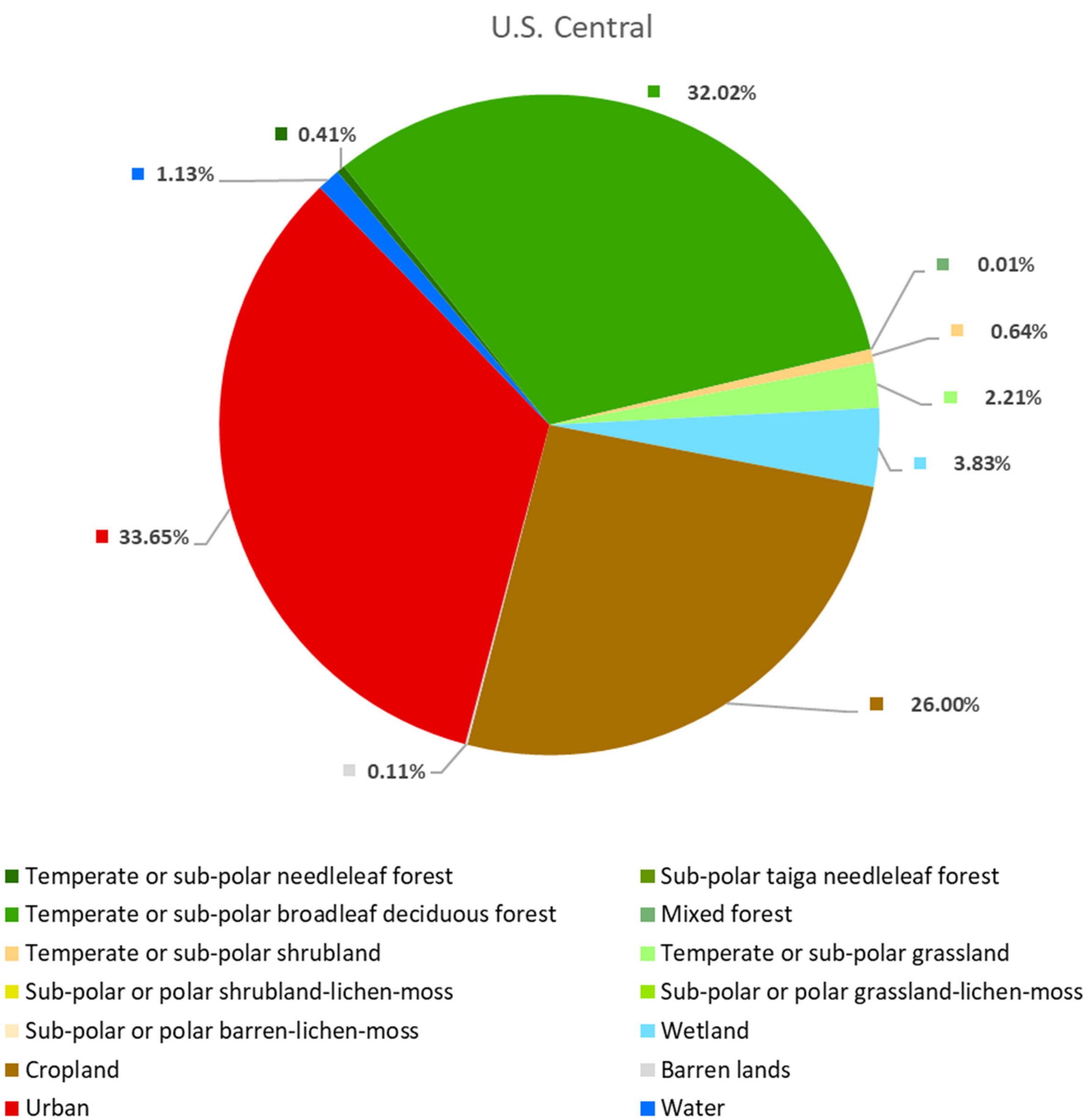
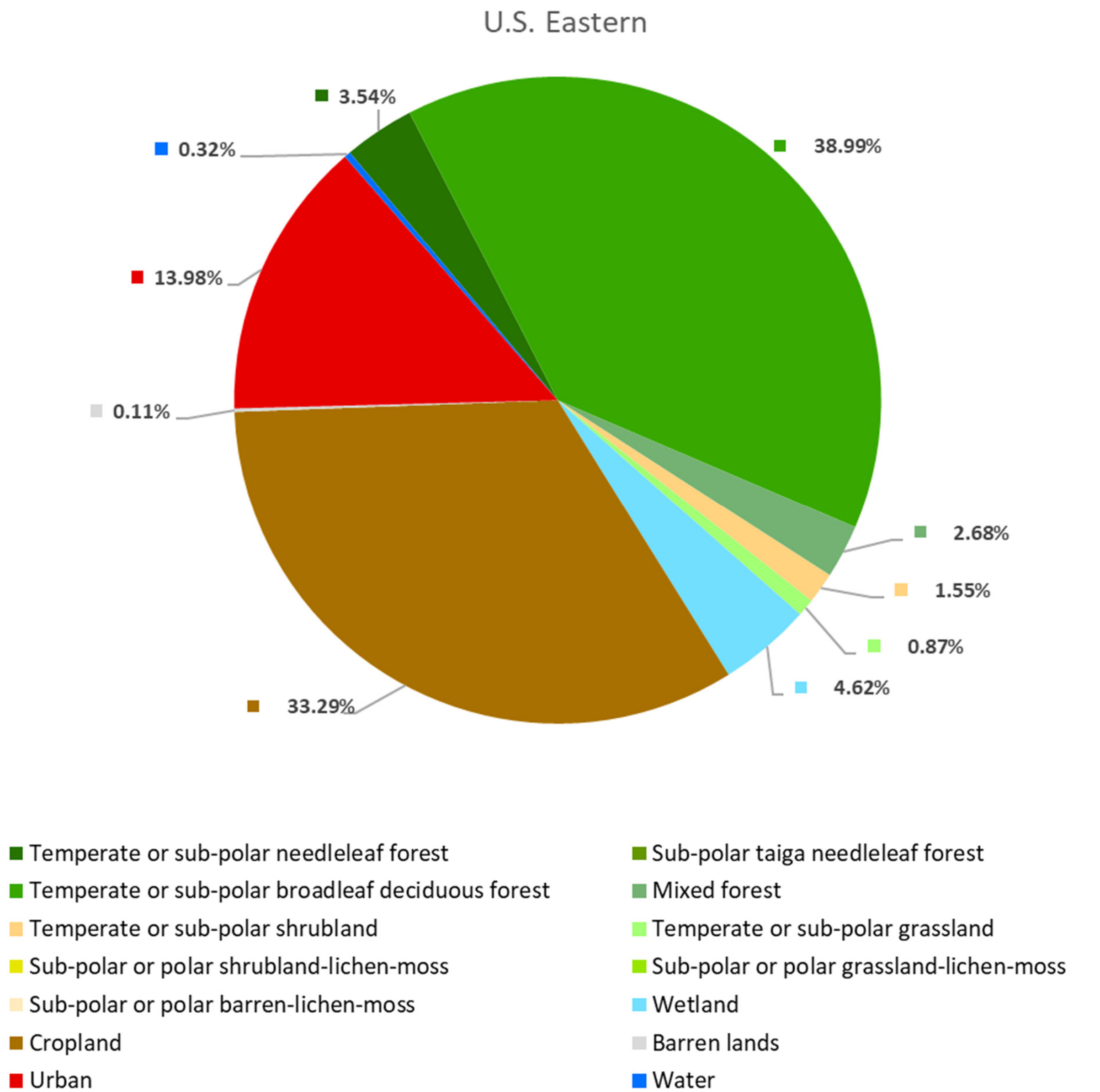


Figure A-5. Land Cover Distribution in the U.S. Eastern Basin by NALCMS Classification



Appendix B: Watersheds Used in the Baseline Ecosystem Service Assessment

The Lake Erie subregion, as defined by the baseline ecosystem service assessment, is comprised of 125 U.S. watersheds (HUC 10 level) and 35 Canadian watersheds (Quaternary level) (Table B-1).

Table B-1. Watersheds, Subbasins, and Basins that compose the Lake Erie Study Region.
Source: U.S. Watershed Boundaries from U.S. Geological Survey, 2018; Canadian Watershed Boundaries from Government of Ontario, 2015 & Canada-Ontario Agreement on Great Lakes Water Quality, and Ecosystem Health, & Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2014

Basins (HUC 6/ Secondary)	Subbasins (HUC 8/Tertiary)	Watersheds (HUC 10/Quaternary)
U.S. Western (041000)	Ottawa-Stony (04100001)	Stony Creek-Frontal Lake Erie (0410000101)
		Otter Creek-Frontal Lake Erie (0410000102)
		Ottawa River-Frontal Lake Erie (0410000103)
	Raisin (04100002)	Evans Creek-River Raisin (0410000201)
		South Branch River Raisin (0410000202)
		Little River Raisin-River Raisin (0410000203)
		River Raisin (0410000204)
	St. Joseph (04100003)	East Branch Saint Joseph River (0410000301)
		West Branch Saint Joseph River (0410000302)
		Nettle Creek-Saint Joseph River (0410000303)
		Fish Creek (0410000304)
		Sol Shank Ditch-Saint Joseph River (0410000305)
		Matson Ditch-Cedar Creek (0410000306)
		Cedar Creek (0410000307)
		Saint Joseph River (0410000308)
	St. Marys (04100004)	Kopp Creek-Saint Marys River (0410000401)
		Twelvemile Creek-Saint Marys River (0410000402)
		Black Creek-Saint Marys River (0410000403)
		Blue Creek-Saint Marys River (0410000404)
		Nickelsen Creek-Saint Marys River (0410000405)
		Saint Marys River (0410000406)
	Upper Maumee (04100005)	Headwaters Maumee River (0410000501)
		Gordon Creek-Maumee River (0410000502)
	Tiffin (04100006)	Lime Creek-Bean Creek (0410000601)
		Mill Creek-Bean Creek (0410000602)
		Upper Tiffin River (0410000603)

Table B-1, Continued.

Basins (HUC 6/ Secondary)	Subbasins (HUC 8/Tertiary)	Watersheds (HUC 10/Quaternary)
U.S. Western (041000)	Tiffin (04100006)	Lick Creek (0410000604)
		Middle Tiffin River (0410000605)
		Lower Tiffin River (0410000606)
	Auglaize (04100007)	Headwaters Auglaize River (0410000701)
		Twomile Creek-Auglaize River (0410000702)
		Upper Ottawa River (0410000703)
		Middle Ottawa River (0410000704)
		Lower Ottawa River (0410000705)
		Upper Little Auglaize River (0410000706)
		Prairie Creek (0410000707)
		Lower Little Auglaize River (0410000708)
		Jennings Creek-Auglaize River (0410000709)
		Blue Creek-Auglaize River (0410000710)
		Powell Creek (0410000711)
		Flatrock Creek-Auglaize River (0410000712)
	Blanchard (04100008)	Headwaters Blanchard River (0410000801)
		Lye Creek-Blanchard River (0410000802)
		Eagle Creek-Blanchard River (0410000803)
		Riley Creek (0410000804)
		Ottawa Creek-Blanchard River (0410000805)
		Cranberry Creek-Blanchard River (0410000806)
	Lower Maumee (04100009)	South Turkeyfoot Creek (0410000901)
		Garret Creek-Maumee River (0410000902)
		Bad Creek (0410000903)
		North Turkeyfoot Creek-Maumee River (0410000904)
		Beaver Creek-Maumee River (0410000905)
		Tontogany Creek-Maumee River (0410000906)
		Upper Swan Creek (0410000907)
		Lower Swan Creek (0410000908)
		Grassy Creek-Maumee River (0410000909)
	Cedar-Portage (04100010)	Rocky Ford-Middle Branch Portage River (0410001001)
		South Branch Portage River-Middle Branch Portage River (0410001002)
		Upper Portage River (0410001003)

Table B-1, Continued.

Basins (HUC 6/ Secondary)	Subbasins (HUC 8/Tertiary)	Watersheds (HUC 10/Quaternary)
U.S. Western (041000)	Cedar-Portage (04100010)	Middle Portage River (0410001004)
		Lower Portage River-Frontal Lake Erie (0410001005)
		Toussaint Creek (0410001006)
		Cedar Creek-Frontal Lake Erie (0410001007)
	Sandusky (04100011)	Mills Creek-Frontal Lake Erie (0410001101)
		Pickerel Creek-Frontal Sandusky Bay (0410001102)
		Broken Sword Creek (0410001103)
		Headwaters Sandusky River (0410001104)
		Upper Tymochtee Creek (0410001105)
		Lower Tymochtee Creek (0410001106)
		Little Sandusky River-Sandusky River (0410001107)
		Honey Creek (0410001108)
		Sycamore Creek-Sandusky River (0410001109)
		Wolf Creek (0410001110)
		Rock Creek-Sandusky River (0410001111)
		Green Creek (0410001112)
		Sandusky River (0410001113)
		Muddy Creek-Frontal Sandusky Bay (0410001114)
	Huron-Vermilion (04100012)	Southwest Branch Vermilion River-Vermilion River (0410001201)
		East Branch Vermilion River-Vermilion River (0410001202)
		Old Woman Creek-Frontal Lake Erie (0410001203)
		Marsh Run-West Branch Huron River (0410001204)
		Slate Run-West Branch Huron River (0410001205)
		Huron River (0410001206)
U.S. Central (041100)	Black-Rocky (04110001)	West Branch Rocky River (0411000101)
		Rocky River-Frontal Lake Erie (0411000102)
		Headwaters East Branch Black River (0411000103)
		East Branch Black River (0411000104)
		West Branch Black River (0411000105)
		Black River-Frontal Lake Erie (0411000106)
		Beaver Creek-Frontal Lake Erie (0411000107)
	Cuyahoga (04110002)	Headwaters Cuyahoga River (0411000201)
		Breakneck Creek-Cuyahoga River (0411000202)
		Little Cuyahoga River-Cuyahoga River (0411000203)

Table B-1, Continued.

Basins (HUC 6/ Secondary)	Subbasins (HUC 8/Tertiary)	Watersheds (HUC 10/Quaternary)
U.S. Central (041100)	Cuyahoga (04110002)	Yellow Creek-Cuyahoga River (0411000204)
		Tinkers Creek-Cuyahoga River (0411000205)
		Big Creek-Cuyahoga River (0411000206)
	Ashtabula-Chagrin (04110003)	Ashtabula River (0411000301)
		Arcola Creek-Frontal Lake Erie (0411000302)
		Aurora Branch-Chagrin River (0411000303)
		East Branch Chagrin River-Chagrin River (0411000304)
		Euclid Creek-Frontal Lake Erie (0411000305)
	Grand (04110004)	Headwaters Grand River (0411000401)
		Rock Creek (0411000402)
		Phelps Creek-Grand River (0411000403)
		Griggs Creek-Mill Creek (0411000404)
		Three Brothers Creek-Grand River (0411000405)
		Big Creek-Grand River (0411000406)
U.S. Eastern (041201)	Chautauqua-Conneaut (04120101)	Walnut Creek (0412010101)
		Canadaway Creek-Frontal Lake Erie (0412010102)
		Chautauqua Creek-Frontal Lake Erie (0412010103)
		Sixmile Creek-Frontal Lake Erie (0412010104)
		Elk Creek (0412010105)
		Conneaut Creek (0412010106)
		Crooked Creek-Frontal Lake Erie (0412010107)
	Cattaraugus (04120102)	Headwaters Cattaraugus Creek (0412010201)
		Cattaraugus Creek (0412010202)
	Buffalo-Eighteenmile (04120103)	Cayuga Creek (0412010301)
		Buffalo Creek (0412010302)
		Buffalo River (0412010303)
		Smoke Creek-Frontal Lake Erie (0412010304)
		Eighteenmile Creek (0412010305)
		Big Sister Creek-Frontal Lake Erie (0412010306)
Lake Erie (041202)	Lake Erie (04120200)	Pelee Island (0412020001)
		Frontal Lake Erie (0412020002)
		Lake Erie (0412020003)

Table B-1, Continued.

Basins (HUC 6/ Secondary)	Subbasins (HUC 8/Tertiary)	Watersheds (HUC 10/Quaternary)
Northern (Canadian-Ontario) (02G)	Upper Grand (02GA)	Upper Grand River (02GA-01)
		Nith River (02GA-02)
		Gait Creek (02GA-03)
		Speed River (02GA-04)
		Eramosa River (02GA-05)
		Conestoga River (02GA-06)
	Lower Grand (02GB)	Lower Grand River (02GB-01)
		McKenzie River (02GB-02)
		Big Creek (02GB-03)
		Fairchild Creek (02GB-04)
		Horner Creek (02GB-05)
	Big (02GC)	Stoney Creek (02GC-01)
		Kettle Creek (02GC-02)
		Catfish Creek (02GC-03)
		Big Otter Creek (02GC-04)
		S. Otter-Clear Creeks (02GC-05)
		Long Point (02GC-06)
		Diedrich-Young Crs. (02GC-07)
		Big Creek (02GC-08)
		Lynn River (02GC-09)
		Gates-Wardell's-Evans Creeks (02GC-10)
		Nanticoke Creek (02GC-11)
		Sandusk Creek (02GC-12)
		Welland River (02GC-13)
	Rondeau (02GF)	Renwick-Erie Beach (02GF-01)
		Flat Creek- Rondeau (02GF-02)
		Morpeth-Palmyra Beach (02GF-03)
		Brock's Creek (02GF-04)

Table B-1, Continued.

Basins (HUC 6/ Secondary)	Subbasins (HUC 8/Tertiary)	Watersheds (HUC 10/Quaternary)
Northern (Canadian-Ontario) (02G)	Rondeau (02GF)	Tyconnel Beach (02GF-05)
		Talbot Creek (02GF-06)
	Cedar (02GH)	Lower Detroit River (02GH-06)
		Cedar Cr.-Oxley-Seacliffe Beaches (02GH-07)
		Sturgeon Cr.-Point Pelee (02GH-08)
		Hillman-Lebo Creeks (02GH-09)
		Pelee Island (02GH-10)

Note: Not included in this list are the watersheds that drain to Lake Erie by way of the Thames, Lake St. Clair, or the Detroit River.

Appendix C: Baseline Ecosystem Service Value in the Lake Erie Subregion

Ecosystem Service Descriptions

Descriptions of the ecosystem services used in the analysis are provided in Table C-1. The descriptions follow Balmford (2010, 2013), Costanza et al. (1997), Reid et al. (2005), and Van der Ploeg et al. (2010).

Table C-1. Ecosystem Service Descriptions

Ecosystem Service	Description
Aesthetics	Formation of landscapes that are attractive to people
Air Quality	Removal of contaminants from the air flowing through an ecosystem, including through filtration or decomposition
Biodiversity	The process of increasing genetic diversity across and within species
Climate Regulation	Modulation of regional/local climate
Cultural, Other	Non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, and more, excluding recreation and aesthetics
Erosion Control	Control of the processes leading to erosion, for example, by controlling the effects of water flow, wind, or gravity
Food/Nutrition	Ecosystems provide the conditions for growing food, principally from managed agro-ecosystems but marine and freshwater systems or forests may provide food for human consumption
Pollination	Contribution of insects, birds, bats, and other organisms to pollen transport resulting in the production of fruits and seeds. May also include seed and fruit dispersal
Protection from Extreme Events	Extreme weather events or natural hazards include floods, storms, tsunamis, avalanches, and landslides. Ecosystems and living organisms create buffers against natural disasters, thereby preventing possible damage
Raw Materials	Materials for construction and fuel including wood, biofuels, and plant oils that are directly derived from wild and cultivated plant species
Recreation	Leisure and activity derived from ecosystems
Renewable Energy	Resource utilization to produce renewable energy, specifically hydropower from open water
Soil Formation	The process by which soil is created, including changes in soil depth, structure, and fertility
Waste Assimilation	Improving soil and water quality through the breakdown and/or immobilization of pollution.
Water Supply	Filtering, retention, storage, and delivery of fresh water—both quality and quantity—for drinking, watering livestock, irrigation, industrial processes, hydroelectric generation, and other uses.

Ecosystem Service Values

Table C-2 provides the literature sources and values for the 306 studies used in the analysis broken out by land cover type.

Table C-2. Ecosystem Service Values Source Studies

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Barren Lands	Aesthetic	(Pompe & Rinehart, 1995)	$656.54
Barren Lands	Aesthetic	(Pompe & Rinehart, 1995)	$1,733.79
Barren Lands	Recreation	(Bruce, Dupont, & Renzetti, 2010)	$115.20
Cropland	Aesthetic	(Bergstrom, Dillman, & Stoll, 1985)	$91.75
Cropland	Aesthetic	(Bergstrom, Dillman, & Stoll, 1985)	$233.88
Cropland	Aesthetic	(Johnston, Opaluch, Grigalunas, & Mazzotta, 2001)	$4,883.58
Cropland	Aesthetic	(Mazzotta, 1996)	$25,826.03
Cropland	Aesthetic	(Mazzotta, 1996)	$48,208.58
Cropland	Aesthetic	(Opaluch, Grigalunas, Diamantedes, Mazzotta, & Johnston, 1999)	$24,077.95
Cropland	Aesthetic	(Opaluch, Grigalunas, Diamantedes, Mazzotta, & Johnston, 1999)	$37,554.52
Cropland	Aesthetic	(Ready, Berger, & Blomquist, 1997)	$268.34
Cropland	Aesthetic	(Ready, Berger, & Blomquist, 1997)	$305.64
Cropland	Biodiversity	(Cleveland et al., 2006)	$37.68
Cropland	Biodiversity	(Cleveland et al., 2006)	$537.20
Cropland	Climate Regulation	(Earth Economics, n.d.)	$1.10
Cropland	Climate Regulation	(Earth Economics, n.d.)	$15.00
Cropland	Erosion Control	(Pimentel et al., 2003)	$190.16
Cropland	Erosion Control	(Pimentel et al., 2003)	$71.59
Cropland	Food/Nutrition	(U.S. National Agricultural Statistics Service, 2014)	$58.60
Cropland	Food/Nutrition	(Kauffman, Homsey, McVey, Mack, & Chatterson, 2011)	$20,461.03

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Cropland	Pollination	(Robinson, Nowogrodzki, & Morse, 1989)	$36.40
Cropland	Pollination	(Winfree, Gross, & Kremen, 2011)	$124.32
Cropland	Pollination	(Winfree, Gross, & Kremen, 2011)	$5,210.59
Cropland	Recreation	(Knoche & Lupi, 2007)	$5.67
Cropland	Recreation	(Knoche & Lupi, 2007)	$13.15
Cropland	Soil Formation	(Pimentel,1998)	$19.08
Cropland	Soil Formation	(Pimentel et al., 2003)	$302.03
Mixed forest	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$1,983.93
Mixed forest	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$5,433.28
Mixed forest	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$722.17
Mixed forest	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$562.99
Mixed forest	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$434.24
Mixed forest	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$400.30
Mixed forest	Aesthetic	(Nowak, Crane, & Dwyer, 2002)	$11,636.75
Mixed forest	Aesthetic	(Nowak, Crane, & Dwyer, 2002)	$47,551.22
Mixed forest	Air Quality	(Bruce, Dupont, & Renzetti, 2010)	$1.23
Mixed forest	Air Quality	(Bruce, Dupont, & Renzetti, 2010)	$224.26
Mixed forest	Air Quality	(Bruce, Dupont, & Renzetti, 2010)	$55.52
Mixed forest	Air Quality	(Bruce, Dupont, & Renzetti, 2010)	$83.02
Mixed forest	Air Quality	(Bruce, Dupont, & Renzetti, 2010)	$7.59
Mixed forest	Biodiversity	(Costanza et al., 2006)	$1.73
Mixed forest	Biodiversity	(Costanza et al., 2006)	$892.58

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Mixed forest	Biodiversity	(Loomis & Ekstrand, 1998)	$6,416.21
Mixed forest	Biodiversity	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$215.36
Mixed forest	Biodiversity	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$293.79
Mixed forest	Biodiversity	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$261.01
Mixed forest	Biodiversity	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$32.77
Mixed forest	Biodiversity	(Phillips, Silverman, & Gore, 2008)	$28.74
Mixed forest	Biodiversity	(Rausser & Small, 2000)	$773.06
Mixed forest	Biodiversity	(Walsh, Loomis, & Gillman, 1984)	$115.31
Mixed forest	Biodiversity	(Weber, 2007)	$1,496.44
Mixed forest	Climate Regulation	(Costanza et al., 1997)	$149.11
Mixed forest	Climate Regulation	(Earth Economics, n.d.)	$8.59
Mixed forest	Climate Regulation	(Earth Economics, n.d.)	$119.48
Mixed forest	Climate Regulation	(Flores, Harrison-Cox, Wilson, & Batker, 2013)	$848.61
Mixed forest	Climate Regulation	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$445.95
Mixed forest	Climate Regulation	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$445.95
Mixed forest	Climate Regulation	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$445.95
Mixed forest	Cultural, Other	(Bishop, 1992)	$110.90
Mixed forest	Cultural, Other	(Bishop, 1992)	$190.90
Mixed forest	Cultural, Other	(Phillips, Silverman, & Gore, 2008)	$0.01
Mixed forest	Cultural, Other	(Shafer, Carline, Guldin, & Cordell, 1993)	$1,087.85
Mixed forest	Erosion Control	(Zhou, Al-Kaisi, & Helmers, 2009)	$8.11
Mixed forest	Erosion Control	(Zhou, Al-Kaisi, & Helmers, 2009)	$94.59

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Mixed forest	Food/Nutrition	(Kauffman, Homsey, McVey, Mack, & Chatterson, 2011)	$6,343.99
Mixed forest	Pollination	(Costanza et al., 2006)	$3.70
Mixed forest	Pollination	(Costanza et al., 2006)	$18.62
Mixed forest	Pollination	(Weber, 2007)	$230.93
Mixed forest	Protection from extreme events	(Bruce, Dupont, & Renzetti, 2010)	$5.17
Mixed forest	Raw Materials	(Weber, 2007)	$437.23
Mixed forest	Recreation	(Haener & Adamowicz, 2000)	$10.35
Mixed forest	Recreation	(Phillips, Silverman, & Gore, 2008)	$13.92
Mixed forest	Recreation	(Prince & Ahmed, 1989)	$97.31
Mixed forest	Recreation	(Prince & Ahmed, 1989)	$119.27
Mixed forest	Recreation	(Shafer, Carline, Guldin, & Cordell, 1993)	$7.30
Mixed forest	Recreation	(Shafer, Carline, Guldin, & Cordell, 1993)	$1,320.93
Mixed forest	Soil Formation	(Weber, 2007)	$52.34
Mixed forest	Waste Assimilation	(Lui, 2006)	$696.64
Mixed forest	Waste Assimilation	(Lui, 2006)	$699.55
Mixed forest	Water Supply	(Bruce, Dupont, & Renzetti, 2010)	$1,500.40
Mixed forest	Water Supply	(Bruce, Dupont, & Renzetti, 2010)	$1,857.99
Mixed forest	Water Supply	(Bruce, Dupont, & Renzetti, 2010)	$466.34
Temperate or sub-polar broadleaf deciduous forest	Biodiversity	(Hall, 2010)	$0.00
Temperate or sub-polar broadleaf deciduous forest	Climate Regulation	(Hall, 2010)	$27.90
Temperate or sub-polar broadleaf deciduous forest	Protection from extreme events	(Bruce, Dupont, & Renzetti, 2010)	$7.95
Temperate or sub-polar broadleaf deciduous forest	Raw Materials	(Hall, 2010)	$136.12

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Temperate or sub-polar broadleaf deciduous forest	Recreation	(Hall, 2010)	$24.16
Temperate or sub-polar broadleaf deciduous forest	Water Supply	(Bruce, Dupont, & Renzetti, 2010)	$2,351.29
Temperate or sub-polar broadleaf deciduous forest	Water Supply	(Hall, 2010)	$70.81
Temperate or sub-polar grassland	Aesthetic	(Bishop, 1992)	$43.89
Temperate or sub-polar grassland	Aesthetic	(Mazzotta, 1996)	$4,878.25
Temperate or sub-polar grassland	Aesthetic	(Mazzotta, 1996)	$9,182.59
Temperate or sub-polar grassland	Aesthetic	(Opaluch, Grigalunas, Diamantedes, Mazzotta, & Johnston, 1999)	$12,149.02
Temperate or sub-polar grassland	Aesthetic	(Qiu, Prato, & Boehrn, 2006)	$657.12
Temperate or sub-polar grassland	Aesthetic	(Qiu, Prato, & Boehrn, 2006)	$3,218.94
Temperate or sub-polar grassland	Aesthetic	(Ready, Berger, & Blomquist, 1997)	$268.34
Temperate or sub-polar grassland	Aesthetic	(Ready, Berger, & Blomquist, 1997)	$305.64
Temperate or sub-polar grassland	Aesthetic	(Rosenberger & Walsh, 1997)	$314.26
Temperate or sub-polar grassland	Aesthetic	(Rosenberger & Walsh, 1997)	$747.99
Temperate or sub-polar grassland	Biodiversity	(Rein, 1999)	$60.24
Temperate or sub-polar grassland	Biodiversity	(Rein, 1999)	$768.37
Temperate or sub-polar grassland	Climate Regulation	(Sala & Paruelo, 1997)	$1.98

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Temperate or sub-polar grassland	Climate Regulation	(Sala & Paruelo, 1997)	$0.08
Temperate or sub-polar grassland	Climate Regulation	(Sala & Paruelo, 1997)	$0.94
Temperate or sub-polar grassland	Erosion Control	(Barrow, 1991)	$45.81
Temperate or sub-polar grassland	Erosion Control	(Rein, 1999)	$96.05
Temperate or sub-polar grassland	Erosion Control	(Rein, 1999)	$68,192.99
Temperate or sub-polar grassland	Erosion Control	(Sala & Paruelo, 1997)	$178.98
Temperate or sub-polar grassland	Food/Nutrition	(U.S. National Agricultural Statistics Service, 2014)	$96.65
Temperate or sub-polar grassland	Protection from extreme events	(Rein, 1999)	$160.60
Temperate or sub-polar grassland	Protection from extreme events	(Rein, 1999)	$10,142.51
Temperate or sub-polar grassland	Recreation	(Rein, 1999)	$38,418.59
Temperate or sub-polar grassland	Waste Assimilation	(Rein, 1999)	$53,590.08
Temperate or sub-polar grassland	Waste Assimilation	(Lui, 2006)	$16,446.50
Temperate or sub-polar needleleaf forest	Biodiversity	(Anielski & Wilson, 2005)	$24.53
Temperate or sub-polar needleleaf forest	Biodiversity	(Anielski & Wilson, 2005)	$0.05
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$3,546.69
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$7.73

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$3,739.02
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$12,077.64
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$9,025.53
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$3.59
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$26.33
Temperate or sub-polar needleleaf forest	Climate Regulation	(Anielski & Wilson, 2005)	$1,648.60
Temperate or sub-polar needleleaf forest	Food/Nutrition	(Anielski & Wilson, 2005)	$0.36
Temperate or sub-polar needleleaf forest	Protection from extreme events	(Bruce, Dupont, & Renzetti, 2010)	$7.95
Temperate or sub-polar needleleaf forest	Raw Materials	(Anielski & Wilson, 2005)	$67.49
Temperate or sub-polar needleleaf forest	Water Supply	(Anielski & Wilson, 2005)	$0.08
Temperate or sub-polar needleleaf forest	Water Supply	(Bruce, Dupont, & Renzetti, 2010)	$2,351.29
Temperate or sub-polar shrubland	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$751.44
Urban	Water Supply	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$8.19
Urban	Water Supply	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$8.19
Urban	Water Supply	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$8.19
Water	Aesthetic	(Troy & Bagstad Ken, 2009)	$222.62
Water	Aesthetic	(Troy & Bagstad Ken, 2009)	$220.55

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Water	Biodiversity	(Farber & Costanza, 1987)	$455.13
Water	Biodiversity	(Farber & Costanza, 1987)	$4,837.06
Water	Biodiversity	(Kahn & Buerger, 1994)	$6.63
Water	Biodiversity	(Kahn & Buerger, 1994)	$13.09
Water	Biodiversity	(Mazzotta, 1996)	$18,365.17
Water	Biodiversity	(Mazzotta, 1996)	$45,052.07
Water	Biodiversity	(Wu & Skelton-Groth, 2002)	$356.74
Water	Biodiversity	(Wu & Skelton-Groth, 2002)	$7,794.26
Water	Cultural, Other	(Young & Shortle, 1989)	$246.21
Water	Cultural, Other	(Young & Shortle, 1989)	$247.28
Water	Food/Nutrition	(Armstrong, Rooper, & Gunderson, 2003)	$67.51
Water	Food/Nutrition	(Armstrong, Rooper, & Gunderson, 2003)	$371.31
Water	Food/Nutrition	(Kahn & Buerger, 1994)	$1,998.21
Water	Food/Nutrition	(Kildow, Colgan, Kite-Powell, Shivendu, & Tindall, 2004)	$179.05
Water	Food/Nutrition	(Lipton, 2009)	$77,707.51
Water	Food/Nutrition	(Mazzotta, 1996)	$9,182.59
Water	Food/Nutrition	(Mazzotta, 1996)	$20,373.86
Water	Recreation	(Troy & Bagstad Ken, 2009)	$158,591.94
Water	Recreation	(Troy & Bagstad Ken, 2009)	$874.94
Water	Recreation	(Troy & Bagstad Ken, 2009)	$61.90
Water	Recreation	(Troy & Bagstad Ken, 2009)	$615.57
Water	Renewable Energy	(Gibbons, 1986)	$301.21
Water	Renewable Energy	(Gibbons, 1986)	$97.89
Water	Renewable Energy	(Gibbons, 1986)	$229.67
Water	Waste Assimilation	(Troy & Bagstad Ken, 2009)	$52,924.68

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Water	Waste Assimilation	(Troy & Bagstad Ken, 2009)	$31,138.10
Water	Water Supply	(Troy & Bagstad Ken, 2009)	$16,245.86
Wetland	Aesthetic	(Amacher & Brazee, 1989)	$100.81
Wetland	Aesthetic	(Amacher & Brazee, 1989)	$100.81
Wetland	Aesthetic	(Johnston, Opaluch, Grigalunas, & Mazzotta, 2001)	$2,513.41
Wetland	Aesthetic	(Johnston, Opaluch, Grigalunas, & Mazzotta, 2001)	$4,026.86
Wetland	Aesthetic	(Johnston, Opaluch, Grigalunas, & Mazzotta, 2001)	$2,513.41
Wetland	Aesthetic	(Johnston, Opaluch, Grigalunas, & Mazzotta, 2001)	$4,026.86
Wetland	Aesthetic	(Mazzotta, 1996)	$15,494.67
Wetland	Aesthetic	(Mazzotta, 1996)	$36,730.35
Wetland	Aesthetic	(Mazzotta, 1996)	$15,494.67
Wetland	Aesthetic	(Mazzotta, 1996)	$36,730.35
Wetland	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$751.44
Wetland	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$367.52
Wetland	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$63.20
Wetland	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$367.52
Wetland	Aesthetic	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$63.20
Wetland	Aesthetic	(Opaluch, Grigalunas, Diamantedes, Mazzotta, & Johnston, 1999)	$18,301.20
Wetland	Aesthetic	(Opaluch, Grigalunas, Diamantedes, Mazzotta, & Johnston, 1999)	$24,687.61

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Wetland	Aesthetic	(Opaluch, Grigalunas, Diamantedes, Mazzotta, & Johnston, 1999)	$18,301.20
Wetland	Aesthetic	(Opaluch, Grigalunas, Diamantedes, Mazzotta, & Johnston, 1999)	$24,687.61
Wetland	Aesthetic	(Thibodeau & Ostro, 1981)	$2,157.48
Wetland	Aesthetic	(Thibodeau & Ostro, 1981)	$2,157.48
Wetland	Aesthetic	(Thibodeau & Ostro, 1981)	$1,210.19
Wetland	Aesthetic	(Thibodeau & Ostro, 1981)	$3,872.62
Wetland	Aesthetic	(Thibodeau & Ostro, 1981)	$1,210.19
Wetland	Aesthetic	(Thibodeau & Ostro, 1981)	$3,872.62
Wetland	Air Quality	(Bruce, Dupont, & Renzetti, 2010)	$12.90
Wetland	Air Quality	(Bruce, Dupont, & Renzetti, 2010)	$12.90
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$5,745.52
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$5,745.52
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$2,013.19
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$2,013.19
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$313.79
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$313.79
Wetland	Biodiversity	(Hughes, 2006)	$808.96
Wetland	Biodiversity	(Hughes, 2006)	$808.96
Wetland	Biodiversity	(Weber, 2007)	$1,644.24
Wetland	Biodiversity	(Weber, 2007)	$1,644.24
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$259.63
Wetland	Biodiversity	(Bruce, Dupont, & Renzetti, 2010)	$259.63
Wetland	Climate Regulation	(Earth Economics, n.d.)	$2.31
Wetland	Climate Regulation	(Earth Economics, n.d.)	$37.40

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Wetland	Climate Regulation	(Earth Economics, n.d.)	$2.31
Wetland	Climate Regulation	(Earth Economics, n.d.)	$37.40
Wetland	Climate Regulation	(Hughes, 2006)	$564.28
Wetland	Climate Regulation	(Hughes, 2006)	$564.28
Wetland	Climate Regulation	(Jenkins, Murray, Kramer, & Faulkner, 2010)	$207.14
Wetland	Climate Regulation	(Jenkins, Murray, Kramer, & Faulkner, 2010)	$268.91
Wetland	Climate Regulation	(Jenkins, Murray, Kramer, & Faulkner, 2010)	$1,511.73
Wetland	Climate Regulation	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$4,072.03
Wetland	Climate Regulation	(Moore, Williams, Rodriguez, & Hepinstall-Cymmerman, 2011)	$4,072.03
Wetland	Climate Regulation	(Flores, Harrison-Cox, Wilson, & Batker, 2013)	$164.29
Wetland	Climate Regulation	(Flores, Harrison-Cox, Wilson, & Batker, 2013)	$12,745.40
Wetland	Climate Regulation	(Flores, Harrison-Cox, Wilson, & Batker, 2013)	$164.29
Wetland	Climate Regulation	(Flores, Harrison-Cox, Wilson, & Batker, 2013)	$12,745.40
Wetland	Cultural, Other	(Gupta & Foster, 1975)	$4,008.01
Wetland	Cultural, Other	(Gupta & Foster, 1975)	$4,008.01
Wetland	Erosion Control	(Weber, 2007)	$464.95
Wetland	Erosion Control	(Weber, 2007)	$464.95
Wetland	Food/Nutrition	(Aburto-Oropeza et al., 2008)	$44,245.41
Wetland	Food/Nutrition	(Aburto-Oropeza et al., 2008)	$44,245.41
Wetland	Food/Nutrition	(Batie & Wilson, 1978)	$15.06
Wetland	Food/Nutrition	(Batie & Wilson, 1978)	$1,885.17
Wetland	Food/Nutrition	(Batie & Wilson, 1978)	$15.06
Wetland	Food/Nutrition	(Batie & Wilson, 1978)	$1,885.17
Wetland	Food/Nutrition	(Bell, 1989)	$2,416.56
Wetland	Food/Nutrition	(Bell, 1989)	$156.95

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Wetland	Food/Nutrition	(Bell, 1989)	$366.75
Wetland	Food/Nutrition	(Bell, 1989)	$156.95
Wetland	Food/Nutrition	(Bell, 1989)	$366.75
Wetland	Food/Nutrition	(Costanza, Farber, & Maxwell, 1989)	$157.98
Wetland	Food/Nutrition	(Farber & Costanza, 1987)	$258.53
Wetland	Food/Nutrition	(Gosselink, Odum, Center, & Pope, 1974)	$410.10
Wetland	Food/Nutrition	(Gosselink, Odum, Center, & Pope, 1974)	$767.63
Wetland	Food/Nutrition	(Gosselink, Odum, Center, & Pope, 1974)	$1,199.42
Wetland	Food/Nutrition	(Hughes, 2006)	$2,137.26
Wetland	Food/Nutrition	(Hughes, 2006)	$2,137.26
Wetland	Food/Nutrition	(Johnston, Opaluch, Grigalunas, & Mazzotta, 2001)	$2,664.75
Wetland	Food/Nutrition	(Johnston, Opaluch, Grigalunas, & Mazzotta, 2001)	$2,664.75
Wetland	Protection from extreme events	(Bruce, Dupont, & Renzetti, 2010)	$409.20
Wetland	Protection from extreme events	(Bruce, Dupont, & Renzetti, 2010)	$409.20
Wetland	Protection from extreme events	(Bruce, Dupont, & Renzetti, 2010)	$2,124.34
Wetland	Protection from extreme events	(Bruce, Dupont, & Renzetti, 2010)	$2,124.34
Wetland	Protection from extreme events	(Woodward & Wui, 2001)	$2,331.00
Wetland	Protection from extreme events	(Woodward & Wui, 2001)	$2,331.00
Wetland	Protection from extreme events	(Costanza et al., 1997)	$20,913.07
Wetland	Protection from extreme events	(Costanza et al., 1997)	$20,913.07

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Wetland	Raw Materials	(Costanza, Farber, & Maxwell, 1989)	$75.01
Wetland	Raw Materials	(Everard, Great Britain, & Environment Agency, 2009)	$131.48
Wetland	Raw Materials	(Everard, Great Britain, & Environment Agency, 2009)	$131.48
Wetland	Recreation	(Anderson & Edwards, 1986)	$1,111.56
Wetland	Recreation	(Anderson & Edwards, 1986)	$1,111.56
Wetland	Recreation	(Bell, 1989)	$2,553.36
Wetland	Recreation	(Bell, 1997)	$38,643.95
Wetland	Recreation	(Bell, 1997)	$5,858.36
Wetland	Recreation	(Bell, 1989)	$406.87
Wetland	Recreation	(Bell, 1989)	$3,121.76
Wetland	Recreation	(Bell, 1989)	$406.87
Wetland	Recreation	(Bell, 1989)	$3,121.76
Wetland	Recreation	(Bergstrom, Stoll, Titre, & Wright, 1990)	$243.22
Wetland	Recreation	(Bergstrom, Stoll, Titre, & Wright, 1990)	$211.55
Wetland	Recreation	(Bergstrom, Stoll, Titre, & Wright, 1990)	$211.55
Wetland	Recreation	(Costanza, Farber, & Maxwell, 1989)	$286.47
Wetland	Recreation	(Costanza, Farber, & Maxwell, 1989)	$1,126.98
Wetland	Recreation	(Costanza, Farber, & Maxwell, 1989)	$286.47
Wetland	Recreation	(Costanza, Farber, & Maxwell, 1989)	$1,126.98
Wetland	Recreation	(Costanza, Farber, & Maxwell, 1989)	$27.30
Wetland	Recreation	(Creel & Loomis, 1992)	$2,728.61
Wetland	Recreation	(Creel & Loomis, 1992)	$2,728.61
Wetland	Recreation	(Farber, 1996)	$47.68
Wetland	Recreation	(Farber & Costanza, 1987)	$34.60

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Wetland	Recreation	(Gosselink, Odum, Center, & Pope, 1974)	$1,016.33
Wetland	Recreation	(Gren & Söderqvist, 1994)	$7,010.14
Wetland	Recreation	(Gupta & Foster, 1975)	$1,039.11
Wetland	Recreation	(Jaworski & Raphael, 1978)	$573.44
Wetland	Recreation	(Jaworski & Raphael, 1978)	$4,393.00
Wetland	Recreation	(Jaworski & Raphael, 1978)	$573.44
Wetland	Recreation	(Jaworski & Raphael, 1978)	$4,393.00
Wetland	Recreation	(Jaworski & Raphael, 1978)	$120.28
Wetland	Recreation	(Jaworski & Raphael, 1978)	$14.90
Wetland	Recreation	(Jaworski & Raphael, 1978)	$1,101.48
Wetland	Recreation	(Jaworski & Raphael, 1978)	$532.41
Wetland	Recreation	(Jaworski & Raphael, 1978)	$11,723.46
Wetland	Recreation	(Jenkins, Murray, Kramer, & Faulkner, 2010)	$19.38
Wetland	Recreation	(Kreutzwiser, 1981)	$545.21
Wetland	Recreation	(Kreutzwiser, 1981)	$545.21
Wetland	Recreation	(Lant & Roberts, 1990)	$549.13
Wetland	Recreation	(Thibodeau & Ostro, 1981)	$138,675.15
Wetland	Recreation	(Thibodeau & Ostro, 1981)	$138,675.15
Wetland	Recreation	(Thibodeau & Ostro, 1981)	$1,514.68
Wetland	Recreation	(Thibodeau & Ostro, 1981)	$27,156.72
Wetland	Recreation	(Thibodeau & Ostro, 1981)	$1,514.68
Wetland	Recreation	(Thibodeau & Ostro, 1981)	$27,156.72
Wetland	Recreation	(Whitehead, Groothuis, Southwick, & Foster-Turley, 2009)	$321.61
Wetland	Recreation	(Whitehead, Groothuis, Southwick, & Foster-Turley, 2009)	$321.61

Table C-2, Continued.

Land Cover	Ecosystem Service	Source	Ecosystem Service Value (2018$ USD/year/ hectare)
Wetland	Recreation	(Whitehead, 1990)	$1,699.93
Wetland	Recreation	(Whitehead, 1990)	$11,018.45
Wetland	Recreation	(Whitehead, 1990)	$1,699.93
Wetland	Recreation	(Whitehead, 1990)	$11,018.45
Wetland	Soil Formation	(Weber, 2007)	$1,385.59
Wetland	Soil Formation	(Weber, 2007)	$1,385.59
Wetland	Waste Assimilation	(Bruce, Dupont, & Renzetti, 2010)	$2,116.04
Wetland	Waste Assimilation	(Bruce, Dupont, & Renzetti, 2010)	$2,116.04
Wetland	Water Supply	(Bruce, Dupont, & Renzetti, 2010)	$1,500.40
Wetland	Water Supply	(Bruce, Dupont, & Renzetti, 2010)	$466.34

Some land covers have multiple source studies associated with one ecosystem service. For those land covers with multiple ecosystem service source studies, we consolidate the ecosystem service values from the individual studies by averaging the estimates across each individual service (Table C-3).

Table C-3. Average Ecosystem Service Value by NALCMS Land Cover Classification

Land Cover	Ecosystem Service	Average Value (2018$ USD/ year/hectare)
Barren Lands	Aesthetic	$1,195.16
Barren Lands	Recreation	$115.20
Cropland	Aesthetic	$15,716.70
Cropland	Biodiversity	$287.44
Cropland	Climate Regulation	$8.05
Cropland	Erosion Control	$130.88
Cropland	Food/Nutrition	$10,259.81
Cropland	Pollination	$1,790.44
Cropland	Recreation	$9.41
Cropland	Soil Formation	$160.55
Mixed forest	Aesthetic	$8,590.61
Mixed forest	Air Quality	$74.33
Mixed forest	Biodiversity	$874.22
Mixed forest	Climate Regulation	$351.95
Mixed forest	Cultural, Other	$347.41
Mixed forest	Erosion Control	$51.35
Mixed forest	Food/Nutrition	$6,343.99
Mixed forest	Pollination	$84.42
Mixed forest	Protection from extreme events	$5.17
Mixed forest	Raw Materials	$437.23
Mixed forest	Recreation	$261.51
Mixed forest	Soil Formation	$52.34
Mixed forest	Waste Assimilation	$698.09
Mixed forest	Water Supply	$1,072.77
Temperate or sub-polar broadleaf deciduous forest	Climate Regulation	$27.90
Temperate or sub-polar broadleaf deciduous forest	Protection from extreme events	$5.17
Temperate or sub-polar broadleaf deciduous forest	Raw Materials	$136.12
Temperate or sub-polar broadleaf deciduous forest	Recreation	$24.16

Table C-3, Continued.

Land Cover	Ecosystem Service	Average Value (2018$ USD/ year/hectare)
Temperate or sub-polar broadleaf deciduous forest	Water Supply	$964.40
Temperate or sub-polar grassland	Aesthetic	$3,176.60
Temperate or sub-polar grassland	Biodiversity	$414.31
Temperate or sub-polar grassland	Climate Regulation	$1.00
Temperate or sub-polar grassland	Erosion Control	$17,128.46
Temperate or sub-polar grassland	Food/Nutrition	$96.65
Temperate or sub-polar grassland	Protection from extreme events	$5,151.55
Temperate or sub-polar grassland	Recreation	$38,418.59
Temperate or sub-polar grassland	Waste Assimilation	$35,018.29
Temperate or sub-polar needleleaf forest	Biodiversity	$12.29
Temperate or sub-polar needleleaf forest	Climate Regulation	$3,759.39
Temperate or sub-polar needleleaf forest	Food/Nutrition	$0.36
Temperate or sub-polar needleleaf forest	Protection from extreme events	$5.17
Temperate or sub-polar needleleaf forest	Raw Materials	$67.49
Temperate or sub-polar needleleaf forest	Water Supply	$929.04
Temperate or sub-polar shrubland	Aesthetic	$751.44
Urban	Water Supply	$8.19
Water	Aesthetic	$222.37
Water	Biodiversity	$9,610.02
Water	Cultural, Other	$246.74
Water	Food/Nutrition	$15,697.15
Water	Recreation	$40,178.48
Water	Renewable Energy	$209.59
Water	Waste Assimilation	$42,180.88
Water	Water Supply	$16,303.63
Wetland	Aesthetic	$8,792.13
Wetland	Air Quality	$12.90
Wetland	Biodiversity	$1,654.82
Wetland	Climate Regulation	$2,477.28
Wetland	Cultural, Other	$4,008.01

Table C-3, Continued.

Land Cover	Ecosystem Service	Average Value (2018$ USD/ year/hectare)
Wetland	Erosion Control	$464.95
Wetland	Food/Nutrition	$5,407.65
Wetland	Protection from extreme events	$6,240.44
Wetland	Raw Materials	$112.66
Wetland	Recreation	$9,394.27
Wetland	Soil Formation	$1,385.59
Wetland	Waste Assimilation	$2,116.04
Wetland	Water Supply	$983.37

Applying average ecosystem service values from Table C-3 to the study region land cover yields $443 billion in natural benefits annually. Table C-4 lists the total ecosystem service value provided by each NALCMS land cover classification type within the study region.

Table C-4. Ecosystem Services Values in the Lake Erie Study Region by NALCMS Land Cover Classification

Land Cover	Average Value (2018$ USD/year)
Barren Lands	$29,095,012
Cropland	$101,482,005,964
Mixed Forest	$1,788,266,740
Temperate or Sub-polar Broadleaf Deciduous Forest	$1,773,547,393
Temperate or Sub-Polar Grassland	$4,097,885,995
Temperate or Sub-Polar Needleleaf forest	$165,079,556
Temperate or Sub-Polar Shrubland	$14,487,524
Urban	$6,871,010
Water	$326,902,992,994
Wetland	$6,737,426,680
Total	**$442,997,658,869**

Table C-5 provides the value for ecosystem services provided by land cover type and by basin, excluding the portion of the study region covered by the lake itself. We were unable to apply benefit transfer methods to four of the 14 land cover types (sub-polar taiga needleleaf forest, sub-polar or polar shrubland-lichen-moss, sub-polar or polar grassland-lichen-moss, and sub-polar or polar barren-lichen-moss) because regions in those source studies were not similar enough to the Lake Erie Subregion. These four land cover types only comprise 1,560 acres (0.01% of the total land area) in the subregion; our baseline ecosystem service assessment is a conservative estimate as the land covers not included would contribute to additional annual benefits.

Table C-5. Ecosystem Service Values by NALCMS Land Cover Classification for the Land Basins of the Study Region

Land Cover (NALCMS)	U.S. Western Basin Average Value (2018$ USD/year)	U.S. Central Basin Average Value (2018$ USD/year)	U.S. Eastern Basin Average Value (2018$ USD/year)	Canadian Watersheds Average Value (2018$ USD/year)
Barren lands	$11,025,319	$1,099,018	$1,228,980	$13,207,433
Cropland	$65,619,734,788	$5,800,255,775	$5,195,964,027	$24,352,903,589
Mixed forest	$17,692,260	$1,247,384	$312,879,876	$1,417,200,386
Temperate or sub-polar broadleaf deciduous forest	$516,131,807	$534,450,060	$455,386,488	$252,991,475
Temperate or sub-polar grassland	$1,775,466,696	$1,729,159,665	$475,013,878	$33,737,213
Temperate or sub-polar needleleaf forest	$12,314,718	$18,606,323	$111,316,468	$21,455,343
Temperate or sub-polar shrubland	$1,294,693	$3,765,525	$6,403,537	$2,005,949
Urban	$3,111,231	$2,168,526	$630,184	$848,713
Water	$3,379,632,115	$1,105,887,228	$216,268,275	$1,516,334,752
Wetland	$3,757,121,536	$1,375,688,347	$1,161,838,402	$236,173,697
Total	**$75,093,525,163**	**$10,572,327,851**	**$7,936,930,114**	**$27,846,858,550**

Note: Ecosystem service values are for the land cover of the basins and does not include the benefits provided by the lake.

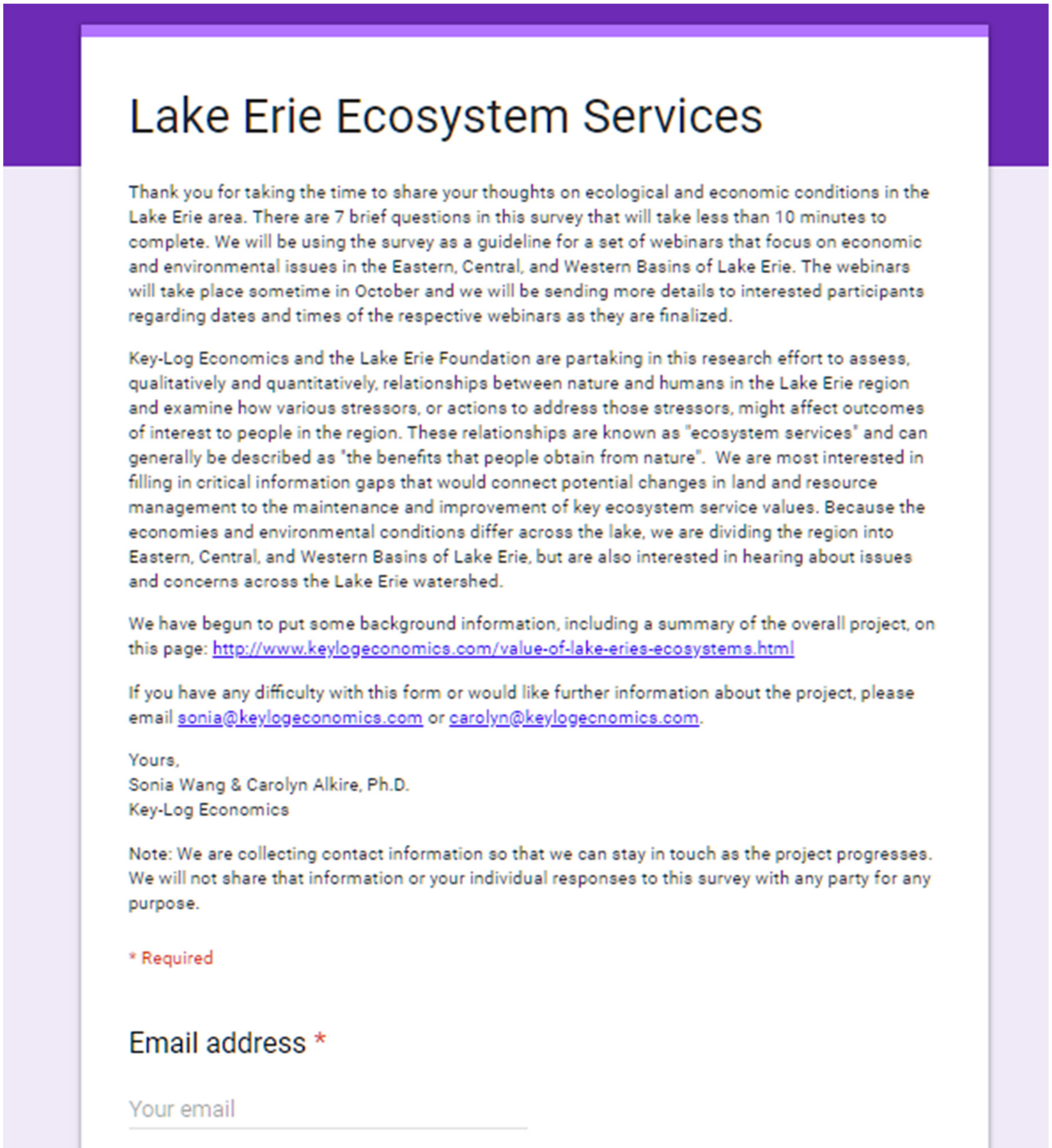
Table C-6 provides ecosystem service values broken out by basin, excluding the area covered by the lake itself. The land cover of the study region provides over $121.4 billion (2018$ USD) in annual benefits and the services of aesthetics, food/nutrition, and pollination provides the largest benefits.

Table C-6. Ecosystem Service Values in the Study Region for the Land Basins of the Study Region

Ecosystem Service	U.S. Western Basin Average Value (2018$ USD/year)	U.S. Central Basin Average Value (2018$ USD/year)	U.S. Eastern Basin Average Value (2018$ USD/year)	Canadian Watersheds Average Value (2018$ USD/year)
Aesthetic	$37,165,595,244	$3,541,282,886	$3,252,695,403	$14,132,228,388
Air Quality	$1,123,089	$392,879	$1,425,432	$5,037,047
Biodiversity	$1,206,637,335	$251,085,017	$181,765,622	$497,966,642
Climate Regulation	$237,543,489	$95,542,852	$148,884,302	$60,695,022
Cultural, Other	$336,573,790	$122,891,915	$107,479,595	$46,952,603
Erosion Control	$646,998,657	$338,716,964	$118,406,734	$124,023,377
Food/Nutrition	$24,613,860,255	$2,402,266,405	$2,138,409,306	$9,452,328,785
Pollination	$4,142,324,536	$366,146,848	$329,242,221	$1,542,925,435
Protection from extreme events	$606,459,115	$278,832,141	$184,595,818	$34,988,246
Raw Materials	$42,881,338	$37,919,351	$39,844,960	$46,302,741
Recreation	$2,576,915,399	$1,315,742,174	$503,066,635	$579,973,787
Renewable Energy	$5,682,771	$1,859,523	$363,650	$2,549,681
Soil Formation	$485,433,598	$74,556,605	$65,420,234	$148,515,107
Waste Assimilation	$1,943,709,381	$1,047,129,326	$304,638,176	$582,630,950
Water Supply	$1,081,787,167	$697,962,964	$560,692,026	$589,740,739
Total	**$75,093,525,163**	**$10,572,327,851**	**$7,936,930,114**	**$27,846,858,550**

Note: Ecosystem service values are for the land cover of the basins and does not include the benefits provided by the lake.

Appendix D: Lake Erie Ecosystem Services Survey



Lake Erie Ecosystem Services

Thank you for taking the time to share your thoughts on ecological and economic conditions in the Lake Erie area. There are 7 brief questions in this survey that will take less than 10 minutes to complete. We will be using the survey as a guideline for a set of webinars that focus on economic and environmental issues in the Eastern, Central, and Western Basins of Lake Erie. The webinars will take place sometime in October and we will be sending more details to interested participants regarding dates and times of the respective webinars as they are finalized.

Key-Log Economics and the Lake Erie Foundation are partaking in this research effort to assess, qualitatively and quantitatively, relationships between nature and humans in the Lake Erie region and examine how various stressors, or actions to address those stressors, might affect outcomes of interest to people in the region. These relationships are known as "ecosystem services" and can generally be described as "the benefits that people obtain from nature". We are most interested in filling in critical information gaps that would connect potential changes in land and resource management to the maintenance and improvement of key ecosystem service values. Because the economies and environmental conditions differ across the lake, we are dividing the region into Eastern, Central, and Western Basins of Lake Erie, but are also interested in hearing about issues and concerns across the Lake Erie watershed.

We have begun to put some background information, including a summary of the overall project, on this page: http://www.keylogeconomics.com/value-of-lake-eries-ecosystems.html

If you have any difficulty with this form or would like further information about the project, please email sonia@keylogeconomics.com or carolyn@keylogecnomics.com.

Yours,
Sonia Wang & Carolyn Alkire, Ph.D.
Key-Log Economics

Note: We are collecting contact information so that we can stay in touch as the project progresses. We will not share that information or your individual responses to this survey with any party for any purpose.

* Required

Email address *

Your email

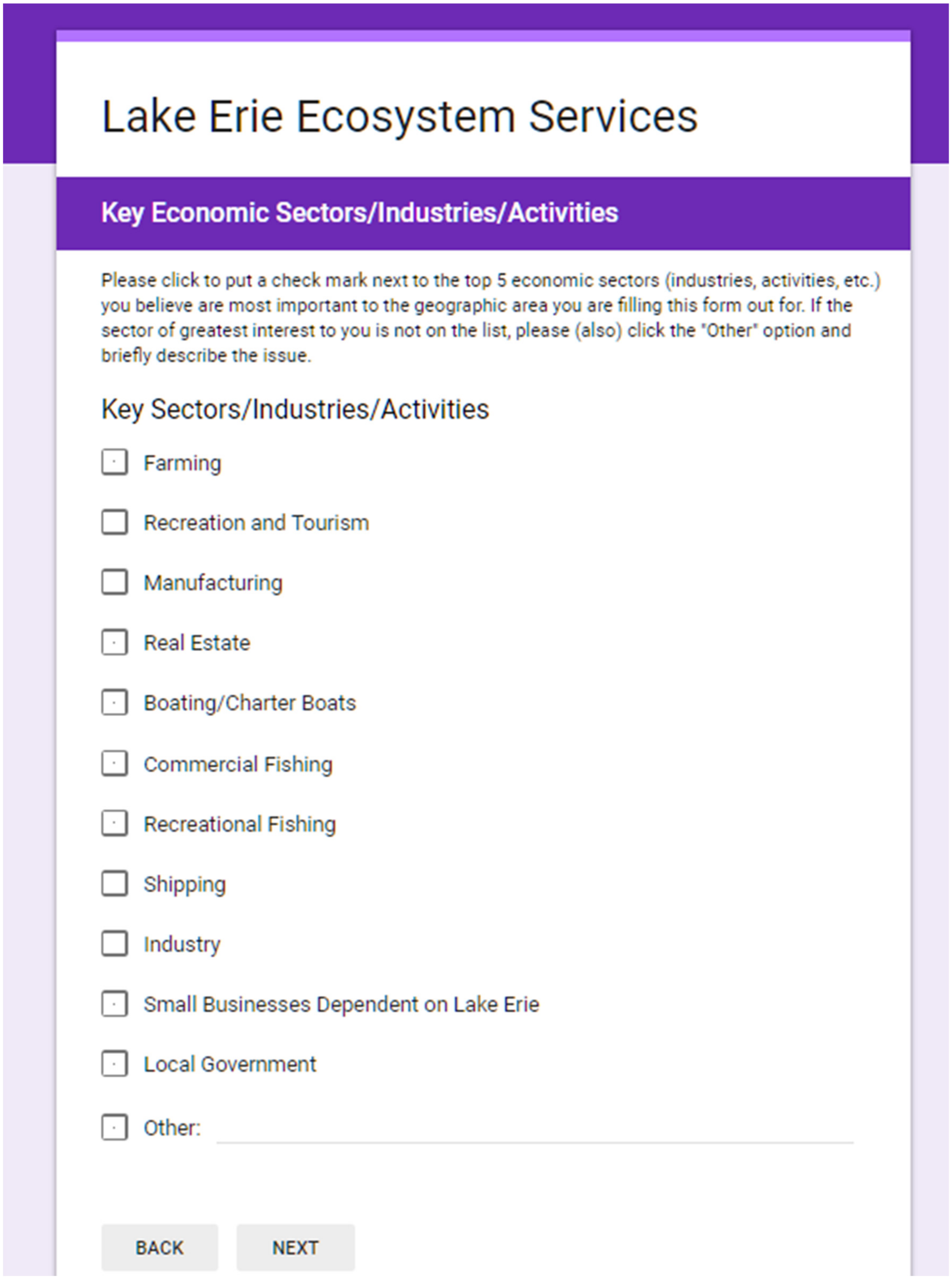
For which part of the Lake Erie Watershed are you answering? *

- ○ Canada side-Central/Eastern basin of the Lake Erie Watershed (i.e., East of Point Pelee)
- ○ Canada side- Western basin of the Lake Erie Watershed (Windsor to Point Pelee)
- ○ US side- Eastern basin of the lake (Erie, PA to Buffalo, NY)
- ○ US side-Central basin of the lake (Sandusky, OH to Erie, PA)
- ○ US side-Western basin of the lake (Fort Wayne, IN -east to Sandusky, OH)
- ○ Entire Lake Erie Watershed Region
- ○ Other:

Which part of the Lake Erie Watershed do you reside in? *

- ○ Canada side-Central/Eastern basin of the Lake Erie Watershed (i.e., East of Point Pelee)
- ○ Canada side- Western basin of the Lake Erie Watershed (Windsor to Point Pelee)
- ○ US side- Eastern basin of the lake (Erie, PA to Buffalo, NY)
- ○ US side-Central basin of the lake (Sandusky, OH to Erie, PA)
- ○ US side-Western basin of the lake (Fort Wayne, IN -east to Sandusky, OH)
- ○ Outside the watershed
- ○ Other: ____________

NEXT



Lake Erie Ecosystem Services

Key Economic Sectors/Industries/Activities

Please click to put a check mark next to the top 5 economic sectors (industries, activities, etc.) you believe are most important to the geographic area you are filling this form out for. If the sector of greatest interest to you is not on the list, please (also) click the "Other" option and briefly describe the issue.

Key Sectors/Industries/Activities

- [ ] Farming
- [ ] Recreation and Tourism
- [ ] Manufacturing
- [ ] Real Estate
- [ ] Boating/Charter Boats
- [ ] Commercial Fishing
- [ ] Recreational Fishing
- [ ] Shipping
- [ ] Industry
- [ ] Small Businesses Dependent on Lake Erie
- [ ] Local Government
- [ ] Other: ____________

BACK NEXT

Lake Erie Ecosystem Services

Stressors/Environmental Issues in the Region

We have identified a number of environmental concerns that could affect human health, well-being, and economic opportunity in the Lake Erie region. Please click to put a check mark next to the top 5 issues you believe are most important to the geographic area you are filling this form out for. If the issue or stressor of greatest interest to you is not on the list, please (also) click the "Other" option and briefly describe the issue.

Key Issues

- [ ] Nearshore Algae Blooms
- [ ] Open Lake Algae Blooms
- [ ] Aquatic Invasive Species (Zebra mussels, sea lamprey, asian carp, etc.)
- [ ] Plastics
- [ ] Industrial Discharge
- [ ] Drinking Water Quality
- [ ] Runoff from Commercial Fertilizer
- [ ] Runoff from Manure from Large Animal Feeding Operations
- [ ] Stormwater Runoff
- [ ] Shoreline Development
- [ ] Loss of Wetlands
- [ ] Changes in Climate (i.e., temperature, storm frequency, etc.)
- [ ] Urban sprawl
- [ ] Population growth
- [ ] Other: ____________

Key Ecosystem Benefits/Values

Ecosystem benefits are things provided by nature that are valued by human beings. They can be tangible (food, raw materials, clean drinking water, places to recreate, natural beauty), or intangible (knowledge, psychological well-being). They can be expressed in monetary terms (the price of a bushel of soybeans, or what one would pay for a day of fishing), but they don't have to be.

For this question, we'd like to hear about services that natural areas (land and water, not just the lake itself), provide in your community. Please check the top 5 benefits in the list below that you think are important, and add any others that are missing in the "Other" option.

Ecosystem Benefits

- ☐ Water for Drinking (quality and quantity)
- ☐ Water for Industrial Processes (including irrigation, brewing, paper making, canning, etc.)
- ☐ Aesthetic Value
- ☐ Recreational Fishing (sport fishing)
- ☐ Commercial Fishing
- ☐ Charter Boat Fishing
- ☐ Boating/Sailing
- ☐ Birding
- ☐ Other Recreation (hiking, kayaking, canoeing, paddle boarding, festivals, etc.)
- ☐ Scientific Research and Educational Value
- ☐ Habitat for Species of all Kinds
- ☐ Erosion and Sediment Control
- ☐ Other: ____________________

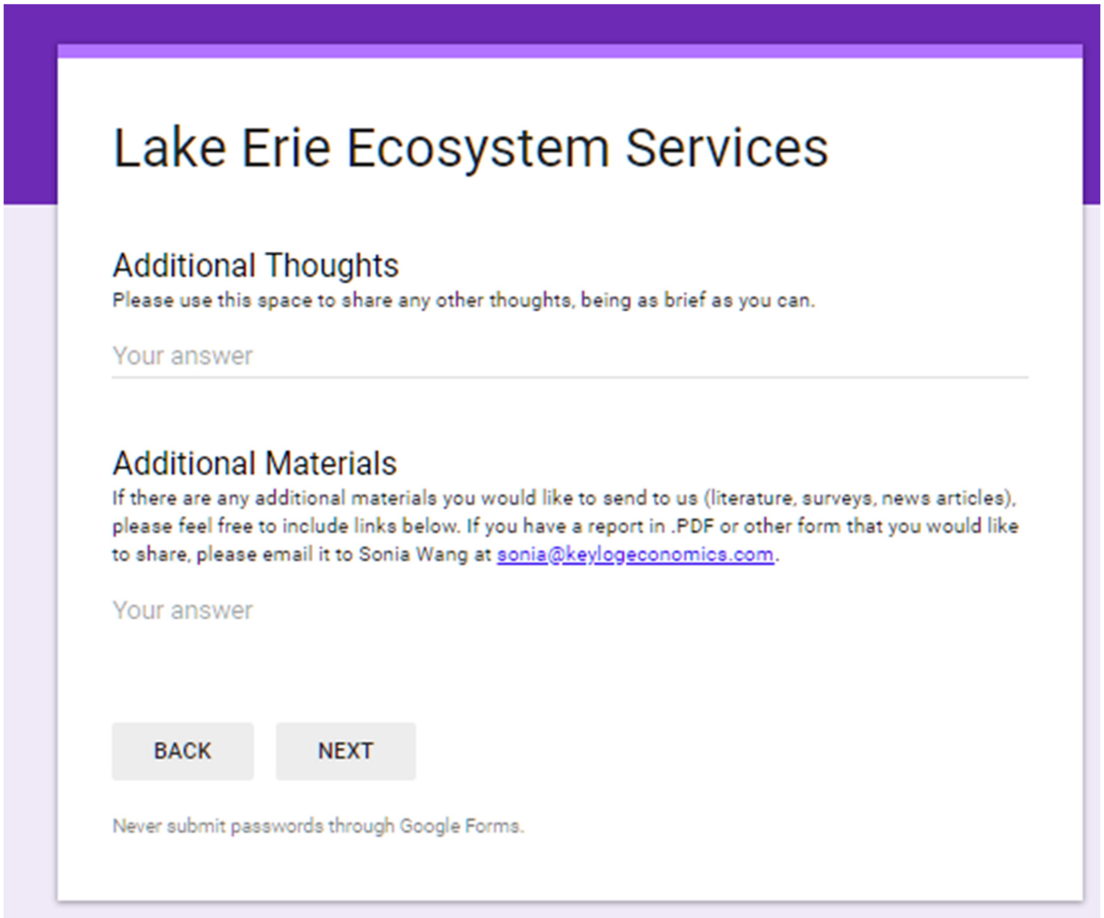
Possible Actions

Please click to put a check mark next the top 5 possible actions you think could or should be done to protect or enhance the ecosystem benefit(s) you noted in the previous question. If the action that is of greatest interest to you is not on the list, please (also) click the "Other" option and briefly describe the action.

Possible Actions

- ☐ Improved manure management for farmlands
- ☐ Improved commercial fertilizer management
- ☐ Improved septic system management
- ☐ Reduced phosphorous in waster water plants
- ☐ Reduced sewage overflows
- ☐ Research/monitoring
- ☐ State tax incentives for cover crops and other conservation practices
- ☐ Restricting development in the 100-year floodplain
- ☐ Federal Farm Bill incentives
- ☐ State incentives (i.e., Water bonds)
- ☐ Other:

BACK NEXT



Lake Erie Ecosystem Services

Additional Thoughts

Please use this space to share any other thoughts, being as brief as you can.

Your answer

Additional Materials

If there are any additional materials you would like to send to us (literature, surveys, news articles), please feel free to include links below. If you have a report in .PDF or other form that you would like to share, please email it to Sonia Wang at sonia@keylogeconomics.com.

Your answer

BACK NEXT

Never submit passwords through Google Forms.

Contact Information

Please provide your contact information so we can keep you up-to-date on the project.

If you are filling out this form for a second time (for a different part of the Lake, for example), you can skip this section...we'll link to your earlier answers via your email address.

Again, we will not share your contact information or your individual answers to the questions in this survey.

First Name (optional)

Your answer

Last Name (optional)

Your answer

Occupation (optional)

Your answer

Affiliation (optional)

If you have a position, company, or organization whose views your answers above represent, please fill this in

Your answer

Are you interested in participating in an in-depth webinar (3 hours on a date in early October) examining ecosystem services? *

If you answer yes, we will email you details regarding the date and time of the webinar for your selected region.

- ○ Yes
- ○ No
- ○ Maybe

Appendix E: Water Treatment Plant Survey

Lake Erie Watershed Drinking Water Plant survey

This survey information is requested as part of the Lake Erie Economic Analysis funded by Lucas County, Oregon and the City of Toledo. Questions, Sandy Bihn 419-691-3788 sandylakeerie@aol.com, or Sonia Wang 703-340-6682 sonia@keylogeconomics.com. Please complete the survey by February 1, 2019, and email to Sandy Bihn at sandylakeerie@aol.com. Please estimate costs and round costs to the nearest $1,000. Please complete as much of the survey you can. It is better to provide some answers than not to respond. Thanks so much for your time.

Lake Erie Economic Survey of algae related to public drinking water treatment costs

Name of Public Water Supply ______________________________

Contact Person ____

1. About your plant:

A. Raw Water source of drinking water_______________________

B. Which Lake Erie basin: West_______ Central ________ Eastern____________

C. Range of gallons treated daily From ___________________ To _______________

Average _____________________________

D. Number of customers served _______________

E. What tests do you conduct because of the algae?_____________________________

2. Treatment because of algae

A. Treat with ________________________

B. Annual Cost Range for treatment: From ________________ To ______________

Average ____________________________

Estimated annual cost that is passed on to customer ____________________

3. Capital projects for algae

    A. Is there one? ____________________________

    B. What is the project? _______________________________________

    C. If there is a project, estimated cost _________________________________

    D. What is the estimated annual cost to the customer for this project?

    ____

Additional Comments____

____

____

Completed by____

Phone Number: ____

Email Address____

Date____________________

Appendix F: Data and Calculations

Beach Recreation Data and Calculations

Data

Number of Trips Taken by Beach-Goers

Lake Erie beach-goers average 15 trips per year while visitors to Presque Isle State Park average 33 visits per year (Murray, Sohngen, & Pendleton, 2001; Mowen, Graefe, Kerstetter, & Ferguson, 2013). Multiplying the number of beach-goers by the average number of trips taken per year results in a total of 14,290,778 beach trips to Lake Erie annually.[24]

Number of Beach-Goers

We estimate the total number of annual beach-goers visiting Lake Erie at 829,010 people. This estimate is comprised of the number of beach visitors from Canada, visitors to Presque Isle State Park in Pennsylvania, and the number of beach-goers from Ohio and Michigan.

- The Ontario Ministry of Tourism, Culture, and Sport estimates that 886,900 beach trips[25] were taken to the southwest Ontario tourism region in 2016 (Ontario Ministry of Tourism, Culture and Sport, 2017). Because this estimate includes trips taken to the entire southwest Ontario region, beach visits could be to Lake Erie, Lake Huron, or Lake St. Clair. We assume that 39.1% of the 886,900 beach trips are to Lake Erie, or 346,778 trips. The 39.1% estimate is from the Southwest Ontario Tourism Corporation's survey results which determined the percentage of visitors travelling to regions in southwest Ontario (Southwest Ontario Tourism Corporation, 2019). We use the highest percentage for the regions that border the Lake—Elgin County/Port Stanley (39.1%), Norfolk County/Simcoe (36.9%), and Haldimand County/Dunnville (22.3%). Assuming the 346,778-trip estimate includes repeat visits by a single beach-goer and the average beach-goer takes 15 trips per year, we estimate that 23,119 beach-goers visited the Ontario portion of Lake Erie in 2016. This estimate includes all visitors from Ontario, other areas of Canada, and overseas. The 2016 data is the most recent data provided on beach visitation numbers and the year was a mild year on the HAB severity index, meaning that we can reasonably assume that this number would reflect the number of annual visitors if the GLWQA target is achieved.
- Presque Isle State Park in Pennsylvania receives over 4.2 million annual visitors a year, with roughly 81% visiting a beach (Mowen, Graefe, Kerstetter, & Ferguson, 2013). This translates to 3,402,000 visitors to beaches in the park. Assuming this estimate includes

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[24] We assume that beach-goers in Ontario, Ohio, and Michigan take an average of 15 trips a year while Presque Isle visitors take an average of 33 trips per year.

[25] Visitation data is provided as a "person-visit", which represents the total number of visitors to Lake Erie. The data does not specify whether a visitor took multiple trips within a year, therefore, we assume total person-visits are synonymous with the total number of trips taken.

repeat visits by a single beach-goer and the average beach-goer takes 33 trips per year, 103,091 people visit beaches in the park annually.[26] The data is from 2012, which measured as a mild year on the HAB severity index.
- Bingham, Sinha, Lupi, & Environmental Consulting & Technology Inc. (2015) estimate that 702,800 people residing in Ohio and Michigan shoreline counties visit Lake Erie's beaches annually.[27] The estimate is derived from the assumption that 43% of Ohioans visit a beach each year and of those, 72% visit a beach on Lake Erie.

Limitations

We believe that 829,010 beach visitors are a conservative estimate and the actual number of visitors to Lake Erie's beaches is higher because the estimate from Ohio and Michigan considers only those living in the states' shoreline counties; it does not include visitors from elsewhere in the states. Also, because of a lack of visitation data, we did not include estimates of the number of beach visitors from New York, other beaches in Pennsylvania besides Presque Isle, Indiana, or other states or countries.

Furthermore, data available for the number of beach trips per visitor is an estimate from 2001, over a decade ago. Future analyses would be informed by additional research on Lake Erie beach recreation (where visitors are from, how long they stay, what activities they pursue, etc.).

Calculations

GLWQA 40% Reduction

Gopalakrishnan, Haab, & Klaiber (2018) estimates that Lake Erie's beach recreators would experience welfare gains of $0.07 per trip taken[28] if the GLWQA 40% phosphorus target is achieved, translating to an annual gain of $1,000,354 (2018$ USD). Welfare implications for beach-goers is calculated by the following equation:

- Welfare Implications for Beach Goers if the GLWQA Target is Achieved (2018$ USD) = Welfare Gain Per Trip Taken (2018$ USD) x Total Number of Trips Taken (Canada and the U.S.)

Where:

- Gains Per Trip Taken (2018$ USD) = $0.07
- Total Number of Trips Taken=14,290,778

Reductions in Beach Closures and Recreational Advisories

Lake Erie beach-goers value a 20% reduction in the average number of water quality advisories and beach closures at $28.66 (2018$ USD) per visitor per year, or $1.87 (2018$ USD) per visit (Austin, Anderson, Courant, & Litan, 2007). A 30% reduction is valued at $43.61 (2018$ USD) per visitor per year, or $2.87 (2018$ USD) per visit (Austin, Anderson, Courant, & Litan, 2007).

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[26] The data does not specify whether a visitor took multiple trips within a year, therefore, we conservatively assume that the 3.4 million estimate represents the total amount of trips taken annually to the park's beaches.
[27] The data specifies that the 702,800 estimate does not include repeat visits by a single beach-goer.
[28] The estimate is a lakewide estimate per trip.

A 20% reduction in the number of beach advisories and beach closures across Lake Erie could result in an annual benefit ranging from $23.8 to $26.7 million (2018$ USD) and a 30% reduction results in benefits of $36.2 to $41.0 million (2018$ USD). The estimates are calculated by the following equations:

Low Estimate (Per Visitor Per Year):

- Economic Benefit for Beach Goers if there is a 20%/30% reduction in the Number of Water Quality Advisories (2018$ USD) = Number of Beach Visitors (Persons) x Per Visitor Per Year Value (2018$ USD)

Where:

- Number of Beach Visitors (Persons) = 829,010
- Low Estimate Per Visitor Per Year (2018$ USD) = $28.66 for the 20% reduction and $43.61 for the 30% reduction

High Estimate (Per Visit):

- Economic Benefit for Beach-Goers if there is a 20%/30% reduction in the Number of Water Quality Advisories (2018$ USD) = Annual Number of Beach Trips (Number of Trips) x Per Visit Value (2018$ USD)

Where:

- Number of Trips Taken = 14,290,778
- Low Estimate Per Visit Value (2018$ USD) = $1.87 value for a 20% reduction and a $2.87 value for the 30% reduction

Recreational Angler Data and Calculations

Data

Total Number of Angler Trips

We estimate between 1,624,986 and 4,308,276 trips are taken by Lake Erie anglers during mild years on the HAB index. [29] The low estimate of 1,624,986 total trips is comprised of Lake Erie trip data from Canada, Ohio, Pennsylvania, New York, and Michigan. The high estimate of 4,308,276 total trips is comprised of Canadian trips and the U.S. Fish and Wildlife Service's estimates of the number of trips taken by anglers in the U.S. to Lake Erie.

- Canada Estimate- 742,065 Trips
  Data from a 2005 Great Lakes survey of recreational fishing in Canada indicates that there were 789,670 fishing days in Lake Erie comprised of residents days (725,362 days), non-resident Canadian days (108 days), and other non-resident days (64,200 days) (Government of Canada Fisheries and Oceans Statistical Services, 2008). Another 2005 survey of recreational fishing in Canada provides data on the number of fishing trips (954,825) and days fished in Ontario

[29] Slight differences in calculations are due to rounding.

(3,676,517) by non-residents (Government of Canada Fisheries and Oceans Statistical Services, 2007).

Assuming one fishing day is equal to one trip for residents,[30] 725,362 trips were taken to Lake Erie in 2005 by residents. Non-residents in Ontario spend on average 3.85 days per trip. If non-resident Lake Erie anglers also spend 3.85 days per trip, we estimate the total trip count of non-residents at 16,703 trips.[31] Combining trip counts of residents and non-residents, a total of 742,065 trips were taken to Lake Erie during 2005.

The recreational angler surveys for Canada are provided every five years and the angler survey for the Great Lakes was last provided in 2005. Because 2015 and 2010's blooms measured extremely significant and significant, respectively, data from 2005 was the most recent year in which there was a non-significant bloom. Therefore, we can reasonably expect that recreational angler trip estimates from 2005 would best reflect estimates of future trip estimates if the GWLQA target is achieved.

- U.S. Low Estimate- 882,921 Trips
    - Ohio- 672,256 Trips

      The Ohio Department of Natural Resources Division of Wildlife provides annual reports on Ohio's Lake Erie Fisheries which includes private and charter boat angler trip estimates (Ohio Department of Natural Resources Division of Wildlife Lake Erie Fisheries Units, 2013; Ohio Department of Natural Resources Division of Wildlife Lake Erie Fisheries Units, 2013; Ohio Department of Natural Resources Division of Wildlife Lake Erie Fisheries Units, 2019). Averaging the total angler trip estimates for 2018, 2016, and 2012, three mild years on the HAB severity index, results in an average of 672,256 angling trips taken to Ohio's Lake Erie waters during mild years.

    - Pennsylvania- 54,312 Trips

      The Pennsylvania Fish and Boat Commission provides annual reports on the status and trends of Pennsylvania's Lake Erie fisheries (Pennsylvania Fish and Boat Commission Lake Erie Research Unit, 2019; Pennsylvania Fish and Boat Commission Lake Erie Research Unit, 2017; Pennsylvania Fish and Boat Commission Lake Erie Research Unit, 2013). Estimates of angler effort are provided for various fish species in Pennsylvania's open lake waters at four fish landing sites and angler effort for walleye, smallmouth Bass, yellow perch, and steelhead trout based on expansion coefficients from a more encompassing open lake angling survey. Combining the data results in an annual estimate of total angling effort hours for walleye, smallmouth bass, yellow perch, and steelhead trout across Pennsylvania's open lake waters and other fish species at the four sampled sites.

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[30] Results from the Great Lakes survey of recreational fishing indicates "recreational fishing activities of residents are much more likely to be in the form of day trips" (Government of Canada Fisheries and Oceans Statistical Services, 2008). No data is provided on the number of days per trip for residents in Lake Erie. If some resident trips exceed one day, then the estimate may overestimate the number of trips taken by residents. However, in lieu of more specific data, we assume that one fishing day is equal to one trip taken by residents.

[31] Non-resident trip estimates could be underestimated if a portion of non-resident trips taken were only day trips.

For 2018, 2016, and 2012, three mild years on the HAB index, the average angling effort was 296,052 hours per year. The reports do not provide information on the number of trips taken or the average time spent per trip. Dividing the average angling effort by the average hours spent per trip estimate from New York (5.5) results in 54,312 trips taken to Pennsylvania's Lake Erie waters during mild years. [32]

According to a fisheries biologist at the Pennsylvania Fish and Boat Commission, estimates for angling effort in Pennsylvania could be underestimated by 40% (C. Murray, personal communication, Sept 25, 2019). First, the estimates of effort for all other species aside from walleye, smallmouth bass, yellow perch, and steelhead trout, are only for open lake boat fishing between May 1st and October 1st at four survey sites. And second, the angling effort estimates for walleye, smallmouth bass, yellow perch, and steelhead trout are based on expansion coefficients calculated from a creel survey conducted in 1996.

- New York- 63,318 Trips

New York State's Department of Environmental Conservation provides annual reports on the status of Lake Erie for the years 2013 through 2018 (New York State Department of Environmental Conservation, 2019). The reports include total angler hours in New York's waters of Lake Erie by year. In 2018 and 2016, two mild years on the HAB severity index, an average of 345,147 angler-hours are estimated. Data from the New York State Department of Environmental Conservation indicates that between 2014 and 2018, New York Lake Erie anglers averaged 5.5 hours per trip. At an average of 5.5 hours per trip, 63,318 trips are taken to New York's waters of Lake Erie during mild years.

- Michigan- 93,035 Trips

Michigan's Department of Natural Resources provides data on the total number of angling trips taken to Lake Erie (Michigan Department of Natural Resources, 2019). Averaging trips taken during 2018, 2016, and 2012, three mild years on the HAB severity index, results in an estimate of 93,035 trips taken to Michigan's section of Lake Erie during a mild year.

- U.S. High Estimate- 3,566,211 Trips
    - The National Survey of Fishing, Hunting and Wildlife-Associated Recreation provides data every five years on the number of anglers in Lake Erie (U.S. Fish & Wildlife Service, 2018a; U.S. Fish & Wildlife Service, 2018b). Averaging the number of anglers in 2006 and 2016[33,34], years that measured not significant and mild on the HAB severity index, respectively, results in an estimate of 458,000 anglers fishing in Lake Erie. Multiplying

[32] We use data from New York to estimate trip counts in Pennsylvania due to the states' geographical proximity.
[33] The number of anglers estimated by the U.S. Fish and Wildlife Service in 2006 and 2016 are 526,000 and 390,000, respectively.
[34] The annual HAB severity index has only been produced since 2002. Data from the U.S. Fish & Wildlife Service is provided every five years, meaning that 2006, 2011, and 2016 were the only years used in calculations. Data for 2011 was not included as the bloom that year measured extremely significant on the HAB index. Furthermore, angler estimates for 2016 represented a historic low between 2001 and 2016. Data from 2006, a year that measured insignificant on the HAB severity index, was included to avoid underestimation of anglers in mild years.

458,000 anglers by the average number of trips taken per angler during 2006 and 2016 (7.8) results in an estimate of 3,566,211 total trips taken by U.S. recreational anglers during mild years. [29] The estimate of 7.8 trips is derived from data on days of fishing and the number anglers in Lake Erie for 2006 and 2016, years that measured not significant and mild on the HAB severity index, respectively.

Number of Angler Trips Affected by HABs

The exact number of angling trips that could be, or are, affected by HABs is currently unknown. In a 2014 survey of Ohio Lake Erie anglers, Sohngen et al. (2014) found that over 50% of respondents indicated that they changed behavior due to HABs, either by changing their fishing location, not taking trips, or spending a different amount of time fishing. In a study assessing how much anglers would be willing to pay for phosphorus reductions, Zhang & Sohngen (2018) assume that only 10% of fishing trips could be affected by HABs.

These estimates of the portion of trips likely to be affected by HABs are used to calculate the following:[29]

- Low Estimate- 725,895 Affected Trips
  - Canada- 331,487 Affected Trips

    We assume a similar distribution of affected trips on the Canadian portion of the lake as on the U.S. portion to approximate the number of Canadian trips that could be affected by HABs. Ohio and Michigan trips account for 86.7% of the total trips taken to Lake Erie and, based on Sohngen et al. (2014), 50% of trips in Ohio waters could be impacted. Assuming 50% of trips in Michigan are also impacted, multiplying 86.7% of the 742,065 Canadian trips by 50% produces an estimate of 321,601 trips that could be affected by HABs.

    Pennsylvania and New York trips account for 13.3% of the total U.S. trips taken to Lake Erie. Given that HAB impacts are less direct in Pennsylvania and New York, we use a lower affected trip estimate of 10%, based on Zhang & Sohngen (2018). We multiply 13.3% of 742,065 Canadian trips by 10% for an estimate of 9,886 affected trips.
  - U.S.- 394,408 Affected Trips

    As noted above, results of surveys of Ohio anglers from counties alongside or close to the western or central basins of Lake Erie from Sohngen et al. (2014) indicate that roughly 50% of anglers changed behaviors due to HABs. We therefore presume that 50% of total trips taken in Ohio and Michigan would be affected, or 382,646 trips. Trips in Pennsylvania and New York are less likely to be affected; we assume 10% of trips, or 11,763 trips, would be affected by HABs in those two states.
- High Estimate-1,907,138 Affected Trips
  - Canada- 331,487 Affected Trips

    The new Canada (low) estimate of 331,487 trips would be used in calculating the high estimate on page 123 of 1,907,138 affected trips.

- U.S.- 1,575,651 Affected Trips

The U.S. Fish and Wildlife Service angler data provides total trip estimates for the entirety of Lake Erie, but no distinction is made between which basins or states trips are taken to. Using the low estimate of total trips taken by state, we can estimate the percent of total trips taken by state.[35] Applying the percentage of trips taken by state to the U.S. Fish and Wildlife Service's total trip estimate (3,566,211), we estimate that 370,487 total trips are taken to Michigan's Lake Erie waters, 2,677,089 to Ohio's, 239,463 to Pennsylvania's, and 279,173 to New York's. If 50% of trips are affected in Michigan and Ohio and 10% of trips are affected in Pennsylvania and New York, a total of 1,575,651 trips could be impacted by HABs.

Calculations

Zhang & Sohngen (2018) found that Ohio Lake Erie anglers are willing to pay $43.12 to $64.68 (2018$ USD) more per trip for a 40% reduction in spring phosphorus loads and $16.17 to $19.40 (2018$ USD) more for a 20% reduction. Assuming only a portion of all fishing trips could be affected by HAB events, 725,895 to 1,907,138 trips could result in welfare benefits.

Applying the willingness to pay estimates to the number of potentially impacted trips taken by Lake Erie anglers, achieving the GLWQA target would result in $31.3 to $123.4 million (2018$ USD) in consumer surplus gains, and a 20% reduction would result in $11.7 to $37 million in consumer surplus gains. Consumer surplus gains are calculated by the following equation:[29]

- Recreational Angler Consumer Surplus (2018$ USD) = Willingness to Pay for Water Quality Improvement Per Trip (2018$ USD) x Number of Affected Trips

Where:

- Willingness to Pay for Water Quality Improvement Per Trip (2018$ USD) = $43.12 (low estimate) or $64.68 (high estimate) for a 40% reduction and $16.17 (low estimate) to $19.40 (high estimate) for a 20% reduction
- Number of Affected Trips = 725,895 (low estimate) to 1,907,138 (high estimate)

Limitations

We recommend that future research focus on the trip characteristics of Canadian anglers (trip length, distance traveled, shore or boat fishing, spending, etc.). Canadian anglers may value phosphorous reductions differently than U.S. anglers. This would allow for a more up to date analyses of differences between those fishing on the U.S. side of Lake Erie and the Canadian side of the lake.

Furthermore, the consumer surplus estimate may be an overestimate if central and eastern basin anglers do not value the 40% target reduction as highly as Ohio anglers. The willingness to pay estimate from Zhang & Sohngen (2017) is derived from a survey for Lake Erie anglers in Ohio. Future analysis

[35] The low estimate of total trips is 895,528. Michigan trips (93,035) account for 10.39% of total trips, Ohio trips (672,256) account for 75.07%, Pennsylvania trips (60,133) account for 6.71%, and New York trips (70,104) account for 7.83% of total trips.

should focus on willingness to pay estimates for anglers in the central basin as well as the eastern basin as their preferences for achieving the 40% target reduction may vary from Ohio anglers. However, in lieu of eastern and central basin willingness to pay estimates, the estimates for Ohio anglers are still applicable to be extended to all of Lake Erie's anglers as impacts from a bloom in the western basin are not confined to Ohio anglers. Negative perceptions of a bloom can still deter eastern and central basin anglers from fishing and those anglers may be willing to pay just as much for a 40% reduction to know that blooms will be limited in frequency and intensity.

We also assume that visitation in previous years measuring "mild" on the HAB severity index could represent visitation numbers in future years where the GLWQA target is achieved. Negative stigmas surrounding HAB events may linger and are often not confined to the year they occur, therefore, the number of anglers in previous mild years could be underestimates of the number of anglers visiting in future years without HABs.

Property Value Data and Calculations

Data

Household Counts

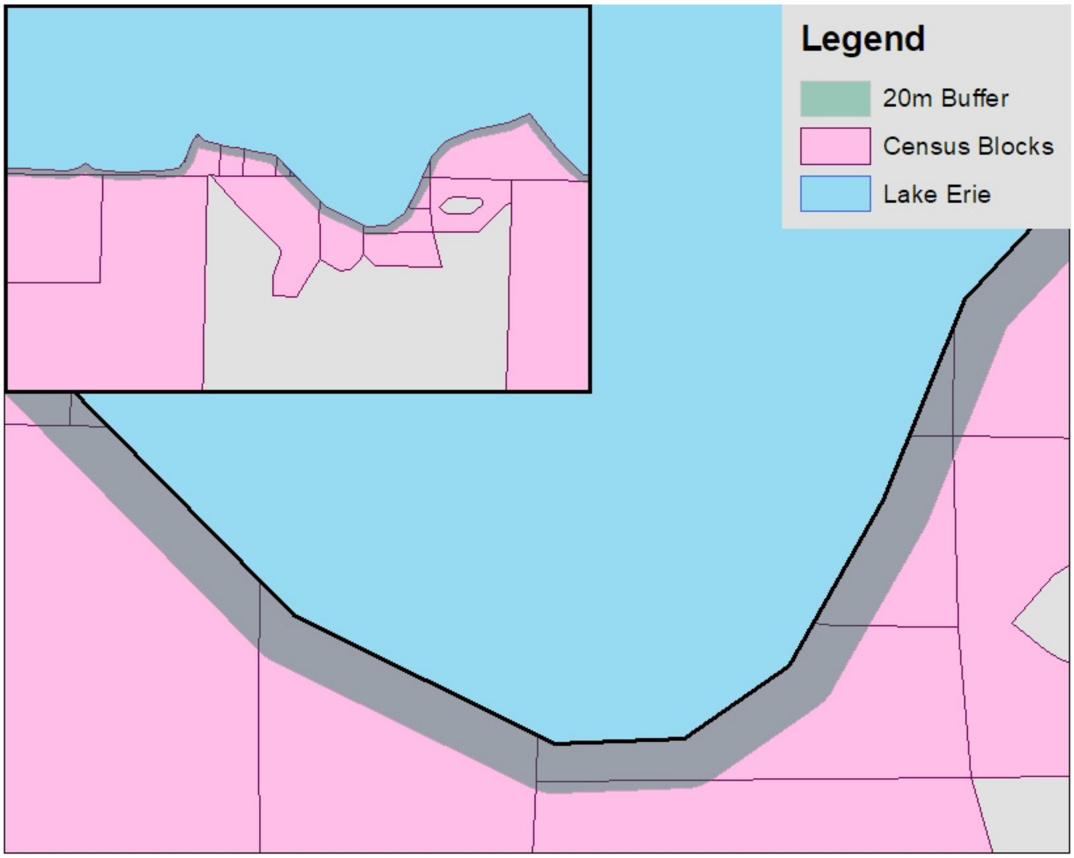
There are 14,025 households within 66 ft of the U.S. Lake Erie lakefront and 1,068 households within 66 ft of the Canadian Lake Erie lakefront. Between 66 and 820 feet, we estimate that there are 62,788 U.S. households and 4,892 Canadian households. For each specified distance, the process for collecting baseline household counts are as follows:

1) Identify the **total** number of census blocks or dissemination areas within 66 ft and between 66 ft and 820 ft from the lake.
    a) Spatial data with household counts are provided by the U.S. Census (on the block level) and by Statistics Canada (by dissemination areas)[36] (U.S. Census Bureau, 2010 & Statistics Canada, 2017).
2) Calculate the **proportion** of households within 66 ft and between 66 ft and 820 ft.
    a) Census blocks have irregular shapes and sizes and counting the number of households in all blocks that intersect the 66 ft and 66 ft-820 ft zones would overestimate the household count. In order to obtain a count of the number of households within 66 ft, we determined the total area of each census block or dissemination area that intersects the zones of influence (pink polygons in Figure 11), the area of the census block or dissemination area that overlaps the 66 ft buffer (dark grey shaded area in Figure 11), the proportion of the overlapping area and the total area of the census block of dissemination area, and applied that proportion to the total number of households by census block or dissemination area. What results is an estimate of the proportion of households within the 66 ft buffer based on the area of a census block or

[36] Statistics Canada provides household counts in the form of "total private dwellings" (Statistics Canada, 2017).

dissemination area that overlaps 66 ft. The number of households between 66 ft-820 ft was derived by performing the same process for the 66 ft-820 ft zone.

Figure F-1. Census Blocks Within a 66 ft (20 m) Section of the U.S. Western Basin



Property Value

The U.S. Census Bureau American Community Survey (ACS), provides five-year average estimates for median housing value by census tract (U. S. Census Bureau, 2018). We estimate the total property value of each block by multiplying the number of households in a block by the median housing value of the tract that the block is a part of.

Statistics Canada provides median housing values by dissemination areas as well as household counts by dissemination areas. We use the same methods as the U.S. property value calculations to estimate total property values within each dissemination area. Using the same methods, we also calculate the total property value of blocks and dissemination areas in the 66 ft-820 ft influence zone.

Calculations

Wolf & Klaiber (2016) estimate that lakeside households within 66 ft lose up to 32% of their value and households within 66 ft-820 ft (20m-250m) lose 11% of their value when microcystin concentrations exceed the WHO drinking standard of 1 µg/L. We estimate that households within 66 ft of the U.S. side of the lakeshore could lose an estimated $624.0 million (2018$ USD) in property value and households within 66 ft-820 ft could lose $948.8 million (2018$ USD). Canadian households within 66 ft could lose $61.9 million (2018$ USD) of their value and households within 66 ft-820 ft could lose $108.3 million.

We calculate potential property value losses using the following equation:

- Property Value Losses (2018$ USD) = Total Property Value by Census Area (2018$) x Expected Property Value Loss (%)

Where:

- Total Property Value by Census Area (2018$) = The total value of all households in a census area (census block or designation areas)
- Expected Property Value Loss (%) = 32% for households within 66 ft and 11% for households within 66 ft-820 ft of the lakeshore

Limitations

It should be noted that our estimates may overstate the potential property losses in the U.S. central and eastern basins, as well as for households in Canada that are within watersheds that drain into the central and eastern basins of the lake. Harmful algal blooms that contribute to high levels of microcystin are not as large of a concern in the central and eastern basins of the lake as compared to the western basin. While the property value loss estimates provided by Wolf and Klaiber (2016) do not allow us to differentiate between households that may feel property value impacts from HABs more than others, we still believe it is important to present the results from all households lakeside and near the lake, if HABs become worse and affect those households.

Algae-Related Costs to Water Treatment Plants

Data

Water Treatment Plants

There are 43 public water suppliers that intake surface water from Lake Erie (Table F-1), including 31 plants in the U.S. and 12 plants in Ontario.

- Data for the Ohio public water supply systems were obtained from Heather Raymond, the State HAB Specialist at the Ohio EPA, and included information on the number of people served, and whether the plant directly sources water from Lake Erie or buys from a system that does. Costs related to algae are only estimated for systems that source water directly from Lake Erie; we did not estimate costs for those systems that buy water from plants sourcing water from Lake Erie.

  The Ohio EPA data did not include information on the plants' average treatment capacity (gallons per day) therefore, we used each system's source water protection assessment to determine the average daily treatment capacity (Ohio EPA, Division of Drinking and Ground

Waters, 2016).[37] The source water protection assessments have not been updated since the early 2000s (2002/2003), and it should be noted that where applicable, we substituted the early 2000s data with survey results (daily treatment capacity and population served estimates).

- In personal communications with a representative from the Pennsylvania Department of Environmental Protection, we were told that there are two public water suppliers in the state that draw water from Lake Erie. Using the state's drinking water reporting system, we obtained the treatment capacity and total population served by the two systems (Pennsylvania Department of Environmental Protection, 2019).
- The Michigan data was obtained from a report on the current state of harmful algal bloom impacts from the Michigan Department of Environmental Quality (2014).
- New York does not have a statewide water reporting system like Pennsylvania. The New York State Departments of Health and Environmental Conservation (2014) report there are five public water suppliers that draw water from Lake Erie. According to the Office of the New York State Comptroller (2017), two of the treatment systems are in Buffalo and Erie County; information on the average daily treatment capacity and the population served is publicly available for the Buffalo Water Authority system and the Erie County Water Authority system (Erie County Water Authority, 2019; Buffalo Water, 2019). The other three public water suppliers are in Chautauqua County, and after personal communication with a representative from the county's public water office, we were informed that there are no available estimates for the systems' average daily treatment capacity. The representative provided us with estimates of the population served for Pines Motel and Bluewater Beach Campground and noted that these estimates are from 2005. Information on the average daily treatment capacity and population served was available for the Dunkirk City plant, the other plant in the county (City of Dunkirk, 2016)

Smith (2015) provides a list of all municipal water treatment plants sourcing water from Lake Erie. We use the same list in this analysis and assume that all data is updated to the year of the Smith study.

[37] We did not use the population served estimates from source water assessments because the Ohio EPA data is more recent.

Table F-1. Water Treatment Plants/Systems that Source Water from Lake Erie

Plant Name	State/ Province	Basin	Gallons Treated	Number of People Served	Plant Size	Year of Data	Source
Monroe South County via city of Toledo WTP	MI	Western	3,000,000	33,816	Medium	2014	Michigan Department of Environmental Quality (2014)
Frenchtown Township WTP	MI	Western	3,200,000	16,481	Medium	2014	Michigan Department of Environmental Quality (2014)
City of Monroe WTP	MI	Western	7,700,000	48,726	Medium	2014	Michigan Department of Environmental Quality (2014)
City of Dunkirk	NY	Eastern	2,900,000	14,000	Medium	2016	City of Dunkirk (2016)
Erie County Water Authority	NY	Eastern	68,180,000	480,939	Large	2018	Erie County Water Authority (2019)
Buffalo Water Authority	NY	Eastern	70,400,000	260,000	Large	2017	Buffalo Water (2019)
Pines Motel	NY	Eastern	Unknown	25	N/A	2005	C. James, personal communication (April 17, 2019)
Bluewater Beach Campground	NY	Eastern	Unknown	500	N/A	2005	C. James, personal communication (April 17, 2019)
Kelleys Island Village	OH	Western	75,000	600	Medium	2018	Ohio EPA, Division of Drinking and Ground Waters (2016)
Marblehead Village	OH	Western	106,000	1,000	Medium	2018	Ohio EPA, Division of Drinking and Ground Waters (2016)
Carroll Water and Sewer	OH	Western	164,384	2,288	Medium	2003	Ohio EPA, Division of Drinking and Ground Waters (2016)
Put-in-Bay Village	OH	Western	1,000,000	700	Medium	2002	Ohio EPA, Division of Drinking and Ground Waters (2016)
Vermilion City	OH	Western	1,400,000	10,594	Medium	2003	Ohio EPA, Division of Drinking and Ground Waters (2016)
Huron City	OH	Western	2,200,000	8,000	Medium	2018	Ohio EPA, Division of Drinking and Ground Waters (2016)

Table F-1, Continued.

Plant Name	State/ Province	Basin	Gallons Treated	Number of People Served	Plant Size	Year of Data	Source
Ottawa County Regional	OH	Western	3,315,000	17,348	Medium	2003	Ohio EPA, Division of Drinking and Ground Waters (2016)
Sandusky City	OH	Western	9,560,000	100,000	Medium	2018	Ohio EPA, Division of Drinking and Ground Waters (2016)
Oregon City	OH	Western	10,000,000	25,000	Medium	2018	Ohio EPA, Division of Drinking and Ground Waters (2016)
City of Toledo	OH	Western	73,000,000	500,000	Large	2018	Ohio EPA, Division of Drinking and Ground Waters (2016)
Fairport Harbor Village PWS	OH	Central	390,000	3,180	Medium	2002	Ohio EPA, Division of Drinking and Ground Waters (2016)
Lake County East Water Subdistrict	OH	Central	3,180,000	37,456	Medium	2002	Ohio EPA, Division of Drinking and Ground Waters (2016)
Painesville City PWS	OH	Central	3,490,000	31,728	Medium	2002	Ohio EPA, Division of Drinking and Ground Waters (2016)
Aqua Ohio- Ashtabula	OH	Central	6,600,000	39,838	Medium	2003	Ohio EPA, Division of Drinking and Ground Waters (2016)
Aqua Ohio- Mentor	OH	Central	8,700,000	73,944	Medium	2003	Ohio EPA, Division of Drinking and Ground Waters (2016)
Elyria Water Department	OH	Central	9,100,000	68,000	Medium	2003	Ohio EPA, Division of Drinking and Ground Waters (2016)
Lake County West Water Subdistrict	OH	Central	9,920,000	78,379	Medium	2002	Ohio EPA, Division of Drinking and Ground Waters (2016)
Lorain City PWS	OH	Central	11,230,000	64,152	Medium	2002	Ohio EPA, Division of Drinking and Ground Waters (2016)
Avon Lake City PWS	OH	Central	15,700,000	23,659	Medium	2002	Ohio EPA, Division of Drinking and Ground Waters (2016)

Table F-1, Continued.

Plant Name	State/ Province	Basin	Gallons Treated	Number of People Served	Plant Size	Year of Data	Source
Cleveland Public Water System	OH	Central	200,000,000	1,500,000	Large	2018	Ohio EPA, Division of Drinking and Ground Waters (2016)
Conneaut	OH	Eastern	1,680,000	12,500	Medium	2003	Ohio EPA, Division of Drinking and Ground Waters (2016)
North East Borough Water Department	PA	Eastern	7,500,000	4,601	Medium	2019	Pennsylvania Department of Environmental Protection (2019)
Erie City Water Authority	PA	Eastern	45,000,000	220,001	Large	2019	Pennsylvania Department of Environmental Protection (2019)
Pelee Island West Shore	Ontario	Western	40,682	190	Medium	2015	Smith (2015)
Harrow and Colchester South	Ontario	Western	2,701,951	8,900	Medium	2015	Smith (2015)
Union	Ontario	Western	32,913,189	56,000	Large	2015	Smith (2015)
Port Rowan	Ontario	Eastern	803,083	1,200	Medium	2015	Smith (2015)
Port Dover	Ontario	Eastern	2,536,051	5,500	Medium	2015	Smith (2015)
Nanticoke	Ontario	Eastern	3,602,249	5,092	Medium	2015	Smith (2015)
Dunville	Ontario	Eastern	3,830,494	5,789	Medium	2015	Smith (2015)
Rosehill	Ontario	Eastern	13,208,600	27,000	Medium	2015	Smith (2015)
West Elgin	Ontario	Central	3,212,332	13,680	Medium	2015	Smith (2015)
Wheatley Harbour	Ontario	Central	6,304,201	10,700	Medium	2015	Smith (2015)
Chatham and South Chatham Kent (two plants sharing one intake)	Ontario	Central	24,037,010	60,000	Medium	2015	Smith (2015)
Elgin	Ontario	Central	24,039,652	112,000	Medium	2015	Smith (2015)

Water Treatment Plant Survey Results

We received responses from ten public water supply systems.[38] The majority of respondents (90%) intake water from the western basin of Lake Erie and are in Ohio (80%). On average, the 10 treatment plants surveyed treat an average of 33.7 million gallons daily and serve an average of 227,733 customers (Table F-2).

Table F-2. Public Water Plant Survey Results-About the Plant

Public Water Supplier	Raw Water Source of Drinking Water	Basin	Minimum Gallons Treated Daily	Maximum Gallons Treated Daily	Average Gallons Treated Daily	Number of Customers Served
Big Island Water Works Sandusky, Ohio (U.S.)	Lake Erie	Western	8,000,000	13,500,000	9,560,000	100,000[a]
Huron Water Plant, Ohio (U.S.)	Lake Erie	Western	1,700,000	2,700,000	2,200,000	8,000[b]
City of Monroe, Michigan (U.S.)	Lake Erie	Western	5,487,000	9,982,000	7,231,000	48,726
City of Oregon, Ohio (U.S.)	Lake Erie	Western	7,000,000	16,000,000	10,000,000	25,000
City of Toledo, Ohio (U.S.)	Lake Erie	Western	50,000,000	120,000,000	73,000,000	500,000
Cleveland Water, Ohio (Baldwin, Crown, Morgan, and Nottingham plants) (U.S.)	Lake Erie	Central	185,000,000	260,000,000	200,000,000	1,500,000
Defiance Water Treatment Plant, Ohio (U.S.)	Maumee River, via Upground Reservoir	Western	2,000,000	4,500,000	3,500,000	24,000
Kelleys Island, Ohio (U.S.)	Lake Erie	Western	0	250,000	75,000	600
Marblehead Water Treatment Plant, Ohio (U.S.)	Lake Erie	Western	65,000	300,000	106,000	1,000
Windsor Utilities Commission (Ontario, Canada)	Lake Erie	Western	26,400,000	47,500,000	31,700,000	70,000

Notes:

a. The plant also reported that within the city they serve 25,000 customers. The total number of customers served ranges from 70,000 to 100,000, and we report the maximum number of customers served.

b. The plant reported that they serve an internal population of 8,000 people and they sell to another 10,000 people in Erie County

[38] Cleveland water is comprised of four separate plants, but we include the results as part of one total system.

Every respondent reports that they test and monitor for microcystin at their plant, with a large majority indicating that they use the process Quantitative Polymerase Chain Reaction (qPCR)[39] (Table F-3). This is expected as most respondents are located in Ohio, and the Ohio EPA requires qPCR testing at plants to aid in the identification of microcystin and cyanobacteria in water samples.

Powdered Activated Carbon (PAC) was the most popular algal treatment method used by the plants surveyed, with 66.7% of the plants using the treatment measure. Half of the plants surveyed also noted that they increased usage of aluminum and chlorine to further treat water.

The four Cleveland plants indicated that they have never had a confirmed microcystin incident, but because they are required by the Ohio EPA to test for microcystin, costs related to algae continually burden the plant. The plant manager indicated that the plants have had to spend in excess of $30,000 just on monitoring equipment, supplies, and OEPA licensing, and an additional $15,000 on labor for sampling, analysis, shipping, and evaluation.

In total, the 10 plants spend a minimum of $3.1 million and a maximum of $3.5 million a year for testing, monitoring, and treatment activities related to algae. On average, a plant spends $416,000 a year, with more than half of the plants reporting that 100% of the costs are passed on to the customer.

[39] qPCR testing identifies and quantifies the presence of genes unique to cyanobacteria, microcystin and nodularin production, cylindrospermopsin production, and saxitoxin production.

Table F-3. Public Water Plant Survey Results-Algae Tests and Costs

Public Water Supplier	Tests Conducted Because of Algae	How Does the Plant Treat Algae	Minimum Annual Cost for Treatment	Maximum Annual Cost for Treatment	Average Annual Cost of Treatment	Annual Cost Passed to Consumer
Big Island Water Works Sandusky, Ohio (U.S.)	1. Continuous sonde monitoring of algae pigments, chlorophyll, phycocyanin, and related values including dissolved oxygen, turbidity, etc. 2. Inside laboratory- Testing for microcystin by ADDA and spectrophotometer testing. 3. Outside laboratory- qPCR testing	1. PAC 2. NAMnO4 3. CI2	$70,000	$100,000	$85,000	Self-funded entity
Huron Water Plant, Ohio (U.S.)	Microcystin (raw/finished) cyanobacteria	Sodium permanganate	$20,000	$35,000	$28,000	None- no rate increase in 11 years
City of Monroe, Michigan (U.S.)	Microcystin testing	1. Increased chlorine and aluminum usage	$24,500	$52,600	$36,600	100%
City of Oregon, Ohio (U.S.)	1. qPCR 2. Microcystin testing 3. Jar testing	1. KMNO4 2. Lime, Ozone, Bio-Filtration	NA	NA	NA	NA
City of Toledo, Ohio (U.S.)	1. ELISA 2. qPCR 3. Algae identification under a microscope 4. Monitoring- pH, the temperature on the lake, Chlorophyll and Phycocyanin levels, ORP	1. Powdered Activated Carbon	$400,000	$700,000	$552,000	100%

Table F-3, Continued.

Public Water Supplier	Tests Conducted Because of Algae	How Does the Plant Treat Algae	Minimum Annual Cost for Treatment	Maximum Annual Cost for Treatment	Average Annual Cost of Treatment	Annual Cost Passed to Consumer
Cleveland Water, Ohio (Baldwin, Crown, Morgan, and Nottingham plants) (U.S.)	1. Monitoring costs are substantial, in excess $30,000 in equipment, supplies, and OEPA licensing. 2. Manpower adds another $15,000 for sampling, analysis, shipping, and evaluation 3. ELISA ADDA - algae identification under the microscope every two weeks with the ELISA test, contract out with a specialized lab for monthly Microscopic Particulate Analysis and Algae 3. qPCR (Ohio EPA Required), identification on samples collected at each plant at the same time as ELISA and microscope tests for cross-referencing results.	1. PAC for extracellular, and taste, and odors 2. Aluminum for normal treatment which removes the intracellular toxin. 3. Chlorine is used for post filtration reduction of any extracellular toxins that could be present. Alum and Chlorine costs are normal and cannot be tied directly to algae presence.[a]	NA	NA	$18,000[a]	All, as with all normal treatment costs
Defiance WTP, Ohio (U.S.)	1. Counts, typing, taste and odor compounds 2. Toxin testing as well as QPCR	1. PAK-27 2. Copper sulfate on the reservoir 3. PAC	$39,000	$53,000	$46,000	$46,000
Kelleys Island, Ohio (U.S.)	1. qPCR 2. Microcystin testing	Carbon	$2,500	$8,000	$3,000	$3,000
Marblehead WTP, Ohio (U.S.)	1. Microcystin testing	PAC	NA	NA	NA	NA

Table F-3, Continued.

Public Water Supplier	Tests Conducted Because of Algae	How Does the Plant Treat Algae	Minimum Annual Cost for Treatment	Maximum Annual Cost for Treatment	Average Annual Cost of Treatment	Annual Cost Passed to Consumer
Windsor Utilities Commission, Ontario Canada	1. Monitor - Ontario has worked with all municipal drinking water systems that take water from the Great Lakes to ensure testing of both the intake and treated water for blue-green algae weekly during peak algae season. Working closely with public health units, municipalities and other partners, we provide data to help inform decisions about taking action to protect public health. 2. Analytical laboratory services **-** If a harmful algal bloom is suspected, samples are submitted to laboratories licensed for analytical testing of total microcystin and microcystin-LR (a common blue-green algae toxin).	Ozone, chemically assisted filtration	$2,564,284 ($3,430,000 Canadian Dollars)	$2,571,738 ($3,450,000 Canadian Dollars)	$2,564,198 ($3,440,000 Canadian Dollars)	100%

Notes:

a. From the plant manager: “Quite honestly, we cannot tie a cost directly to PAC either. This is complicated by the fact that we have never had a confirmed microcystin incident at any of our four water plants. As a result, it is difficult to say we fed more [PACs] because of HABs. However, I tried to estimate the increase in PAC usage during the "HAB" season for us of July, August, and September. During this time period, we spent an extra $18,000 on PAC versus the months of May, June, October, and November. This was adjusted for increased water pumpage by determining a PAC dose per million gallons per day differential between the HAB season and non-HAB season dose”

Seven plants have completed a capital project related to algae, with costs totaling over $81.2 million (Table F-4). Ozone projects are the most expensive capital project—Toledo paid $53 million for its ozone facility and the City of Oregon paid $15 million.

Table F-4. Public Water Plant Survey Results-Capital Projects for Algae Costs

Public Water Supplier	Does the Plant Have a Capital Project for Algae?	Type of Project	Estimated Cost of Project	Estimated Annual Cost Passed to Consumer
Big Island Water Works Sandusky[b]	2 completed in 2017	1. Permanganate feed to intake 2. PAC silo feed system	$400,000 and $2,200,000	Paid with budget and WSRLA loan
Huron Water Plant	Yes	Acid feed, Tube Settlers, Sludge Rakes	$2,100,000	As of this time $0 due to no rate increase, we are however anticipating rate increases for 2020, likely in the 3% range
City of Monroe	Yes, in 2017	Cyanotoxin Automated Array System (CAAS)	$35,000	$35,000
City of Oregon	Yes	Ozone, Biofiltration	$15,000,000	$180/household
City of Toledo	Yes	Ozone Treatment Facilities	$53,000,000	$2,956,000 annually to retire loans and bonds (Capital Improvement and technical services)
Cleveland Water (Baldwin, Crown, Morgan, and Nottingham plants)	No	NA	NA	NA
Defiance Water Treatment Plant	Yes	Granular activated carbon	$8,500,000	Unknown due to uncertainty about terms of finance
Kelleys Island[a]	Yes	Second Carbon feed point	$8,000	0
Marblehead water treatment plant	No	NA	NA	NA
Windsor Utilities Commission	No	NA	NA	NA

Notes

a. In 2018 the plant also spent about $10,000 on a HAB general plan.

a. The plant has also spent money (cost unknown) on a HAB general plan and water quality studies.

Canadian Water Treatment Plant Survey Results

Smith (2015) provides algal related costs for three Canadian water treatment plants—Union, Port Rowan, and Port Dover. The plants report that microcystin tests cost roughly $47.66 per test (2018$ USD) and they spend an average of $1,223 (2018$ USD) a year over and above normal testing costs. In addition, some plants have invested in equipment to allow for in-plant testing for microcystin to complement formal laboratory analysis, which costs on average $8,472 (2018$ USD) (Smith, 2015).

In the eastern basin, where the algae *Cladophora* is present, algal blooms impose additional infrastructure costs for plants because source water intake pipes need to be cleaned to remove algal biomass collecting in pipes. The two plants Smith (2015) surveyed in the eastern basin reported higher average expenditures of about $0.63 (2018$ USD) per cubic metre of treated water capacity for pipe cleaning and plants expect these costs to rise by 50% if blooms worsen in the future (Smith, 2015).

The survey found that the most significant costs reported by the plants were associated with water treatment when algal blooms were present. Annual increases in operating costs for granular activated carbon (to remove impurities that lead to problems with color, taste, and odor) was $0.72 (2018$ USD) per cubic metre of treated water capacity, increasing to $0.95 per cubic metre if HABs worsen in intensity. The costs for backwashing filters (to remove algal biomass) ranges between $6.07 and $7.07 (2018$ USD).

If blooms worsen, annual fixed costs for western and central basin plants would increase, ranging from $2,859 (2018$ USD) for large plants (treating over 29.4 million gallons per day) to $2,875 (2018$ USD) for medium sized plants (treating less than 29.4 million gallons per day). In the eastern basin, fixed costs would increase by $2,891 per plant (2018$ USD). Incremental annual operating costs would also increase per gallon of rated plant capacity: $1.14 (2018$ USD) for large plants in the western basin, $1.99 (2018$ USD) for medium plants in the western basin, and $2.84 (2018$ USD) for eastern basin plants.

All three respondents indicated that they have, and expect to make, new capital and operating expenditures if HABs continue to worsen. The two eastern basin plants have each made investments ($3,971- 2018$ USD) in new capital infrastructure to support filter backwashing and investments ($39,713- 2018$ USD) in pH control systems. The Port Rowan plant has invested $67,511 (2018$ USD) in an improved system to remove taste and odor problems arising from *Cladophora*. The western basin plant is planning a $3.2 million-dollar investment (2018$ USD), with a $59,569 (2018$ USD) annual operating cost, to install a dissolved oxygen floatation system. The Port Rowan plant plans to invest $158,850 in its system to improve taste and odor if *Cladophora* worsens.

Calculations

Estimating Annual Costs for U.S. Water Treatment Plants

There are 31 public water suppliers that draw water from Lake Erie in the U.S. and our survey indicates that the basin the plant is located in heavily influences differences in algae-related treatment costs (Table F-5). Average costs related to monitoring and treatment at U.S. water treatment plants in the western basin are $38,150 a year[40] for medium-sized plants (treating less than 29.3 million gallons a day) and $552,000 a year[41] for large plants (treating more than 29.3 million gallons a day). Because we did not receive any results from medium-sized plants in the central basin, we use the estimate from Smith (2015) that medium-sized plants incur an average additional operating cost of $111,532[42] a year due to algae. Results from our survey indicate that annual costs for large plants in the central basin are $63,000 a year. We did not receive any survey responses from eastern basin treatment systems, large[43] or medium, and therefore assume that all costs for eastern basin plants reflect the estimates derived by Smith (2015), $54,370.

Table F-5. Average Algae Related Cost Estimates for Public Water Suppliers by Basin and by System Size

Basin	Size	Annual Cost Estimate (2018$ USD)	Notes
Western	Medium	$38,150	Estimate from survey responses
Western	Large	$552,000	Estimate from survey responses
Central	Medium	$111,532	Estimate derived from Smith (2015)
Central	Large	$63,000	Estimate from survey responses
Eastern	Medium	$54,370	Estimate derived from Smith (2015)
Eastern	Large	$54,370	Estimate derived from Smith (2015)

To estimate costs for plants not surveyed, we assume that each plant will incur costs equal to the annual cost estimates established in Table 24, by basin and plant size.[44] In the western basin, the 13 plants (12 medium and one large plant), incur annual costs of $933,500 (2018$ USD).[45] The ten central basin plants (nine medium plants and one large plant) will incur incremental annual operating costs

[40] The estimate does not include the results from the Defiance Water Treatment Plant. The respondent indicated that the system sources water from the Maumee River via their upground reservoir, not directly from Lake Erie's surface waters.

[41] This estimate does not include the survey response from Windsor Utilities Commission in Ontario. The respondent indicated that the systems sources water from the Detroit River, not directly from Lake Erie's surface waters.

[42] Two plants, the Chatham and South Chatham Kent system (two plants sharing one intake) and the Elgin system, used in the Canadian average treat over 24 million gallons a day, which could be driving the high cost for medium-sized plants in the central basin. This average is also only for Canadian plants as we did not receive any survey responses from central basin plants treating less than 29.3 million gallons a day.

[43] Erie City Water Authority is the only large plant in the eastern basin. Smith (2015) did not provide estimates for additional operating costs for large plants, and we therefore conservatively assume that medium and large plants in the eastern basin incur the same cost.

[44] For plants that responded to our survey, we use their reported cost estimates rather than the annual average cost estimates presented in Table 24.

[45] The Marblehead Village plant and the Oregon City plant indicated in the survey that they have no algae-treatment related costs. We did not include any cost estimates for these two plants.

$1.1 million (2018$ USD). The eight eastern basin plants would incur total annual costs of $434,960 (2018$ USD).[46] In total, U.S. plants sourcing water from Lake Erie incur total annual operating costs related to algae of $2.4 million.

Estimating Annual Costs for Canadian Water Treatment Plants

Smith (2015) identified 12 Canadian water treatment plants that source water from Lake Erie, including five medium-sized plants in the eastern basin, four medium-sized plants in the central basin, two medium-sized plants in the western basin, and one large plant in the western basin (See Table 20 for plant information). They surveyed three Canadian plants and the respondents indicated that they would incur incremental annual operating costs (fixed and variable) if blooms worsen. In the western and central basins, fixed costs for large plants would increase by $3,812 (2018$ USD) and by $3,834 (2018$ USD) for medium-sized plants. Fixed costs for medium-sized plants in the eastern basin would increase by $3,855 (2018$ USD).[47] Variable costs would also increase, by dollars per gallon of rated plant capacity, at a rate of $1.52 (2018$ USD) for large plants in the western and central basins, $2.66 (2018$ USD) for medium plants in the western and central basins, and $3.78 (2018$) USD for eastern basin plants.

If blooms worsen, the 12 plants would incur additional annual operating (fixed and variable) costs of $889,778 (2018$ USD). The three plants in the western basin would incur additional operating costs of $171,803, with an average annual cost of $57,268 per plant.[48] For the four plants in the central basin, annual operating costs would total $446,126, with an average annual cost of $111,532 per plant. The five plants in the eastern basin would incur total annual operating costs of $271,848, and an average annual cost of $54,370 per plant.

Limitations

Future analyses should aim to incorporate more updated survey data for U.S. medium-sized central basin plants and both large and medium-sized U.S. eastern basin plants. Heather Raymond, the Ohio EPA State HAB specialist, indicated in personal communication with us that there will be an updated survey on algae-related costs to public water suppliers. That information should be used in future studies as a more accurate estimate of costs to medium-sized central basin plants. Because we also received no responses from any eastern basin plants, we used the cost estimates defined by Smith

[46] Without data on treatment capacity for the Bluewater Beach Campground and Pines motel, we classify the two systems as medium-sized plants because of the small number of people served. Although these two plants serve the smallest populations compared to other plants in the analysis, we presume that ascribing medium cost estimates to these two plants does not result in an overestimate of total costs as large eastern basin plants are also ascribed the same cost estimate. We assume that the three large plants in the eastern basin may incur more treatment costs associated with algae compared to medium sized plants, but the lack of survey data does not allow us to differentiate between the differing costs of medium and large eastern basin plants.

[47] The estimate did not differentiate between medium and large plants because there are only medium plants in the Canadian eastern basin.

[48] The two medium-sized plants in the western basin would incur total annual costs of $26,448 (2018$ USD) and an average annual cost of $13,224 (2018$ USD). The large western basin plant would incur total annual costs of $145,355 (2018$ USD).

(2015), which only examines medium-sized eastern basin plants. We recommend another survey that specifically targets eastern basin plants, especially on the U.S. side, as the main algae (*Cladophora)* imposes a different set of treatment and monitoring costs compared to the blue-green algae dominant in the western basin.