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The Costs of Aquatic Invasive Species to Great Lakes States

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Executive Summary

The purpose of this report is to analyze the economic impact of existing Aquatic Invasive Species (AIS) on businesses and households in Great Lakes states. We explore the economic impact of AIS from two perspectives. First, we examine the existing evidence of AIS-related costs to households and businesses. Second, we identify the set of industries most directly affected by AIS in the region and quantify their size.

Overall, we find that AIS disrupt economic activity on a large scale in each of the Great Lakes states. AIS impose real costs on industries, consumers, and governments. Costs to individual companies and households include direct expenditures on combating an invasive species or repairing the damage it has done, and include indirect costs such as reduced productivity and higher prices in industries particularly affected by AIS. Governments and private actors such as nonprofits also devote significant resources to addressing AIS.The industries most acutely affected by AIS include sport and commercial fishing, water treatment, power generation, industrial facilities using surface water, and tourism. Together, these industries employ over 125,000 workers in the Great Lakes region.

While comprehensive cost estimates (including all industries, species, and waterways of the Great Lakes region) are not available, there are many individual estimates focusing on part of the problem. These cost estimates range from millions of dollars in cost and lost output for individual large industrial and power facilities to hundreds of dollars annually spent by individual households to control AIS on their property. It is likely that the overall aggregate level of cost to the Great Lakes region is significantly over $100 million annually.

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I. Introduction and Summary of Findings

For as long as there have been ecosystems there have been outside species introduced into them. Sometimes, these new species significantly disrupt the population balance of native species in the ecosystem. The runaway success stories of newly introduced species are often called "invasive species," though this term is not rigorously defined and is used differently by different people. While there is a case to be made that *any* ecosystem disruption has the potential to cause harm in the future, we consider this definition too broad for this paper. Instead we use another common definition, applying the term "invasive" to introduced species that have harmful effects on things humans find useful, such as logging, recreational boating, or catching commercially valuable fish.[1]

This report focuses on *aquatic* invasive species (AIS), which are organisms that affect water-based ecosystems in particular. More specifically, this report is about AIS in the Great Lakes. The first known AIS detected in the Great Lakes was sea lamprey, which arrived in the 1830s and continues to be a problem today.[2] Since then, over 180 AIS have invaded the Great Lakes, including both plants and animals. Invasive species, including aquatic invasive species, often impose economic damage on businesses and households.

The Great Lakes are interconnected and share the same water. Because of this, AIS present in Michigan's waters may eventually spread to New York's. As a result, there are AIS initiatives underway by both government and private actors, acting at the local, state, and federal levels. Millions of taxpayer dollars at the federal and state levels go toward programs to help prevent and manage AIS problems in the Great Lakes. Businesses and households also act to fight AIS on their own property using their own resources.

PURPOSE

The purpose of this report is to analyze the economic impact of AIS currently present in the region on businesses and households in Great Lakes states.

OVERVIEW OF APPROACH

We explore the economic impact of AIS from two perspectives. First, we examine the existing evidence of AIS-related costs to households and businesses. Second, we identify and quantify the size of the set of industries most directly affected by AIS in the region.

1. This definition is similar to how many use the term "nuisance species."
2. Sea lamprey are parasites that often prey on commercially significant fish. These organisms are attributed as a major cause of the collapse of lake trout, white fish, and chub populations in the Great Lakes during the 1940s and 1950s.

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Reviewing Evidence of AIS-Related Costs

As of this report's release date there were no rigorous studies quantifying the economic impact of all AIS on the entire Great Lakes region.[3] Existing studies of costs to households and businesses typically isolate one part of the picture, such as the impact of one species, or the effect on one industry. As a result, we are essentially trying to estimate the size of a forest using detailed studies of individual trees. Our approach is to identify existing high-quality research quantifying costs to businesses and households, then put them into their proper context, noting what types of costs are quantified by existing studies, and what types of costs are not. In the case of expenditures by government and private conservation groups (which are ultimately funded by businesses and households), we were able to identify specific examples of expenditures.

Taken together, this wide range of information makes use of the few specific, credible studies to provide an overall sense of the economic costs of AIS in the Great Lakes region.

Quantifying Size of Industries Most Directly Affected

We quantified the size of the existing industries that are most directly affected by AIS. We identified these industries by noting their presence in studies quantifying the cost of AIS. We then collected data on the size of these industries from several sources, including our own GIS facility, that allowed us to estimate the number of firms and workers in certain industries within a given distance of the Great Lakes. We also relied on other sources such as water quality officials from Great Lakes states that track water use by industrial water users on the region's lakes.

Limitations

The sheer volume of AIS and the variety of costs they impose on households and business prevent all-encompassing estimates of their damage. Existing research quantifying the effects of AIS focuses on a small handful of high-quality studies. There are many costs that we know exist and that impact people and industries, but for which we do not have specific or accurate estimates of their value. Even within the 19 high-quality studies quantifying impacts of AIS in the Great Lakes region, most of the information was aggregated from the same eight original studies.

Another limitation is our ability to identify the specific firms affected by AIS. While our research allowed us to define industries that are most affected, knowing the specific firms that actually incur costs was not within the scope of this project.

3. See "Methodology and Exhibits" on page 30.

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SUMMARY OF FINDINGS

1. AIS in the Great Lakes impose economic damage on households and businesses on a large scale.

Existing research on the economic costs imposed by AIS is sparse. The majority of studies quantify costs based on a handful of high-quality surveys of businesses in specific geographic areas. Despite the dearth of large scale original research, the cost examples that do exist are startling, as shown in Table 1 below.

TABLE 1. Selected Costs Imposed by AIS on Industry and Households

Industry Affected	Cost Examples
All Industries	* $29.6 million annual cost aquaculture and aquatic-related industries in the Great Lakes * $34 million annual cost of control and research by the Great Lakes Fishery Commission
Sport and Commercial Fishing	* $18 million Great Lakes Fishery Commission sea lamprey control program. * $3.9 - $7.1 million annual benefit to anglers in the St. Mary's river system of a sea lamprey control program using sterile male release and lampricide.
Power Generation	* $1.2 million annual cost for one power plant to monitor and control zebra mussels * $1.7 million annual cost for researching better control methods for zebra mussels
Industrial Facilities	* $1.97 million to remove 400 yd^3 of zebra mussels from one Lake Michigan paper plant * $144,000 - $685,000 annual cost to monitor zebra mussels at an industrial facility
Water Treatment	* $480,000 - $540,000 annual cost of zebra mussel control for water treatment plant * $353,000 annual cost of zebra mussel control for municipal water treatment facility
Households	* $210 cost of filtration system installation per lake-shore homeowner requiring system * $1,040 - $26,000 cost per acre of water milfoil removal

Sources: See Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34 and Exhibit 3, "Studies that Estimate the Total Economic Impact of Existing Aquatic Invasive Species," on page 35.

Analysis: Anderson Economic Group, LLC

Such examples of existing high-quality estimates show that AIS-imposed costs come from many species, affect households and many industries, operate on industry- and region-wide scales, and come in many direct and indirect forms. The costs imposed by AIS now present in the Great Lakes region are clearly large. While we cannot provide a single number for the total cost imposed by AIS, it is likely that the overall aggregate level of cost to the Great Lakes region is significantly over $100 million annually.[4]

4. This order-of-magnitude estimate is the result of our professional judgement based on the few available large scale cost estimates found in the literature (see Exhibit 3 on page 35) and the size of the industries most affected by AIS (Exhibit 5 on page 47). Also see "Limitations" on page 3 for further discussion of the challenges of providing an aggregate economic cost estimate.

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2. *We have identified five categories of costs to businesses and households. Existing high-quality studies provide examples in only three of the five categories.*

We have identified five main categories in which households and industries face costs due to AIS, including both direct and indirect costs. Table 2 below defines these five categories and reports the number of high-quality studies we found providing examples of each. For government expenditures we contacted federal, state, and local government agencies to compile additional cost data that could not be found in high-quality studies.

TABLE 2. Categories of Costs Imposed By AIS

Cost Category	Definition	Number of Published High-Quality Studies Providing Examples in Cost Category	Additional Data Sources
Direct Operating Costs	Payments made due to AIS infestations that show up on a business's income statement.	8	-
Indirect Operating Costs	High prices for consumers and industries that are a result of other industry's direct operating costs.	0	-
Decreased Productivity Costs	Occurs when an industry cannot perform to its full potential because of an AIS infestation.	0	-
Reduced Demand Costs	Can be caused by AIS when an infestation limits the availability or desirability of an industry's products or services.	1	-
Government Expenditures	Taxpayer dollars used to aide households and businesses with the burden of AIS imposed costs.	3	Expenditure data from Federal, State, and Local Government Agencies

Analysis: Anderson Economic Group, LLC

We discuss the cost categories and the specific studies we examined in detailed exhibits at the end of this paper:

- Exhibit 1, "Description of the Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 33 provides many hypothetical examples of costs affecting businesses and households.
- Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34.
- Exhibit 3, "Studies that Estimate the Total Economic Impact of Existing Aquatic Invasive Species," on page 35 show available quantified cost estimates.

One under-appreciated cost category is government expenditures. There are wide-reaching efforts by public and private actors to manage the costs imposed by AIS. Such activities include AIS species research, engaging

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in AIS control and management, and educating the public. Without this hard work other AIS-related costs to industries, households, and governments would likely be higher. Below in Table 3, we show an estimate of some of the expenditures made specifically to address AIS within each Great Lakes state.[5]

TABLE 3. State Expenditures on AIS Years 2009 and 2010

State	State Funds	Non-Great Lakes Restoration Initiative Federal Funds	State Expenditures on AIS [a]
Indiana	$1,677,166	$94,725	$1,771,891
Illinois	$571,487	$2,831,961	$3,403,448
Michigan	$2,280,000	$846,250	$3,126,250
Minnesota	$7,700,000	$69,000	$7,769,000
New York	$2,206,100	$34,677	$2,240,777
Ohio	$34,668	$58,064	$92,732
Pennsylvania	$284,947	$70,132	$355,079
Wisconsin	$12,000,000	$70,000	$12,070,000
TOTALS	**$26,754,368**	**$4,074,809**	**$30,829,177**

Source: Author's estimates based on review of partial and incomplete data from Michigan DEQ, New York DEC, U.S. Fish and Wildlife Service.

a. This is not the total amount of money states spent on AIS in 2009 and 2010; we were unable to procure GLRI funding for all states, which would increase AIS related expenditures.

3. The industries which feel the impact of AIS most acutely have a large presence in each Great Lakes state.

While the entire Great Lakes economy is affected in some way either directly or indirectly by AIS there are six main industries that bear the majority of AIS-related costs. To determine these industry categories we noted which types of facilities and operations are most frequently studied in other research and mentioned in discussions of the effects of AIS.

We then grouped these specific instances together into industry categories:[6]

5. Note that the regional total only includes what each state specifically indicates it uses for AIS; is not a comprehensive picture of spending by the states, and the data available at the time of original publication is incomplete. Many state agencies and departments do not separate spending for AIS and other environmental expenditures. For example, the New York Bureau of Fisheries estimates that it spends at least 10% of its staff time on AIS related issues, which translates into more than $350,000 annually.

6. We discuss the methodology used to identify which facilities are likely affected by AIS in "Appendix A: Methodology and Exhibits" on page 30.

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- Sport and commercial fishing
- Power generation
- Industrial facilities
- Shipping-related businesses
- Tourism and recreation
- Public water supply intakes

These industries employ over 125,000 in the Great Lakes. Table 4 below shows the employment, sales volume, water usage, and number of firms and facilities we identified. It also highlights selected examples of the breadth of AIS impacted industries in each Great Lakes state.

TABLE 4. AIS-Affected Industries in Great Lakes States

		Aggregate Estimates for Six Industries Most Affected By AIS[a]			
Great Lakes State	**AIS-Affected Industries With Most Facilities In State**	**Number of Facilities**	**Employment**	**Total Sales Volume 2010 (millions of U.S. Dollars)**	**Annual Great Lakes Water Use[b] (millions of gallons)**
Illinois	Tourism, Sport and Commercial Fishing, Power Generation	2,449	30,831	$8,853	749,365
Indiana	Shipping, Power Generation, Industrial Facilities	616	4,280	$1,102	702,738
Michigan	Power Generation, Industrial Facilities, Tourism, Sport and Commercial Fishing	3,495	29,381	$11,987	2,796,731
Minnesota	Sport and Commercial Fishing, Tourism	798	5,136	$1,259	95,785
New York	Shipping, Power Generation, Sport and Commercial Fishing	2,213	16,454	$6,755	2,042,281
Ohio	Sport and Commercial Fishing, Power Generation, Tourism	1,759	19,490	$4,469	985,752
Pennsylvania	Industrial Facilities, Shipping, Tourism	302	2,687	$989	13,472
Wisconsin	Sport and Commercial Fishing, Tourism, Shipping, Power Generation	1,766	17,502	$6,532	1,689,170

Note: Employment and firm data from 2010. Water use data from 2008.
Source: ESRI Inc.; Indiana DNR, Michigan DEQ, Minnesota DNR, New York DEC, Ohio DNR, Wisconsin DNR, Great Lakes Commission 2008 Annual Water Use Report

Analysis: Anderson Economic Group, LLC

a. For each group, we used our GIS system with data from ESRI, Inc. to estimate total sales revenues of and employment in the industry. Where available, we used state-collected data on water use for industries that have water intake pipes directly located in the Great Lakes or the Great Lakes watershed.

b. Annual water use includes water used by power generation plants, industrial facilities with intakes directly in the Great Lakes, and public water supply.

For more details see "Costs to Industries and Households" on page 9. For specific locations of businesses affected see Maps 1-6 in "Appendix A: Methodology and Exhibits" on page 30.

4. *Costs imposed by existing AIS gives a sense of what could be avoided for possible future infestations by successful prevention efforts.*

In addition to managing current efforts to eradicate, control, or adapt to existing AIS, Great Lakes region residents must consider the potential value of efforts to prevent future infestations of AIS that have not yet taken hold. This presents a challenge: no one knows for sure which species will pose the next threat, how it will interact with the existing ecosystem, or how much (if at all) it will disrupt economic activity in the region. The research in this report, though focused on the impact of *existing* AIS, provides important information to the discussion of forward-looking policy. This is because the economic impact of AIS *currently* present in the region shows the scale of the effect AIS can have on the Great Lakes region. Having a sense of the costs AIS are currently imposing, as well as the size of the most vulnerable industries, shows the scale of what is at stake: increased costs, potentially millions of dollars annually, for industries employing thousands of workers across the region.

ABOUT ANDERSON ECONOMIC GROUP

Anderson Economic Group, LLC offers research and consulting in economics, finance, market analysis, and public policy. Since AEG's founding in 1996, the company has helped clients including universities, state and local governments, non-profit organizations, and private and public companies. For more information on the report's authors, please see "Appendix B: About AEG" on page 49.

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II. Costs to Industries and Households

AIS imposed costs are not only environmental in nature. Business and households share in the burden created by AIS in the Great Lakes. These costs are high not only because AIS are difficult to manage once an infestation has occurred, but because the Great Lakes are so large and affect such a large economically interconnected region. The water from the Great Lakes provides many cities and towns with fresh drinking water. It is used by industry for manufacturing and for power generation. It is also one of the main attractions for recreational activities in the Great Lakes region.

AIS infestations negatively impact the vital center of the Great Lakes region. AIS impose monetary costs to businesses and households that frequently result in large expenditures that could be avoided if AIS were not present. In this section we describe the breadth of Great Lakes water use by industries and households, define the categories of costs imposed by AIS, and then discuss each affected industry in-depth.

WATER USE IN THE GREAT LAKES

Businesses and households make extensive use of water from the Great Lakes. Power plants along the shoreline of the Great Lakes, their tributaries, and connected in-land lakes use the water to safely produce power for the region. Niagara falls relies on the Great Lakes to supply power to a large part of the Northeastern United States. Industrial facilities use the water for production. Hundreds of municipalities across the region depend on the Great Lakes basin to bring fresh water to their communities. Sport and commercial fishing companies make use of the great bounty of fish in the lakes. The tourism and recreation industries rely on the lakes for customers and sight-seers year-round.

One way to estimate the importance of the water is to measure how much water is used. 18% of the world's fresh surface water and 90% of the fresh water in the United States is found in the Great Lakes. Combined, the Great Lakes hold 5,500 trillion gallons of water.[7] Many Great Lakes states collect annual data on water use in the Great Lakes basin. Each year, power plants, industrial facilities, and public water suppliers use over 9.1 trillion gallons of water from the Great Lakes basin. Table 5 on page 10 shows water use from each Great Lakes state where such data is collected. Power generation uses by far the most water and the majority of this water is released back into the lakes. The second largest water use category is public water supply consuming more than 1.3 trillion gallons of Great Lakes basin water per year.

7. EPA, Great Lakes Factsheet No.1, http://www.epa.gov/glnpo/atlas/gl-fact1.html.

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TABLE 5. Annual Water Use in Great Lakes States (millions of gallons)[a]

Great Lakes States	Public Water Supply	Power Generation Facilities	Industrial Facilities	Total Water Use
Indiana	5,772	242,535	501,058	749,365
Illinois[b]	348,996	346,615	7,158	702,738
Michigan	285,434	2,415,766	95,531	2,796,731
Minnesota	1,064	83,822	10,899	95,785
New York	394,859	1,646,596	826	2,042,281
Ohio	182,843	752,280	50,629	985,752
Pennsylvania[c]	10,987	-	2,486	13,472
Wisconsin[d]	109,015	1,221,323	358,832	1,689,170
Total	1,338,939	6,708,937	1,027,419	9,075,294

Data: Indiana DNR, Michigan DEQ, Minnesota DNR, New York DEC, Ohio DNR, Wisconsin DNR, Great Lakes Commission 2008 Annual Water Use Report

Analysis: Anderson Economic Group, LLC

a. All data are 2009 or 2010 use collected by state DNR or DEQ unless otherwise noted.

b. Illinois data are from 2008 collected by the Great Lakes Commission

c. Pennsylvania data are from 2008 collected by the Great Lakes Commission

d. Wisconsin public water supply use data are 2008 values collected by the Great Lakes Commission. Power generation use data are 2008 data and industrial facility data are from 2010 collected by the Wisconsin DNR.

Water used by the sport and commercial fishing industry as well as tourism and recreation-based businesses is hard to estimate. Both of these industries rely on the existence of the Great Lakes. Sport and commercial fishing rely on the bounty that the lakes support, and tourism and recreation use all aspects of the water and surrounded land. It would be impossible to estimate their use in gallons however we can estimate how large each industry is and what types of costs they face because of AIS. In the next section we will discuss the different categories of costs that AIS impose on businesses and households. After a discussion of cost categories we describe in depth how AIS affect each of the above mentioned industries.

CATEGORIES OF AIS-CREATED COSTS TO INDUSTRY AND HOUSEHOLDS

Costs imposed by AIS are diverse. Some costs are directly measurable while others are more difficult to estimate even though we know they exist. Exhibit 1, "Description of the Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 33 gives a detailed list of cost examples by industry. This exhibit shows possible costs that businesses and households must bear because of AIS. These costs can take the following forms:

- **Direct Operating Costs.** AIS cause costs requiring regular, direct expenditures by companies and households. These costs can take the form of having to take maintenance-type actions, perform routine procedures to comply with current laws, and fixing damaged infrastructure. Examples of these actions may include industrial facilities scraping mollusks off of water intake and irrigation pipes, ships changing how they exchange ballast water, and purchasing chemicals to treat AIS. There is an additional sub-category of operating costs that must also be considered: indirect operating costs. An indirect operating cost occurs when an industry has a direct cost due to AIS and a portion of that cost is pushed onto consumers. This increases the customer's operating costs. For example, when power generation becomes costly energy prices rise across the board, or when a particular fish species is low in supply the cost to purchase that fish at the market increases.
- **Decreased Productivity.** In addition to the expenditures needed to deal directly with AIS, productivity overall can be affected in several ways. For example, commercial fisheries may have lower productivity if fish stocks are affected by competition from an invasive species that is not as valuable a catch. Pipeline systems at water treatment plants or energy generation plants can become clogged reducing their output level and production abilities. Other productivity costs include decreased revenue and profits because production is low due to time away from general operations cleaning pipes, reprocessing fouled water, or repairing infrastructure damages.
- **Reduced Demand.** Reduced demand can come in many forms. In some cases, industries may have fewer customers than they otherwise would due to AIS. The demand for their products or the demand to enter the industry in general is lower than what it otherwise would be if AIS were not a problem. Examples include sport fishing companies affected by fish stocks competing with AIS where the catch of fish is simply not large enough to attract customers, and tourism and hospitality industries affected by changes to scenery and water use due to an invasive plant. Also impacted, but less easy to quantify are those not entering a business at all because there simply is not a large enough market due to AIS infestations. Worst off are businesses forced to close because of AIS. A beach that is chronically covered with rotting algae and dead fish or a lake that is unusable due to aquatic weeds could cause a business reliant on tourism to see a reduction in demand that threatens its viability.

We provide more examples of costs to industries in Exhibit 1, "Description of the Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 33. These focus on the industries identified and discussed in the next section, "Industries likely to be affected by AIS" on page 12.

In the following section we discuss each industry affected by AIS and the costs that each bear. Where possible, we give monetary examples of costs to industry due to AIS. Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34 shows the high-quality examples we found in existing research.

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INDUSTRIES LIKELY TO BE AFFECTED BY AIS

We describe some examples of how AIS affects the Great Lakes in "Categories of AIS-Created Costs to Industry and Households" on page 10 and this section individually discusses each impacted entity. This is important because each industry that is affected by AIS infestations has different costs and repercussions. The industries we identify are not only those directly located on or using the Great Lakes. The entire Great Lakes basin is affected. We will discuss each affected industry as defined by our research, discuss specific ways in which the industry is affected, and give a monetary example of costs that have been estimated to date.

Sport and Commercial Fishing

The sport and commercial fishing industry is of great importance to the Great Lakes region. As the largest body of fresh water in the world the Great Lakes is home to many species of fish and other aquatic beings that are of high economic value. This industry stretches widely across the Great Lakes region. Even though fisheries and the lakes themselves are in confined areas, many companies manufacture equipment, which sport fishers may purchase all across the Great Lakes states. Not only are the sport fishing companies and fisheries affected by AIS infestations directly, but manufacturers and retailers supplying the industry are also impacted.

Fish populations can be severely affected by many factors, including human activity and natural disasters; AIS infestations often increase stress on fish populations in a way that can cause or exacerbate such crashes. Fisheries in the Great Lakes have experienced multiple fish population crashes since the first invasive species, sea lamprey, was first found in the 1830s in Lake Ontario.[8] Since then, many once prominent and economically valuable fish have completely disappeared or have declined in population. Lake trout, sturgeon, and lake herring are three examples. Lake trout can now only naturally spawn in Lake Superior, while in the past they were prevalent in all Great Lakes. Two other economically important species of fish, blue pike, and Lake Ontario Atlantic salmon, are now believed to be extinct due to lack of food and competition with other predator fish.[9]

Other species of economically valuable fish have replaced those that have become extinct. Nevertheless, in the past century, fish harvests have declined in the Great Lakes. Fish catches once measured at 147 million pounds per year in the late 1800s. Since the 1950s they now weigh in at 110 million pounds annually, a significant decline.[10] This is over a period in which fish catches should have increased due to both increased

8. Indiana Department of Natural Resources, *History of Lake Michigan Fisheries*, Michigan City, Indiana.
9. EPA, The Great Lakes: Environmental Atlas and Resource Book, epa.gov/glnpo/atlas. 2011

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demand, as the (human) population has grown, and improved technology that should enable larger catches. The declining catches are thought to be due to a combination of over-fishing, declining food at key points on the food chain, and the presence of AIS.

The sport and commercial fishing industry as a whole employs over ten thousand people in the Great Lakes and brings in revenues of $3.4 billion each year. See Map 1, "Identified Great Lakes U.S. Sport and Commercial Fishing Related Businesses," on page 41 for the locations of businesses affected by AIS in the Great Lakes region.[11] AIS affect fishing directly by competing with native species for food and space. If a non-native invasive species reproduces quickly and has no predators, for example asian carp, they are more likely to compete with and deplete the stock of economically valuable native species. For the fishing industry the direct effect of lower fishing stocks is the greatest cost to bear. The industry is also affected by other AIS, such as mollusks and aquatic weeds. Zebra mussels must be scraped off of boats and docks and aquatic weeds can cause shallow waters to become impassable to boats and clog engines.

Sea lamprey is a nuisance to fisherman and have been around since they were first found in the 1830s. They are an eel-like creature that prey on fish by attaching themselves like a leech. They severely reduce the fish population and there have been efforts from releasing sterile-male sea lampry into the lakes to poisoning the waters where they spawn. As a result, many control measures are taken (typically by or coordinated through the Great Lakes Fishery Commission) to reduce the population. Chemicals and other substances are applied to the water to keep fish populations safe.

One way to estimate the cost of lower fish stocks is the benefit received from efforts to keep them higher through controlling AIS. An econometric study of three types of sea lamprey control measures in the St. Mary's River estimated the benefits to anglers to be between $3.9 million and $7.1 million each year in the St Mary's River. Another study estimates the benefits of controlling European Ruffe between $146.4 million and $1.3 billion annually.[12] Additional estimates of costs to the sport and commer-

10. EPA, The Great Lakes: Environmental Atlas and Resource Book, epa.gov/glnpo/atlas. 2011

11. Note that a portion of Pennsylvania and New York have been excluded from this analysis while the complete state areas of the six other Great Lakes states are included. This is because residents and businesses in these two states have access to the ocean and the Great Lakes. In an attempt to isolate industry within the Great Lakes region, we excluded portions of each of these states that are have closer access to the ocean versus the Great Lakes. This certainly may exclude some activities of residents and commerce among businesses within the Great Lakes that happen to reside in the areas not included. Due to these factors, our estimates for total employment and revenues should be considered very conservative.

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cial fishing industry can be found in Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34.

Power Generation

Power generation seems like an unlikely industry to be affected directly by AIS, however many power generation facilities have water intake pipes required for production that sit in the Great Lakes. Power generation is the largest user of Great Lakes water in the region. Almost 7 trillion gallons of water are used annually by the power generation industry. These plants provide energy to millions of residents through coal, natural gas, petroleum, hydroelectric, and nuclear power. Water is used for cooling in each plant's operations and is necessary for safety. Water is also used for actual power generation at places such as Niagara Falls which provides power to a large portion of the Northeast United States.

As shown in Map 2, "Available Locations of U.S. Power Generation Facilities in the Great Lakes Watershed," on page 42, there are more than 100 power plants located directly on the lakes. For safe operations and effective cooling techniques, these plants must have water pipelines clear of obstructions. Mollusks, for example asian clams and zebra mussels, colonize any solid mass in waters they infest. Often, pipelines for power plants become clogged due to these invasive creatures.

The most direct cost to the power industry comes from controlling and monitoring mollusks that attach themselves to water intake pipes. Infestations of mollusks can clog intake pipes causing power generation facilities to stop production in order to clean the pipes before operations continue. Zebra mussels, for example, have become such a problem for power generation that in 1989 the Detroit Edison plant in Monroe, Michigan, the largest fossil-fuel plant in the world, had to shut down operations for three days to clean their pipes, which cut off power to the surrounding area.[13]

One group of researchers surveyed power plants in Ontario and found that each plant spends approximately $1.2 million each year for monitoring and controlling zebra mussels. Approximately $1.7 million is spent by the industry each year on research for more effective methods of controlling and monitoring zebra mussels.[14]

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12. For Sea Lamprey estimates see Lupi, Hoehn, and Christie 2003. For European Ruffe estimates see Leigh 1998. For this and all further citations of specific papers, see full citations in Exhibit 3 on page 35.
13. See Park, H. and Hushak, L. 1999.
14. For costs to the power generation industry due to zebra mussels, see Colautti et al. 2004.

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Industrial Facilities Including Shipping

Many industrial facilities are affected by AIS. These facilities include but are not limited to manufacturing plants with water intake pipes, manufacturers of ships and shipping supplies, and industrial shipping and vessel transport companies. According to our analysis of firms located in Great Lakes states, the shipping industry alone employs approximately 8,660 people throughout the Great Lakes states and generates revenues of over $1.7 billion annually.[15] For the locations of shipping-related businesses, see Map 3, "Identified U.S. Shipping Industry Business Locations in Great Lakes States," on page 43.

The industrial base in the Great Lakes relies heavily on the water. The steel industry has a large presence in the area because of the natural resources available such as iron ore, coal, and limestone. The lakes are used to transport the ore from the Upper Peninsula of Michigan and northern Minnesota to integrated steel mills in Indiana, Michigan, Ohio, and Pennsylvania. Shipping is also a large economic driver in the Great Lakes that relies on the water. Grain is transported on the lakes along with iron ore, coal, and limestone. Economic decline, change in the structure of global industry, and other factors have reduced the number of ships and the tonnage of cargo transported on the Great Lakes in recent decades.[16]

Industrial facilities that have water intake pipes located in the Great Lakes use over one trillion gallons of water annually. These facilities are likely affected by AIS infestations because of their proximity to the lakes and likelihood of having water intake pipes in the Great Lakes and Great Lakes basin. They face similar issues as power generation plants, such as removing mollusks from their pipes. For the locations of businesses that have intakes in the Great Lakes basin, see Map 4, "Available Locations of U.S. Industrial Facilities in the Great Lakes Watershed," on page 44.

The specific cost examples we found for industrial facilities are generally for zebra mussels because their affects tend to be the most visible. It was reported to the U.S. Geological Survey in 1997 that a paper company on Lake Michigan had spent $1.97 million removing 400 cubic yards of zebra mussels from its structures. Other researchers who surveyed water using facilities in the Great Lakes found that for zebra mussel monitoring and control, each year the average medium sized industrial facility spent around $144,000 and the average large facility spent almost $700,000. Other costs such as re-outfitting plants and re-building infrastructure have

15. One other study, which uses a much broader definition of the industry, including rail and trucking workers, and which does not use a method comparable to our location-based analysis, finds over 44,000 workers in US states. See "The Economic Impacts of the Great Lakes - St. Lawrence Seaway System" published by Martin and Associates in 2011.

16. Fact and timing of decline from AEG analysis of Lake Carriers Association annual statistics.

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not yet been measured but they too represent large costs to industry. For a full listing of cost estimates to industrial facilities see Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34.

Tourism and Recreation

The largest industry that is affected by AIS in the Great Lakes is tourism and recreation. The counties that border the Great Lakes shores, which are home to many recreational sites and attractions for tourists, employ 90,000 people and have revenues of $30.3 billion per year.[17] Tourism-related businesses within only a half-mile of the Great Lakes shoreline generated about $800,000 in annual revenues and employ almost 6,000 people.[18] See Map 5, "Identified U.S. Tourism-Related Sites, Organizations, and Businesses near the Great Lakes," on page 45.

AIS imposes multiple costs onto the tourism and recreation industry. They range from actual monitoring and control costs, to lost revenues from tourists not coming to the lakeshore because of aquatic weeds and fouled beaches. The latter hitting restaurant and retail businesses that rely on lake-bound tourists each year the hardest.

There are some interesting affects of AIS. For example, while zebra mussels and other mollusks clean water and make it clearer, this encourages weed growth. These weeds often wash up on the shores of Great Lakes beaches along with dead mussel shells rendering the beaches very unpleasant and almost unusable. Rotting seaweed is very difficult to remove from beaches as well. Unfortunately, there are not many estimates of monetary costs available for this industry. Two that do exist focus solely on water millfoil removal. It can cost around $26,000 for the required equipment and between $1,040 and $26,000 for the actual removal.[19] Other major costs have yet to be estimated despite the economic importance of this industry.

Water Treatment

The Great Lakes are the largest bodies of fresh water in the world and one of the most important natural resources to the eight surrounding states, which is why water treatment is such an important industry to the region. Almost 400 municipalities use Great Lakes water for their public water supply taking in over 1.3 trillion gallons each year. Map 5, "Industries in

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17. Estimate is based on AEG identified entities. See Map 5, "Identified U.S. Tourism-Related Sites, Organizations, and Businesses near the Great Lakes," in Appendix for locations of tourism-related entities.

18. Estimate is based on AEG identified entities. See Map 5, "Identified U.S. Tourism-Related Sites, Organizations, and Businesses near the Great Lakes," in Appendix for locations of tourism-related entities.

19. See Zhang and Boyle 2010.

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Great Lakes States," on page 47 shows the locations of municipalities that rely on the Great Lakes basin for their water supply.

The costs to public water facilities affect both governments and businesses. Many municipalities locate water treatment plants and intakes on the Great Lakes, as do private water companies. The city of Windsor, Ontario spends between $480,000 and $540,000 per year on direct maintenance due to zebra mussels.[20] Another estimate places the cost of controlling quagga mussels at $4,650 for an infested facility each year.[21] Additional cost estimates can be found in Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34.

The costs incurred by water treatment are similar to that for power generation and industrial facilities. Similar to ship fouling, water pipes can also become fouled by mollusks.[22] This creates the need for more removal, development of control technology, and more frequent water purification than would otherwise be necessary.

Households

Households bear many costs associated with AIS presence and infestation in the Great Lakes. Households are affected by AIS in multiple ways, but in general, because they are not production oriented businesses, household costs fall into two categories; indirect operating costs and reduced demand. The most prevalent problems for households with lake-front property are milfoil and mollusks. Examples of indirect operating costs include waterfront property residents needing to physically remove weeds or mollusks from their shoreline. For example, in Ontario, lakefront cottage owners have spent $210 per cottage to install a filtration system to combat the presence of quagga mussels.[23] Additional indirect costs include increased household water and energy costs, which are being passed along from water treatment and energy plants that are affected by the presence of AIS.

Lakefront property may experience a decline in demand due to AIS infestations, such as aquatic weeds, which make beaches aesthetically unappealing or unusable. These same weeds can make swimming difficult and create areas that are impassable by motor boats. Removing invasive weeds, such as millfoil can range from $1,040-$26,000.[24]All of these fac-

20. See Colautti et al. 2004.

21. Ibid.

22. When mollusks attach themselves to the hull of a ship or inside of a pipe, this is called "fouling."

23. Ibid. Quagga mussels have similar effects as zebra mussels.

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tors can contribute to a decline in property values for these types of households.

Aggregated Cost Estimates

Few researchers have attempted to come up with aggregate cost estimates for the affects of AIS. These range from government budget appropriations to aggregations of research on damages due to AIS infestations. For example, in 1999, the state of Michigan appropriated $4.2 million specifically for control, eradication, prevention, and education related to AIS, but this was only a portion of the nearly $6 million in appropriations for invasive species in general.[25]

The U.S. Fish and Wildlife Service recently collected data from each Great Lakes State on state and federal expenditures on AIS in each Great Lakes state between 2009 and 2010. Exhibit 6, "Government Expenditures on AIS Control, Monitoring, and Prevention in Great Lakes States," on page 48 shows these estimates. Other studies show that costs are much higher than what the government budget states. A 1999 survey of Great Lakes water users estimates the control costs of zebra mussels at about $40.5 million annually.[26] The Great Lakes Fishery Commission has spent approximately $34 million each year on research and control of AIS. Another study in 2004 reports that Great Lakes businesses suffer $50 million every year in losses and reduced demand simply due to mollusks and sea lamprey.[27]

See Exhibit 3, "Studies that Estimate the Total Economic Impact of Existing Aquatic Invasive Species," on page 35 for details on studies that attempt to aggregate costs. For a complete list of referenced studies as well as those we examined but chose not to use see Exhibit 4, "Aggregated List of Consulted Cost Research Studies," on page 36.

24. Cost estimate for milfoil involve the actual per-acre removal charges as well as the necessary equipment. See Zhang and Boyle 2010.

25. See U. S. GAO 2000.

26. See Park and Hushak 1999.

27. See Colautti et al. 2004.

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III.Existing AIS Initiatives Come At A Cost

The Great Lakes region is extensive, encompassing a large area of the U.S. across eight states. AIS infestations in the region affects not only the Great Lakes states but all others that have integrated economies with the those states. As previously discussed in "Costs to Industries and Households", dealing with existing AIS invasions comes at a cost. There are many ongoing initiatives trying to address these costs and the spread of AIS in the Great Lakes. While we have not attempted to comprehensively catalogue these efforts, we discuss the types of existing initiatives and the range of activities they engage in to give a picture of what is being done to combat existing AIS in the Great Lakes.

LEVELS OF RESPONSE TO AIS

There are many ways of responding to the threat of AIS invasions. The appropriate response depends on the information available and the costs and benefits of each action. The three broad categories of action are:

1. **Prevention**: Prevention comes before an invasion occurs and is perceived as less costly than eradicating an existing AIS.[28] To be proactive, some countries, such as New Zealand and Australia, employ risk-assessment framework to identify potential invasive species. All flora and fauna that could potentially show up in these countries due to trade or other means are given a risk-assessment to see their level of infestation and interaction with current ecosystem versus whether or not they would be beneficial to the economy. [29]
2. **Rapid-Response**: Rapid-response can prevent a small-scale infestation from expanding out of control if enough properly-targeted resources are used at the right places early in an infestation. It is very difficult to use rapid-response if a species is caught too late and has already established itself in an area. Many states in the Great Lakes have rapid-response offices and initiatives. For example, New York State has a rapid-response office employing two people. However, the majority of their efforts go toward terrestrial plants rather than AIS.
3. **Monitoring and Control**: The majority of existing initiatives are at this level. Once an infestation has spread enough that it is not practically eradicable, resources go toward minimizing further geographic spread and managing the costs and practical challenges posed by the infestation. Most regulations and laws associated with AIS control fall into this category. The majority of costs discussed in the previous section, "Costs to Industries and Households" on page 9, focus on monitoring and control.

28. Source: National Oceanic and Atmospheric Administration

29. Based on these assessments, countries may limit trade involving sea transportation to protect their ecosystems from infestations, which can be a barrier to trade. Many cite this as the reason why the U.S. has not passed more strongest regulations. Springborm Romagoa, Keller, "The Value of Nonindigenous Species Risk Assessment in International Trade, Ecological Economics, June 2011.

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All of the existing initiatives discussed in the following section fall into one of the above categories. However, it is important to note that the majority, if not all, of the existing initiatives in the fight against AIS are those that monitor and control current invasions.

Combatting AIS

Existing initiatives to combat AIS, though often necessary and carried out with great dedication, are sometimes limited in their impact due to some of the following factors:

- Each species is unique and needs to be dealt with in a particular way. This has spurred many organizations to be particularly devoted to one specific species of invasive aquatics. Many of these organizations engage in research efforts to better understand that AIS, as well as control and eradication activity.
- Most efforts are restricted by boundaries.
  The majority of organizations work within their own jurisdictions. Whether they are geographically bounded or hindered by politics, wandering outside these parameters is beyond their ability. Additionally, resources available to organizations can limit their ability to be widereaching. By contrast, AIS are not hindered from travelling from state to state and even country to country.
- Most initiatives primarily engage in monitoring and controlling AIS.
  It is often easier to motivate people when a problem is present. The possibility of invasive species is not as threatening or inspiring as seeing the evidence, which is why many efforts to combat AIS are reactive. Many organizations control what they see and try to limit the damage, which only addresses existing AIS. This can be the most challenging way to address the problem.[30]

Each of these factors indicates an overall lack of coordination to address the pervasive problem of AIS within the Great Lakes region. As we describe existing AIS initiatives, it becomes apparent that, despite the interconnectedness of the region's ecosystems, most states have pursued their own stand-alone AIS programs that are not primarily focused on inter-state coordination. Those efforts that are coordinated are often too broadly focused. Of the many federal agencies and task forces devoted to water conservation and other environmental efforts, few exclusively focus on AIS.

Existing AIS Initiatives

Combatting aquatic invasive species in the Great Lakes has become a ubiquitous effort by both public and private entities. Each organization's scope and access to resources dictate the type of activities they participate in.

30. See "Levels of Response to AIS" on page 19 and "Avoiding AIS Related Costs" on page 29.

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Most initiatives are responsive, rather than preventative- they are formed and/or react to existing AIS rather that trying to prevent future invasions. Some examples of these activities include:

- Creating AIS Policy and Regulations

  Activists and policy-makers continue to try to control aquatic invasive species through legislation that regulates certain operations within industries associated with spreading AIS. These regulations impose costs to hinder certain actions of businesses and individuals. We further discuss the impact legislation and existing policies have in "Costs of AIS Regulation" on page 24.

- Research

  Scientists are conducting experiments and research to better understand the biology of invasive species and their effects on ecosystems. Using this knowledge they hope to minimize the spread of AIS, develop methods to safely control AIS populations, as well as create tools for ecosystem restoration. Companies impacted by AIS often devote resources to developing better management methods to address the problem.

- Controlling and Managing AIS

  These two activities are ongoing and require physical action. To control an AIS, initial intensive activity is necessary to minimize, and, when possible, remove infestations. Following those efforts, consistent monitoring and suppression activities are necessary to ward off additional outbreaks or re-infestation in areas previously focused on.

- Education and Outreach

  In general, AIS is not a widely discussed topic and many people are unaware that their own behavior may assist in its spread. This has spurred agencies, organizations, and individuals to create pamphlets, fliers, and other educational materials to distribute to the public, to promote and protect activities and industries threatened by AIS. We show an example of a common type of outreach to the right. This sticker in particular can be seen on recreational boats throughout the Great Lakes.[31]

Each of these activities diverts the time, effort and resources of people throughout the Great Lakes. Local and regional entities, along with the U.S. and Canadian governments, which include eight states and two provincial governments, are working towards combatting existing aquatic invasive species. These and other entities are discussed below.

31. This sticker is part of a public awareness campaign by the Aquatic Nuisance Species Task Force, which is sponsored by the U.S. Fish and Wildlife Service. It encourages others to do their part in preventing the further spread of AIS. Many people are unaware of the negative effects AIS "hitchhikers" can have; they can reduce game fish populations, ruin boat engines, and make lakes unusable by boaters and swimmers.

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Federal Efforts

Several federal agencies are actively involved in AIS efforts, including the President's office, the Department of State, U.S. Forest Service, U.S. Fish and Wildlife Service, National Park Service, and U.S. Coast Guard. Many of these efforts are coordinated with other agencies such as the Environmental Protection Agency (EPA). Most of these efforts include funding research, creating and enforcing policy, as well as providing outreach to the public. Some agencies, such as the National Park Service, and the U.S. Fish and Wildlife Service participate in control and management activities. However, not all of these coordinated efforts focus on AIS specifically. More often than not controlling AIS is paired with water preservation and other conservation efforts.

Regional Government Cooperatives

The EPA and nine other federal agencies administer some 140 programs that fund and implement environmental programs in the Great Lakes basin. Some of these programs include AIS, although few focus solely on this issue and action to prevent further problems has not always been coordinated. To address this, President George W. Bush created a cabinet-level interagency task force to call for a "regional collaboration of national significance" in May 2004.[32] After extensive discussions, the following organizations and groups moved to convene and create the Great Lakes Regional Collaboration:

- Federal Great Lakes Interagency Task Force
- Council of Great Lakes Governors
- Great Lakes St. Lawrence Cities Initiative
- Great Lakes Indian Fish and Wildlife Commission, which represents the Great Lakes Tribes
- Great Lakes Congressional Task Force

The GLRC is both a federal and state initiative that is a cooperative and wide-ranging effort. Their goal is to design and implement a strategy to restore, protect and sustain the Great Lakes. There are other regional public entities engaged in combatting AIS, such as the Great Lakes Panel on Aquatic Nuisance Species, which develops monitoring and early detection methods for AIS. The panel also creates prevention, control policy, and management documents for policymakers, although it is unclear how and if these recommendations are implemented.[33]

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32. This interagency taskforce was created by Executive Order 13340. Source: www.glrc.us.com.

33. AEG found several reports and presentations at conferences about recommendations and methods of preventative activities, but did not find documentation of ongoing programs implementing these activities.

State Initiatives

Each state varies in the extent of their involvement in AIS programs and activities. Michigan, Pennsylvania, and Indiana have the largest range of activities, participating in everything from research and control efforts to regulation and outreach.[34] However, Table 6 indicates that Wisconsin has spent the most on AIS recently.[35] Each state varies in its support for AIS, some with more stable funding than others. The sources of stable funding each Great Lake state has in common includes the following to combat AIS:

- U.S. Fish and Wildlife Service
  Each state receives $30,000 annually if they have an approved AIS management strategy.
- Great Lakes Restoration Initiative Fund
  This funding is distributed by the EPA to improve stakeholders ability to combat chemical and biological pollution. A small portion of the $60 million for invasive species is used by states to combat AIS.[36]

TABLE 6. State Expenditures on AIS Years 2009 and 2010

State	State Funds	Non-Great Lakes Restoration Initiative Federal Funds	State Expenditures on AIS
Indiana	$1,677,166	$94,725	$1,771,891
Michigan	$2,280,000	$846,250	$3,126,250
Minnesota	$7,700,000	$69,000	$7,769,000
New York	$2,206,100	$34,677	$2,240,777
Pennsylvania	$284,947	$70,132	$355,079
Wisconsin	$12,000,000	$70,000	$12,070,000
Ohio	$34,668.00	$58,064.00	$92,732
Illinois	$571,487	$2,831,961	$3,403,448
TOTALS	$26,754,368	$4,074,809	$30,829,177

Note: State expenditures on AIS make up only part of the overall regional effort on AIS. A full picture would include other sources, including expenditures by the Great Lakes Restoration Initiative.

Source: Author's estimates based on review of partial and incomplete data from Michigan DEQ, New York DEC, U.S. Fish and Wildlife Service.

34. See Great Lakes Regional Collaboration, "Appendix A. Aquatic Invasive Species Strategy Team Implementation Actions and Milestones," October 2005.
35. Table 6 indicates that spending on AIS is an extremely small portion of a state's budget (especially over two years). However, it is also not a comprehensive look at state spending on AIS, as several states do not provide budget items to that level of detail.
36. Due to the asian carp problem in the Great Lakes, $13 million of this funding was specifically earmarked to address this issue.

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When a state lacks a dedicated stream of funding, often initiatives at a state level become very specific. This is because without dedicated funding, initiatives cannot plan as well for the future. Additionally, the state legislature has control over what state-wide measures can be taken and regulations passed, which forces initiatives to take place on a smaller level and generally engage in monitoring and control activities. Even states that have a steady stream of funding are engaging primarily in piecemeal initiatives. Such as New York, which only is performing early detection and risk assessments for terrestrial plants, and having two people employed in their rapid-response office, despite being one of the largest states in the U.S.

Non-profits and Other Associations

Environmental and conservation organizations frequently find partners in business, industry, and citizen associations who share similar concerns over AIS. Many of these efforts rely on government grants and volunteers. Sharing the goal of eradicating a specifically threatening AIS encourages local cooperation for control and management. However, many of these efforts are confined to relatively small land parcels. For example, the Nature Conservancy and the Land O' Lakes Fish and Game Club collaborated to dig up invasive plants, but were limited to nine acres. Underlying reasons that these and other efforts are limited can include intense labor requirements, high cost, and geographic jurisdiction.

COSTS OF AIS REGULATION

As discussed in "Existing AIS Initiatives" on page 20, there are numerous public and private efforts currently underway, which engage in a range of activities that provide benefits and sometimes impose costs. One activity in particular, AIS related regulation, disrupts economic activity by imposing additional costs on industries who do business in the Great Lakes. Nevertheless, these regulations may be beneficial on net if the AIS-related harm they prevent outweighs the cost of the regulation.

The potential costs of AIS-related regulations include creating perverse incentives, and having high compliance costs. In this section we discuss some of the difficulties that entities face to comply with current requirements, the additional costs that can result, and other unintended consequences. Specific features of AIS regulation that can increase these costs include:

- Lacking a consistent definition for AIS
- Enforceability issues that lead to avoidance
- Costs to businesses to understand and comply with AIS-related regulation
- Unintended consequences, such as lawsuits

Federal and state laws that specify certain practices to prevent the spread of AIS do not always share a consistent definition for what an AIS is. This

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can cause disagreement and confusion for parties expected to abide by regulations, as well as the legal taskforce assigned to enforce them. The federal government and the Great Lakes states are not yet unified in this respect, which would help alleviate discrepancies between state and federal legislation.[37]

Regulation pertaining to AIS can be difficult to agree upon, enact, and enforce. For example, one of the most common forms of spreading AIS is ballast water, which is taken in or discharged by nearly every commercial ship in the world (see right).[38] While regulating ballast water is "enforceable" in the sense that each ship could be addressed as it enters the Great Lakes, agreeing on a standard and enacting laws funding enforcement has taken time, long past when ballast water was recognized as a source of AIS.[39] Additionally, there are exceptions for ship safety and the penalties for failing to meet set standards can be weighed against other business considerations.[40]

Another regulation that is difficult to enforce is the Lacey Act. This act prohibits the import or transport of "injurious" species, including their eggs or hybrids of the species by imposing a fine. In March of this year, bighead carp, which have been in the news recently, were added to the federal list of injurious wildlife, joining several other AIS that are affected by this act.[41] This act has modest penalties ranging from fines of $5,000 per individual to larger sums and even jail time, depending on what results from breaking this law. For example, it is not always obvious who would be at fault for transporting an injurious species, such as carp, which makes it difficult to punish. Litigation often results from the diffi-

37. Note that Michigan's legislature is currently discussing SB510 (2011), which would coordinate the definition of AIS in both federal and state laws.

38. Ballast water is taken into or discharged from a ship when it loads (or unloads) cargo in order to accommodate the change in weight. The EPA estimates that 30% of invasive species were introduced into the Great Lakes through ballast water. See www.epa.gov.

39. See the Clean Boating Act of 2008 and the National Pollutant Discharge Elimination system, in place since 2008.

40. According to the U.S. Coast Guard, ballast water management "shall not jeopardize the safety of the vessel, its crew, or its passengers", although only the "minimal amount" should be dispensed for necessary operations. Penalties for failure to comply with ballast water requirements are a maximum fine of $27,500 per day and a Class C felony for willful violators. See http://www.uscg.mil/hq/cg5/cg522/cg5224/ans.asp.

41. Other AIS included on the U.S. Fisheries and Habitat Conservation list are black carp, silver carp, zebra mussels, and salonids. See http://www.fws.gov/fisheries/ans/ANSInjurious.cfm.

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culty of finding who is responsible for AIS introductions, which we further discuss in "AIS-Related Litigation" on page 26.

Another problem with regulation is consistency; court rulings and regulation do not always find matching counterparts beyond U.S. borders. For international companies, learning the differences in AIS requirements depending on what water boundaries they travel in could be confusing and costly to keep up with. Currently, the U.S. prohibits ballast water exchange in U.S. economic borders, among other requirements under federal law, but it has not signed an international agreement sponsored by the International Maritime Organization, which would regulate ballast water in the rest of the world.[42] This agreement will come into force when 30 countries and 35% of the world merchant shipping tonnage have agreed to participate. France, Sweden and the U.S. are among the majority that have not signed this agreement, while Canada has done so.[43]

Our current level of regulation and enforcement has both costs and benefits, and further regulation could provide increased protection that reduces AIS-related costs, which can be weighed against other costs of regulation. Furthermore, issues related to enforcement and the level of protection can result in lawsuits, which we discuss below.

AIS-RELATED LITIGATION

In the absence of more direct and effective means of managing and preventing AIS infestations, lawsuits have been used by governments and private actors as a tool of both prevention and cost recovery. Attempting to resolve a problem in court can be an expensive and lengthy process. While lawsuits allow for damages to be collected, they do not in fact solve problems caused by AIS nor cover the costs they impose on future companies and individuals. One example is a lawsuit filed in 1999 that took seven years to complete. Environmental groups filed a complaint against the EPA and were joined by the states of Illinois, New York, Michigan, Minnesota, Pennsylvania, and Wisconsin in 2005. This lawsuit was aimed at commercial ships to mandate ballast water treatment in an effort to control the spread of AIS.[44] The result was a court decision

42. Signatories of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) are expected to carry a ballast water record book and carry out certain ballast water management procedures. See International Maritime Organization website, http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships'-Ballast-Water-and-Sediments-(BWM).aspx.

43. Although this particular piece of legislation does not impact the Great Lakes directly because it is considered to be within the U.S.' economic borders, it touches upon a similar problem in the Great Lakes; to what extent does someone become liable for the spread of AIS across water? Additionally, it would not hurt the Great Lakes for their regulations to be in agreement with Canada, which is the U.S.' largest trade partner. See the U.S. Census "Top Ten Countries with which the U.S. Trades".

44. This regulation was discussed in "Costs of AIS Regulation" on page 24.

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requiring the EPA to develop a permit system that regulates the discharge from ships and boats of certain sizes.[45]

Meanwhile, governments began taking private companies to court for failing to comply with regulation to control the spread of AIS. In October of 2003, Carnival Cruise Line paid $200,000 in administrative fees to settle with the California State Lands Commission regarding the state's requirements for dispersing ballast water. Shortly thereafter, cruiseliners Holland America, Princess, and Royal Caribbean settled out of court by agreeing to adhere to the state's mandates and spend $75,000 to research alternative ballast water management methods.[46] State mandates do not always result in immediate compliance and sometimes additional lawsuits ensue.

This was the case for Michigan after they enacted a law requiring ocean-going vessels to obtain a permit from Michigan's Department of Environmental Quality, if they were to engage in port operations. In response, the privately owned shipping company based in Montreal, Fednav Limited, along with a coalition of shipping companies and trade groups took legal action.[47]To add to the litigation frenzy, some of these same companies now face lawsuits prompted by conservation groups for other repeat violations in the Great Lakes.

One of the most recent AIS related lawsuits in the Great Lakes is between the U.S. Army Corps of Engineers, Metropolitan Water Reclamation District of Greater Chicago and the Great Lakes states over Asian carp (shown to the right).[48] Their large size and rapid reproduction rates pose a significant risk to ecosystems and they have been found in the Illinois River (which connects to the Mississippi River and in turn Lake Michigan). The states are pursuing a lawsuit a federal court against these federal and local government entities in response to how the invasion was handled. [49] Their complaint alleges when the defen-

45. Congress exempted recreational vessels from ballast water permitting requirements with the Clean Boating Act of 2008.

46. See "Judge Orders Carnival Cruise Line to Stop Illegal Dumping," San Francisco Call, April 11, 2003, accessed August 18, 2011. See also www.cruisejunkie.com/large-fines.html (last accessed August 28, 2011).

47. The legislation raised by the state was aimed at stopping the further introduction and spread of AIS. However for the private sector, it raised serious constitutional and water rights issues. See http://www.mied.uscourts.gov/Opinions/feikenspdf/fednav%20opinion.pdf.

48. Photo is courtesy of U.S. Fish and Wildlife Service and was found on the EPA's website; www.epa.gov/glnp/invasive/asiancarp.

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dant allowed Asian carp to invade waterways that connect to the Great Lakes, a "public nuisance" was created that threatens public resources.

The plaintiffs are requesting the "best available methods to block the passage of, capture or kill" the species be used and for agencies "to develop and implement plans to permanently and physically separate carp-infested waters in the Illinois River basin and the [Chicago Canal] from Lake Michigan".[50] This dispute has yet to be resolved, and at least $16 million has already been spent to try to combat this particular invasion. Below in Table 7 we show some spending that does not include litigation expenses, but has already taken place by state governments. [51]

TABLE 7. State Spending on Asian Carp Invasion, 2009 and 2010

State	State Funds	Non GLRI Funds	Total [a]
Indiana	$62,129	$16,734	$78,863
Michigan	$128,750	$80,000	$208,750
Minnesota	$168,000	$0	$168,000
New York	$250	$0	$250
Pennsylvania	$10,224	$2,019	$12,243
Wisconsin	$2,000	$0	$2,000
Ohio	$3,230.00	$0	$3,230
Illinois	$512,500	$2,700,000	$3,212,500
Totals	$887,083	$2,798,753	$3,685,836

Source: Michigan DEQ, New York DEC, U.S. Fish and Wildlife Service
Analysis: Anderson Economic Group, LLC

a. This total is not all inclusive. The News on Aquatic Invasive Species from the Great Lakes Commission reports $13 million in GLRI funds were spent in 2009 on emergency actions to prevent the spread of asian carp in the Great Lakes.

Throughout this paper, we have demonstrated the various ways that AIS impacts governments, businesses and taxpayers, as well as consume resources. AIS is imposing real costs onto the Great Lakes region, so to conclude, we discuss what costs would be diminished and resources regained by preventing additional AIS from entering its waters.

49. To prevent carp from entering the Great Lakes, the U.S. Army Corps of Engineers, EPA and several other agencies and organizations have been working to install and maintain a permanent electric barrier between the fish and Lake Michigan. This lawsuit brings into question the long term effectiveness of the fence.

50. See the Complaint for Injunction and Declaratory Relief by the State of Michigan, Wisconsin, Minnesota, Ohio and Commonwealth of Pennsylvania, United States District Court, Northern District of Illinois.

51. Estimated by adding the amount of state and non-GLRI funds spent ($3.6 million) with GLRI expenditures in 2009 (13 million).

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IV. Avoiding AIS Related Costs

The spread of AIS has impacted the Great Lakes in a multitude of ways. As demonstrated throughout this paper, AIS imposes costs that impact people and industries. We have provided examples of specific species and the types of costs that AIS can cause in the Great Lakes. As new AIS invade the Great Lakes, new costs will accrue, additional resources will be used, and new initiatives will be needed. Preventing the spread of new AIS into the Great Lakes would benefit each state given the following potentially avoidable costs:

- **Entities and initiatives would spend less time and resources focused on AIS**

  Even if we assume that all initiatives combatting AIS are currently necessary, our society is engaging in these activities at a cost. State governments are budgeting for these types of activities and task-forces. Initiatives currently devoted to AIS could be re-purposed towards other problems plaguing the Great Lakes. Shifting focus towards other causes might also be more effective given the complex nature of the current problem, which we discussed in "Levels of Response to AIS" on page 19.

- **Industries would not incur new AIS related costs**

  New AIS mean additional direct and indirect operating costs, reduced demand and decreased productivity in a variety of industries. The sport and commercial fishing industry, power generation, industrial facilities with water intakes, water treatment facilities and the tourism and recreation industry already are dealing with the impact of existing AIS in the Great Lakes. Allowing more AIS to accumulate would only increase the cost to do business in the Great Lakes.

- **Policymakers would see less need for new regulation**

  We cannot suppose that legislation regarding AIS would be repealed, but there certainly would be fewer regulations to adhere to than if AIS continued to invade the Great Lakes. If invasion continues, people would need to further contemplate the best way to regulate actions to minimize further spread and enact them. Additional resources would potentially be allocated for enforcing the new legislation. There would be companies required to follow these new guidelines, which would need to learn about the new laws and enact methods to comply with them. To do both requires time and resources. Lastly, there would potentially be fewer unintended consequences (i.e. lawsuits), if there were not new legislation to base complaints on.

Aquatic invasive species impose real costs both directly and indirectly on industries and consumers, as well as divert resources, stimulate initiatives and provide reasons to write regulation. Overall, AIS are able to disrupt economic activity on a large scale in each of the Great Lakes states.

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Appendix A.Methodology and Exhibits

In this section we describe our methodology for finding credible research on the costs related to AIS as well as our methods for defining industries that are affected by AIS. We took the following steps:

1. We surveyed the existing literature quantifying costs to Great Lakes region businesses and households, and identified the specific studies we found credible. (See "Criteria for Credible Sources" on page 30.) The credible studies we found providing examples of costs to businesses and households are cited in Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34. The complete list of studies we examined can be found in Exhibit 4, "Aggregated List of Consulted Cost Research Studies," on page 36.
2. From the credible studies we identified the main industries affected by AIS and the broad categories of costs due to AIS. We noted which of these costs could be quantified using existing high-quality research, and which are not quantifiable based on completed research.
3. We then collected information about specific industries affected by AIS in the Great Lakes region to provide a sense of the scale of economic activity that is at risk of disruption by AIS. During this process we identified the main types of economic costs associated with AIS.
4. We identified broad categories and specific examples of existing initiatives to reduce the harm imposed by AIS, including efforts at the regional, state, and local levels by governments and private actors such as businesses and environmental groups.

CRITERIA FOR CREDIBLE SOURCES

While researching the costs related to AIS we encountered many studies that discuss the topic. However, much of the current research is an aggregation of a few original studies. In order to choose specific studies to cite in this report we went through a careful review process. Each resource was read by at least two senior analysts or consultants and we used the following criteria to select cost estimates qualifying for citation in our report:

- The authors performed original research.
- The authors disclose their methodology and state assumptions.
- Empirical research appears to use a sound methodology such as surveying businesses about specifically defined actual costs.
- Model-based research appears to use sound assumptions.

Of the 19 government and academic studies we reviewed, we found eight that had credible estimates using the above criteria. There are many studies that aggregated cost estimates for AIS. Many of these studies were not used because we could not find original sources or methodology. While many of these studies may have been very well researched with sound methodology, the lack of publication of methods and sources prevented us

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from using many studies in this report. An example of this is a 1993 document from the Office of Technology Assessment.[52] This report cites many values for costs of AIS to business and households. However, upon looking at the footnotes for each cost estimate the original research either was done by an outside contractor and we were unable to identify the methodology, or the research itself was unavailable because the original source no longer exists or it was not published.

We contacted several researchers that were cited in aggregated studies in order to obtain their methodology if an original study was not publicly available. One such researcher we called informed us that the difficulties we faced were not surprising. This researcher has previously been contracted to perform a similar analysis in 2001 and found that the majority of research studies were aggregations of the same few original studies that existed. This conversation as well as our difficulties in finding original studies are evidence that this field needs considerably more original research on the costs imposed by AIS.

We recognize that there are studies that we did not review for this paper that may have been well carried out with accurate methods. The majority of research reviews are academic studies and government commissioned reports. There are many other reports from advocacy groups and other entities that were not consulted for this report because we could not find enough detail on methods or original sources. The assumptions we have made about the research cited and reviewed for this report come from what was publicly available at the time of writing.

Also, state-level data and data on specific industries are difficult to aggregate. Many states collect data on businesses that use Great Lakes water however their methods and resources differ greatly making it difficult to fully visualize and grasp the size of these industries.

INDUSTRY DEFINITIONS

Research on the costs of AIS to businesses tended to group industries affected by AIS by their own definitions. The industries we define in this report stem from those defined by researchers we have cited. We found the estimates for employment and sales revenues using our Geographic Information System (GIS). GIS estimates business locations, employment, and sales revenues using information from Infogroup which is updated annually.[53] Through GIS we were able to identify all businesses in a given geographic area that are identified by the U.S. Census using

52. Office of Technology Assessment, Harmful Non-Indigenous Species in the United States, September 1993.

53. Infogroup uses many sources to aggregate their information from the Securities and Exchange Commission to the U.S. Census. For more information on ESRI data using Infogroup see www.esri.com.

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specific NAICS codes. We provide the location of the businesses in the industries we've identified in the following maps:

- Map 1, "Identified Great Lakes U.S. Sport and Commercial Fishing Related Businesses," on page 41.
- Map 2, "Available Locations of U.S. Power Generation Facilities in the Great Lakes Watershed," on page 42.
- Map 3, "Identified U.S. Shipping Industry Business Locations in Great Lakes States," on page 43.
- Map 4, "Available Locations of U.S. Industrial Facilities in the Great Lakes Watershed," on page 44.
- Map 5, "Identified U.S. Tourism-Related Sites, Organizations, and Businesses near the Great Lakes," on page 45.
- Map 6, "Available Locations of U.S. Public Water Supply Intakes in the Great Lakes Watershed," on page 46

We took a two step process in defining the industry affected as well as the appropriate geographic area for analysis. First, we defined an industry using NAISCS codes that describe the businesses surveyed by researchers. For example, water treatment, sewage treatment, and waste-water treatment are all considered part of the water treatment industry. Any business with a NAICS code that had those key words in the description was considered part of the industry based on our definition. Next, we defined a geographic area for the parts of the industry that would be directly affected. To continue with the water treatment example, industrial facilities with water intake or outflow structures tend to locate two miles or closer to a body of water. Therefore, only businesses within the water treatment industry that were between zero and two miles from the Great Lakes shoreline were considered for analysis. Another example would be shipping-related businesses. Because ship building and other maintenance services are not necessarily confined to area long the water, we chose to include all shipping-related businesses in Great Lakes states.

DATA TABLES

In this section we include detailed data tables summarizing our assumptions, and the results of our analysis. These exhibits are:

- Exhibit 1, "Description of the Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 33.
- Exhibit 2, "Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes," on page 34.
- Exhibit 3, "Studies that Estimate the Total Economic Impact of Existing Aquatic Invasive Species," on page 35.
- Exhibit 4, "Aggregated List of Consulted Cost Research Studies," on page 36.
- Exhibit 5, "Industries in Great Lakes States," on page 47.
- Exhibit 6, "Government Expenditures on AIS Control, Monitoring, and Prevention in Great Lakes States," on page 48

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Exhibit 1: Description of the Costs of Existing Aquatic Invasive Species in the Great Lakes

	Affected Industry or Entity					
Type of Cost Incurred by Industry Due to AIS	**Sport and Commercial Fishing**	**Power Generation**	**Industrial Facilities**	**Tourism and Recreation**	**Water Treatment**	**Households**
Direct Operating Costs	• Purchasing Insurance • Purchasing Herbicide • Re-stocking Fish • Physically removing plants • Scraping mussels off of boats • Hiring workers to perform control and maintenance operations • Purchasing lampricide chemicals • Increased energy costs due to AIS-incurred costs in other industries	• Re-designing plants • Hiring workers to perform control and maintenance operations • Scraping mussels off of water pipes • Fixing damaged infrastructure • Purchasing mulluscicide chemicals • R&D for more cost effective control and removal techniques • Compliance costs with new regulations • Increased water costs due to AIS-incurred costs in other industries • Hiring workers to monitor the prevalence of AIS	• Re-designing plants • Fixing damaged infrastructure • Hiring workers to monitor prevalence of AIS • Hiring workers to perform control and maintenance operations • R&D for more cost effective control techniques • Compliance costs with new regulations on AIS policies • Scraping mussels off of water pipes • Increased energy and water costs due to AIS-incurred costs in other industries • Purchasing mulluscicide chemicals	• Purchasing Herbicide • Physically removing plants • Purchasing lampricide chemicals • Scraping mussels off of boats/docks • Purchasing mulluscicide chemicals • Removing algae from beaches • Increased energy and water costs due to AIS-incurred costs in other industries	• Re-designing plants • Scraping mussels off of water pipes • Re-treating fouled water • Fixing damaged infrastructure • Hiring workers to monitor the prevalence of AIS • Purchasing mulluscicide chemicals • Hiring workers to perform control and maintenance operations • Increased energy costs due to AIS-incurred costs in other industries	• Purchasing Herbicide • Physically removing plants • Scraping mussels off of boats/docks • Repairing damages docks, boats, shoreline • Removing algae from property • Increased energy and water costs due to AIS-incurred costs in other industries • Increased food prices due to low fish production and AIS-incurred operating costs in other industries
Decreased Productivity	• Decreased fish stock and decreased yield • Competition lowers stock of valuable species	• Clogged pipelines cause reduced intake for cooling water • Disrupted production due to control operations	• Shipping delays • Dense aquatic weeds make water impassable to ships • Ship fouling (residue from AIS) reduces ship speeds • Clogged pipelines cause reduced intake of water needed for the plant • Disrupted production due to AIS control operations	• Scenery and water value decreased, AIS lower the value of each site	• Clogged pipelines cause reduced intake and delivery • Disrupted production due to AIS control operations	
Reduced Demand	• Marina changes and closures do to un-navigable waters • Sport fishing draws a smaller crowd because yield is low and the activity is not as enticing			• Fewer visitors because scenery and water are ruined by AIS		• Land and property value decreased by AIS interfering with use

Note: Though we try to represent single net costs we recognize that some costs are substitutions rather than net costs (for example: shifting from fishing to hiking).Also, we recognize that some costs to the represented entities in the table are possible benefits to other entities. For example, the chemical companies that make herbicide and other AIS treatments benefit from the presence of AIS.

Analysis: Anderson Economic Group, LLC 2016

Exhibit 2: Studies Estimating the Direct Costs of Existing Aquatic Invasive Species in the Great Lakes

	Affected Industry or Entity					
Type of Cost Incurred by Industry Due to AIS	**Sport and Commercial Fishing**	**Power Generation**	**Industrial Facilities**	**Tourism and Recreation**	**Water Treatment**	**Households**
Cost to Single Entity	• $26,000 equipment for water milfoil removal per user [5] • $1,040-$26,000/acre water milfoil removal per shoreline owner [5] • $5.2 million bayluscide application to kill sea lamprey paid by Great Lakes Fishery Commission [2] • $1.5 million for 5-year rotation of trapping and sterile male release (sea lamprey) paid by Great Lakes Fishery Commission [3]	• $1.2 million monitoring and control costs of zebra mussels per Ontario power plant per year [13]	• $1.97 million removal of Zebra Mussels from 400 yds3 from one Lake Michigan Paper Company plant [10] • $144,000 medium size facility/plant/yr. monitoring & control (zebra mussels) [7] • $685,000 large size facility/plant/yr. monitoring & control (zebra mussels) [7]	• $26,000 equipment for water milfoil removal per user [5] • $1,040-$26,000/acre water milfoil removal per shoreline owner [5]	• $480,000-$540,000 per year for municipal water treatment facility in Windsor [11] • $131,000-$240,000 in 1993 monitoring and control per municipal water treatment plant (zebra mussels) [6] • $4,650 per infested facility per year for monitoring and control of quagga mussels [17]	• $26,000 equipment for water milfoil removal per user [5] • $1,040-$26,000/acre water milfoil removal per shoreline owner [5] • $355 per cottage owner for filtration system installation do to damage from quagga mussels [16]
Aggregate Costs	• $3.9-$7.1 million/yr. benefits from control (sea lamprey) [1] • $146.4 million-$1.3 billion benefits from control of Ruffe [4] • $18 million for Great Lakes Fishery Commission sea lamprey control program [20]	• $1.7 million/yr. Ontario Power Plants research costs (zebra mussels) [14]	• $81 million budget expenditures for AIS in 2006 from the St. Lawrence Seaway Management Corporation [18]	• Cannot find estimates	• $353,000/yr. Ontario Municipalities control costs (zebra mussels) [15]	• Cannot find estimates

Note: Number in bracket indicates source in Exhibit 4.

Analysis: Anderson Economic Group, LLC 2016

Exhibit 3: Studies that Estimate the Total Economic Impact of Existing AIS

Cost Estimate	Type of Cost and Entity Affected
$40.5 million annually	Monitoring and control costs to Great Lakes water users with water intake structures. [8]
$4.2 million	Michigan budget appropriations for AIS control. [9]
$29.6 million annually	Reduced demand in the Great Lakes, all industries, from mollusks and sea lamprey. [12]
$34 million annually	Control and research costs to Great Lakes Fishery Commission for all AIS. [15]

Sources: See Exhibit 4 for specific citations of studies. Number in bracket corresponds to studies in Exhibit 4.
Analysis: Anderson Economic Group, LLC 2016

Exhibit 4: Cost Research Studies

Type of Study	Industry/Entity Affected	Cost Category	Species	Monetary Value: Direct From Study	Monetary Value 2011 Dollars	Source	Ref #
Econometric model: travel cost method and random utility model	Fishing in Michigan (94-95 season) Lake Huron trout	Direct Operating Cost: Benefits of Control	Sea Lamprey	$3.2-$5.8 million/yr. (2003)	$3.94-$7.13 million/yr.	Lupi, Hoehn, Christie, Using an Economic Model of Recreational Fishing to Evaluate the Benefits of Sea Lamprey Control on the St. Marys River, Journal of Great Lakes Research 29, 2003	1
Econometric model: travel cost method and random utility model	Great Lake Fishery Commission	Bayluscide per application	Sea Lamprey	4.2 million (2003)	$5.2 million per application	Lupi, Hoehn, Christie 2003	2
Econometric model: travel cost method and random utility model	Great Lake Fishery Commission	Sterile male release and trapping	Sea Lamprey	1.5 million (2003) per 5 year rotation	$1.8 million for 5 year program	Lupi, Hoehn, Christie 2003	3
Econometric model	Great Lakes commercial and sport fishing	Direct Operating Cost: Benefits of Control	European Ruffe	$119 million-$1.05 billion cumulative (2003)	$146.4 million-$1.3 billion	Leigh, Benefits and Costs of the Ruffe Control Program for the Great Lakes Fishery, *Journal of Great Lakes Research 25* , 1998	4
Econometric model	Any lake	Direct Operating Cost: Removal costs	Eurasian Water milfoil	$20,000-$30,000 for removal equipment $1,000-$25,000 per acre for removal	Average $26,000 for removal equipment/ between $1,040- $26,000 per acre for removal	Zhang and Boyle, The effect of an aquatic invasive species (Eurasian watermilfoil) on lakefront property values, *Ecological Economics 70* , 2010	5
Survey	Municipal Water Treatment-GL	Direct Operating Cost: Monitoring and Control	Zebra Mussels	$84,000-$154,000 in 1993	$131,040-$240,240 in 1993 per plant	Park and Hushak, Zebra Mussel Control Costs in Surface Water Using Facilities, Ohio Sea Grant Program, 1999	6
Survey	Utility/Industry-GL	Direct Operating Cost: Monitoring and Control	Zebra Mussels	$92,000-medium $439,000-large (1993 average annual/per facility)	$143,520 medium facility/yr. $684,840/large facility/yr.	Park and Hushak 1999	7
Survey	Great Lakes water users with water intake structures	Direct Operating Cost: Monitoring and Control	Zebra Mussels	$30 million/year (1999)	$40.5 million/yr.	Park and Hushak 1999	8
Survey	Michigan	Direct Operating Cost	AIS	AIS $3.1 million 1999	$4.2 million in 1999 on AIS	GAO 2000	9
Survey	Paper Company on Lake Michigan	Direct Operating Costs: removal from 400 yards^3	Zebra Mussels	$1.4 million (1997)	$1.97 million	US Geological Survey, Zebra Mussels Are Spreading Rapidly, USGS News Release, September 18, 1997	10
Survey	Municipal Water Treatment-Windsor	Direct Operating Cost: Maintenance	Zebra Mussels	$400,000-$450,000/yr.	$480,000-$540,000/yr.	Colautti, Bailey, van Overdijk, Amundsen, MacIsaac, Characterized and projected costs of nonindigenous species in Canada, Biological Invasions, 2006	11
Survey	Great Lakes	Reduced Demand	Mollusks and Sea Lamprey	$32.3 million/yr. (2004 Can)	$29.6 million/yr.	Colautti et al 2006	12
Survey	Ontario Power Plants	Direct Operating Cost: Monitoring and Control	Zebra Mussels	$800,000/plant/yr. (Can)	$1.2 million/plant/yr.	Colautti et al 2006	13
Survey	Ontario Power Plants	Direct Operating Cost: Research	Zebra Mussels	$1,092,000 /yr. (Can)	$1.7 million/yr.	Colautti et al 2006	14

Analysis: Anderson Economic Group, LLC 2016

Exhibit 4 continued: Cost Research Studies

Type of Study	Industry/Entity Affected	Cost Category	Species	Monetary Value: Direct From Study	Monetary Value 2011 Dollars	Source	Ref #
Survey	Great Lakes Fishery Commission	Direct Operating Cost: Control and Research	Sea Lamprey	$22 million/yr. total $6 million paid by Canadian government. (Can)	$34 million/yr. total $9.3 million paid by Canada	Colautti et al 2006	15
Survey	Ontario Lake Cottages	Direct Operating Cost: Filtration system installation	Quagga Mussels	$229/cottage (2004 Can)	$210/cottage	Colautti et al 2006	16
Survey	Ontario Municipalities-GL	Direct Operating Cost: Monitoring and Control	Quagga Mussels	$3,000/infested facility/year (Can)	$4,650/infested facility/year	Colautti et al 2006	17
Survey	St Lawrence Seaway Management Corp	Budget	AIS	63.7 million Canadian 2006	$80.9 million	National Research Council, Great Lakes Shipping, Trade, and Aquatic Invasive Species, Transportation Research Board Special Report 291, 2008	18
Survey	Great Lake Fishery Commission's sea lamprey program	Sea Lamprey Control Program	Sea Lamprey	$17 million (2008)	$17.9 million	National Research Council	19
Estimates Not Used in Report							
Econometric model: original data not found	Great Lakes	Total Economic Cost	Zebra Mussels	$6.5 billion 1990-2000 (2003$)	$7.996 billion 1990-2000 or $799.6 million/yr.	U.S. Fish and Wildlife Estimate as found in Lovell, Stone, and Fernandez, The Economic Impacts of Aquatic Invasive Species: A Review of the Literature, Agricultural and Resource Economics Review, April 2006	20
Methodology Unknown	US. Canada water users	Total Economic Cost	Zebra Mussels	$5 billion 2000-2010	$655 million/yr.	GLSC fact sheet, Zebra Mussels Cause Economic and Ecological Problems in the Great Lakes 2000	21
original article not available	Recreational Benefits: All GL	Direct Operating Cost: Benefits of Control	Sea Lamprey	$2.1-$4.3 billion/yr. (2003)	$2.58-$5.23 billion/yr.	Great Lakes Fishery Commission as found in Lovell, Stone, and Fernandez	22
original article not available	Lake Erie Sport Fisheries	Direct Operating Cost: Estimated Losses	European Ruffe	$724 million 1985-1995 (2003)	$891 million from 1985-1995 or $89.1 million/yr.	Hushak as found in Lovell, Stone, and Fernandez	23
original article not available	125 Industrial facilities	Direct Operating Cost: Monitoring and Control	Zebra Mussels	$509,000 89'-94' (2003)	$125,214/yr.	Hushak as found in Lovell, Stone, and Fernandez	24
original article not available	Average Large water use	Direct Operating Cost: Monitoring and Control	Zebra Mussels	$400,000-$460,000/yr. (2003)	$492,000-$565,800/yr.	Reutter as found in Lovell, Stone, and Fernandez	25
Interview with industry scientists	Industry: intake pipes, water filtration equipment, and power plants	Direct Operating Cost: Damages	Zebra Mussels	$3.2 billion over 10 yrs. (2003$)	$3.94 billion over 10 yrs. or $394 million/yr.	Cataldo, "Musseling" in on the Ninth District economy, Fedgazette, Federal Reserve Bank of Minneapolis, 2001	226
Interview with industry scientists	Large ships in the GL	Direct Operating Cost: Damages and Losses	Zebra Mussels	$360,000 per ship/yr. (2001)	$460,800 per ship/yr.	Cataldo	27
Interview with industry scientists	Six Power plants in the UP	Direct Operating Cost: Maintenance	Zebra Mussels	$1 million (1993)	$1.56 million in 1993	Cataldo	28

Analysis: Anderson Economic Group, LLC 2016

Exhibit 4 continued: Cost Research Studies

Type of Study	Industry/Entity Affected	Cost Category	Species	Monetary Value: Direct From Study	Monetary Value 2011 Dollars	Source	Ref #
Interview with industry scientists	Wisconsin Power Plants/water utilities	Direct Operating Cost: Maintenance	Zebra Mussels	$250,000-$500,000 per plant/year (2001)	$320,000-$640,000 per plant/yr.	Cataldo	29
Review of Current Scholarly Literature	Total U.S. Costs	Direct Operating Cost: Damages and Losses	Aquatic Weeds	$10 million (2005)	$11.6 million	Pimentel, Zuniga, Morrison, Update on the environmental and economic costs associated with alien-invasive species in the United States, *Ecological Economics* , 2004	30
Review of Current Scholarly Literature	Total U.S. Costs	Direct Operating Cost: Control Cost	Aquatic Weeds	$100 million (2005)	$116 million	Pimentel et al, 2004 and Office of Technology Assessment, Harmful Non-Indigenous Species in the United States, 1993	31
Review of Current Scholarly Literature	Total U.S. Costs	Direct Operating Cost: Damages and Losses	Exotic Fish	$5.4 billion (2005)	$626.4 billion	Pimentel et al, 2004	32
Review of Current Scholarly Literature	Total U.S. Costs	Direct Operating Cost: Damages and Control	Zebra Mussels	$1 billion (2005)	$1.16 billion	OTA 1993 and Army Corp of Engineers 2002 as cited in Pimentel et al, 2004	33
Review of Current Scholarly Literature	Total U.S. Costs	Direct Operating Cost: Damages and Losses and compliance	Asian Clam	$1 billion (2005)	$1.16 billion	OTA 1993 as cited in Pimentel et al, 2004	34
Review of Current Scholarly Literature	Total U.S. Costs	Direct Operating Cost: Damages and Losses	Shipworm	$205 million (2005)	$238 million	Cohen and Carlton 1995 as cited in Pimentel et al, 2004	35
Review of Current Scholarly Literature	Fishing Industry	Direct Operating Cost: Damages and Losses	Exotic Fish	$5.4 billion/yr.	$6.26 billion/yr.	Pimentel et al, 2004	36
Survey	Great Lakes Power Plants (46 power plants)	Direct Operating Cost	Zebra Mussels	$6,700 per hour for a 200-megawatt system-$127/year (2003)	$8,241/hr. for 200 megawatt system or $156.21 million/yr.	Office of Technology Assessment 1993 as found in Lovell, Stone, and Fernandez	37
Survey	Great Lakes Power Plants (46 power plants)	Direct Operating Cost: Plant re-design (damages)	Zebra Mussels	$800 million (1993)	$1.25 billion	Office of Technology Assessment 1993 as found in Lovell, Stone, and Fernandez	38
Survey	Great Lakes Power Plants (46 power plants)	Direct Operating Cost: Maintained	Zebra Mussels	$60 million/yr. (1993)	$93.6 million/yr.	Office of Technology Assessment 1993 as found in Lovell, Stone, and Fernandez	39
Survey	All Water Users in U.S.	Direct Operating Cost: Herbicide	Aquatic Weeds	$10/hectare-$100 per hectare (1993)	$15.6-$156 per hectare	Office of Technology Assessment as found in Lovell, Stone, and Fernandez	40

Analysis: Anderson Economic Group, LLC 2016

Exhibit 4 continued: Cost Research Studies

Type of Study	Industry/Entity Affected	Cost Category	Species	Monetary Value: Direct From Study	Monetary Value 2011 Dollars	Source	Ref #
Survey	Fishing in U.S.	Direct Operating Cost: Control	Sea Lamprey	$10 million (1993)	$15.6 million	Office of Technology Assessment as found in Lovell, Stone, and Fernandez	41
Survey	Fishing in U.S.	Direct Operating Cost: re-stocking fish	Sea Lamprey	$10 million (1993)	$15.6 million	Office of Technology Assessment as found in Lovell, Stone, and Fernandez	42
Survey	Fishing in U.S.	Direct Operating Cost: Benefits of Control	Sea Lamprey	$500 million/yr. (1993)	$780 million/yr.	Office of Technology Assessment as found in Lovell, Stone, and Fernandez	43
Survey	Fishing in U.S.	Direct Operating Cost: Benefits of Control	European Ruffe	$90 million/yr. (1993)	$140.4 million/yr.	Office of Technology Assessment as found in Lovell, Stone, and Fernandez	44
Survey	Nuclear Industry-total U.S.	Direct Operating Cost: Cost of compliance with new regulation in 1980s	Asian clam	$4.5 million (1993)	$7.02 million	Office of Technology Assessment as found in Lovell, Stone, and Fernandez	45
Survey	Power Plants, water plants, industrial facilities, lock and dam structures, marinas	Direct Operating Cost: Removal Cost	Zebra Mussels	$1-5 billion since 1998 (2008)	$1.1-$6.5 billion since 1998 or $110-$650 million/yr.	National Research Council	46
Survey: original data not found	Hydro-electric plant	Direct Operating Costs	Zebra Mussels	$92,000/plant/yr. (2003)	$113,160/plant/yr.	U.S. Geological Survey as found in Lovell, Stone, and Fernandez	47
Survey: original data not found	Fossil-Fuel Plant	Direct Operating Cost	Zebra Mussels	$160,000/plant/yr. (2003)	$242,064/plant/yr.	U.S. Geological Survey as found in Lovell, Stone, and Fernandez	48
Survey: original data not found	Nuclear Plant	Direct Operating Cost	Zebra Mussels	$908,000/plant/yr. (2003)	$1.1 million/plant/yr.	U.S. Geological Survey as found in Lovell, Stone, and Fernandez	49
Survey: original data not found	Boat Owners-Lake Erie	Direct Operating Cost: Maintained and Insurance	Zebra Mussels	$660/yr./boat owner (2003)	$800/yr./boat owner	U.S. Geological Survey as found in Lovell, Stone, and Fernandez	50

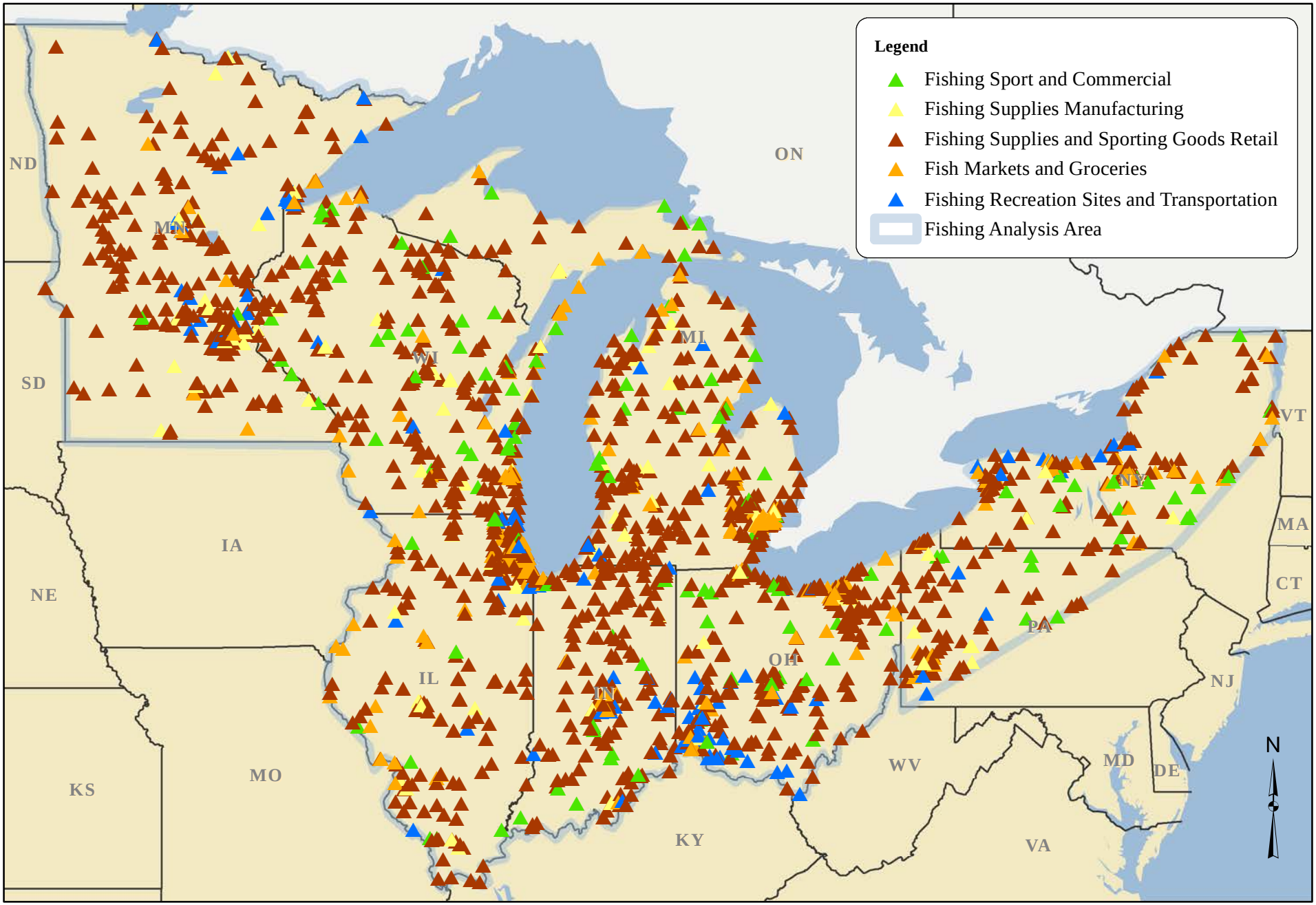
Analysis: Anderson Economic Group, LLC 2016

Exhibit 4 continued: Cost Research Studies

Type of Study	Industry/Entity Affected	Cost Category	Species	Monetary Value: Direct From Study	Monetary Value 2011 Dollars	Source	Ref #
Survey	Nuclear Electric Industry-U.S.	Direct Operating Cost: Damages and Losses	Asian Clam	$2.2 billion in 1980 (2003)	$2.7 billion in 1980	Office of Technology Assessment as found in Lovell, Stone, and Fernandez	51
Author Contacted for Methods	Great Lakes native fisheries	Direct Operating Cost: Estimated Losses	European Ruffe	$520,000/yr. (2003)	$639,600/yr.	Jenkins as found in Lovell, Stone, and Fernandez	52

Analysis: Anderson Economic Group, LLC 2016

Map 1. Identified Great Lakes U.S. Sport and Commercial Fishing Related Businesses



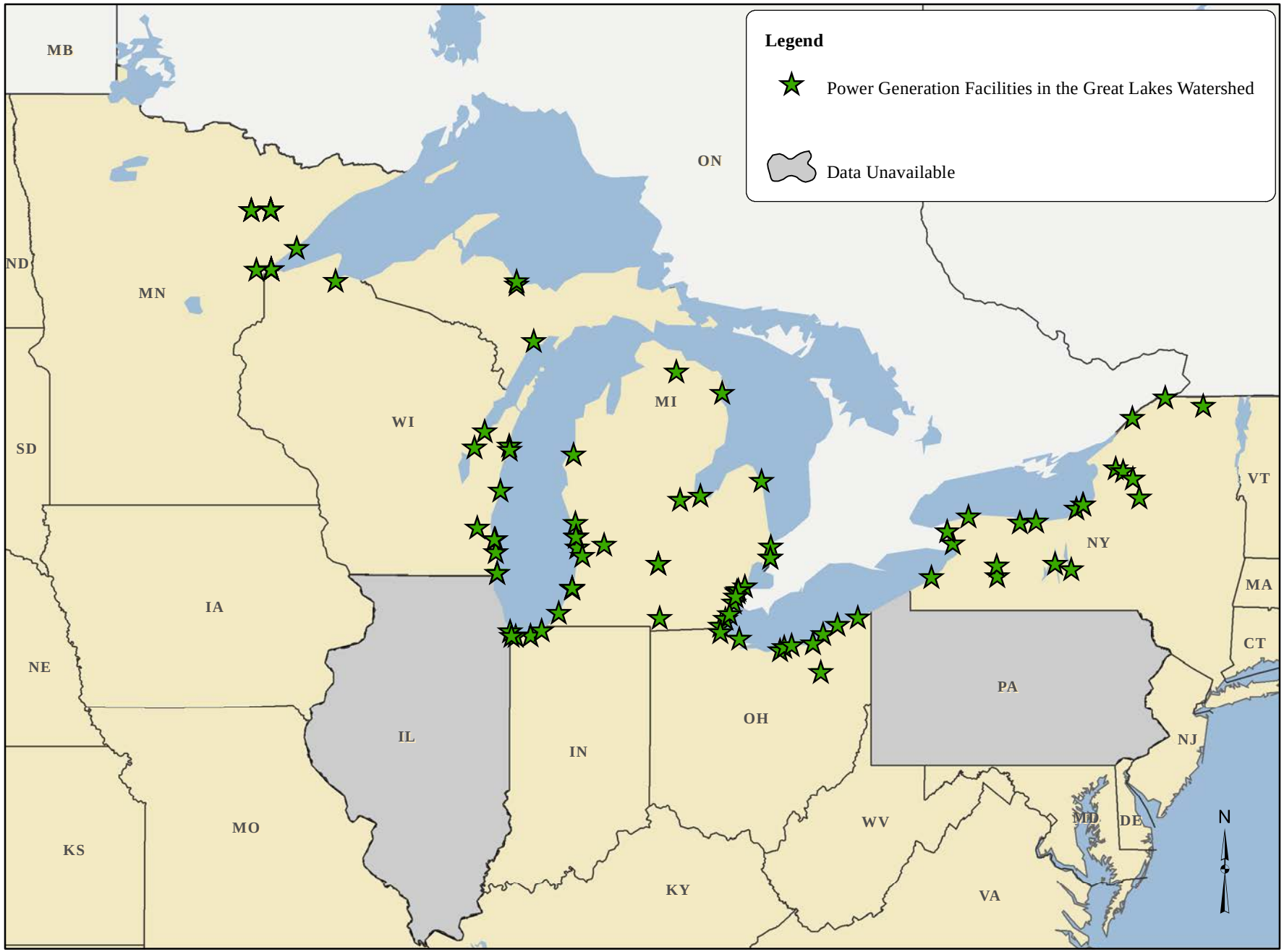
**Note: The analysis area includes businesses in the portions of Pennsylvania and New York that have easier access to the Great Lakes than the Atlantic Ocean. We assume that fishing-related business in this geographic area are more negatively affected by changes in the Great Lakes than businesses outside of them.*

0 50 100 200 Miles

Data Source: ESRI, Inc.

Analysis: Anderson Economic Group, LLC 2016

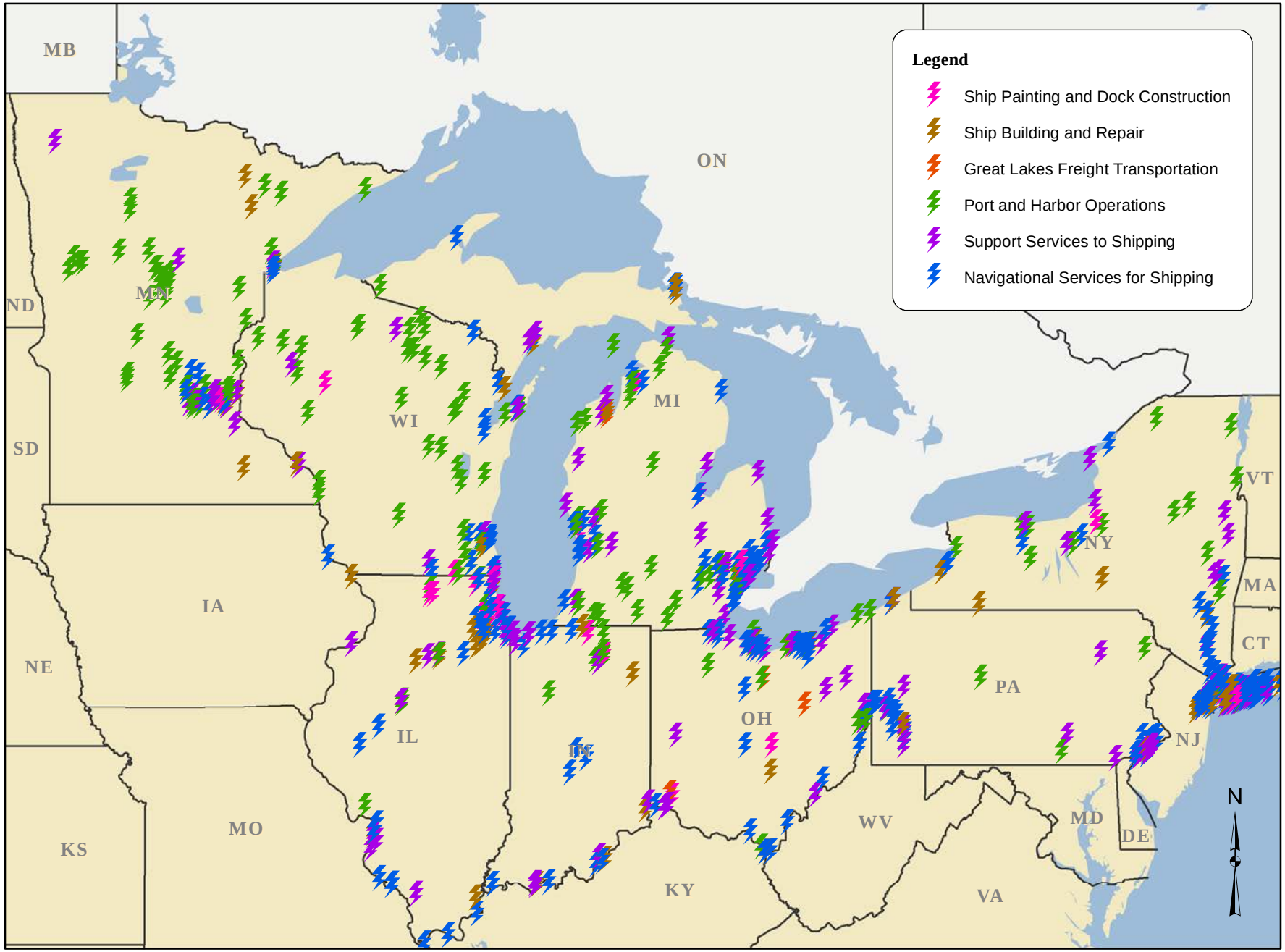
Map 2. Available Locations of U.S. Power Generation Facilities in the Great Lakes Watershed



Data Sources: Michigan DEQ, Minnesota DNR, Indiana DNR, Ohio DNR, New York DEC, ESRI Inc.
Analysis: Anderson Economic Group, LLC 2016

0 50 100 200 Miles

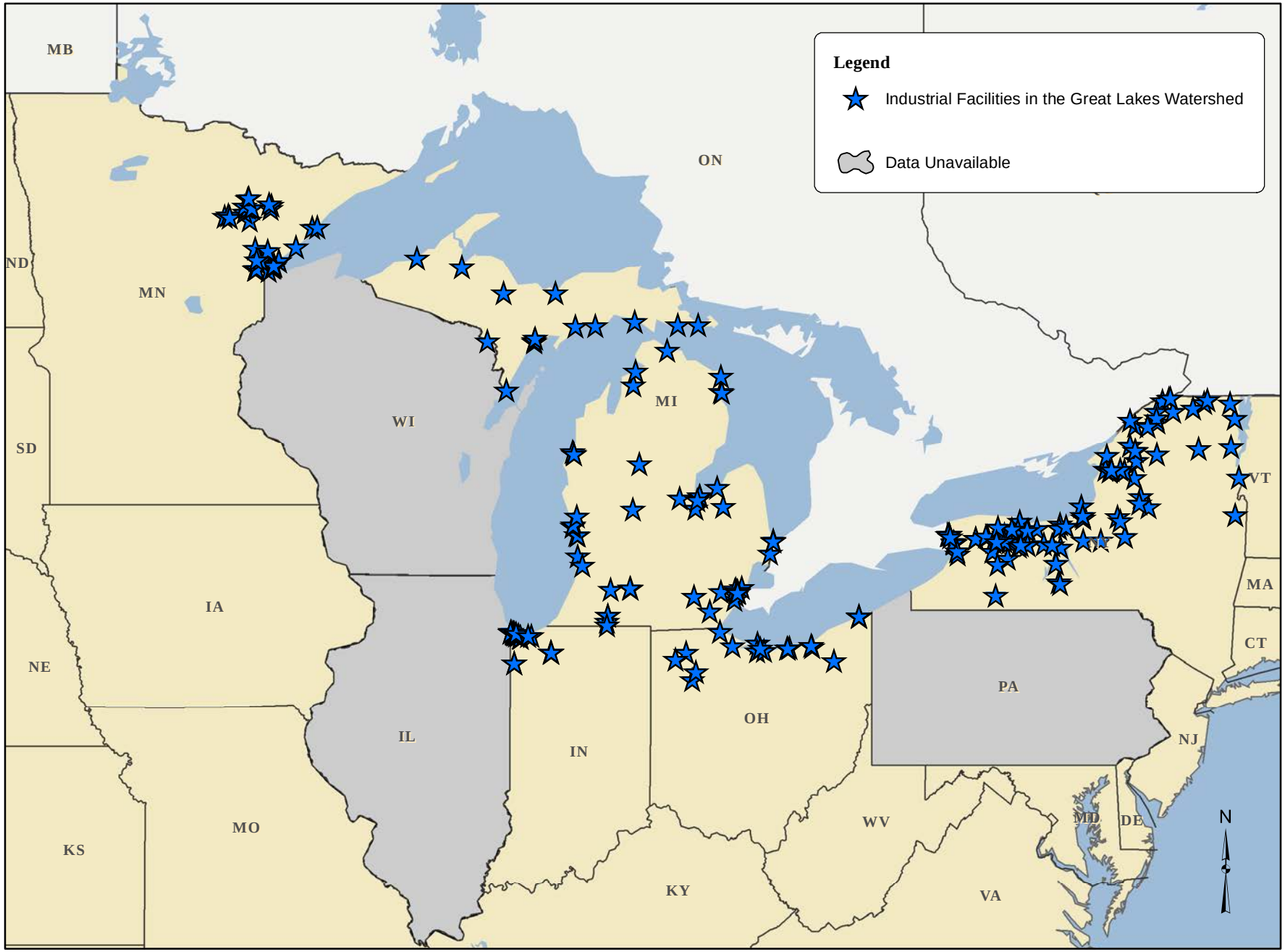
Map 3. Identified U.S. Shipping Industry Business Locations in Great Lakes States



Data Source: ESRI, Inc.
Analysis: Anderson Economic Group, LLC 2016

0 50 100 200 Miles

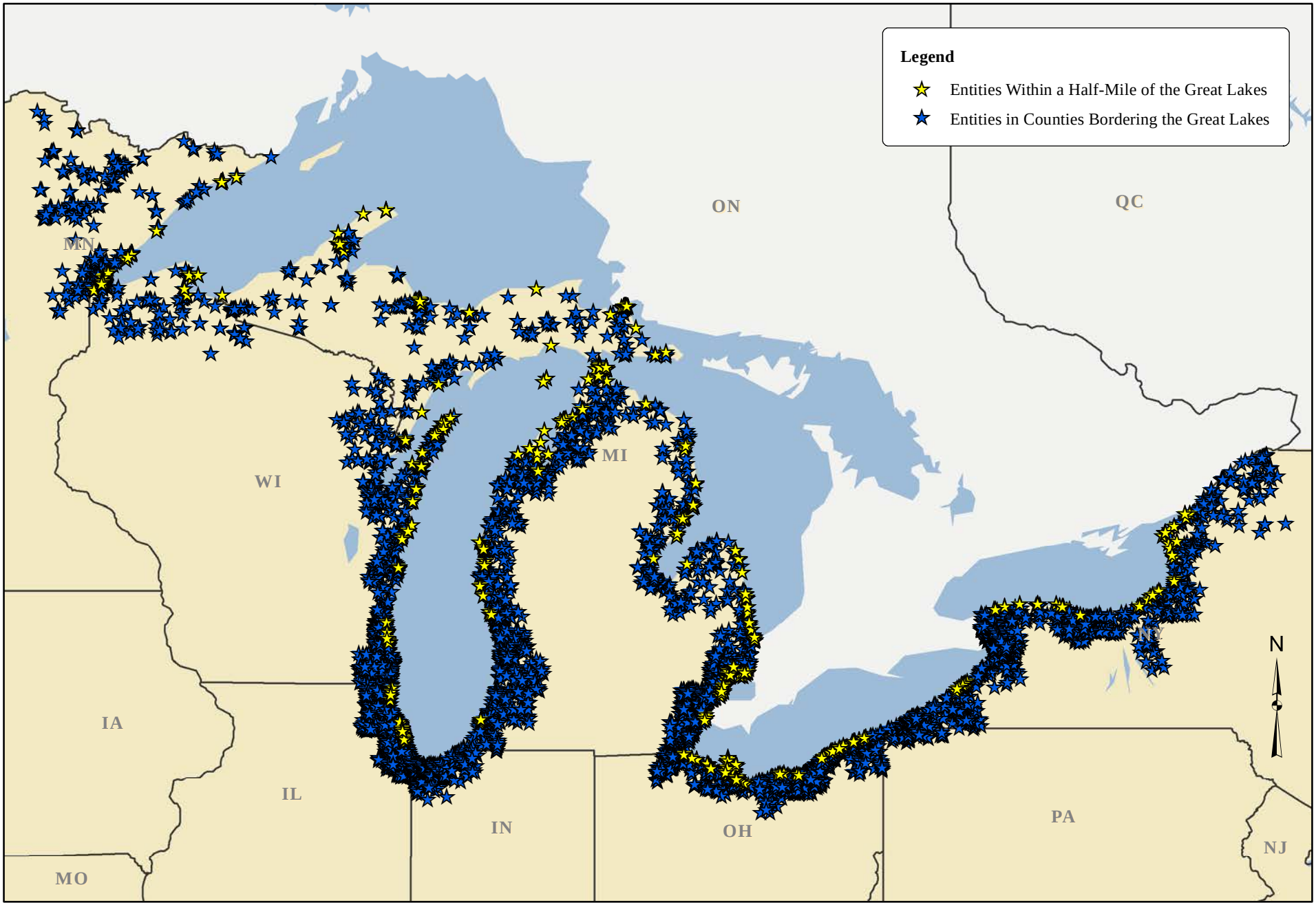
Map 4. Available Locations of U.S. Industrial Facilities in the Great Lakes Watershed



Data Sources: Michigan DEQ, Minnesota DNR, Indiana DNR, Ohio DNR, New York DEC, ESRI Inc.
Analysis: Anderson Economic Group, LLC 2016

0 50 100 200 Miles

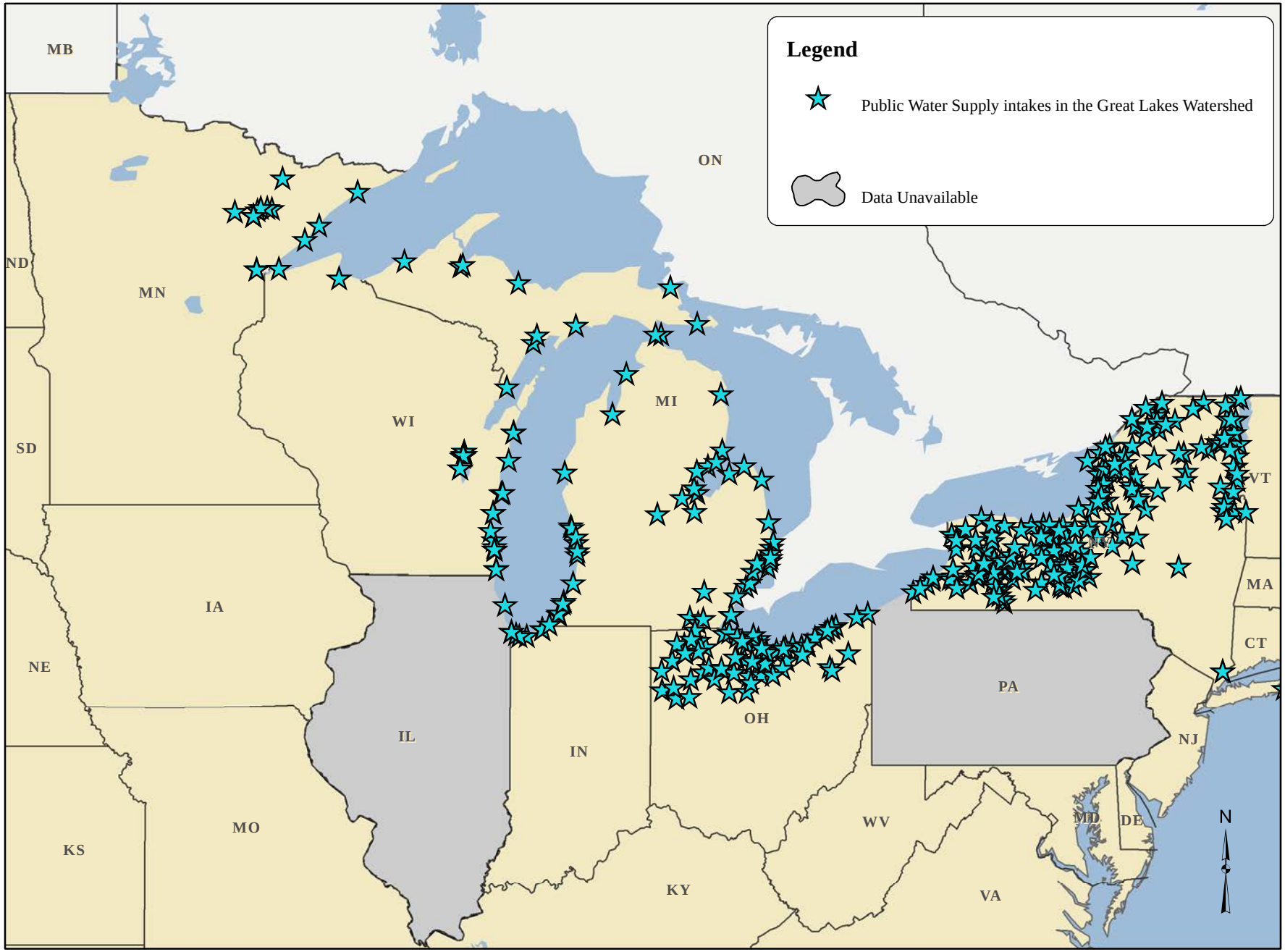
Map 5. Identified U.S. Tourism-Related Sites, Organizations, and Businesses Near the Great Lakes



Data Source: ESRI, Inc.
Analysis: Anderson Economic Group, LLC 2016

0 50 100 200 Miles

Map 6. Available Locations of U.S. Public Water Supply Intakes in the Great Lakes Watershed



Data Sources: Michigan DEQ, Minnesota DNR, Indiana DNR, Ohio DNR, New York DEC, Wisconsin DNR, ESRI Inc.
Analysis: Anderson Economic Group, LLC 2016

0 50 100 200 Miles

Exhibit 5: Industries in Great Lakes States

Sport and Commercial Fishing in the Great Lakes

Great Lakes Region	Total Employment		Total Related-Businesses	Industry Sales Volume 2010 (Thousand of U.S. Dollars)
	10,053		2,094	$ 3,429,413
States	Jobs in State	State Share of Great Lakes Total	Related-Businesses in State	Estimated Sales Volume in State
Illinois	2,437	24%	315	$ 833,068
Indiana	507	5%	180	$ 102,725
Michigan	1,285	13%	382	$ 420,095
Minnesota	1,767	18%	302	$ 691,899
New York	1,007	10%	215	$ 317,744
Ohio	1,288	13%	304	$ 464,155
Pennsylvania	619	6%	86	$ 250,720
Wisconsin	1,143	11%	310	$ 349,007

Industrial Facilities in the Great Lakes Watershed (Available Data)

Great Lakes Region	Total Firms
	248
States	Related-Businesses in State
Indiana	20
Michigan	62
Minnesota	33
New York	88
Ohio	19
Wisconsin	26

Identified Shipping Industry Related Business in Great Lakes States

Great Lakes Region	Total Employment		Total Related-Businesses	Industry Sales Volume 2010 (Thousand of U.S. Dollars)
	8,651		719	$ 1,748,423
States	Jobs in State	State Share of Great Lakes Total	Related-Businesses in State	Estimated Sales Volume in State
Illinois	1,211	14%	77	$ 273,557
Indiana	925	11%	38	$ 69,930
Michigan	312	4%	125	$ 86,476
Minnesota	460	5%	79	$ 91,723
New York	2,137	25%	198	$ 509,846
Ohio	956	11%	77	$ 182,822
Pennsylvania	815	9%	55	$ 145,405
Wisconsin	1,835	21%	70	$ 388,664
	8651			1,749,142.00

Public Water Supply Intakes in the Great Lakes Watershed (Available Data)

Great Lakes Region	Total Intakes
	381
States	Intakes in State
Indiana	7
Michigan	60
Minnesota	14
New York	208
Ohio	64
Wisconsin	28

Identified Tourism-Related Sites, Organizations and Businesses

Great Lakes Total	One-County Area Employment		Total Related-Businesses	Industry Sales Volume 2010 (Thousand of U.S. Dollars)
	90,072		9,850	$ 30,312,011
States	Jobs in State	State Share of Great Lakes Total	Related-Businesses in State	Estimated Sales Volume in State
Illinois	24,615	27%	2,052	$ 6,496,530
Indiana	2,842	3%	366	$ 839,183
Michigan	22,066	24%	2,832	$ 9,696,954
Minnesota	2,496	3%	350	$ 375,134
Ohio	15,484	17%	1,285	$ 4,908,652
New York	11,718	13%	1,484	$ 2,847,671
Pennsylvania	1,253	1%	161	$ 574,529
Wisconsin	9,598	11%	1,320	$ 4,573,358

Power Generation Facilities in the Great Lakes Watershed (Available Data)

Great Lakes Region	Total Power Facilities
	106
States	Plants in State	Share of Great Lakes Total
Indiana	5	5%
Illinois	5	4%
Michigan	34	32%
Minnesota	20	19%
New York	20	19%
Ohio	10	10%
Wisconsin	12	11%

Data: Michigan DEQ, Indiana DNR, Minnesota DNR, Ohio DNR, New York DEC, Wisconsin DNR, ESRI 2011
Analysis: Anderson Economic Group, LLC 2016

Exhibit 6: Government Expenditures on AIS Control, Monitoring, and Prevention in Great Lakes States

		Federal FY 2009-2010		
State	GLRI Funds for AIS 2010 and 2011	State AIS Spending	Federal non-GLRI AIS Spending	Stable Sources of Funding
Indiana		$1.7 million	$0.9 million	
Illinois		$0.6 million	$2.8 million	
Michigan*	$1.8 million	$2.3 million	$0.9 million	None; all programs are funded by grants and project specific funds
Minnesota		$7.7 million	$0.7 million	
New York*	$1.4 million	$2.7 million	$0.03 million	$3.8 million annually from Environmental Protection Fund which is funded by Real Estate Transfer Taxes; funding for the Office of AIS Coordination also comes from the New York State General Fund
Ohio		$0.03 million	$0.06 million	
Pennsylvania		$0.3 million	$0.07 million	
Wisconsin		$12 million	$0.07 million	Wisconsin has an AIS grant program which require a 25% local match for communities that receive the grant. The local match may be given in terms of volunteer time.

Note: The data were collected by the U.S. Fish and Wildlife Service and have been supplemented by data given by states marked with an arterisk (*). Many states calculated the amount of spending while other estimated the value. Data on funding sources were gathered from each state where available.

Source: Author's estimates based on review of partial and incomplete data from Michigan DEQ, New York DEC, U.S. Fish and Wildlife Service.
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Appendix B.About AEG

Anderson Economic Group LLC is a research and consulting firm that specializes in economics, public policy, finance, market analysis, and land use economics. AEG has offices in East Lansing, Michigan and Chicago, Illinois. AEG's past clients include:

- *Governments*, such as the states of Michigan, North Carolina, and Wisconsin; the cities of Detroit, MI, Cincinnati, OH, Norfolk, VA, and Fort Wayne, IN; counties such as Oakland County, Michigan, and Collier County, Florida; and authorities such as the Detroit-Wayne County Port Authority;
- *Corporations* such as GM, Ford, Delphi, Honda, Metaldyne, Taubman Centers, The Detroit Lions, PG&E Generating; SBC, Gambrinus, Labatt USA, and InBev USA; automobile dealers and dealership groups representing Toyota, Honda, Chrysler, Mercedes-Benz, and other brands;
- *Nonprofit organizations*, such as Michigan's University Research Corridor, Michigan State University, Wayne State University, Van Andel Institute, the Michigan Manufacturers Association, International Mass Retailers Association, American Automobile Manufacturers Association, Automation Alley, and the Michigan Chamber of Commerce.

Visit AEG's website at: http://www.andersoneconomicgroup.com.

ABOUT THE AUTHORS

Patrick L. Anderson. Mr. Anderson founded Anderson Economic Group in 1996, and serves as a Principal and Chief Executive Officer in the company. He has taken a leading role in several major public policy initiatives in his home state; he was the author of the 1992 Term Limit Amendment to the Michigan Constitution, and also the author of the 2006 initiated law that repealed the state's 4-decade-old Single Business Tax. Before founding Anderson Economic Group, Mr. Anderson was the deputy budget director for the State of Michigan under Governor John Engler, and Chief of Staff for the Michigan Department of State.

Mr. Anderson has written over 100 published works, including the book *Business Economics and Finance* and the chapter on business valuation in the book *Litigation Economics*. He is also the executive editor of three editions of the *State Economic Handbook.* His 2004 article "Pocketbook Issues and the Presidency" and his 2009 paper "The Value of Private Businesses in the United States" have each been awarded for outstanding writing from the National Association of Business Economics. Anderson's views on the economy are often cited by national news media including *The Wall Street Journal, New York Times, National Public Radio,* and *Fox Business News.*

Anderson is a graduate of the University of Michigan, where he earned a Master of Public Policy degree and a Bachelor of Arts degree in political science. He is a member of the National Association for Business Economics and the National Association of Forensic Economists. The Michi-

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gan Chamber of Commerce awarded Mr. Anderson its 2006 *Leadership Michigan Distinguished Alumni* award for his civic and professional accomplishments.

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Prior to coming to Anderson Economic Group Ms. Spencer worked with the Michigan Municipal League on the 21st Century Communities project providing consulting services to local governments in Michigan concerning local economic development initiatives. Ms. Spencer held a fellowship at Columbia University as a teaching assistant for Quantitative Analysis and Operations Management. She has also taught in the District of Columbia Public Schools.

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NOTES ON 2016 REVISION

This paper was originally published on March 5, 2012. This edition reflects revisions made in response to an unpublished set of notes circulated by the Lake Carriers Association in mid-2016. There are several sentences and tables throughout the report that we have updated in this edition. The revisions include the removal of two cited papers from the appendix, correction of an error in currency conversion calculations from one source, and several clarifications of sources and background information in the report. None of the revisions necessitated any changes to the overall methods and conclusions of this paper, which have not changed from the original edition.

We appreciate this opportunity to improve the accuracy and clarity of our work.