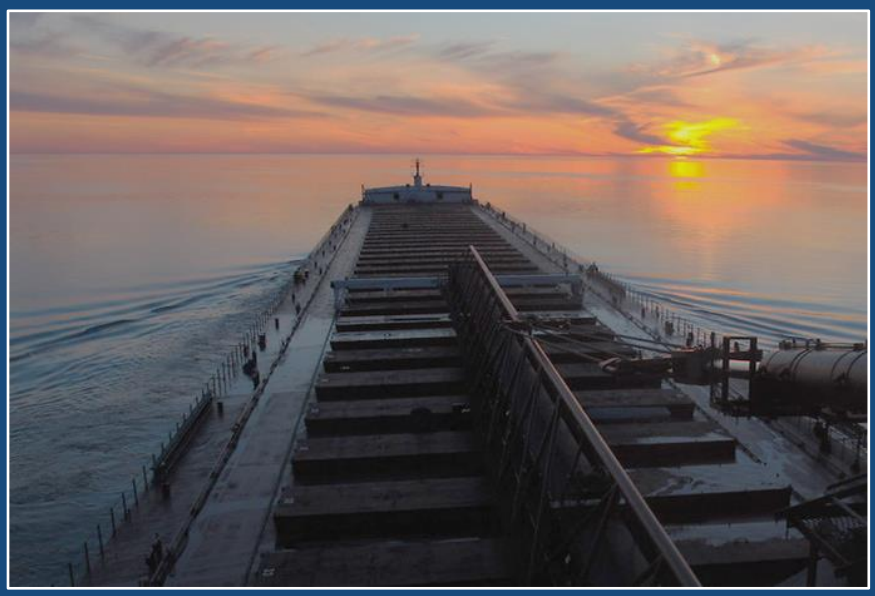
On the Great Lakes Horizon: Scenarios, Opportunities, Threats, and Responsive Governance

Final Report

Prepared for: International Joint Commission

March 31, 2023



Upper photo by Jack Brandenburg, Interlake Steamship Company, M/V *Mesabi Miner*, 2018, Lake Michigan; lower photo by Vermilion (OH) Photographers, 2015, Interlake Steamship Company, *M/V Paul R. Tregurtha.*

LimnoTech
Water Environment | Scientists Engineers

in association with RAND CORPORATION

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Prepared by:
LimnoTech, Ann Arbor, Michigan

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Acknowledgments

The consulting research team gratefully acknowledges the time and energy of the Work Group members and International Joint Commission (IJC) staff who provided advice and guidance for this study and report, and the generous contributions of time and knowledge by participants in engagement sessions and workshops.

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EXECUTIVE SUMMARY

LimnoTech and its project partner, RAND Corporation, have prepared this report summarizing the process and results of the project titled, "On the Great Lakes Horizon: Scenarios, Opportunities, Threats, and Responsive Governance". The study was performed for a work group (WG) of the International Joint Commission Water Quality Board (IJC-WQB). The Great Lakes Horizons project was a binational effort conducted for the IJC to explore future drivers of societal health and water quality in the Great Lakes basin. As one of the major unifying elements in the lives of people in the region, the lakes serve not only as a resource to be stewarded and enjoyed but also as common ground from which to approach decisions impacting the future.

Through this project, IJC has sought to promote conversations around future drivers of change in the region, including both threats and opportunities. Four categories of drivers were considered: societal values, governance, and geopolitics; population, economic development, and trade; climate change and infrastructure; and biological, ecological, and chemical systems.

By beginning to identify these drivers and consider their hypothetical outcomes, leaders in the region will be better equipped to influence their direction and impacts. Questions that have been posed and that have helped guide the project include:

- Which drivers of change do subject matter experts in the region consider to be of greater significance regarding water quality and health outcomes?
- Which drivers do regional leaders expect to be able to influence most strongly?
- What are some management strategies for influencing these drivers toward desirable outcomes for stakeholders?
- What are the current gaps or limitations in the region's ability to influence outcomes?
- How can the IJC use the future scenario narratives developed in this project to help inform and engage wider circles about these issues?

The first phase of the project included: 1) a literature review related to recent trends in Great Lakes environmental driver conditions, 2) a symposium during which trends and threats were ranked and prioritized by a group of subject matter experts, and 3) system mapping to produce causal loop diagrams that help depict the concepts discussed during the symposium. The project then moved to engagement with Great Lakes leaders from diverse backgrounds and locations to develop hypothetical management strategies that could influence drivers and outcomes. The last phase of the project had members work together to define scenarios that will help communicate conceptions of potential future conditions to wider audiences so that residents of the region will understand the value of preparing for and acting to influence changes in the region.

Discussions during the project focused on drivers of change that not only have a greater likelihood of occurring and impacting society, but also that the region has greater potential to influence. These especially include factors that will potentially impact large land areas, or drive large water uses or population changes. Examples include changes in agricultural intensity, irrigation, and type due to climate change and ownership transitions; transitions of agricultural land for solar and wind energy development; changes in population due to immigration to the Great Lakes; and shifts in

relative growth rates and political representation in the Great Lakes compared to other areas with potential future water shortage crises.

The report contains the following components:

- An introduction to the Great Lakes Horizons project and related literature and information on environmental drivers;
- A narrative description of discussion topics from the project symposium during which regional subject matter experts explored and prioritized drivers of change;
- A description of gaps and limitations that may limit the degree to which regional leaders can influence change;
- Results of regional engagement sessions;
- Narrative and pictorial depictions of four creative scenarios of better or worse future states of the Great Lakes (Figure 1) and descriptions of signposts and monitoring to determine trajectories along the paths to future (2053) states of the system; and
- Recommendations on how to move forward in the near term to enhance the probability of positive outcomes in the longer term (see below).

Figure 1. Four-panel depiction of future Great Lakes scenarios, as described in the report, ordered from the worst future state on the left to the best future state on the right (original artwork by Jennifer Clausen, www.jacdraws.com).

Recommendations

To promote positive and improving environmental conditions in the Great Lakes of the future, and to protect against declines, the following actions should be implemented by IJC Commissioners, staff, and board members within three to five years:

- Review the US Clean Water Act (CWA), Canada Water Act, US Farm Bill, and Great Lakes Restoration Initiative Action Plan III, among other legislation and program guidance, with special consideration of ways that the combination of nonpoint nutrient control and climate change can be more effectively implemented and prepare a white paper or policy brief suggesting improvements that are specific to the Great Lakes several decades into the future.

- Develop a plan for integrating and enhancing existing monitoring programs across driver disciplines in and outside the region, where appropriate, on a five-year cycle to identify actionable shifts, accelerations, or decelerations where pressure can be applied to steer trajectories in desired directions. This would serve as a threat analysis companion to other indicator tracking efforts and would target socio-political, cultural, and economic actions to a greater extent than existing efforts, as well as incorporating ecosystem services restoration concepts in prioritization.

- Engage with individuals and groups who are working on innovative technological approaches to support decisions that span the international and inter-regional divides such as transboundary numerical models (e.g., the US National Water Model that spans the Canada border in the Great Lakes) and dynamically track status and trends or rapidly evaluate quantitative future scenarios. Leverage the Great Lakes decadal science planning documents prepared in 2022 by IJC.

- Seek standardization of tributary watershed governance structures across the border, along the lines of Canadian Regional Conservation Authorities or Florida's watershed management districts. Task existing and new bodies like this with developing future scenario documents and mitigation plans.

- Support expansion or realization of new and proposed forward-looking boundary organizations such as the Council of the Great Lakes Region, the Great Lakes Authority, regional environmental think tanks, or disciplinary Centers of Excellence.

- Consider the 30-year horizon explicitly when updating the Canada-US Great Lakes Water Quality Agreement (GLWQA) and other related agreements, treaties and commitments.

ACRONYMS

AOC – Area of Concern
AZ – Arizona (postal abbreviation)
BMP – Best Management Practice
CAFO – Concentrated/Confined Animal Feeding Operation
CERCLA - Comprehensive Environmental Response, Compensation and Liability Act (US; Superfund)
CGLR – Council of the Great Lakes Region
COVID-19 – Coronavirus Disease of 2019
CSO – Combined Sewer Outfall/Overflow
CWA – Clean Water Act (US)
CWMP - Coastal Wetland Monitoring Program
EPA – US Environmental Protection Agency
ESG - Environmental, Social, and Governance
FPL – Federal Poverty Level
GLAAC - Great Lakes Adaptation Assessment for Cities
GLANSIS – Great Lakes Aquatic Nonindigenous Species Information System
GLC – Great Lakes Commission
GLCWRA - Great Lakes Coastal Wetland Restoration Assessment
GLEAM - Great Lakes Environmental Assessment and Mapping
GLEI - Great Lakes Environmental Indicators
GLEWS – Great Lakes Early Warning System
GLFC – Great Lakes Fishery Commission
GLISA - Great Lakes Integrated Sciences and Assessments
GLOS – Great Lakes Observing System
GLRI – Great Lakes Restoration Initiative
GLSC – Great Lakes Science Center
GL-TAPP – Great Lakes Thirst Abatement Pipeline Plan (fictional)
GLWA – Great Lakes Water Authority (Detroit area)
GLWQA – Great Lakes Water Quality Agreement
HAB – Harmful Algal Bloom
IHS - Indian Health Service
IJC – International Joint Commission
IL – Illinois (postal abbreviation)
KY – Kentucky (postal abbreviation)
MGD – Millions of Gallons per Day
MKE – Milwaukee (airport code)
MN – Minnesota (postal abbreviation)
MPCA – Minnesota Pollution Control Agency
MPR – Minnesota Public Radio
MS4 – Municipal Separate Storm Sewer System (US)
MSU – Michigan State University

MWEA - Michigan Water Environment Association
NASA – National Aeronautics and Space Administration (US)
NEORSD – Northeast Ohio Regional Sewer District
NOAA – National Oceanic and Atmospheric Administration (US)
NPDES – National Pollutant Discharge Elimination System (US)
NRDC - Natural Resources Defense Council
NREL - National Renewable Energy Laboratory (US)
NWF – National Wildlife Federation
NYSERDA - New York State Energy Research and Development Authority
OH – Ohio (postal abbreviation)
PALSAR- Polarimetric Phased Array L-band Synthetic Aperture Radar
PFAS - Per- and Polyfluoroalkyl Substances
PNEC - Predicted No-Effect Concentration
RCA – Regional Conservation Authority (Canada)
RCP - Representative Concentration Pathway (for future greenhouse gases)
REI – Relative Exposure Index
SDWA – Safe Drinking Water Act (US)
SRF – State Revolving Fund
TFP – Total Factor Productivity
TN – Tennessee (postal abbreviation)
TSCA – Toxic Substances Control Act (US)
UN – United Nations
USD – US Dollars
USDA – US Department of Agriculture
USGS – US Geological Survey
UV - Ultraviolet
VR – Virtual Reality
WBEZ – Chicago's National Public Radio Station
WG – Work Group
WQB – Water Quality Board
WRRF – Water Resource Recovery Facility
WWTP – Wastewater Treatment Plant

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INTRODUCTION

LimnoTech and its project partner, RAND Corporation, conducted a research and analysis study titled, "On the Great Lakes Horizon: Scenarios, Opportunities, Threats, and Responsive Governance" beginning in late 2020 and continuing through early 2023. The team prepared this report to summarize the process and results of the project for a work group (WG) of the International Joint Commission (IJC) Great Lakes Water Quality Board (WQB). The project was conducted collaboratively with Canadian and US contributors to support the IJC in exploring current drivers of societal health and water quality in the Great Lakes basin. The project also examined how these drivers may change the system over the next three decades. As a major unifying element in the lives of people in the shared region, the lakes serve as a resource to be stewarded and enjoyed. The lakes are also an international commons where decisions impacting the future are made—for better or worse. Through this project, the IJC promoted conversations about many future threats and opportunities. Four categories of drivers were considered: societal values, governance, and geopolitics; population, economic development, and trade; climate change and infrastructure; and biological, ecological, and chemical systems.

The first phase of the project included: 1) a literature review related to recent trends in Great Lakes environmental driver conditions, 2) a symposium during which trends and threats were ranked and prioritized by a group of subject matter experts, and 3) system mapping to produce causal loop diagrams which help depict the concepts discussed during the symposium. The project then moved to engagement with Great Lakes leaders from diverse backgrounds and locations to develop hypothetical management strategies that could influence drivers and outcomes. The last phase of the project had members work together to define scenarios that will help communicate about potential future conditions to wider audiences about the need to prepare for and act to influence changes in the region to head off negative outcomes.

Discussions during the project focused on drivers of change that not only have a greater likelihood of occurring and impacting society, but also that the region has greater potential to influence. These especially include factors that will potentially impact large land areas or drive large water uses or population changes. Examples include changes in agricultural intensity, irrigation, and type due to climate change and ownership transitions; transitions of agricultural land for solar and wind energy development; changes in population due to immigration to the Great Lakes; and relative growth rates and political representation in the Great Lakes compared to other areas with potential future water shortage crises.

LITERATURE REVIEW: DRIVERS OF GREAT LAKES REGIONAL CHANGE

Organized by terms used in the project Scope of Work and by driver themes identified in the 2005 Millenium Ecosystem Assessment (https://www.millenniumassessment.org/en/index.html), the following literature review summary gives a snapshot of driver states and particular threats based on a mix or sources. The full references for each citation are included at the end of the report and include peer-reviewed journal articles, reports, news stories, trade books, editorials and blog posts. In addition to typical scientific studies in sources such as the *Journal of Great Lakes Research*,

sources considered here include work by journalists, legal scholars, popular authors, environmental advocates and public affairs specialists. The mix of information reviewed was intended to inform symposium discussions, engagement sessions, scenario development, signpost identification and recommendations.

Driver States

Information was compiled on the states and related threats associated with the following 14 drivers for the Great Lakes from journal articles, newspaper articles, websites, and other sources.

1. Demographics
2. Vulnerable Populations and Sectors
3. Climate
4. Water Quality
5. Drinking Water
6. Coastal Wetlands
7. Emerging Contaminants
8. Invasive Species
9. Water Infrastructure
10. Affordability and Financing
11. Economic Impact
12. Agriculture
13. Renewable Energy
14. Public Health

Details for each driver state are provided below.

1. Demographics

- The Great Lakes region has a strong and diverse economic base; a population with increasing diversity by age, race, and national origin; and growing numbers of skilled workers. Further, the region has many significant assets that can be leveraged to support its future prosperity: the perennial resilience and innovation of its manufacturers, a wealth of colleges and universities, strong philanthropic and civic organizations and natural resources such as the Great Lakes themselves (Pendall et al. 2017).
- An Urban Institute analysis of future population growth and demographics across the eight-state Great Lakes region within the United States developed three scenarios: fast (55.9 million by 2040), average (54.6 million by 2040), and slow (53 million by 2040). These rates are still below US national averages and anticipated future growth rates (Gold et al. 2018).
- Toronto in particular is very important, as it is growing most rapidly of all Great Lakes cities, largely due to immigration. Toronto's population is projected to rise from 2.97 million in 2019 to 3.73 million in 2046, an increase of 25.9 percent, though slower than the provincial growth rate. The population of Central Ontario is projected to grow by 1.07 million or 33.9 percent, from 3.16 million in 2019 to 4.23 million in 2046 (Ontario.ca 2021).

2. Vulnerable Populations and Sectors

- An analysis by Headwaters Economics and researchers at the University of Michigan as a part of the Great Lakes Adaptation Assessment for Cities (GLAAC) highlights counties with populations and economic sectors vulnerable to climate change (Headwaters Economics, 2015). These analyses highlight Northern Michigan (including the Upper Peninsula) and Northeastern Wisconsin as regions with counties that have a high job dependence on climate-vulnerable sectors. They also highlight the greater Chicago area and portions of the Upper Peninsula and Northern Michigan as those with populations highly vulnerable to extreme heat (University of Michigan 2023).
- The government of Canada identifies children, seniors, chronically ill persons, low-income or unhoused persons, disabled persons, persons living off the land and Northern residents as vulnerable groups and most likely to be impacted by the effects of a changing climate (Health Canada 2018).

3. Climate

- Projected changes in average annual temperature by mid-century range from 3 degrees F to 6 degrees F (1.7 degrees C to 3.3 degrees C) across the Great Lakes region. Greater warming is projected in the central and northern Great Lakes region (GLISA 2019).
- Projected changes in the number of days per year over 90 degrees F (32.2 degrees C) range from zero to 90 days greater per year. Opposite to the trend in average annual temperature, southern Illinois, Indiana, and Ohio will see greater increases (at least 50 more days per year) in the number of days about 90 degrees F (32.2 degrees C) (GLISA n.d.).
- Projected changes in cooling degree days, which impact energy demand and crop growth, will increase across the region. The warmest parts of the region – Illinois, Indiana, and Ohio – are likely to see the largest increases (GLISA n.d.).
- Total annual precipitation is also projected to increase by 2070 by 1-6 inches per year (2.5-15 centimeters per year) across the region. A few portions of the region – the Upper Peninsula of Michigan, Northern Wisconsin, and Northern Minnesota -- may see no or decreasing changes (GLISA n.d.).
- The number of days per year with heavy precipitation is expected to increase across the region, with greater changes in the eastern half of the region (GLISA n.d.).

4. Water Quality

- There are 291 cities in the Great Lakes basin with combined sewer systems that experience combined sewer overflows (CSOs): 109 in Canada and 182 in the United States (Mezzacapo 2017). Combined sewer overflows continue to impact water quality. In 2014, the US Great Lakes states reported 1,482 CSO events, and 22 billion gallons (83 billion liters) of untreated wastewater was discharged from CSOs in 2014, with the vast majority by volume from Michigan and Indiana, although Ohio had major gaps in its data (US EPA 2016).
- CSO controls are continuing to move forward. As of October 2018, the Minnesota Pollution Control Agency (MPCA) terminated Minnesota's last remaining CSO permit (MPCA 2018). Toronto is beginning the first phase of a five-phase CDN$3 billion CSO control project with the construction of the CDN$400 million, 10.5-kilometer-long Coxwell Bypass Tunnel (Davey 2019). Also in 2019, the Great Lake Water Authority (GLWA) Water Resource Recovery Facility (WRRF) completed the construction of the Rouge River Outfall

Disinfection Project, marking the completion of its core CSO control program. Large-scale sewer separation projects continue in the cities of Dearborn, Port Huron, St. Joseph, Wakefield, and Manistique. (Michigan Department of Environment, Great Lakes, and Energy 2019).

- Continued investment in infrastructure to control CSOs pays dividends. Alexander (2010) cites data from the Water Infrastructure Network indicating that every US$1 billion invested in wastewater infrastructure creates between 20,003 and 26,669 jobs. He also cites Brookings Institution findings that eliminating sewage contamination in the Great Lakes would provide US$2 in economic benefit to the region for every US$1 investment.
- The Natural Resources Defense Council (NRDC) (2011) cites a 2008 study on the Toronto Green Development Standard that estimated that by investing CDN$36 million over 10 years (with the cost borne largely by private building owners and developers), six percent of Toronto's roofs can become green roofs, resulting in an annual savings of CDN$100 million in stormwater costs and CDN$40 million in CSO capital costs.
- Stormwater utilities and stormwater fee programs are becoming more prevalent as a way to pay for stormwater controls.
- While stormwater utilities and stormwater fee programs are becoming more prevalent as a way to pay for stormwater controls, they can be contentious. Detroit residents sued the City over its drainage fee, but the Michigan Court of Appeals ruled against the plaintiffs in 2018 (Horan 2019). Duluth delayed the implementation of its drainage fee because of financial hardships caused by COVID-19 (Duluth News Tribune 2020).

5. Drinking Water

- Some Great Lakes states have gone beyond the federal standards in the Safe Drinking Water Act (SDWA) to protect their drinking water. For example, Ohio has significantly improved policies related to algal blooms in response to Toledo's "do not drink" advisory (Leonard et al. 2019).
- Some researchers believe that drinking water source monitoring methods will need to change to adapt to changing conditions. Edge et al. (2013) state that, based on studies in the western basin of Lake Ontario, it is uncertain whether past experience with nearshore water dynamics, water treatment practices and use of water quality indicators such as *E. coli* will be a reliable guide for the safe operation of drinking water treatment plants on the Great Lakes into the future. Rapid urbanization will present a variety of stormwater and municipal wastewater challenges. In addition, climate change projections for more extreme precipitation events and milder winters could significantly change river runoff patterns and offshore water column mixing dynamics. In the future, water treatment plants (WTPs) around the Great Lakes will need data on the occurrence of key waterborne pathogens such as *Cryptosporidium* in their source water considering the limitations of water quality monitoring tools such as those used for determining *E. coli* concentrations.
- Costs for invasive species control are becoming more important for drinking water systems. The capital cost and operations and maintenance (O&M)-based equivalent annual unit cost for treatment for dreissenid mussel control vary from US$78.56 for 1 million gallons per day (MGD) (3.8 million liters per day) capacity to US$13.41 for 2,640 MGD capacity. The cost for larger water treatment plants (i.e., >10 MGD [>38 million liters per day]) varies

between $1.00/MG and US$14.00/MG (Chakraborti et al. 2016).

6. Coastal Wetlands

- Many studies have investigated the impact of human development and land use (e.g., agriculture, population growth, urbanization, pollution) on the extent and quality of coastal wetlands in the Great Lakes (Albert 2015; Bourgeau-Chavez et al. 2015; Chow-Fraser 2013; Harrison et al. 2020; Host et al. 2019; Morrice et al. 2008; Trebitz et al. 2007). Water level variations in the lakes are also known to significantly impact coastal wetlands (Ciborowski et al. 2009; Great Lakes Commission et al. 2014; Mortsch et al. 2006).
- Historically, a large percentage of coastal wetlands have been lost (Chow-Fraser 2013).
- The Great Lakes Coastal Wetland Monitoring Program (CWMP; Central Michigan University n.d.; www.greatlakeswetlands.org) monitors Great Lakes coastal wetland biota, habitat and water quality to provide information on coastal wetland condition using fish, birds, calling anurans, wetland vegetation, aquatic macroinvertebrates and water quality. The website includes semi-annual and 5-year summary reports, compared to the 2011-2015 baseline.

7. Emerging Contaminants

- Arvai et al. (2014) assessed the performance of wastewater treatment plants (WWTPs) in the Great Lakes basin concerning the removal of chemicals of emerging concern (CECs). They find that while WWTPs can be a source, well-operated, conventionally designed plants are capable of achieving effective reductions of a variety of substances. The authors make recommendations for treatment processes to increase the effective treatment of CECs.
- Uslu et al. (2013) provide an overview of the literature on the occurrence and potential risks of pharmaceutical substances in the WWTPs, natural waters, and drinking water treatment plants served by the Great Lakes basin (Canada and the USA) between the years of 2007–2012. Their findings indicated that conventional treatment processes are inefficient in the degradation of pharmaceutical compounds. Surface waters located around septic systems and agricultural areas were also found to be contaminated with pharmaceutical substances. Similarly, while pharmaceutical compounds were not detected frequently in treated drinking water, the concentrations of some pharmaceutical substances were high and in the same range as source water concentrations, indicating pass-through from source waters. Overall, some pharmaceuticals detected exhibit a high environmental risk in Great Lakes WWTP effluents and surface waters, although none seem to pose a risk to human health in drinking water sources.
- Tertiary wastewater treatment techniques to remove micropollutants provide an indirect opportunity to remove very small microplastics. However, obtaining funding for microplastic work is challenging due to the lack of regulations (Hettiarachchi 2019).
- Lyandres (2012) identifies the top 20 emerging contaminants for surface water and the top 20 chemicals for purified drinking water based on occurrence, ecological and human health impacts, and the treatment capabilities of water utilities. He notes that public water utilities are in a position to take the first steps in reducing exposure to emerging contaminants by collecting data and possibly implementing controls.
- Engel (2020) identifies Michigan as a leader in creating thorough action and testing plans to address and monitor Per- and Polyfluoroalkyl Substances (PFAS) contamination. State-level action is especially important because of the lack of enforceable standards at the federal

level. Murray and Salim (2019) concur regarding the need for state action. These authors identify state and local level tools/options to address PFAS, including developing comprehensive inventories of sources of PFASs in the region; developing a better understanding of environmental cycling; developing a framework for identifying priority monitoring needs; support studies on potential PFAS impacts to wildlife; increasing understanding of human exposures and potential effects; and initiating or expanding, as appropriate, the incorporation of PFASs into fish contaminant advisory programs. The authors also make recommendations on how states can use federal laws and regulations such as the Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, or US Superfund), and Toxic Substances Control Act (TSCA) to address PFAS.

8. Invasive Species

- Many researchers have attempted to understand the trends of invasive species in the Great Lakes, including key species like zebra and quagga mussels, round goby, non-native *Phragmites* and non-native *Typha* (Bansal et al. 2019; DeRoy and MacIsaac 2020; Evans et al. 2011; Stanton 2018; Tuchman et al. 2009; Tulbure et al. 2007). When assessing the distribution of nine exotic and invasive species in coastal wetlands, Trebitz and Taylor (2007) found that these species were substantially more prevalent in wetlands in Lakes Erie and Ontario.
- The rate of introduction of invasive species capable of becoming established has declined over the past 25 years (to 0.25 species/year), partly due to the 2006 expansion of ballast regulations (Sturtevant et al. 2019)
- Some impacts from climate change are expected to favor invasive species spread, while others will hinder them (Lubner and Simons, 2014; Rahel and Olden, 2008).
- Several websites and tools have been implemented to help monitor and educate the public on invasive species, including the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS; https://www.glerl.noaa.gov/glansis/), AsianCarp.us, and the Phragmites Decision Support Tool (USGS n.d.; https://wim.usgs.gov/phragmites/).

9. Water Infrastructure

- The current price tag for addressing all maintenance, upgrades, and replacement needs for water infrastructure assets across the eight states and two provinces in the binational Great Lakes region is estimated at US$13.6 billion annually over 20 years. However, due to the lack of a comprehensive inventory of the region's water infrastructure assets, the actual needs are likely much greater (Great Lakes Commission 2017a and 2017b). The Healing Our Waters Coalition (2018) used the US Environmental Protection Agency (EPA) Clean Watersheds and Drinking Water Needs Surveys to calculate that the Great Lakes Region needs almost US$180 billion to fund its drinking water and wastewater needs over the next 20 years.
- Across the Great Lake states, US$179 billion is needed over the next two decades to upgrade drinking water infrastructure, according to Molly Flanagan, vice president of policy at the Alliance for the Great Lakes (Tucker 2019).
- An analysis by Headwaters Economics and researchers at the University of Michigan as a part of the Great Lakes Adaptation Assessment for Cities (GLAAC) highlights counties with

high rates of infrastructure spending. Those with the highest rates of spending per capita include coastal Minnesota, the greater Chicago area, northeastern Wisconsin, and counties throughout Michigan (University of Michigan 2023).

10. Affordability and Financing

- According to the Center for Neighborhood Technology (2018), Great Lakes cities are challenged by the loss of residents and industry and higher rates of poverty and unemployment. Many water utilities in these cities are faced with 1) decreased water sales due to fewer customers; 2) legacy infrastructure nearing the end of its service life; and 3) historically low water rates insufficient for adequate infrastructure investment. Water rates are increasing to address funding shortfalls. However, rising water rates significantly impact households that are already experiencing financial distress. Recommendations include asset management, resource conservation and efficiency, appropriate water rates, affordability programs and customer protections.
- The cost of water in the six largest US cities near the Great Lakes--Chicago, Cleveland, Milwaukee, Detroit, Buffalo, and Duluth--has risen rapidly over the past 10 years and is considerably higher than in water-scarce cities like Phoenix, Arizona. Cleveland's water and sewer rates (US$1,249.29 for a family of four in 2017) are higher than in any of the other five cities. In Duluth, MN, the average family of four pays US$1,064 a year for sewer and water. The cost of water for an average family of four in Chicago was about US$178 in 2007 and it increased to about US$576 in 2018. In 2018 in Milwaukee, a family of four paid around US$233 for city water; this rate has gone up approximately 60 percent in the last decade. However, cities are using these increased revenues to improve infrastructure and complete overdue maintenance. Duluth approved an annual rate hike of nearly five percent each year from 2018 until 2023 to pay for the replacement of an average of 4.3 miles (6.9 km) of pipe per year. Northeast Ohio Regional Sewer District (NEORSD) in and around Cleveland has committed to a US$3 billion infrastructure project to dramatically reduce sewer overflow into Lake Erie. In addition, Cleveland Water recently completed a US$650 million investment to modernize treatment plants. Part of Chicago's rate increases are for pipe replacement, but part is to generate money for the city's ailing pension fund for municipal workers (American Public Media Reports 2019).
- The Great Lakes Commission (GLC) (2017a and 2017b) provides recommendations for maintaining water infrastructure in the Great Lakes. Recommendations include maintaining support for the Clean Water and Safe Drinking Water State Revolving Funds (SRF), funding and implementing novel approaches for financing water infrastructure, promoting integrated water resource management, and supporting the use of green infrastructure to help communities manage stormwater.
- Teodoro (2019) evaluated water and sewer service affordability in Ohio. Potential approaches for policy development aimed at improving household-level water and sewer affordability for low-income households include building economies of scale and organizational capacity through utility consolidation, encouraging greater residential water and sewer affordability through rate design, and development of a statewide customer assistance program. Efforts at improving affordability are likely to be most successful when viewed as part of a comprehensive affordability strategy that encompasses many aspects of utility operations, finance and pricing.

- Public-private partnerships may provide opportunities to fund some type of needed infrastructure. A paper by Sinha, et al. (2017) identifies a set of regulatory and other drivers and presents a decision tree that can be used to answer: not only what conditions enable a community to look to the private sector for the delivery or finance of their green infrastructure needs, but also which communities can attract private sector interest. This paper uses the amount of revenues from existing stormwater utilities to identify Milwaukee, Cleveland, Toledo, Fort Wayne (Indiana), and Lima Township (Ohio) as the top five United States CSO communities in the Great Lakes that may be good prospects for public-private partnerships. Among United States Municipal Separate Storm Sewer System (MS4) communities, top prospects include Lake County, Illinois; Kenosha, Oshkosh and Appleton, Wisconsin; and Ann Arbor, Michigan.

11. Economic Impact

- An analysis by the University of Michigan Research Seminar in Quantitative Economics (2018) found that every dollar of federal spending on projects funded under the Great Lakes Restoration Initiative (GLRI) from 2010–2016 will produce a total of US$3.35 of additional economic output in the Great Lakes region through 2036.
- The Office for Coastal Management of the US National Oceanic and Atmospheric Administration (NOAA) reported that from 2009 to 2019 the Great Lakes marine economy in the United States grew by 18 to 28 percent based on metrics including number of marine businesses, employees, average wages, and gross domestic product (NOAA 2022).

12. Agriculture

- There is a surging demand for food crops (Dhatrak 2020), and both rising populations and shortages of agricultural lands are key driving factors for the farming market (Business Wire 2018).
- The US agricultural sector is advancing from a technological perspective. There is growing implementation of advanced technologies in farming for maximum profitability and production, availability of low-cost cloud services and an increasing need for remote monitoring services. These advances are supported by an increasing focus on farm efficiency and productivity, reductions in the costs of sensors, and the increasing adoption of Big Data and “Internet of Things” (IoT) in smart farming (Business Wire 2018).
- Among consumers there is a push to shift to purchasing products that are organic and chemical-free to ensure healthy living; this growing consciousness is driving the farmers to adopt technically advanced tools to fill this desire (Dhatrak 2020).
- Important in-field agricultural trends include gradually increasing yields with gradually decreasing fertilizer application, and an overall reduction of fertilizer application to equal or fall below crop needs. The total numbers of animals (in the Lake Erie basin) have remained fairly constant over time, except for increases in swine and chickens, but there is a trend toward higher concentrations of animals per farm (LimnoTech 2017).
- Some sources point to increasing rates of drainage tile installation. Few data exist that quantify actual trends in tile drainage in the Great Lakes basins. Anecdotal evidence suggests that tiling has increased in the recent decade, both in acres tiled and in the relative efficiency of installed systems (LimnoTech 2017).

- For much of the 20th century, there has been a strong trend for farm consolidation, with declining numbers of farms, and larger overall farm sizes. Given US Department of Agriculture (USDA) census data from QuickStats, it appears the majority of US Western Lake Erie basin cropland acres are owned by a relatively small number of farms, and that there has been a continuing trend towards fewer and larger farms in both Canada and the United States. While farm acreage decreased by six to seven percent, the number of farms decreased by two to three times as much (11 and 20 percent; USDA 2011). Trends as well as the distribution of farm sizes and numbers are comparable in Canada and the United States (LimnoTech 2017). In addition to the number of farms decreasing, the number of agricultural cooperatives in the United States has declined. However, based on data between 1976 and 2016, their size, total assets and equity have been increasing (Demko 2018).
- Valliant et al. (2017) found that farms diversifying their agricultural products are going against a prevailing trend of product specialization.
- Greenhouse vegetables have, in recent years, been a growing industry in Ontario. From 1979, the total reported production of greenhouse-grown tomatoes, cucumbers, and peppers has increased from approximately 23,000 tonnes to over 520,000 tonnes. Greenhouse vegetable production in the midwest United States is growing as producers move to take advantage of decreased transit times to population centers, abundant water resources, and affordable utilities (LimnoTech 2017).
- There is an indication that the adoption of some practices that support for the 4Rs (Right Source, Right Rate, Right Time, Right Place for fertilizer application; https://nutrientstewardship.org/4rs/) is increasing. The rate of soil testing is quite high, at about 75 to 86 percent. The use of broadcasting fertilizer without incorporation seems to be decreasing. On the other hand, winter application seems to have increased, with the opposite trend for spring application. There appears to be an increase in the broadcasting of fertilizer on the soil surface followed by incorporation into the soil by some form of tillage (LimnoTech 2017).
- Burnett et al. (2018) reviewed some of the driving factors that predict farmers' adoption of certain BMPs. They found farmers were more likely to be using cover crops already if they were more willing to take risks, more educated, owned more acreage, had a higher sense of control over nutrient loss, and had stronger beliefs about the effectiveness of cover crops at reducing phosphorus runoff. Farmers were more willing to adopt cover crops in the future if they were younger, had a stronger conservation identity, owned more acreage, had less gross farm income and had greater response efficacy. Denny et al. (2019) found that farmers who reported being risk-takers concerning new practices and those with a college education both used more BMPs on average than farmers who did not. They also found that, for part-time farmers, the amount of time they work off the farm can shape their BMP adoption. Part-time farmers (those working 50 to 199 days off-farm per year) were less likely to use more BMPs compared to full-time farmers who did not work off-farm. Finally, they found the number of BMPs a farmer used in the past, uses now, and intends to use in the future increases as their stewardship attitudes do.

13. Renewable Energy

- The Great Lakes Basin is home to more than 580 power plants with a combined capacity of over 69,000 megawatts (US Energy Information Administration 2009a). More than 80

percent of this power generation involves a steam cycle fired by coal, natural gas, or nuclear fuels. As over 62 percent of this generation uses open-cycle cooling (a water-intensive process in which cooling water flows from its source through the plant condenser and then directly back to its source), the electric power sector draws more water from the basin than any other sector. The US Geological Survey estimates that thermoelectric power accounts for 98 million cubic meters of water withdrawals per day, or 76 percent of total water withdrawals in the Great Lakes basin (Kenny et al. 2009). The majority of these withdrawals, 79 percent come directly from the Great Lakes." (Quoted from Tidwell and Pebbles 2015.)

- Various Great Lake states have set renewable energy portfolio standards or goals (Table 1) (Ye 2018).
- Offshore wind would likely involve multi-state cooperation (Conger, 2011). The Icebreaker Wind project off Cleveland has been under development for over 10 years (Pollack 2020). New York and Illinois have shown interest in building the necessary workforce and supply chain (Stromsta 2020). The New York State Energy Research and Development Authority (NYSERDA) is currently conducting a feasibility study that will also look at the potential for floating turbines (Prohaska 2021). The National Renewable Energy Laboratory (NREL) found that Michigan had the most potential with generation covering three-quarters of Michigan's predicted electricity use by 2050, assuming full decarbonization (Haelterman 2021).
- Downtown Toronto buildings use a Deep Lake Water Cooling System for air conditioning to reduce electricity use, especially in the summer months. Drawing frigid, clean water from below the thermocline, it is the largest system of its kind in the world, and it also provides drinking water (Langan 2007). Whether climate change could threaten this system is of interest in shallower Great Lakes (Anderson et al. 2021)

Table 1. Renewable energy power targets by state.

State	Most Recent Policy Year	Target Standard
Illinois	2016	25 percent by 2025 (with 75 percent of the goal coming from wind and six percent coming from solar)
Indiana	2011	10 percent by 2025
Michigan	2021	15 percent in 2021
Minnesota	2013	30 percent from utilities with nuclear by 2020 and 25 percent from utilities with other assets by 2025, along with a required 1.5 percent purchase from solar switching to 10 percent in 2030
New York	2016	50 percent by 2030 (customers 70 percent by 2030, and 100 percent by 2040)
Ohio	2019	8.5 percent by 2026 (reduced benchmark from 2008)
Pennsylvania	2004	18 percent by 2021
Wisconsin	2006	10 percent by 2015

14. Public Health

- The IJC Great Lakes Water Quality Board conducted an opinion poll on many Great Lakes topics. Among the results was a finding that approximately three-quarters of respondents either agreed or strongly agreed with statements that the health of residents or the economy of the region would suffer without healthy Great Lakes. There were no significant regional differences, but indigenous respondents were more likely to agree and agree more strongly than the non-indigenous population (Graydon, 2019).
- An online survey of local health departments in Michigan found 62 percent of respondent jurisdictions have experienced climate change in the last 20 years, "*and 77% agreed that climate change will impact their jurisdictions in the coming 20 years. However, only [about a third] of Michigan officials agreed that climate change is a priority in their departments. About one quarter [of] respondents did not know about the level of expertise of either the state and federal agencies, responsible for assisting them with information and programs related to climate change and health"* (Carter et al., 2021). The Network for Public Health Law used a Great Lakes Integrated Sciences and Assessments (GLISA) grant to "partner with public health associations and departments to determine how to enhance practitioners' capacity to utilize public health law to address climate change. The project consists of online webinars and a small number of in-depth, in-person trainings" (Kreuger 2021).

Driver Threats

1. Demographics

- Many parts of the Great Lakes region face severe demographic challenges, including both urban and rural areas. Manufacturing jobs fell by over one third in the first decade of the 21st century. The proportion of its residents who are 65 and over is growing rapidly. State and local governments in the Great Lakes states face growing fiscal constraints (Pendall et al. 2017).

2. Vulnerable Populations and Sectors

- Poverty rates in Canada and the United States have both declined in the region in recent years. Poverty in Ontario dropped from 18.1 percent of all families in 2013 to 13.8 percent in 2019 (Robinson et al. 2021). Similarly, poverty in Michigan dropped from a peak of 17.4 percent in 2011 to 13.7 percent in 2020 (US Census data reported by Statista; https://www.statista.com/statistics/205477/poverty-rate-in-michigan/). Note that white residents in Michigan still have substantially lower poverty rates than black (24.7 percent), Native American (21.9 percent) and Hispanic (18.2 percent) residents in 2020.

3. Climate

- Currently, only one percent of the world's land mass experiences wet-bulb temperatures greater than 35 degrees C (95 degrees F), generally considered to be the upper limit of human habitability. By 2070, however, that portion could go up to 19 percent. This could result in a mid-range number of 50 to 300 million displaced people globally (Lustgarten, 2020a, 2020b and 2020c).
- Scientists have estimated from state-level data in Mexico that "a 10% reduction in crop yields would lead an additional 2 [percent] of the population to emigrate," (Feng et al. 2010). This may translate to a rise from an estimated 700,000 migrants arriving from Central America and Mexico in 2025 to 1.5 million a year by 2050 ((Lustgarten, 2020a, 2020b and 2020c).
- There are a lack of international legal frameworks to deal with the range of climate consequences from forced displacement to migration (Sherbinin, 2020) and a lack of frameworks to understand how to address the causes and impacts (Yayboke and Staguhn 2020). While there are many historical examples of climate-induced population shifts, the causal chain is often complex, and this is just one of many adaptation mechanisms – and typically not the first choice for most individuals or groups (McLeman 2014). For example, in the Dust Bowl era, from 1929 to 1934, crop yields across Texas, Oklahoma, Kansas, and Missouri dropped 60 percent, resulting in 2.5 million people moving out of the region (Lustgarten, 2020a).
- At the regional level, scientists estimate the habitable suitability zone will move towards the Midwest in 2070 under Representative Concentration Pathway (RCP) 4.5, or under RCP 8.5 nearly beyond the Canadian border, suggesting a shift in where Americans live and grow food (Shaw et al., 2020). Research that couples climate with changes in wage rates and housing prices, however, suggests that these factors dampen migration patterns, resulting in an estimated 5.5 percent decline in gross regional product for the Midwest. (Fan et al. 2018).

- At the state and local level, sea level rise-based in-migration estimates for US counties on ocean coasts suggest that New York, Illinois, Ohio, Michigan, Indiana, Minnesota and Wisconsin all stand to gain, in descending order, under a 1.8-m sea-level rise scenario (Hauer, 2017). In contrast, other researchers have found relatively few people will move to the Midwest based on more recent hurricane-related data, though there will be substantial indirect effects to supply new population centers (Robinson et al. 2020). Models that look to other hazards, however, see relatively large gains to be made in St. Paul, Minnesota; Madison, Wisconsin; Toledo, Ohio; and Buffalo, New York (McDonnell and Shendruk 2020).
- The American Society of Adaptation Professionals commissioned work on understanding Michigan's place and potential for climate migration (Schneider 2021; Sullivan and Jacobson 2021). A specific study on Southeastern Michigan by Hauer suggested there could be an additional 50,000 climate migrants by mid-century, creating a need for water infrastructure upgrades (McDonnell and Shendruk 2020; Stults 2020). Tourism patterns are already shifting, with greater emphasis on summer or winter, lengthening the activity during shoulder seasons (Nissen 2017).
- Second-order studies looking at policy responses are varied. For example, a variety of stakeholders considering how to manage potential change with land trusts, etc. (Main and Lindsay 2021). Buffalo has already declared itself a climate refuge city (McDonnell and Shendruk 2020; Vock 2021) and Duluth has a slogan of "Climate Proof Duluth" (Pierre-Louis, 2019; Kraker, 2021; Sutter, 2021). North of the border, a Canadian group of business and academic elites called for a population target of 100 million by 2100 (Century Initiative, 2021). The Canadian Government independently examined the international dimensions of climate change (Eyzaguirre et al. 2021)

4. Water Quality

- Some CSO control projects are not as effective as planned, potentially due to increased precipitation and runoff due to climate change. Milwaukee is still experiencing CSOs despite completing its Deep Tunnel in 1993. For example, while Milwaukee's permit allows only six CSO overflows per year, by October 2019, six had already occurred (Lydersen 2019).
- Stormwater control is still a challenging issue. Multiple papers describe the barriers to green infrastructure implementation and stormwater control (Beery 2018; Belise and Bogert, 2011; Great Lakes Stormwater Collaborative 2019; Great Lakes Commission and Credit Valley Conservation 2018; Polich 2017). Barriers to innovative designs of stormwater management technologies and designs include difficulty matching technology to needs, confidence in the performance of innovative technologies, uncertainty over cost and cost/benefit, risk aversion, and lack of regulations, leadership and coordination (Great Lakes Stormwater Collaborative 2019). The need to implement green infrastructure on private property is also increasing to address gaps in the ability to address needs through potential projects on public land. The greatest barrier to taking action to control stormwater on private property was cost; other barriers were time, adequate information, aesthetics and opinions of neighbors (Beery 2018).

5. Drinking Water

- Multiple researchers identify specific threats to drinking water in Canada's First Nations. Klasing (2016) notes that the Canadian federal government has no binding regulations for

water on First Nations reserves. In addition to the lack of binding regulations, Klasing identifies problems including persistent under-funding and arbitrary budgeting for water system costs, including the capital, operation, and maintenance costs; lack of support for household water and wastewater systems; worsening conditions of source water; and lack of capacity and support for water operators. According to Lui (2015), as of January 2015, there were 1,838 drinking water advisories in effect across Canada, including 169 in Canada's First Nation communities.

- Weak environmental laws, industrial pollution, and water privatization continue to put drinking water sources at risk. Canada's Water Research Institute (2001) identified water quality-related threats to drinking water and aquatic system health. In addition to wastewater effluent and polluted runoff from urbanization, these include waterborne pathogens; algal toxins and taste and odor; pesticides; persistent organic pollutants and mercury; endocrine disrupting substances; nutrients (nitrogen and phosphorus); aquatic acidification; ecosystem effects of genetically modified organisms; landfills and waste disposal; agricultural and forestry land use impacts; natural sources of trace element contaminants; and impacts of dams/ diversions and climate change.

6. Coastal Wetlands

- Climate change is expected to significantly reduce the quantity and quality of Great Lakes coastal wetlands. It is expected that lower lake levels in the future will cause many coastal wetlands to be lost or degraded, resulting in alterations in plant and wildlife composition and a reduction in ecosystem services – for example: fish and wildlife production, habitat for rare and endangered species, shoreline protection against wind and waves, aesthetics and green space, water storage for flood protection, groundwater recharge, water filtration and pollution control, and carbon sequestration (Christie and Bostwick 2012; Great Lakes Commission et al. 2014; Mortsch et al. 2006). Mortsch et al. (2006) assessed the vulnerability of select Great Lakes wetlands to four climate change scenarios using literature sources, field surveys, stakeholder engagement, and modeling.
- Rising lake levels in recent years have damaged coastal wetlands, like those at Illinois Beach State Park, which has the potential to release large amounts of stored carbon into the atmosphere (Briscoe 2018).
- The Great Lake Commission and National Wildlife Federation (2014) created a toolkit with 18 different strategies and practices (institutional and project-level) to help Michigan's coastal wetlands adapt to climate change. The online toolkit is available at https://www.glc.org/library/2014-best-practices-for-climate-change-adaptation-mi-wetlands.
- The Great Lakes Coastal Wetland Restoration Assessment (GLCWRA; glcwra.wim.usgs.gov) uses models to identify, assess, and restore areas along the US coast of the Great Lakes that have the most potential to restore coastal wetland habitat. Models have been developed for Western Lake Erie, the Connecting River System, and Saginaw Bay, with assessments for Green Bay and Lake Ontario available soon.

7. Emerging Contaminants

- Emerging contaminants of concern include pharmaceuticals/personal care products (PPCPs), microplastics, PFAS, and excess nutrients causing harmful algal blooms.

- Elliott et al. (2017) conducted a basin-wide study to identify the presence of CECs and other chemicals of interest in 12 US tributaries to the Great Lakes during 2013 and 2014. Cluster analyses revealed chemicals that frequently co-occurred such as pharmaceuticals and flame retardants at sites receiving similar inputs such as WWTP effluent. Concentrations of multiple chemicals of concern often exceeded benchmarks. Corsi and Walker (2016) studied the presence and concentrations of several classes of emerging contaminants in the Great Lakes and their tributaries. Water-quality benchmarks were exceeded at 35 percent of the 57 sites monitored for trace organic chemicals. In the waterborne pathogen study, human and bovine viruses were detected in 17 percent and 18 percent of samples, respectively. Microplastics were found in all 107 samples collected from 29 tributaries of the Great Lakes.
- Klaper and Welch (2011) suggest that combinations of emerging contaminants similar to those found in the environment may have an even greater impact than individual chemicals and that most exposures to these chemicals are long-term and chronic. They note that despite this finding, most current studies focus on the effects of a single chemical in the lab, and few studies document the effects of long-term exposures.
- The Alliance for the Great Lakes (2010) summarizes the impacts of pharmaceuticals on humans and wildlife, identifies sources, summarizes research on pharmaceuticals at drinking water intakes and wastewater discharge points, summarizes existing policy, summarizes source reduction measures, and identifies areas where additional research and/or legislative change is needed.
- Blair et al. (2013) evaluated the concentration, and corresponding risk, of PPCPs from a wastewater effluent source at varying distances in Lake Michigan. PPCPs were detected in surface water and sediment up to 3.2 km (2.0 miles) away from the shoreline. 14 PPCPs were found to be of medium or high ecological risk based on a comparison of the maximum measured environmental concentrations to the predicted no-effect concentration (PNEC).
- Rochester Institute of Technology estimated that nearly 22 million pounds of plastics (10 million kilograms) enter the Great Lakes every year. WWTPs can be a source through effluent and runoff from biosolids land application (Hettiarachchi 2019).

8. Invasive Species

- Invasive species have ecosystem-wide effects on the Great Lakes, altering biodiversity, habitat structure, productivity, water quality, contaminant cycling and ecosystem services (DeRoy and MacIsaac, 2020; Evans et al. 2011; Pagnucco et al. 2015). Aquatic invasive species negatively influence many industries (sport and commercial fishing, water treatment, power generation, industrial facilities, tourism) by requiring direct expenditures to combat invasive species or repair damage and indirect costs like reduced productivity and higher prices. It is estimated that aquatic invasive species currently cost the Great Lakes region over US$100 million annually (Lauber et al. 2020; Rosaen et al. 2016).
- Many researchers have attempted to predict and quantify the future impacts of invasive species (Davidson et al. 2017; Lauber et al. 2016; Pagnucco et al. 2015; USEPA 2008). The future spread and impacts of invasive species are expected to be exacerbated by anthropogenic stressors, including live trade and climate change. Climate change is expected to lift thermal barriers, enhance the competitive and predatory effects of invasives on native species, and increase the virulence of some diseases (Pagnucco et al. 2015; Rahel

and Olden, 2008). Climate change is also predicted by some to reduce lake water levels, increasing the potential for invasive macrophytes, like non-native *Typha* species (Lishawa et al. 2010).

- Many researchers have attempted to assess the potential spread and impact of Asian Carp (Alsip et al. 2020; Wittmann et al. 2014; Zhang et al. 2015). Asian Carp are believed to be a major threat to the Great Lakes, where they are expected to disrupt food webs and fisheries due to their high consumption of plankton. It has been predicted that, if invasion occurs, they could account for a third of the total fish weight in Lake Erie and cause a decline in most other fish species (Zhang et al. 2015).

9. Water Infrastructure

- As cited by the Great Lakes Commission (2017a and 2017b), the American Society of Civil Engineers projects a US$500 billion loss to the national economy and the loss of nearly 500,000 jobs by 2025 from not making needed investments in the nation's water infrastructure. In contrast, water infrastructure investments will create jobs and strengthen the economy. Every US$1 million spent on water infrastructure is projected to generate nearly US$3 million in economic output, and every new job created in the water workforce is estimated to add almost four new jobs to the national economy.

10. Affordability and Financing

- Zamudio and Craft (2019) found that many cities have been forced to raise rates to deal with failing infrastructure. With the federal government allocating less money for water infrastructure, most cities passed the costs on to their customers, including those who can least afford the increases. The rising cost of water has hit poor families the hardest (Zumudio and Craft n.d.); the government-run water utilities in these six cities have issued at least 367,740 shutoff notices in the past decade. An analysis of shutoff data revealed disproportionately high concentrations of water shutoffs in poorer areas and majority black and Latino neighborhoods in every city. They cite a potential solution supported by Manuel Teodoro, associate professor at Texas A&M University, which is for city water departments to change their pricing structure. He is advocating that utilities switch to a new formula he has researched that better reflects how much families can afford to pay for water by basing rates on the hours people work, using an hourly minimum wage. This research was used by officials in Phoenix to restructure water rates to increase affordability and equity.
- Rockowitz et al. (2018) found that, despite the provision of assistance, low-income customers continue to pay unaffordable water rates, requiring them to cut-back on other expenses needed to lead healthy and productive lives. It also demonstrates that low-income customers value and are willing to pay what they can afford for water and wastewater service. Recommendations include: pursuing system efficiencies and equitable cost-sharing across the region to reduce fixed costs to residential customers; providing adequate funding for assistance – including securing new financing – for discounts; arrearage forgiveness, household repairs and fixture replacements; exploring alternative rate structures; guaranteeing shutoff protection for households with vulnerable populations; increase outreach to residents unfamiliar with the program; incentivize participation in assistance

programs through financial support, co-administration, etc.; and expand eligibility for assistance and support for those at or above 150 percent of the Federal Poverty Level (FPL).

- Drainage fees and other stormwater-related charges are controversial to rate payers and may cause economic hardships to some residents. Horan (2019) writes about Detroit, where residents sued the City over the drainage fee, but lost their case when the charge was ruled a fee and not a tax. His article states that some communities may be hesitant to adopt stormwater or drainage fees because they fear lawsuits like the one filed against the Detroit Water and Sewerage Department. He continues by noting that one method for other communities in Michigan to address funding needs is for the state to pass legislation offering a roadmap for communities to set up separate stormwater utilities that would fund infrastructure upgrades. Other community-wide issues can impact the implementation of fees. According to the Duluth Tribune (2020), Duluth Utilities Commission voted to delay the increase in stormwater utility fees due to the financial hardships of COVID-19.

11. Economic Impact

- From 2000 to 2010, manufacturing jobs in the US Great Lakes region fell by 35 percent or nearly 1.6 million jobs. The region added 1.2 million jobs from 2000 to 2015 but most of these were low-wage positions (Pendall et al. 2017).
- The educational system in the Great Lakes, especially the highly ranked regional public universities, are an asset that has strong potential to drive economic recovery over the next few decades (Maxim and Muro 2020).

12. Agriculture

- Work conducted by Morton et al. (2017) found that farmers' uncertainty about projected climate change impacts on their production systems is influenced by their beliefs about climate change, experiences with drought, concern about heat stress on crops, and agricultural information networks. Results from a random sample survey show the majority (89.5 percent) of farmers in the Upper Midwest perceived there was too much uncertainty about the impacts of climate to justify changing their agricultural practices and strategies, despite scientific evidence regarding the causes and potential consequences of climate change.
- Mase et al. (2017) found that farmers' perceptions of risk to their farm, attitudes toward innovation, and adaptation attitudes were the most important determinants of climate change adaptation.
- Climate change adaptation will be particularly important for specialty crop producers. Temperature and precipitation fluctuations across the Midwest directly impact specialty crop production quantity and quality as well as indirectly influence the timing of crucial farm operations and the economic impacts of pests, weeds and diseases. Increasingly variable weather and climate change pose a serious threat to specialty crop production in the Midwest. Current weather-induced losses can vary by state, with excessive moisture resulting in the highest total number of claims across all Midwestern states followed by freeze and drought events. Overall, specialty crop growers are aware of the increased production risk under a changing climate and have identified the need for crop-specific weather, production, and financial risk management tools and increased crop insurance coverage (Kistner et al. 2018).

- Liang et al. (2017) found that the total factor productivity (TFP) of the US agricultural economy has grown continuously for over half a century, with most of the growth typically attributed to technical change. To date, the aggregate effects of these regional climate trends on TFP have been outweighed by improvements in technology. Should these relationships continue, however, the projected climate changes could cause TFP to drop by an average of 2.84 to 4.34 percent per year under medium to high emissions scenarios. As a result, TFP could fall to pre-1980 levels by 2050 even when accounting for present rates of innovation.
- While not a new threat, agriculture does continue to be subject to profitability risks. While productivity improvements have lowered operating costs for farmers over this span, they have also contributed to lower real prices for their goods (as supplies have increased). Corn and soybean yields (bushels per acre) in the five states of the Seventh Federal Reserve District have more than doubled over the past 55 years, but in the cases of corn and soybeans, their real prices have been trending lower over the past five decades (Oppedahl 2019; Schnitkey 2017). Prices for key agricultural products have fallen from their peaks in recent years, while input costs have not fallen as much. Consequently, many farm operations in the Midwest have had lower revenues and thinner profit margins—and some even losses (Oppedahl n.d.).

13. Renewable Energy

- Although substantial investments have been made in renewable energy in recent years in the Great Lakes region, many obstacles remain. Proposed offshore wind energy projects have routinely been delayed by legal challenges (St. Clair 2022), technical barriers and uneven government and private sector investments (The Nature Conservancy 2020). Ontario has had a moratorium on offshore wind development in the Great Lakes in place since 2011 (CBC 2017).
- High natural gas prices due to Eurasian conflicts and resulting increased global demand have made renewables more competitive in recent months (Mulder 2022), but it is unclear how long this situation will continue.

14. Public Health

- In addition to the lingering effects of the COVID-19 pandemic, public health in the Great Lakes continues to suffer from widespread chronic conditions including obesity, diabetes, asthma, and heart disease. The impacts of all of these conditions are amplified by climate change, and minority communities with high poverty rates, especially in urban areas, are especially vulnerable to health disparities in comparison with more affluent communities.

DRIVER PRIORITIZATION

Volume 2 of the Millennium Ecosystem Assessment (2005), launched by the United Nations in 2001, defines a system driver as “any natural or human-induced factor that directly or indirectly causes a change in an ecosystem”. Anticipating potential system-wide scale changes to the Great Lakes requires a broad and thorough scan of the drivers behind the current symptoms of water quality impairments and scenario analysis (Creed and Laurent 2015). In addition, a systemic analysis also requires understanding shifting patterns and conditions, which may include

demographic shifts within and external to the region; climate, land use and water use trends; or conflicts driven by differences in water access, water availability, and droughts worldwide. These changes may create new threats or exacerbate existing ones in the Great Lakes region.

The IJC-WQB critically needs such broad scans to identify the direct and indirect factors that will influence water utilization, water quality, commerce and trade, maritime use patterns, pharmaceutical use, infrastructure state and condition (including stormwater, drinking water and wastewater in particular), and thus overall Great Lakes health, over the next several decades. The more that is understood about what these systemic influences (considered perhaps as the "demand function" for the Great Lakes) will or might be, the better we will be able to infer and anticipate potential and emerging threats to the lakes and the region.

Similarly, the Great Lakes has a "supply function" that has seen major and rapid change. This is largely the characteristics of how water (rain, snow, and ice) is delivered to the Great Lakes: the intensity, the evaporative loss, ice cover, and other climatic functions. Other types of supply functions, however, include human and financial capital, ecological capital, the built environment, stable governance structures and shared societal values.

This project has built on the past Great Lakes Futures Project (Creed and Laurent 2015) and resulting scenarios, and other work on developing adaptive capacity in the Great Lakes, including the IJC Great Lakes Science Advisory Board's Great Lakes Early Warning System (GLEWS) project. Additional recent or current work related to the topic includes Great Lakes Policy Research Network studies of water governance indicators; Ohio State Sustainability Institute's National Science Foundation project on Climate; University of Minnesota's project on Governance Variability and Great Lakes Communities; the University of Minnesota's Great Lakes Environmental Indicators (GLEI) project; the University of Michigan Sustainability Institute's Great Lakes Environmental Assessment and Mapping (GLEAM); work of the Great Lakes Observing System (GLOS) on Smart Great Lakes; and work by the Council of the Great Lakes Region (CGLR) and others on the circular economy.

The analysis has included deep consideration of the effects of supply and demand functions on a wide range of people, residents, visitors and the coming groups of citizens in the Great Lakes. Also considered throughout are the effects of such future scenarios on Indigenous peoples and their ways of life. Of equal importance is the consideration of issues related to access, equity, justice and voice as related to water and in particular, water quality.

The goal of this project has been to understand the forces that will have a material effect on the Great Lakes (ecologically, economically, socially, and culturally) over the next 30-plus years. Further, it has been to take the current understanding of these impingements and system changes and turn them into a small set of cogent actionable scenarios.

The project has identified potential system-wide emerging conditions and threats and has highlighted the external drivers (forcing functions) that may impact Great Lakes water quality and the region beyond those that are typically considered such as newly identified chemicals or failing infrastructure. The project has produced a set of deeply informed scenarios that describe potential

future trajectories and end states for the Great Lakes of the future, and a set of signposts for identifying which trajectory we may be on along the way in 2030, 2040, or 2050.

The three specific objectives of this analysis were to:

- Identify and prioritize emerging and potential long-term system-scale conditions, impingements, policy effects and threats to Great Lakes water quality through examining trends and projected future conditions in Canada and the United States economic sectors and trade shifts including agricultural supply chains, energy, transportation, climatological changes, socio-geopolitical and demographic shift, public health and medical domains.
- Frame these system-wide conditions into a small suite of plausible and defensible forecasts or projections and identify critical signposts to identify and reinforce which path is most likely emerging in the region as the dominant path in Canada and the United States.
- Identify policy and scientific gaps in Canada and the United States that materially add to forecast and scenario uncertainty. Recommend engagement, monitoring and governance strategies including improving the inherent capacities of governments and nongovernment sectors to anticipate and respond to these uncertainties.

Drivers Symposium

On June 15, 2021, the Great Lakes Horizons contractor team facilitated a symposium to identify and prioritize future drivers of Great Lakes water quality and societal health. Over thirty people participated and were divided into four breakout groups to discuss drivers pertaining to: 1) societal values, governance, and geopolitics; 2) population trends, economic development, and trade; 3) climate change and infrastructure; and 4) biological, ecological, and chemical systems. After discussing these driver categories, all participants joined a large group to prioritize drivers by vote. Following the symposium, the project team conducted a system mapping exercise (Figures 3, 5, 7 and 9) to illustrate and explore interrelationships among the drivers discussed during the symposium. The team also completed the literature review summarized above, which was used in part to prepare discussion topics for the symposium and in part to develop information related to each driver. This work provided part of the basis for regional engagements that explored opportunities to manage these drivers toward maintaining and growing the vibrancy of the Great Lakes region at the subregional scale.

Category 1: Societal Values, Governance and Geopolitical Drivers

Prioritized threat: Power conflicts and diminished external water security

Ambiguous drivers: Tension of local, regional, and global rights and responsibilities

Prioritized opportunities: Populist water culture/citizenship, collaborative governance

The Societal Values, Governance, and Geopolitical Drivers breakout group discussed a variety of wide-ranging topics at multiple scales, including:

- **Regional trends in land tenure from changing tourism patterns and usage of second homes:** The COVID-19 pandemic had immediate impacts on travel, decreasing visits to urban

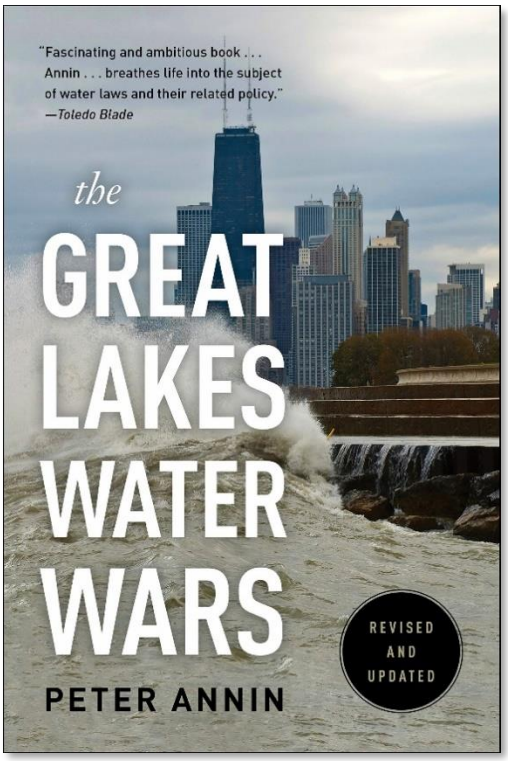
centers, and increasing recreation activities. Over time, it is uncertain if the trend will return to pre-pandemic levels, especially with the increased adoption of remote and hybrid work patterns for some workers, which may facilitate the dispersion of the population, or shift permanently towards preferential locations along the lakeshore and near other amenities. Regardless, with movement in and out of cities, or between inland and lakeshore areas, the tenure on the land of residents will be transformative, along with their accompanying political priorities and other socioeconomic influences.

- **Broader societal shifts in government function and democratic priorities:** Federal elections in 2020 and 2021 in the United States and Canada, respectively, resulted in a shift towards increased spending on social welfare programs and infrastructure. South of the border, increasing grassroots activism has introduced new policies. In contrast, federal-level apathy and center-right politicians at the provincial and metro-Toronto levels leave more of a mixed picture for policy directions, despite the continuation of large infrastructure projects such as Port Lands 2024.

The conversation also touched upon the existence of several potential feedback loops (i.e. driver relationships that are mutually reinforcing and can act towards persistent and/or amplified outcomes):

- **Balance of government authority and resources:** The political parties on both sides of the border tend to set different bounds for what they see as the realm of government authority and the relative level of resources assigned to socioeconomic or environmental policies. Currently, with economic expansion and greater interest in solving long-standing infrastructure and climate change challenges, both authority and resources are increasing, but over the long term this tends to balance, and the pendulum could swing back to a lower authority and resource regime.
- **Push-pull of technical versus traditional knowledge:** While the Great Lakes system has historically been maintained through quantitative metrics and legal agreements, recent scholarship and political advocacy have increased awareness of traditional knowledge from the lived experience of area residents, especially indigenous communities. In part, the socio-environmental justice movement has had a self-reinforcing impact on increasing the prominence of diversity, equity and inclusion outside typical power structures in political dialogue.

Perhaps in part the product of national elections in Canada and the United States, participants saw the greatest threat to be cultural-political power conflicts (Annin 2018; book cover shown in Figure 2). The interplay of existing residents and new immigrants has created a dynamic landscape, a trend that is likely to continue if not accelerate. As new groups establish greater democratic rights, grassroots activism could drive power conflicts with established interests. Not only is this trend present at the local, provincial/state, and federal levels, but likely to engage decision-makers in geopolitical dialogue, where the Great Lakes will be seen as one of several places around the world where likely diminished water security outside of the region may potentially lead to conflict. Other breakout groups explored in more detail many of the implications of a water-rich region, but this breakout group discussion focused on the potential value-based decision point of whether the Great Lakes would be a sustainable versus an extractive economy.

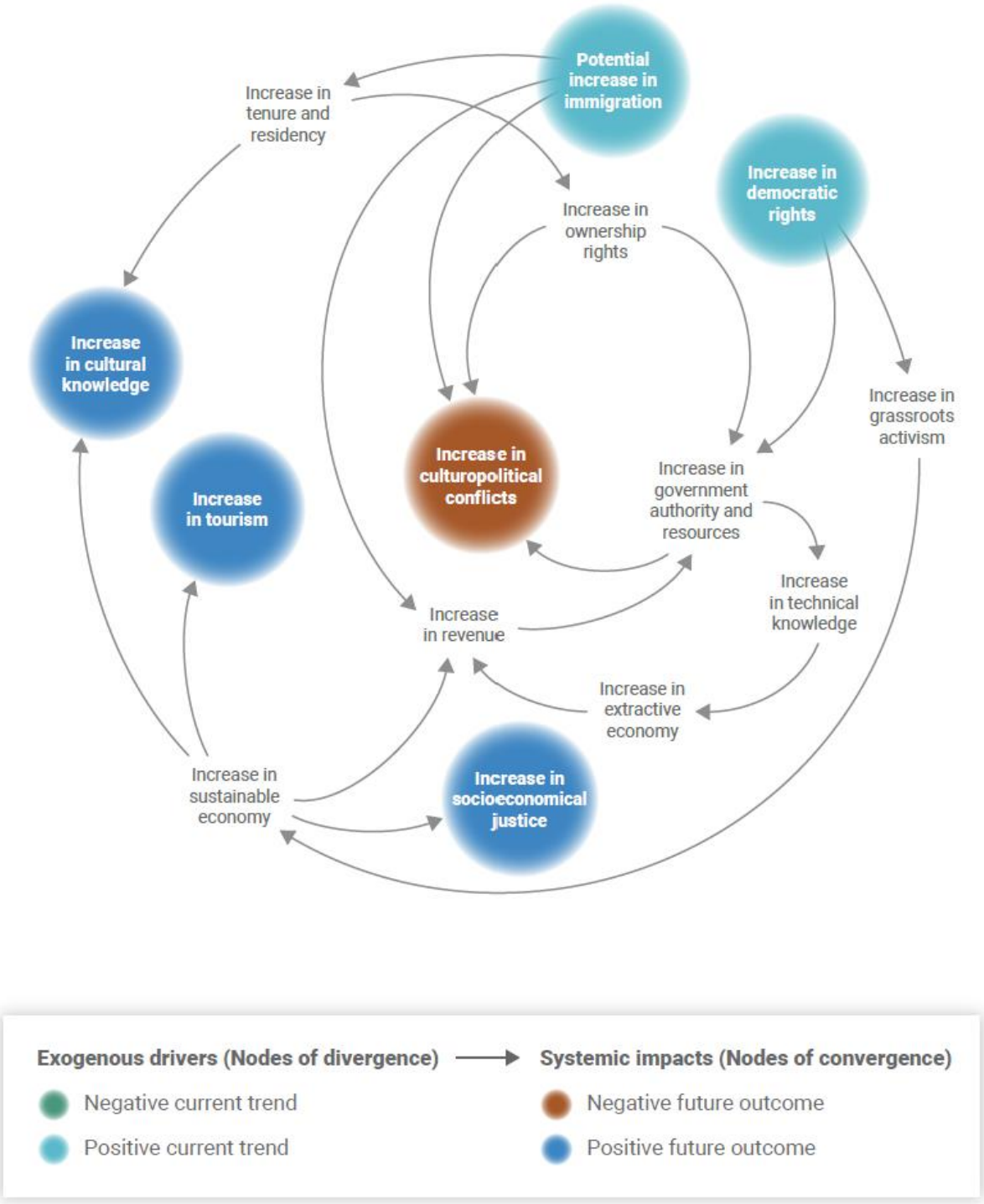


The context surrounding these potential future power conflicts, especially over water security, is contingent on two sets of ambiguous drivers. First, whether the region experiences a dramatic shift in population stock, or even grows substantially, because of climate refugees. Second, the relative location (urban/peri-urban, states or provinces, etc.) and emergent politics of these hypothetical individuals and groups are yet too uncertain to understand fully the future condition as an opportunity for greater prominence of the Great Lakes and/or a potential threat to existing physical and socioeconomic infrastructure. Participants felt this uncertainty merited its own second-order ambiguity: what decision-makers might do in the face of these tensions about local, regional and global rights and responsibilities. There is a clear opportunity for leadership, but will the people and systems be in place to embrace the change and thrive?

The focus group participants were encouraged by the continuing and deepening of long-standing trends toward collaborative governance, with the alignment of foundations and interest groups at least at the local and state/provincial levels. Likewise, the binational stewardship of Canada and the United States was held in high regard, though recent trade-based fractures in the relationship were noted as a potential threat on the horizon. Overall, the region has seized the opportunity, but there is room for growth and greater stability. Individuals suggested that this could be bolstered by the development of a populist water culture or sense of shared citizenry around the Great Lakes. Along the lines of the Dutch, representatives suggested that aspects of existing frameworks and localized understandings have the potential to coalesce around a more sustainable set of socioeconomic values and anchor cultural-political discourse with water quality as a shared set of values and vocabulary.

A causal loop systems mapping diagram (Figure 3) was developed for this driver category and those described below. These diagrams show positive and negative feedbacks and loops, as well as points of divergence and convergence. Systems mapping can provide a simplified conceptual understanding of a complex system, such as those described here. Note that there is overlap among the four diagrams.

Figure 2. Systems mapping diagram for societal values, governance, and geopolitical drivers.



Category 2: Population, Economic Development and Trade Drivers

Prioritized threat: Dispersed development

Ambiguous drivers: Climate refugees' immigration to Great Lakes region

Prioritized opportunities: Decarbonization and the energy transition

Discussions in this group were centered around three topics: growth in land-intensive renewable energy development, large-scale shifts in agricultural land use, and dispersed residential development toward lower-density places with water recreation and beauty (see the uneven spatial intensity of coastal environmental risk in the map shown in Figure 4).

Growth in solar and wind energy was presented as an opportunity to supplant farmland which would reduce soil and fertilizer loss to water bodies. Participants also pointed to the potential for a transition away from coal as a path toward reducing legacy contaminant levels such as mercury. However, land use policy, including federal subsidization of grains, limits the rate at which a transition from farming to energy development is occurring. Farmers face increased uncertainty about crop yields due to a warming climate and intensifying precipitation, which could be an ongoing justification for subsidies. Conversely, generational transitions in agricultural property ownership are one factor that could help stimulate the energy transition, as new farmland owners make decisions about future land use based on different considerations.

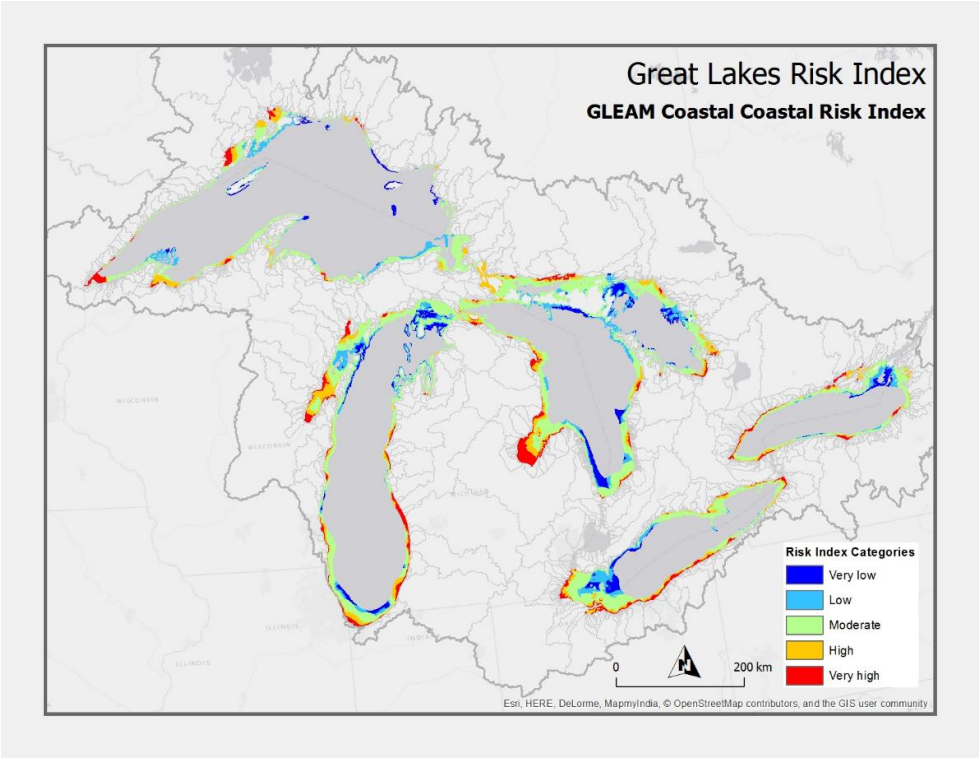


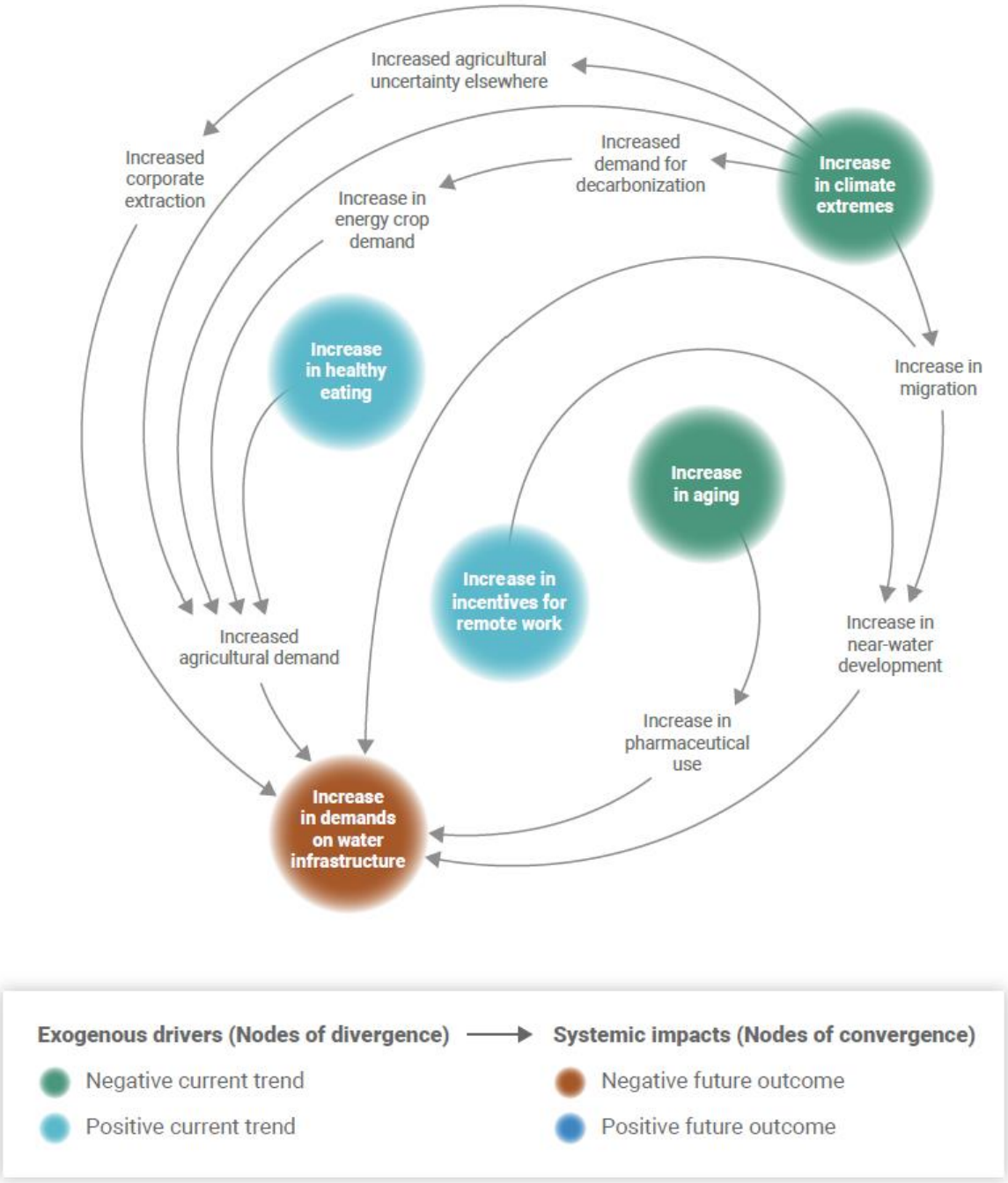
Figure 3. Map of relative coastal risk based on GLEAM data (https://www.glahf.org/blog/staff-data/coastal-risk-index/).

Another ongoing transition that received significant attention was a shift toward dispersed development in the Great Lakes region. In the current absence of regulations and policies requiring careful management of water impacts, an intensification of near-water development was considered a major threat to water quality. Factors driving this shift toward dispersed development near water in the Great Lakes include the ongoing expansion of internet infrastructure (e.g., rural broadband), increasing remote work options which were set off by COVID-19, increasing wealth and purchase of second homes, and increasing summer heat beyond tolerable thresholds in some other regions. Some recently advanced and emerging technologies that could help to mitigate the effects of dispersed development were described by participants, including decentralized water treatment systems and lower-cost water monitoring technology.

Some topics that repeatedly came up in the project team's literature review were not addressed in much detail during the symposium: changes in trade policy that could impact land use, especially concerning agriculture and industry; immigration policy and population stagnation and their long-term potential to undermine the Great Lakes region's power and agency over water in the region; transitioning away from an extractive economy toward a circular economy, and attracting manufacturers to the Great Lakes with the appeal of reducing their corporate risks due to water supply uncertainty in more water-scarce regions.

A systems mapping diagram developed for this driver category is shown in Figure 5.

Figure 4. Systems mapping diagram for population, economic development and trade drivers.



Category 3: Climate Change and Infrastructure Drivers

Prioritized threat: Warmer regional temperatures

Ambiguous drivers: Climate refugees' immigration to Great Lakes region

Prioritized opportunities: None prioritized

The climate change and infrastructure breakout group discussed several key drivers of change to the Great Lakes that impacted water quality either directly or indirectly. The four drivers that were discussed in detail are described below.

- **Warmer temperatures:** The breakout group discussed a variety of impacts from warmer temperatures on water quality. For agricultural watersheds, these impacts included the potential for drier soils in the summers and higher heat stress on existing crops, as well as lower crop yields. For ecosystems and the environment, the group highlighted impacts such as species migrations and warmer water temperatures, which could trigger a potential increase in invasive species, a shift or reduction in fish population and reproduction, or deeper thermoclines in lakes. For urban areas, a variety of secondary impacts due to warmer temperatures were discussed, including increased energy demand for cooling, public health effects (such as emergency room visits due to heat-related illnesses), and mental health effects. The group also noted the tertiary impacts of warmer temperatures on infrastructure demand, as warmer temperatures lead to urban heat islands that may require additional energy generation, transmission or distribution infrastructure for cooling. The group also noted an important temperature change gradient across the Great Lakes region: the magnitude of warming increases as you move farther north in the region.
- **Climate refugees/climate changes outside of the Great Lakes region:** The breakout group often came back to the theme of climate refugees throughout the discussion, noting these as critical secondary impacts of climate changes outside of the region. Notably, they mentioned the resource burdens a growing population could place on the region, including increased energy, food and water demand, as well as increased demand for the Great Lakes as a natural resource. The discussion highlighted several opportunities related to a potential influx of climate refugees. Breakout group members highlighted the opportunity to instill in new residents a better, more sustainable ethic about the environment and increased awareness among new residents of key environmental and climate challenges.
- **Extreme precipitation:** This driver was discussed in detail and related to a wide variety of impacts for the region. Principally, the group highlighted several physical impacts, including flooding, both pluvial and fluvial, erosion along bluffs and stream banks, sedimentation of waterways, and a decrease in groundwater infiltration (and potentially groundwater availability) as the water table declines at a faster rate than the infiltration capacity of soils. The group also noted several secondary impacts of urban flooding, namely increased incidence of CSOs, basement backups, limited emergency response, and diminished urban connectivity during urban flood events. They also noted that communities of color and low-income communities disproportionately felt the impacts of urban flooding. Recurrent flooding can increase housing instability in affected areas. Extreme precipitation also has important public health impacts, which the group highlighted as increased incidence of vector-borne diseases, gastrointestinal illnesses from contaminated water sources following flooding events, and asthma from mold and building dampness. They also noted

that housing is a social determinant of health and that housing instability, due to recurrent flooding, could have more systemic impacts on public health. The group followed up the discussion of impacts by addressing several questions around management, including the need for updated design standards, and the challenge of removing impervious cover and implementing green infrastructure at scale.

It is also important to note that the breakout group spent a considerable amount of time discussing the impacts of extreme precipitation, even though this did not emerge as a priority driver from the symposium. This may be due to more familiarity among this group with extreme precipitation and therefore less uncertainty and more confidence with its effects or its management, rather than this driver having overall less importance to the region.

- **Wave strength/force:** Wave strength/force (Figure 6) was discussed primarily in terms of two classes of impacts: those on physical systems and those on private property. For the former, the group mentioned habitat loss, shoreline instability from erosion, and loss of open water wetlands. For the latter, which was discussed in more detail, the group discussed dynamics around the government's role in shoreline protection for the benefit of private property. The group noted the potential cost burden on governments to restabilize shorelines as a mechanism that made public a private good, as much of the shoreline that is being stabilized is owned by private landowners. Related dynamics included the need for higher fidelity information of risk to a given property, so potential landowners can make more informed decisions about their risk, as well as whether the insurance market should continue to have a role in insuring private property.

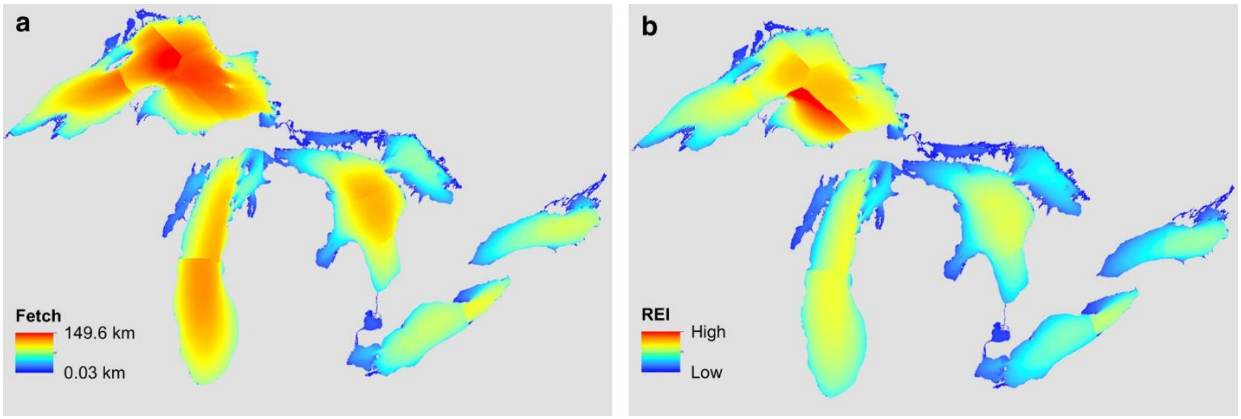


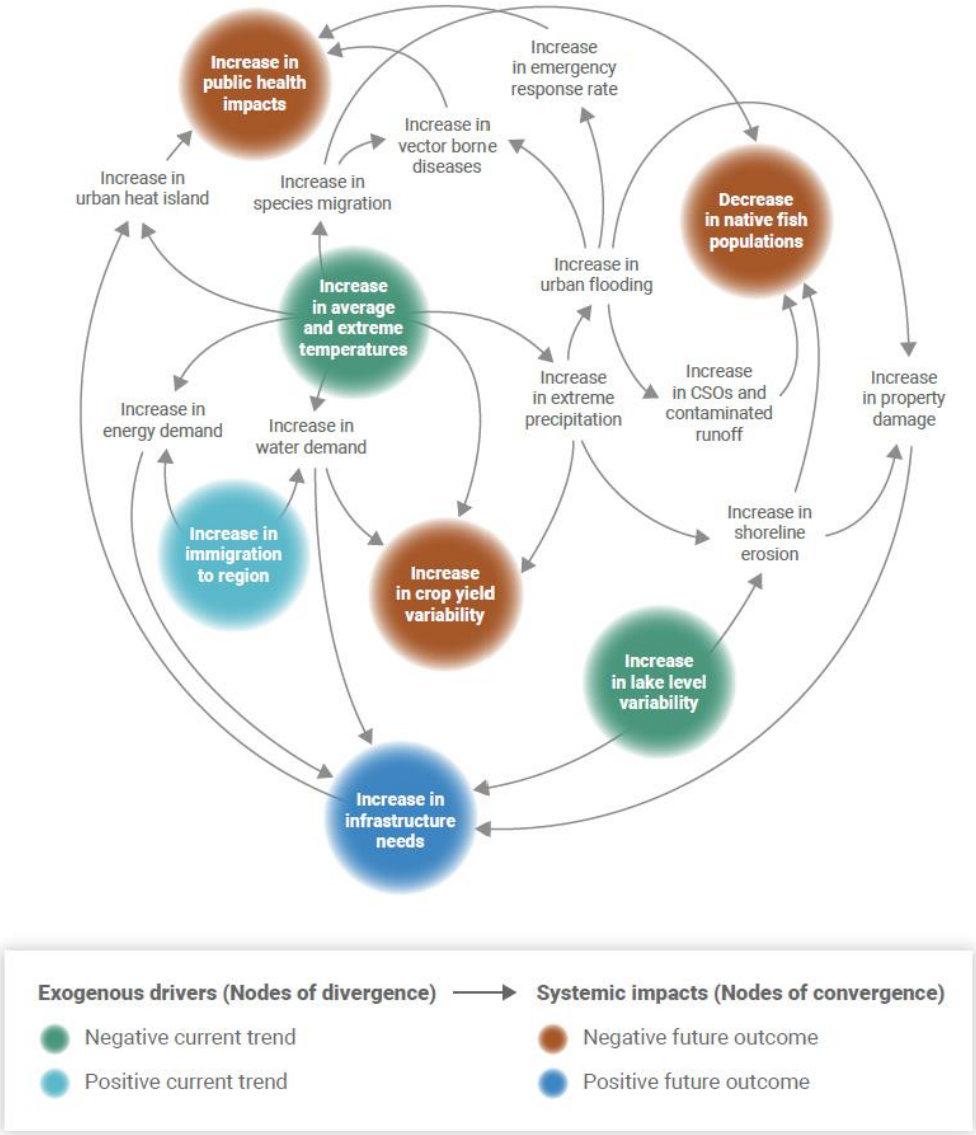
Figure 5. Modeled effective fetch for the year 2010 in the Great Lakes based on geography and buoy data (left) and relative exposure index [REI]; right), from Mason et al. (2018).

To conclude the breakout group discussion, the first two drivers (warmer regional temperatures and climate refugees) were prioritized by the breakout group as key climate change-related factors affecting water quality. The breakout group also prioritized a driver around local perception, as a key driver of action for climate adaptation and environmental management – the perception of local rights and responsibilities for climate action (including adaptation and mitigation) compared to the perception that some of these activities were, instead, regional rights and responsibilities. The full symposium group selected warmer temperatures as a priority threat to water quality

among the three. In addition to the drivers, the issue of public funds being used to pay for private property risks (and private gains), such as lakeshore protection, was a recurring theme.

During the breakout groups, several points were raised that were not discussed at length. Notably missing from the discussion, given the magnitude of anticipated changes for these topics, were the impacts of climate change on drinking water supplies, a robust discussion around the energy transition and its implications for both urban areas and agriculture, as well as more depth on fluvial flooding and stormwater. The group did not address many topics related directly to infrastructure management, such as increased needs for operations and maintenance, or the economics of water utilities given the vast number of adaptations needed. Additionally, there were no clear opportunities identified from climate and infrastructure drivers of concern, though some noted the potential to harness climate refugees to help change the culture around environmental management. A systems mapping diagram developed for this driver category is shown in Figure 7.

Figure 6. Systems mapping diagram for climate change and infrastructure drivers.



Category 4: Biological, Ecological and Chemical Systems Drivers

Prioritized threat: Governance and collaboration to raise access and awareness

Ambiguous drivers: Emerging contaminants—microplastics/microfibers, PFAS, tire compounds

Prioritized opportunities: Decreasing concentrations of legacy toxic pollutants.

The biological, ecological and chemical systems drivers breakout group discussed multiple topics that represent threats as well as opportunities, in some cases, for the future of the Great Lakes including:

- **The threat of inadequate governance structures and policies**, which may have been expected to arise mostly under Category 1, was recognized by the group as a real concern for the biology, ecology, and chemistry of the lakes. The threat was characterized as concern that policies and programs that had been created in the past may be more vulnerable to alteration or rescission due to political forces than appreciated, including the Great Lakes Water Quality Agreement, CWA programs and enforcement, and ballast water regulations. Along with this was a sense that people were becoming less engaged with the Great Lakes due to a decline in outdoor recreation, which could lead to the erosion of the broad stewardship ethic. Pandemic-related shifts in how people are recreating may mitigate this if the changes persist.
- **Pollutant sources and legacy sources**, including combined sewer systems and Areas of Concern (AOCs), were broadly recognized as declining, with positive ecosystem results. Areas of slow progress were still recognized such as control of nonpoint agricultural pollutants (and possible expansion of agriculture with climate change).
- **Emerging contaminants including microplastics/microfibers, PFAS compounds, pharmaceuticals, road salt, and tire compounds (quinones)** were recognized as present or potentially present in many parts of the Great Lakes, but with unknown or ambiguous impacts due to a lack of understanding about the severity of impacts (e.g., detectable presence does not necessarily equate to significant impact; Backhaus and Wagner 2020; Tian et al. 2021). The existence of these drivers has raised specific concerns as well as general thoughts along the lines of, "What else is out there that we don't know about yet?"
- Although there was recognition that "hot topics" may not end up being the most important drivers in the long run, the group still felt this "bias of the recent" was not overly problematic for prioritization.

The discussion also covered interactions among Category 4 drivers and the potential amplifying or damping influences of these and other categories of drivers:

- **Driver interactions** discussed included impacts of climate change on lake levels and corresponding coastal habitat loss and erosion. This would compound stresses resulting from prior coastal development and the human destruction of habitats. Climate change was also seen as impacting agricultural runoff, harmful algal blooms (HABs), invasive species, and fish recruitment, as well as driving climate refugees to relocate near Great Lakes coasts, further stressing these habitats.

- One opportunity for a continued decline in pollutant loads and shifting away from an industrial economic base is the trend toward more technology and finance jobs, and away from manufacturing, as exemplified by recent data from Toronto, the fastest-growing metro area in the region (Figure 8). The future ecological and chemical impacts of this shift over the next decades would be expected to be positive, if corresponding residential and commercial development is done more sustainably than it has been in the past.

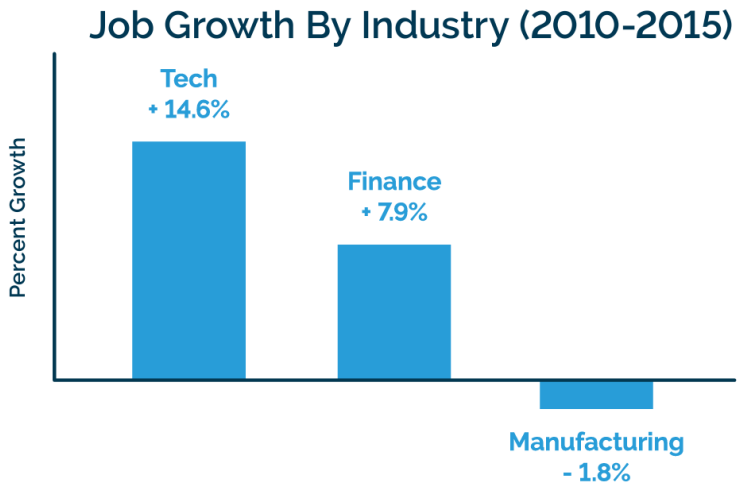


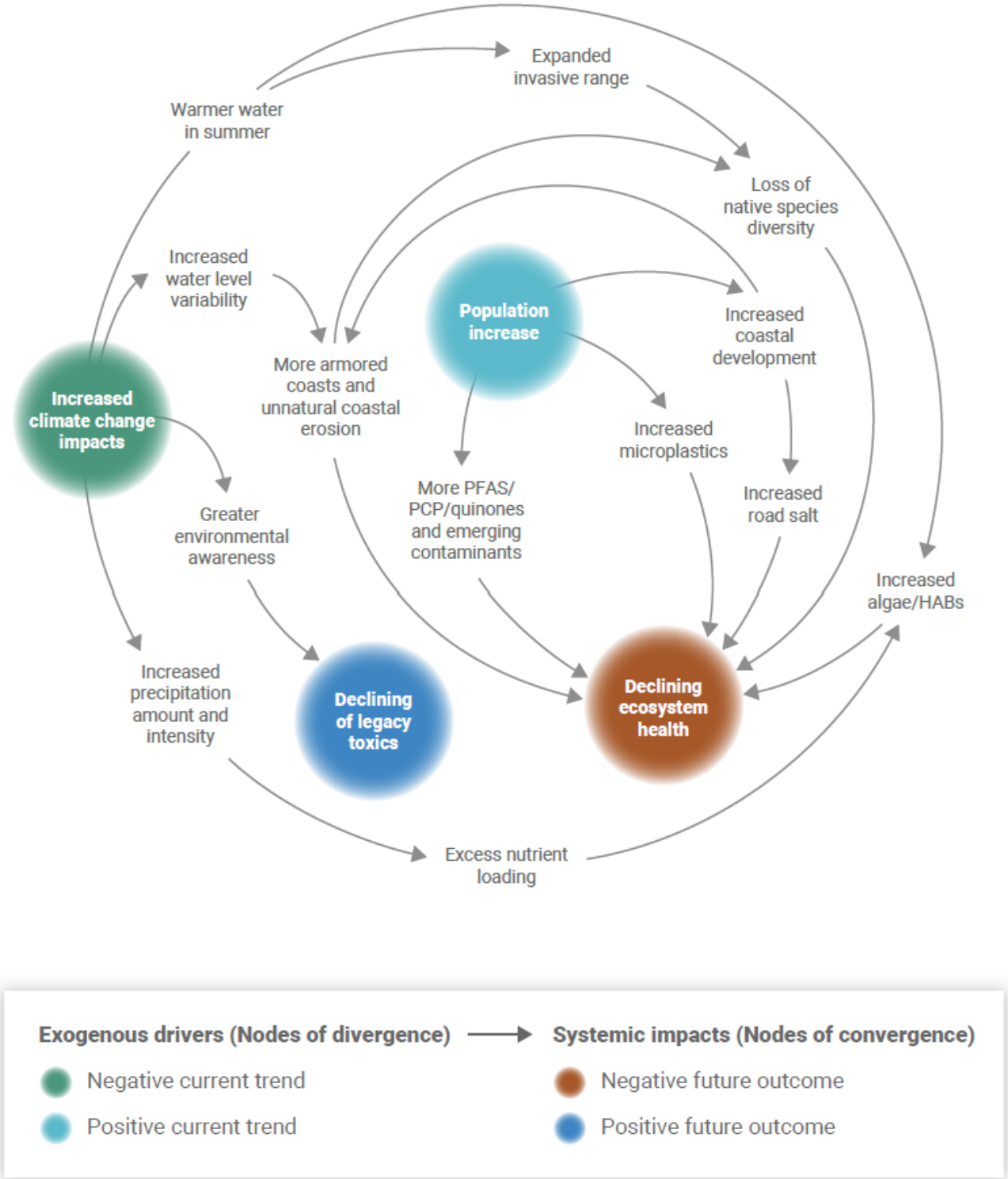
Figure 7. Growth of clean jobs and decline of manufacturing in Toronto, 2010-2015 (https://munkschool.utoronto.ca/wp-content/uploads/2016/10/TechTO_Report2016.pdf)

As with Category 1, concerns expressed about governance stability may represent the influence of recent political events in Canada and the United States on the group's relative threat perception. Time will tell if these concerns are prescient or short-lived, but scenarios that reflect the ecological and chemical impacts of changing political landscapes and corresponding environmental policies in the future will be important to consider.

Many of the impacts of Category 3 changes, especially climate change, were anticipated as negative. The reality may be more nuanced. The Great Lakes region is characterized by large natural variations in weather due to competing influences from the Arctic, the Pacific, and the Gulf of Mexico. If the primary impact of climate change will be to increase variability, there will likely be ecological winners and losers, given that the ecosystem in general, and certain organisms are already adapted to variability (Dippold et al. 2020). A general warming trend, however, is likely to favor less desirable species including existing or potential invasive species. Warming could trigger larger or more toxic HABs, but reduced snowfall and spring snowmelt, along with longer growing seasons, may reduce spring nutrient loading to the lakes from tributaries (Kalcic et al. 2019).

A systems mapping diagram developed for this driver category is shown in Figure 9.

Figure 8. Systems mapping diagram for biological, ecological and chemical systems drivers.



GAPS AND LIMITATIONS IN GREAT LAKES ADAPTIVE POTENTIAL

Gaps and Limitations: Governance, Policy and Regulations

The Great Lakes region is quite robust and collaborative in its national and transnational governance structures. Multiple treaties, conventions, and compacts, along with associated boards, commissions, societies, agencies, and councils cover areas including water quality, water withdrawals, water levels (dams influencing Lake Superior and Lake Ontario), fisheries, Indigenous interests, trade, municipal issues, economic development, shipping, science and interstate and provincial relationships, among other topics. There are also large, diverse and effective networks of nongovernmental environmental organizations. Despite these governance structures, there are areas where gaps and limitations exist that can prevent or hinder adaptive improvement in Great Lakes ecosystems and water quality over the next few decades.

As with many areas of governance, some of the largest gaps and limitations are related to overlapping jurisdictions and tensions between individual rights and the public good, which often manifest as debates between voluntary versus mandatory measures to improve environmental conditions and preferences for public versus private funding of these measures. This is simplified as big government versus small government philosophies.

The use of active adaptive management, as opposed to passive management, to structure the region's governance approaches is in its infancy (Stow et al. 2020). The active approach incorporates proactive and intentional experimentation, tracking of results and learning from responses of the managed environment, along with systematic reduction of uncertainty by targeted research and monitoring. In contrast, passive management is reactive and typically inefficient. It tends to accept the inertia of the status quo and "letting nature take its course", expecting small incremental gains in environmental conditions at best. Active adaptive management includes structured engagement with technical reviewers and stakeholder panels where uncertainty and lessons learned are communicated in transparent ways and adjustments to approaches are made collaboratively.

Some of the biggest areas of technical and policy uncertainty at present in the Great Lakes center around the following topics:

- empowering underrepresented, under-resourced, and historically excluded groups to effectively engage in collaborative decisionmaking about the Great Lakes,
- planning for economic growth that does not result in environmental degradation,
- control of invasive species (dreissenid mussels and round gobies in particular),
- restoration of native aquatic species and habitats,
- reduction of nonpoint nutrient loads without crippling agricultural production,
- retrofitting cities to handle runoff more effectively (e.g., event shown in Figure 10),
- determining the relative importance of emerging contaminants,
- understanding and managing groundwater-surface water interactions,
- understanding winter processes in the lakes,

- finding effective ways to mitigate climate change impacts in the region, and
- dealing with the legacy of high-level radioactive waste (spent fuel) stored around the lakes.

Figure 9. US Senator Stabenow announcing federal funding for flood mitigation in Detroit in 2015, including new water-absorbing landscape installations (photo provided by the office of Sen. Stabenow).

Among these areas, recent activity to create a binational adaptive management framework for control of Lake Erie nutrient loading and impacts has highlighted typical governance gaps and limitations for the Great Lakes region. The governmental and scientific planning activity has highlighted two primary gaps: 1) the lack of a coordinated technical infrastructure to support management decisions, and 2) the lack of an effective stakeholder review and engagement infrastructure to inform decisionmaking and policy development. The GLWQA outlines binational water quality goals for the Great Lakes, and existing commissions and agencies have taken on the tasks of advancing these goals, but there is no direct connection between national commitments to advance goals and allocation of substantial resources toward priority actions. The missions and priorities of the US federal and research institutions that are expected to support this treaty are not directly aligned with it. For example, there is overlap between the GLRI and the GLWQA annex goals, but GLRI resources are not allocated based on direct GLWQA impacts.

Fishery management is another area of imperfect binational governance. The fishery is jointly managed by US Tribes, Canadian federal and provincial agencies, and US federal and provincial agencies. The management is coordinated by the Great Lakes Fishery Commission (GLFC), which was established in 1955 by the Convention on Great Lakes Fisheries. The role of the GLFC is to coordinate fisheries research, control the invasive sea lamprey, and facilitate cooperative fishery management. There is no binding, centralized authority to compel cooperative fishery management, but past failures have motivated the collaborative approach for over 55 years. The funding split is designated as 69 percent from the United States and 31 percent from Canada, although this split has not always been maintained. Collaborative fishery management is currently

in a state of flux, and the existing structures may not be able to survive the current stresses related to declining offshore fisheries due to multiple factors, expiration of a federal Consent Decree in 2020 between five Tribes and the State of Michigan, tensions between Canadian commercial fishing and US charter fishing for walleye and perch in Lake Erie, growing net-pen aquaculture in Canadian waters of Lake Huron, and a shifting emphasis on restoration of native fish species over preservation of nonnative fish stocks. The collapse of the collaborative binational and multi-Tribal arrangements of the past could have dire consequences for the fishery and ecosystems of the future.

A final aspect of Great Lakes governance that is limiting its future potential is the lack of diversity in its policy development and decisionmaking organizations and structures. Groups that are not routinely involved include Indigenous communities, urban minorities, and recent immigrants. Barriers include financial resources, cultural obstacles, language and communication issues, technology access, historical patterns, and educational differences. The net result is a disproportionate representation of a subset of the Great Lakes community in planning and allocating resources for future protection and restoration of water quality and ecosystems. In addition to justice and equity concerns, this situation also deprives the existing governance structures of insights and creative solutions that exist within the communities that are not represented.

Gaps and Limitations: Technical and Societal Capacities

The Great Lakes are large and complex, with diverse communities, economies and ecosystems distributed across the basin. The technical and societal capacities to deal with current and future threats and to respond to opportunities vary based on resources, history, geography and serendipity. One area where some of this diversity manifests itself is in the partnership committees that update and promote the implementation of the Lakewide Action and Management Plans. Some of these committees are very active and have a long history of effective public engagement and progress. Others are uneven in their levels of engagement and their ability to sustain implementation activities or attract resources. Several factors seem to be important in these efforts, which may represent more broadly applicable principles:

- high and sustained commitment by key leaders who are visionary and strategic,
- availability of intellectual and technical resources from universities and federal laboratories that are located on or near particular lakes,
- a critical mass of supporting organizations and individuals who work cooperatively to advance agendas and who can effectively prioritize,
- the economic vitality of the cities and regions that support Great Lakes protection and restoration, including private-sector and philanthropic investment,
- engagement by politicians who are effective at influencing policies and resource allocations for the lakes that are used by their constituents, and
- effective advocacy for improved policies and procedures by non-governmental organizations.

Among the most substantial technical and societal challenges that exist is generally aging infrastructure, broadly construed. That is, the inherited built environment, research infrastructure,

policy infrastructure and even the staff who manage and implement these things are getting on in years. The environmental innovations of the 1970s including the GLWQA, clean water and air legislation, endangered species legislation, and the creation of environmental agencies with supporting technical arms are reaching their fiftieth anniversaries. Much progress has been made over that time, but some of the intensity and the passion associated with the early years have been lost as communities become accustomed to improved conditions and take the necessary hard work that has been done in the past for granted.

As the broader environmental movement has matured, there has been progress in shifting away from adversarial engagements and toward collaborative problem-solving and mediated negotiation. Changing hearts and minds while seeking to better understand the underlying motivations of diverse stakeholder communities that may have different goals and priorities has become a greater priority in many areas than winning lawsuits and forcing compliance with unpopular and inelegant legislation. That said, one commentator has described our modern political state of affairs more generally as a 'kludgeocracy' (Teles 2013), defined as "an ill-assorted collection of parts assembled to fulfill a particular purpose...a clumsy but temporarily effective solution to a particular fault or problem." It may be time for some of those 'kludges' to be replaced with more permanent solutions. One US-side proposal is for a system of cooperative horizontal federalism, utilizing "a constitutional mechanism for states to bind themselves to common substantive and procedural environmental protection standards, implemented individually with regional resources and enforcement" (Hall 2006).

One set of technical challenges to the monitoring of the lakes that is presented by their large size is starting to be addressed by a suite of technological innovations. It is difficult to manage a system where the current state is hard to determine and the response to management actions is difficult to assess. Four technologies that are changing are real-time sensor arrays, autonomous vehicles, acoustic telemetry of fish and environmental genomics. These technologies are reasonably mature and have been deployed on a pilot-scale or quasi-operational scale at present. What is needed now is more support for data management and decision-support aspects of their deployment, as well as broader adoption of the technologies, coordination among users, and access for organizations and scientists who are not part of the major laboratories and research organizations where the technologies exist. Indigenous nations and urban minority communities may not have the technical expertise to take advantage of these technologies or the data that they generate and could benefit from strategic investments in capacity building.

Additional economic opportunities that could have positive environmental impacts are currently out of reach for many individuals and communities. The historical focus of the region on agriculture, forestry, extractive industries and manufacturing has not prepared the communities well for lower-impact economies built on professional services and finance. Much of the growth in these areas has come from the immigration of those with skills developed elsewhere. Likewise, many of the colleges and universities in the region train students to work in these fields, but many of the alumni then leave to work in other regions. Greater retention of these students and greater local direction of research by academic institutions that are located in the Great Lakes region could bear great dividends in the future.

Finally, the low cost and minimal latency of communication, engagement and education presented by new media present huge opportunities for enhancing environmental literacy and promoting sustainable behavior among Great Lakes communities. This opportunity is already being leveraged by some entrepreneurial communicators, but more strategic investment in professional programmatic planning and content creation in this area has the potential to greatly amplify messaging and education to achieve positive environmental outcomes over the next several decades.

REGIONAL ENGAGEMENTS

This section of the report aggregates input from regional scoping sessions that were conducted as part of the study. Prior project phases included the literature review related to recent trends in driver conditions, the symposium during which trends and threats were ranked and prioritized by a group of subject matter experts, and the production of causal loop diagrams which helped depict the concepts discussed during the symposium. Four regional scoping sessions were completed—note that actual participants did not include representatives from all of the targeted communities and Indigenous groups listed:

- Western Lake Superior (Duluth-Superior and Thunder Bay communities, Fond du Lac Band of Lake Superior Chippewa) on December 14th, 2021
- Southwestern Lake Michigan (Milwaukee-Chicago-Gary communities) on January 18th, 2022
- Lake Ontario-Niagara-Buffalo-Cleveland on February 1st, 2022
- Detroit-St. Clair River System-Toledo (Sarnia-Detroit-Windsor-Toledo communities, Walpole and Aamjiwnaang First Nations) on March 3rd, 2022

New and Notable Topics of Conversation

Western Lake Superior

The Western Lake Superior scoping session centered organically around several themes: how does the lake compare to the other Great Lakes from a research standpoint; what is the unique impact of industry in this region on the lake; and how to connect science to Indigenous knowledge? Moderators asked participants to expand on why communities aren't engaging in convening, monitoring, and taking ownership. What are the barriers? What should the science-informed policy of the future look like? What are examples of effective cross-lake management? What gaps are there concerning climate change?

Southwestern Lake Michigan

This session saw participants discuss watershed stakeholders, various threats to the watershed (including climate change), forward-looking opportunities, and regional challenges, and looked forward to the need for fostering more unified efforts among stakeholders. Moderators asked participants to expand on monitoring (community vs top-down from federal agencies such as the EPA) asking “what is the right way to do this?” They also wanted to know what was missing in creating a unified effort. Once we acknowledge that willingness to pay is a cultural measure (e.g., meat prices), where should we focus? Is there anything additional that is special about your region and priorities there?

Lake Ontario-Niagara-Buffalo-Cleveland

The Lake Ontario session participants seemed to focus their topics of conversation on a few key areas: where are there nonlinear impacts and opportunities, how will agriculture change, what strategies are useful for moving forward, and what are some key emerging contaminants/problems? Participants noted that, with gradual changes, there may come opportunities as well as threats. They also called for better "big data" collection, management and dissemination.

Detroit-St. Clair River System-Toledo

In this session, participants discussed the communication issues generally experienced when scientists attempt to "report out" to stakeholders and other non-scientists. They pointed out that there is currently lowered trust in government agencies and expertise. Creative communication strategies were proposed, including reaching out to the public with newer forms of visual social media. Participants also discussed the lingering impacts of COVID on housing and population movement.

Regional Scoping Session Notes

In addition to the summaries of new topics provided above, additional detail from the engagement sessions is provided in the notes below. These bullet-formatted notes are provided approximately in the sequence they were discussed. Although not all topics raised are considered in detail in this report or in the final scenarios developed as part of the project, many topics and elements of the discussion show important regional considerations that vary substantially from region to region. One weakness of the regional engagement sessions was that the full breadth of invitees did not all respond to the invitation to participate. Certain target cities, such as Duluth, did not participate in the sessions. Also, representatives of faith communities, economic development authorities, financial institutions, tourism boards, Indigenous groups, and urban minority communities were not as responsive to invitations as hoped, suggesting that different engagement approaches may be necessary to reach groups such as these, some of which are not routine participants in IJC studies, workshops, or boards.

Western Lake Superior

- Western Lake Superior is unique from a research standpoint and a use standpoint.
    - This lake is often viewed as a special case, with less emphasis on water quality
    - Research vessels are very limited
    - Untreated drinkability is extremely important
- What are the impacts/situations of past and future industries?
    - The north side of Superior is likely to see more mineral development
    - Thunder Bay is a transportation hub--rail, pipelines, shipping
    - There are only two pulp mills; gold and lithium outside the basin. The mill is a known source of pollution, but can't close the mill because of the economics
    - Concern about oil spill response; ELA oil spill studies motivated by transport issues

    - Broad community interest in combining aquaculture with wild rice in inland lakes (aquaponics)
- Indigenous community engagement with and management of the lake
    - One step could be that the *community* holds the grants for data collection rather than the researchers
    - Interest in influencing sampling location and design; voices in communities are asking "why aren't we hosting conferences" and “why aren't experts coming to us?”
    - Overall, the interaction is too paternal at present; feeling that the trust isn't there to let communities make management decisions
    - Acknowledge the attitude of the lake as Mother Teacher
    - Importance of mutual vulnerability and transparency in building trust
- Where are there gaps concerning climate change? Known impacts?
    - Thunder Bay is in a colder region, so people don’t feel an urgency to act around climate change, they’re “thrilled”
    - Residents may not recognize the sensitivity of the region to warming and evaporation; the Canadian Shield makes for minimal surficial aquifers
    - Participants noted that the moose population has crashed in the last 10 years--more deer, more ticks, and moose are mostly gone as well as caribou. Ice is not reliable; the history of skiing on the lake is being lost

Southwestern Lake Michigan

- Stakeholders
    - One difficulty is the size of the system and the historical element; how do you reverse what's already been done?
    - The stakeholder list is incomplete or bundled - community groups, public health, enviro-justice communities, and people living in sacrifice zones. Can also think of the natural world is its own interest group; expands the opportunity of promoting water culture and Indigenous ways of knowing
    - Community leadership is not explicitly included; strongly invested in other conservation efforts
- Climate change and other threats
    - Increase in precipitation which will increase water levels beyond current lake levels. In 30 years, climate change means more runoff and more CSO outflow, especially if cities become denser. Food systems may experience problems with excessive rain
    - Ever-growing Concentrated/Confined Animal Feeding Operations (CAFOs) throughout the watershed are a significant and unregulated threat
    - Road salt in Milwaukee yields uncontrolled pollution and runoff. There was a feeling that there was no good handle on managing this at a basin scale
    - Great Lakes Compact is critical; need stronger and clearer policy on diversions; scarcity is driving more straws toward the Great Lakes
- Opportunities for government and other agencies
    - Grassroots vs grass tops activism
    - Need a combination of feds, professionals, and volunteers.

    - Another effective approach is just a good Community Advisory Committee; either super-passionate people but not diverse, or really diverse and strategic, including funding; should be integrated, e.g., the fisherman who fishes the same spot for 30 or 50 years
    - Human health board, science advisory board, One Health
    - How do GLRI funds trickle down to water quality?
    - One opportunity would be CWA; expand CWA to include groundwater
    - Management strategies question--when have we done enough in one area and decide it's time to divert in a new direction? Example of CSOs and diminishing returns
- How can we create a more unified effort?
    - When things are dealt with on an issue-specific basis, balancing economics vs environment, does it become too expensive to address? Need to subsidize solutions and possibly carve out some regulatory slack
    - Requires collective will
    - The community is listening and may point out ag has not been touched. They see irrigation styles and perceive that trends are only getting worse; some radical changes in the past, but not happening anymore
    - Participants used to think of the Great Lakes as virtually infinite (we prefer to see it as convenient, easy, and cheap) which made us conditioned against sustainability. Now we need to lead by example; bend culture
    - As people get engaged they get impatient; maybe journalists should focus on these grassroots movements
    - Engagement requires a role in the decision-making for participants (take the extra step to engage in a meaningful way to get buy-in to solutions so can't complain). Need to see examples of Indigenous groups being empowered vs. just involved; think about procedural equity
- Region specifics
    - Drinking water protection is very important.
    - Fish passage and native species are a concern. This speaks to and is integrated with water quality (think about plastics [Plastic-Free MKE], what happens when the recycling center is flooded and broken).
    - COVID to-go culture and associated trash; 4,000 volunteers were overwhelmed with trash last year. With more runoff and storm events, more trash in the lakes; the Chicago area scuba diving experience is showing way more trash getting washed into the lake
    - CAFO; PFAS; industry impacts; industry discharge permits (NPDES) are for individual toxins, but the collective impact of the full suite of toxins is key

Lake Ontario-Niagara-Buffalo-Cleveland

- Gradual change and non-linear impacts/thresholds/tipping points/opportunities
    - There is an infrastructure deficit at present, so the affordability of modifications is out of reach.
    - Recognize the cumulative power of developers over politicians as well as the threat of scientific uncertainty and knowledge gap

  - Toronto urbanization resulted in a 42 percent runoff increase over 42 years without climate change; there may be major water quality impacts from temperature alone
  - Ambiguous drivers include industries migrating because of the attraction of water, but also temperature stress too. Remember that industry stress is not just water. Can you continue to afford to cool a warehouse for your employees in Texas?
  - Are there opportunities for more economic activity? Possible that more people might equal more industry and thus more dollars to put into water quality management
  - There are many challenges presented by population growth and development including the fragmentation of landscape - loss of landscape itself which impacts human health and biodiversity
- How will agriculture change?
  - There may be opportunities in agriculture from longer growing seasons; adaptation to this is happening at community/state-provincial/fed levels. However, how do we know we're becoming more resilient?
  - The agricultural landscape may shift toward less cold-tolerant crops.
  - We also might see livestock-based development in Ontario because of low-fertility land.
  - Some industry in Canada is moving northward in search of cold water
  - Places with good transportation infrastructure may attract facilities
  - Opportunity cost – travel, cost to move goods back south where the people are
- Strategies as we move forward?
  - How do you create feedback loops?
  - Monitoring is nascent at best, but so hard to know where we're at and where we're going. Does our monitoring allow us to measure how we value water?
  - Need to distinguish between monitoring for impacts vs. monitoring for implementation and effectiveness
  - There's a struggle with big data; where, why, how; what's the story? Insurance companies have done a great deal of this, what are the lessons learned there; short-erm cost and long-term benefit? We need decision-grade data
  - There is a need for making sure that big data are shared and formatted to be interoperable
  - There is increasing scientific uncertainty. Look at the Everglades adaptive management example. Hierarchical structures are not set up to manage this uncertainty adaptively.
  - Participants noted we should all be aware that we're not sure what's reversible and irreversible at this point anymore
  - Stability can be good news; it allows for adaptation and resilience to build. Looking at regional background and averages is key for putting change in context.
  - Focus on bio-eco-chem systems; the value of ecological systems underemphasized; ecosystem services framework
  - The prioritization of strategies needs to be distilled down by watershed type (e.g., urban vs. ag; developed vs. pristine/northern)

- Emerging contaminants and problems?
    - IJC could encourage more caution around emerging contaminants; example of microbead removal but ignoring microsilver in fabrics, etc.
    - Migration barriers, like perched culverts
    - Nutrient governance in Canada (managed on a concentration basis vs. load), allocation approach is not in practice, but only started in Lake Simcoe so far

Detroit-St. Clair River System-Toledo

- Communication Issues? What happens when trust is broken by things not going as expected?
    - Communication management is important – scientists/farmers don't speak the same language.
    - Falling to the same traditional pitfalls such as mixing of issues, and interactions. Attacking one or two things at a time. We simplify things too much. Not enough emphasis on interactions of issues – e.g., climate and contaminants.
    - Farmers trying to do good things, no-till for example, but that "good thing" is now intersecting with the phosphorus issue in Ohio for Lake Erie
    - There is deteriorating trust over time in government following retracted information or 'bad science', examples:
        - Planted reed canary grass and now it's everywhere, the same type of issue with planting Russian olive everywhere
        - Similar to public perception during the pandemic
    - How do you not act too soon but not wait too long?
    - During continued communication between the US and Canada, there should be state and federal-level folks. Even more, local connections are important and not in place yet
    - Too often, one might find that others are doing the same thing
- Capacity and Outreach
    - Maybe less about signposts, and more about seeing who the visionaries are so we can reach out to them
    - Agencies are experiencing high turnover, particularly young people. They're trying to retain staff and it is not working. Therefore, knowledge transfer needs to be thought about. We're not all going to be here for 30 years at a time
    - Capacity concerns at all government levels. Need to have a mechanism for bringing parties to the table. Agency staff are spread thin and find themselves needing to wear many hats. No priorities are driven from the top down, rather issues we need to be engaged in fully. Agencies can't just throw money at the issue but need to define who writes the plan, who does the work, and even who answers the phone.
    - Additional stakeholders need to be identified. Identify who else is doing the work – look at collaboration with them.
    - What does the public want to pay for? Agency funding is somewhat a reflection of the public's values and willingness to pay.
    - What is the public's engagement? You might put up an interesting meeting, but low attendance. People like to protest, but no one shows up for informational

meetings/participatory meetings. With COVID shift to virtual meetings, there may be fewer barriers to participation
    - We must know who to reach out to, can't just take out a 2-page ad in the Free Press
    - Think about influencers – who are they (Twitter, TikTok, YouTube, etc.)
        - Soft skills – how do you be a communicator? Need to be able to tell the difference between social media platforms, (i.e., TikTok is different than Twitter) and use them differently
        - Great Lakes Twitter Influencers ranked, top 500 (Katie Stammler)
        - What are the communication models thirty years from now?
    - Make it interesting and understandable. Everything is snippets. Need to say it in a short way or people disengage. Be thoughtful about knowledge and policy translation
    - This engagement should help us know where to go with comments about populism because we know we can say "this is what the social media landscape is". Remember, people speak with different voices. More votes aren't necessarily the best idea or most important thing, it's just about how it's presented
    - Need replicable models for strategy implementation/working together toward goals
- Remote work and the decoupling of housing costs
    - One participant gave an example of a new couple next door who just bought the house for half a million in cash and continued making Toronto wages while living in Windsor
    - Lots of development, seeing houses built in floodplains, and participants wonder - where are the permits?
    - People are moving to areas where it is more pleasant, cooler in the summer, no wildfires. People from the American Southwest are buying houses in the Great Lakes sight unseen
        - Realtors say they haven't seen such interest in their history
        - Lumber mills say they can't keep up with the demand
    - A need for the Great Lakes to get their "act" together before the mass of people moving here gets worse. Where is the place where nobody is going? Where are all these people coming from?
- Wrap-up and Priorities
    - Great Lakes premiers see the same types of threats that are identified in the lists that participants viewed early in the session. There are a variety of situations that it would make sense to help them help us - what better way to make sure we're standardizing approach if they're already working on these situations? Need leaders to agree that what we're working on has merit, so they throw their weight behind it.
    - The Lakes reflect the decisions that have been made in the past. We're managing the system with impacts that were from decades and decades ago. We're still dealing with some of the impacts that the CWA was meant to address. Some of the issues we're trying to deal with now, we'll still be trying to deal with decades from now.
    - Need an entity to facilitate further discussions on future topics.

SCENARIOS

Below are the details of four hypothetical scenarios that describe the Great Lakes of 2053—30 years into the future (Figure 11). The scenarios span a discontinuous spectrum from worst to best states, including moderately degraded (bad or worse) and moderately improved (good or better) states relative to 2023 conditions. The scenarios were built from prior analysis of drivers of potential system-wide changes to the Great Lakes, presented above, and feedback obtained from multiple engagement sessions with workgroup members, outside experts and stakeholders across the region.

The scenarios were developed using a sampling of imaginative and sometimes intentionally humorous or provocative devices, such as creative future news headlines, to allow readers to enter into the future worlds we describe here more fully, including intentionally eliciting strong positive or negative emotional reactions. The use of specific names of regions, countries, locations, positions, or incidents is for illustration purposes only and should not be construed as a critique, endorsement or political commentary on current events or policies. The relative plausibility of scenarios is stretched as the extremes are considered and logical "plot holes" may exist in some cases. In addition, some scenarios include references to past occurrences to help readers understand linkages from the past to the near and more distant future. The overall focus is ultimately on changes to Great Lakes water quality, although some scenario elements are fairly removed from direct water quality impacts to set the socio-economic and cultural stage for coeval water impacts.

As background, this project builds on the prior Great Lakes Futures Project (Creed and Laurent 2015) and current work engaged in developing adaptive capacity in the Great Lakes (e.g., Stow et al. 2020). The project scenarios describe not only potential future system states but also potential trajectories for the Great Lakes, as well as signposts for distinguishing one trajectory from another. The three specific objectives of the overall analysis were to:

- Identify and prioritize emerging and potential long-term system-scale conditions, impingements, policy effects, and threats to Great Lakes water quality through examining trends and projected future conditions in Canada and the United States economic sectors and trade shifts including agricultural supply chains, energy, transportation, climatological changes, socio-geopolitical and demographic shifts, public health and medical domains.
- Frame these system-wide conditions into a small suite of plausible and defensible forecasts or projections and identify critical signposts to identify and reinforce which path is most likely emerging in the region as the dominant path in Canada and the United States.
- Identify policy and scientific gaps in Canada and the United States that materially add to forecast and scenario uncertainly. Recommend engagement, monitoring, and governance strategies including improving the inherent capacities of governments and non-government sectors to anticipate and respond to these uncertainties.

The four scenario narratives use similar elements, but they are not identical in structure. For example, the first (worst) scenario contains a more detailed description of potential lake-specific or subregional conditions in the "Regional Considerations" section than the other three, building from information obtained in regional engagement sessions. This approach is not repeated with the same resolution in the other three scenarios. Details of the accompanying graphic illustrations also may not align with all of the specific narrative description elements, as the illustrations were developed to show consistent scenario "bins" along a gradient. For example, warm-water fish species and invasive species that are tolerant of degraded water quality are shown in the foreground of the "worst" scenario panel, and desirable native species, including those that require cooler and cleaner water, are shown in the "best" panel. Key drivers that are specific to each scenario are highlighted in the narratives, although aspects of each driver could probably be considered in each scenario (Table 2; note that scenario narrative descriptions may not be consistent with all driver matrix table entries).

A consolidated crosscutting treatment of policy gaps and recommendations arising from the scenario illustrations is presented at the end of the scenario-by-scenario descriptions. The recommendations describe actions that are intended to protect the Great Lakes from slipping into negative future states and to increase the likelihood that positive changes will continue or accelerate over the next few decades. There is no expectation that all or most of these recommendations will be realized soon, as several pertain to longstanding challenges in environmental management, some of which extend well beyond the Great Lakes region in both countries. That said, stating or restating these points is designed to keep them prominent in policy discussions, hopefully with new inspiration from considering the potential best/worst states described in the scenarios.

Table 2. Driver state matrix for scenarios.

	Possible Future Scenarios			
Driver	**Worst**	**Bad/Worse than Present**	**Good/Better than Present**	**Best**
Demographics	Depopulation	Slow population decline	(1) Population increase, which brings economy, investments, and development, or (2) population declines that relieve stress on natural resources.	Population and diversity increase
Water Demands	Unsustainably high water demands	Slightly increased water demands	Slightly reduced water demands	Significantly reduced water demands
Economy	Economic collapse	Slow economic declines	Steady but marginal economic growth	Booming economic growth, development, and investments
Agriculture	Rampant ag. waste production. Crop yields crash, widespread famine	Steady increases in agricultural waste production, declines in overall yield	Some improvements in Ag. waste management and slight increases in yield	Ag innovations relieve ag. waste stress while yield improves
Infrastructure	Crumbling infrastructure unable to support societal needs	No substantive infrastructure improvements or investments	Some small infrastructure improvements and resiliency measures	significant investments and innovation in resilient infrastructure and planning
Sociopolitical	Civil War, political turmoil	Loss of some congressional seats, political unrest, no substantive laws supporting people or environment	Stable political power balance, steady congressional representation, few laws passed to address climate and resource protection,	Increasing seats in Congress and influence in Parliament, increased political power, united opinion, laws passed to protect and restore water resources and curb climate change
Climate and hydrogeology	Apocalyptic storms and flooding, coastal communities uninhabitable, extreme temperature and precipitation variability, complete loss of coastal wetlands and Great Lakes ice, northward biome migration	Storm intensity, coastal erosion, and flooding impacts continue to increase, continued steady rise in GHG emissions, increasing temperature and precipitation variability with prolonged periods of drought and storms	Storm intensity, erosion, and flooding stabilizes, some wetland and watershed restoration, progress towards zero emissions	Storm intensity decreases, coastal erosion and flooding minimized, significant watershed and wetland restoration, zero GHG emissions achieved and active carbon capture occurring
Cultural and Religious	Widespread cultural and religious turmoil, cultural devaluation of people and environment. Broad closemindedness	Continued increases in cultural and religious disputes, loss of unity and devaluation of people and environment throughout cultures	Improvements in unity and increased social harmony, improvements in cultural valuation of the environment. Declines in religious and cultural disputes	Social engagement, unity, and harmony. Environment is widely and deeply valued as cultural foundation. Diverse schools of thought
Medicine	Loss of access to medical resources, frequent epidemics	Declines in medical innovation and access, increase in widespread illness	Some improvements in medical innovations and access, epidemics managed	Substantial improvements in medical innovations and access, pandemic prevention and declines in epidemics
Science and Technology	Defunding of science and technology research and development, loss of innovation	Science and technological stagnation, declines in participation and support for research and development	Some new innovations and scientific development, steady increases in support and resources for science, education, research and development	Vast and innovative technological advancements, broad participation in prioritization of science.
Chemical	Critical biogeochemical cycles disrupted, toxic and unsafe water resources, no toxin clean ups or pollution management	Declines in pollution management and toxin clean ups, increases in nonpoint source pollution and CSO discharges	Some pollution management, slow but steady progress in toxin cleanups, CSO elimination, and non-point pollution management	Effective pollution management, legacy toxins cleaned up, combined sewer overflows eliminated non-point source pollution management
Physical	Vast and unpredictable temperature swings, frequent fires, floods, and storms	Temperature variability increases, increasing occurrence of fires, floods, and storms	Temperature variability stabilizes, improved fire, flood, and storm occurrence	Temperature variability returns to historical average, decreases in fires, floods, and storms
Biological	Widespread native species extinction and invasive species invasion, significant loss of biodiversity, fundamental shifts in habitat function	Steady invasive species invasion and native species loss, declines in biodiversity, loss of habitat function and ecosystem services	Effective exclusion of most invasives, few new invasives and some native population recovery, biodiversity stabilizes	Improved invasive species management, no new invasives introduced, some completely eradicated, native species population restoration and recovery, biodiversity and ecosystem services greatly improved.

Figure 10. The four panels in this picture depict aspects of the four scenarios described below, with the worst case in the left panel, the best case in the right panel, and intermediate cases (bad and good or worse and better than today) in the center panels. The images show states and components of agriculture, power generation, water infrastructure and diversions (pipeline in the left panel), transportation, water levels, water quality, terrestrial ecosystems, aquatic ecosystems (fish and invasive species), industrial and residential development, recreation, economic status, and human wellbeing or unrest (artwork by Jennifer Clausen, www.jacdraws.com).

While the focus of the narrative descriptions that follow is the 30-year end states of the system, an action priority is to consider signposts, trajectories and demand functions along the way from 2023 to 2053 which can inform reprioritization and policy course corrections. Natural evaluation points exist in the form of national and state/provincial elections (president, prime minister, premier, governor, representatives), turns of the decades (2030, 2040, 2050), or natural disasters and anniversaries. Revision of documents such as Lakewide Action and Management Plans, Triennial Assessments of Progress, or State of the Great Lakes reports also requires retrospective and prospective analysis of drivers and system status and trajectories. Driver-related goals and milestones provide benchmarks against which to measure progress such as delisting targets for AOCs, legal commitments by municipalities for abatement of CSOs, or nutrient load reductions (e.g., 40 percent reduction in phosphorus load for Lake Erie by 2025).

A simple schematic depiction of three trajectory types (dashed lines) and a widening wedge of uncertainty as we move farther into the future is shown in Figure 12.

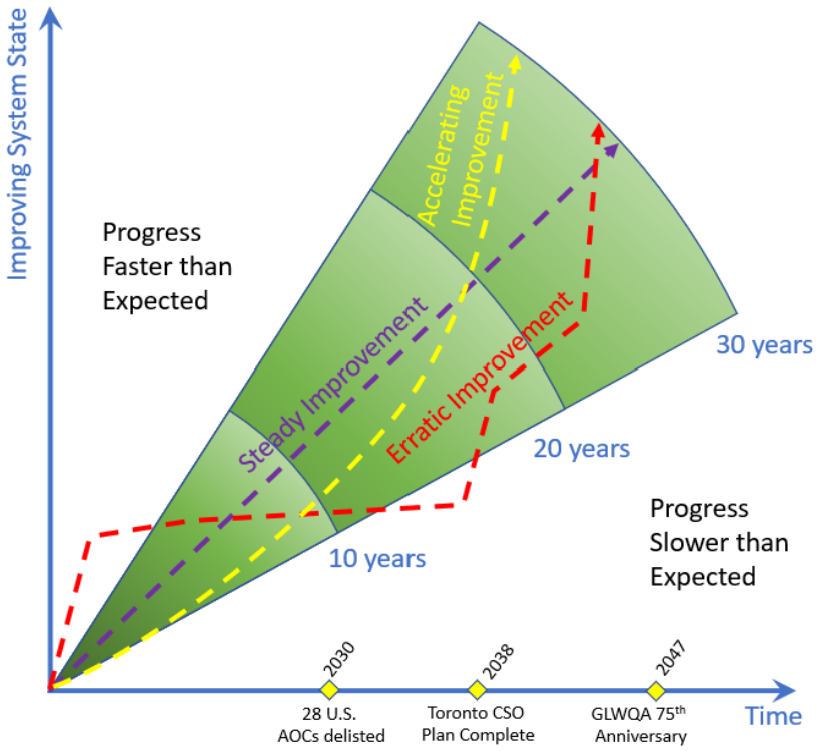


Figure 11. Schematic diagram of scenario trajectories for a positive future state of the Great Lakes.

Figure 13 shows a more complex schematic depiction of two sets of trajectory types, two widening wedges of uncertainty for fairly flat and declining scenarios, and initial driver states (blue vectors to the left, where arrow length depicts relative driver magnitude and orientation shows the direction of positive or negative "push" of the driver.

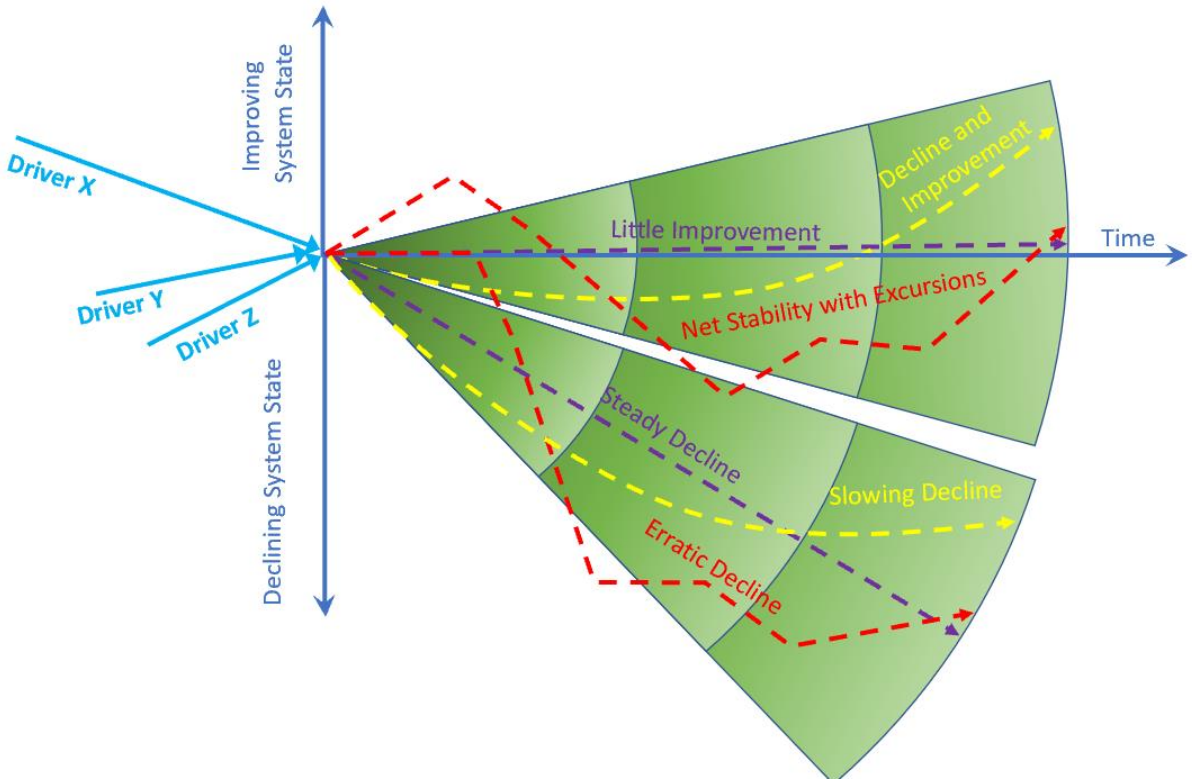
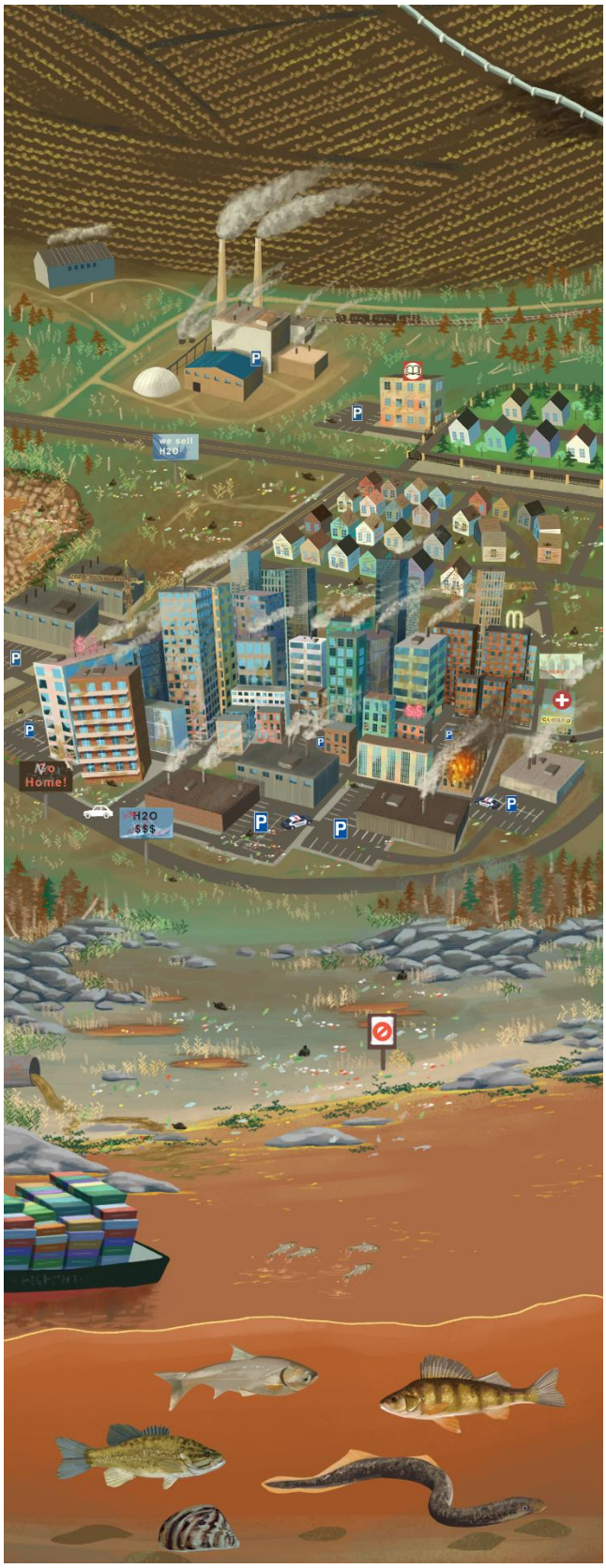


Figure 12. Two-scenario schematic with trajectories and driver arrows.



Scenario 1: **Worst** (sovereignty slipping, extreme climate change driving)

Great Lakes Going Down the Drain

Today is February 6, 2053. A lot has changed over the past thirty years.

A sample of missed headlines from the past few decades:

2030s Headlines:

- **Sunbirds' Arctic Tern Around: Desperate Office Landlords Convert Downtown Towers Into Retirement Homes**
- **Region Agrees to Ban New Lakefront Development After Sewer Plant Exceeds Capacity**
- **The Seiche Came in Like a Scythe: Stormwater Interceptor and UV Treatment Facility Damaged Beyond Repair During High Water Event**
- **New Federal Subsidies Open Semiconductor Factory to Great Fanfare**
- **Fire Out at PFAS Incinerator: Regulators Still Assessing Extent of Fallout**
- **Second Self-Cloning Invasive Found After State Loses its Marbled Crayfish Fight**

2040s Headlines:

- **Cities On Lockdown as Drug-Resistant Form of Virus Appears in Sewer Monitoring Data**

- **Clean, Green, and Mean? Automakers Shift to Right-To-Work Factories as They Struggle to Compete With Foreign Producers**
- **Erie-ly Familiar: Algal Bloom Forces Emergency Water Imports from Lake Mead via Reversal of Vegas Pipeline**
- **Proposed 20-Year Census Gap Floated as State Loses Two More Representatives**
- **Bullion in the China Shop: State-Owned Corporations Re-Invest in Regional Infrastructure as They set up Their North American HQs**
- **Governor and Premier Guilty of Kickback Scheme for Oil Pipeline Cleanup Contract, Ratted out by Russian Mafia Saboteur They Hired**

Overall, changing precipitation patterns have wrought havoc in the region. With a longer ice-free season and warmer lake temperatures overall, the lake-effect snow totals have become astronomical in some years, especially around Lake Superior and Michigan in late winter (Di Liberto 2017). Paradoxically, with more precipitation coming as rain, there has been more drought and many more invasives as they are better able to overwinter through what would usually be a late fall/early winter hard, long frost (Ruppenthal 2017; Donegan 2017).

The increased commercialization and vertical integration of agriculture have made the Midwest and High Plains one of the last reliable breadbaskets of the world (Bruess 2021), but often at the cost of large-scale intervention and immense disruption. Attempts at establishing a national water market have been subject to intense speculation and volatility, feeding a small industry of experts in the Chicago region – akin to the location of petroleum expertise in Houston last century.

Similarly, the commodities sector and its associated finance and real estate interests are thriving. Both federal governments, having taken over failed crop insurers, have become backers of last resort for these influential crop, livestock, and water supply companies, organizing massive water trains--repurposed from the fracking boom earlier in the century (https://www.watertrain.us/klamath-lake/) --moving resources between regions. At the end of the season, these rail networks reorient to either the St. Lawrence Seaway or towards ports in Louisiana, as barges are no longer reliable forms of transport along a Mississippi that sometimes barely reaches the Gulf (Dennis et al. 2022; McFall-Johnsen 2022). In other years, levees have been realigned through entire neighborhoods and reservoirs overflow into the remaining individually or family-owned land to protect export-driven crops and feedlots.

Other cities, however, have experienced an outmigration of talent, somewhat countered by an influx of lower-wage workers in right-to-work facilities associated with the semiconductor or clean energy industries, as American chipmakers and automakers strive to compete despite massive federal subsidies. In contrast, Canada's real estate market experienced a glut of speculation about incoming climate migrants, but a high-profile financial scandal and banking crisis unleashed the need for the bailout of several pension funds. This in turn nearly precipitated a foreign debt default, in which the country had to turn to Indo-Pacific countries for help, given the United States' ongoing fiscal instability.

Key Drivers

In this scenario, some of the post-industrial declines in population continue, but there are growing populations along the shores of Lake Erie and Lake Ontario. The cities along Lake Superior and Michigan have reached an uneasy equilibrium but are facing substantial quality-of-life headwinds. Overall, there are regional economic strengths in single industries, but these have become debt-financed by other regions of the world that import some instability into Canada-US bilateral relations. Failing agriculture abroad, struggling agriculture domestically, and regional rivalries have upended traditional assumptions about water rights. Continued drought in the High Plains and a surplus of water in some seasons in the Great Lake basin have accelerated transfers for agriculture and its barge-based trade movements. High technology has returned to the Great Lakes basins--centered on batteries, water processing and pharmaceuticals--but has translated unequally to job growth and opportunities, especially given an influx of climate migrants to some parts of the region. Infrastructure is typically aging and over-scaled unless operating under a consent decree or privatized and owned by sovereign wealth funds.

Regional Considerations

Lake Superior -- Continued droughts and conflict in wheat, corn and livestock-producing regions of the world have put enormous productivity pressures on the three Prairie Provinces and six states of the High Plains. Existing irrigation systems such as groundwater associated with the Ogalla Aquifer or surface conveyance in the South Saskatchewan River Basin have come under increasing strain and have failed in some years.

To better regulate remaining resources, the US Army Corps of Engineers has reactivated a proposed diversion from White Cloud just above Kansas City on the Missouri River (Stokes 1982). Long deemed infeasible due to the requirement to lift and transport water such a vast distance, wind power resources installed but not connected to the grid due to broader political infighting became trapped, resulting in inexpensive renewable power. Furthermore, breakthroughs in advanced power technologies for nuclear fission and fusion have rapidly decreased the cost of decarbonized energy options for industrial scale uses (Bulkley et al. 1984).

Cities like Duluth and Thunder Bay, having lost national political power due to continued population declines, see a chance at revival through being regional water brokers due to their westernmost geography and continued high water quality. Pressures from development led by climate migrants and second homeowners from further south seeking to escape the life-threatening summer heat, as well as other ecological uses, have dramatically increased with warmer temperatures and the decline of viable tourism and fishing industries on the other lakes.

In addition, they already have numerous water-intensive industries, such as new metals and mining operations, as well as semiconductor facilities. Milk and other dairy products have become astoundingly valuable due to high carbon fees on cattle's methane emissions. Tired of competing with California's State Water Project and other investments subsidizing that state's industry, Wisconsin and Minnesota installed water distribution infrastructure leading from the Great Lakes back towards the Mississippi, which is now subject to upstream withdrawal restrictions, to ensure

adequate animal feed for their prized herds (Szalasny 2021). In particular, the Nipigon-Des Plaines-Cuyahoga triangle has speculative water rights investment due to positions at the continental divides, between the Gulf of Mexico, Hudson Bay and Great Lakes drainage basins. Shipping out of increasingly ice-free Hudson Bay ports continues to grow, as plans for the James Bay Seaway move forward.

These key geographic points have taken on new prominence. For example, Sault Ste. Marie now has a sizeable Canadian and US armed forces presence. The Upper Peninsula of Michigan is rapidly depopulating after the sale of the Mackinac Bridge to a group of Middle Eastern sovereign wealth funds and the institution of exorbitant tolls—anti-government survivalists are the only growing demographic. While the world's longest international land border is still unfortified, there is a diminishing level of trust that joint interests will be protected. In part, this is due to investments in rare earth processing by Indo-Pacific state-owned firms on the Canadian side and their patrol boats regularly transiting international border waters.

Lake Michigan-- Political unrest, chronic flooding and urban heat island effects have led to a lost decade of growth in Chicago. Supply chains are beginning to shift out of the region, a former logistics hub, in favor of points further south. As a result, the tax base has eroded, and there are few resources available for environmental investments, yielding declining water quality and health. The Metropolitan Water Reclamation District of Greater Chicago has been operating under consent decree as the federal government rebuilt its main treatment plants, which were not designed to handle increasingly variable water quality.

Copi (Asian carp), which breached Chicago's defenses in 2035 and also escaped from an unlicensed live fish market in Toronto's Don Lands Waterfront the same year, are now established throughout all lakes except Superior. Great Lakes native species and fisheries are reeling, but the exploding sea lamprey population has had some impact on carp numbers after supply chain issues interrupted lampricide production from 2038-2043.

There is increasing disagreement about how to manage Great Lakes water levels, especially given the multi-year feedback response system of the lower lakes, devastating coastal ecosystems. Flooding has destabilized shoreline infrastructure and extreme temperatures are reducing economic productivity.

Several years of very high levels led to extensive flooding. After completing a dredging project, the US Army Corps of Engineers now operates the Sanitary and Ship Canal at the maximum diversion rate to help lower levels and supply more water to a Mississippi River system starved of water in many years, halting barge traffic (Matheny 2015).

The Great Earthquake of 2045 along the New Madrid Seismic Zone/Reelfoot Rift, destroyed much of the public infrastructure from Paducah, KY and Cairo, IL south past Memphis, TN. With the river sedimented as it cuts new banks, the US Army Corps stepped in by creating flexible water barges – first pioneered after a series of Caribbean hurricanes and Indo-Pacific typhoons causing the failure of critical infrastructure, shipping treated water from Chicago's upgraded, but overcapacity plants down the Des Plaines River (Bouchaert 2010, Walters 2009).

St Clair-Detroit River and Western Lake Erie--The federal government has taken the unprecedented step of placing the State of Michigan under de-facto receivership. Ironically, the state assumed the debts of Detroit and Wayne County in an attempt to unleash economic growth, but due to an interest rate spike and greater fiscal austerity in the face of domestic unrest, foreign creditors and Middle East sovereign wealth funds are invoking a clause to demand early repayment. This was part of a series of poor leadership decisions made by the former corrupt governor, and it has resulted in the privatization of nearly every public asset ranging from water systems to highways and art museums. There are protests if not riots most days in Lansing against the President's constitutionally questionable overreach, but federal officers have the resources to suppress and detain individuals *en masse*.

In stark contrast, the Sarnia, Detroit, Windsor, Ann Arbor, and Toledo corridor represents nothing short of an economic miracle. Climate and political migrants have flocked to a reinvigorated electric vehicle, battery, wind turbine and semiconductor industry, displacing other residents into vulnerable housing situations. The rapid development has created some environmental stress by consuming valuable farmland in Ontario and overburdening drainage and sewerage systems around Lake St Clair. Furthermore, the stark divide between these thriving communities and those left out such as Saginaw, Flint, Lansing, Grand Rapids, and Kalamazoo fuels resentment and political impasses.

Unlike Sault Ste. Marie, where the US and Canadian governments have an uneasy stance due to the critical raw materials that are of keen national interests, the nature of Middle East investment on both sides of the St. Clair and Detroit Rivers is much more hands-off due to the establishment of a binational free trade zone, where shares to purchase seats on the corporation's board can be owned by foreign governments. In exchange, the Michigan, Ontario, Canadian, and US governments each receive a quarter share of the profits, the terms of which the US government threatens to up-end due to Michigan's bankruptcy requiring *force majeure*.

Toronto-Buffalo-Cleveland--An aging population has driven strong growth of the biomedical industry in the Cleveland metropolitan area. Not wanting to threaten this economic bonanza, wastewater standards have been held artificially low for pharmaceutical manufacturing, damaging water quality and leading to unsettling effects on wildlife, a decline in native species, and a near-total fishing ban. The ecosystem damage has led to ever larger and more toxic algal blooms on the southeast side of Lake Erie, which is also vulnerable to wave action as nature-based solutions have failed to be maintained due to higher insurance rates eroding the local tax base.

Alongside these big pharmaceutical plants in the Cuyahoga's Industrial Valley and at the former US National Aeronautics and Space Administration's (NASA) Glenn Research Center lies the thriving, if secretive, heart of the American drone industry. Initially seeded by Department of Defense and Homeland Security investments, commercial firms have ballooned, drawing comparisons to Ohio's being the birthplace of aviation. National security concerns, however, have led this area to be nearly cut off from all outside monitoring and influence, leading regulators to wonder whether there are environmental and other violations, as well as undetected foreign espionage. Accordingly, there are air and exclusion zones around this area preventing any people or boats from entering the water.

Buffalo has had a massive influx of climate migrants from New York City, lured by generous resettlement incentives in the wake of Hurricane Randy that breached many of the New York and New Jersey flood defenses (Chicago Tribune Editorial Board 2015; Mack and Treuer 2022). The lakefront parks, Tifft Nature Preserve, and Lackawanna Canal industrial area have been turned into temporary villages for those displaced along the Gulf and East Coast as they find new homes within the region. Homelessness and illegal encampments under I-190 and the Buffalo Skyway have stretched municipal resources thin, especially with the rise of addiction to a new synthetic opioid, first synthesized in Cleveland. The city and state have sued Ohio for material damages, but the increasingly political Supreme Court--now a retirement option for party elders--has shown little appetite for meaningfully resolving disputes between states for many years.

After a brief pause, Toronto continued to grow rapidly for two decades but has recently suffered economic setbacks from over-investment. Promising attempts at invasive species management and native species restoration have been abandoned for lack of budget resources to sustain regional infrastructure. Though originally thought far-fetched, given ongoing turmoil in the High Plains and Midwest of the United States, there are some parties in Canada clamoring for exporting water via the Northern Sea Route (Bruess 2021; Clean Water Action 2023). Generally, there is concern about increasing Indo-Pacific influence in Canadian policymaking, given their large-scale bailout of the Toronto commercial real estate market and financing of some of the best public infrastructure in the world. The city has become the North American headquarters of many state-owned enterprises, both by Indo-Pacific and Middle Eastern sovereign wealth funds.

Signposts

By 2030, permanent post-pandemic shifts in the economy are likely to be apparent, after a business and commercial leasing cycle has passed. There will likely be major federal and international commitments to investment in high technology and manufacturing given ongoing supply chain disruptions and competition with Indo-Pacific countries. With populism and states' rights on the rise currently, it remains to be seen if these trends become cemented in political dialogue; this scenario assumes they do. Aging populations will shift investment priorities, and changes in lifestyles will alter the available tax base. Infrastructure fails to accommodate the stresses of population migration and shocks of new weather patterns. There are emergent pollutant and invasive species threats.

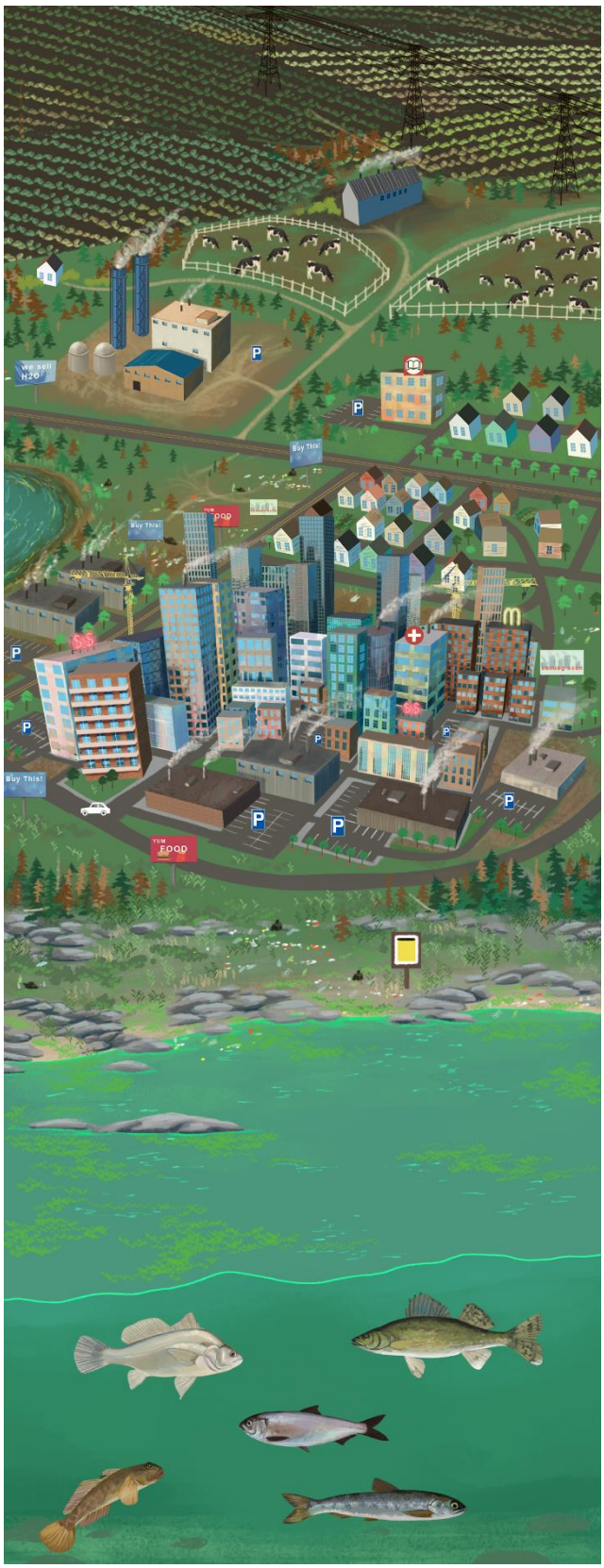
By 2040, the physical and transition risks of climate change should be apparent, and whether they are accelerating. With two decades of erosion of democratic norms, the states and federal government are often in tension, as are cities and their states. Collectivism is on retreat across the board, even in states that had the last bastions of unions in the nation. With a decade of underfunded public infrastructure due to reduced tax receipts, either the assets are failing, or facilities have had forced or speculative reinvestment from the private, federal, or international sectors. Outmigration from the region has left it with less political power, especially by this decade's census. New technologies such as advanced fission and fusion reactors are finally leaving the lab, but perhaps not in time to counter some of the more harmful effects of climate change and communicable diseases.

Uncertainties

The fluctuations in precipitation from flood to drought, and the impact of outflows on transportation are imagined here to be sporadic and trending toward more volatility to inject the greatest amount of uncertainty into decisionmaking, but there may be more clearly defined directions that emerge. We assume no meaningful recovery after storms and flooding and very little resiliency of coastal ecosystems, especially to invasive species, but no fundamental shifts in function. We do not assume that waves of pandemics lead to a fundamental restructuring of society. Similarly, the level of research and development investment is assumed to hold steady, just being plowed into a narrower set of considerations. While electric vehicles are likely in the future, it is unclear what their adoption rate will be and whether they will change commuting or development patterns. It is unclear how adversarial the competition with Indo-Pacific countries may become, and whether foreign direct investment might be enough to bring into question longstanding Canadian-US partnerships. Similarly, this scenario envisions a fracture across the various levels of government, with some parts of it being weak and others strong, which might not be mutually consistent.

Scientific Gaps

There is a key scientific gap – notably about how a lack of knowledge outside of the region might affect the basin's own fate. For example, could new forms of energy generation change the dynamics of long-distance water supply to make larger diversions possible? One might think about this challenge as akin to geoengineering, arguably worth researching and either putting to bed or understanding its perils to set up the appropriate policymaking realm.



Scenario 2: **Worse** than Present (agricultural impacts, reversing downward trends)

Things Could Be Worse for the Lakes, but Help May be on the Way

2053 Headlines:

- **Tariffs Curbing Asia's Appetite for Pork – Will Great Lakes get Less Green?**
- **Virus-Fueled Epidemic of Lactose Intolerance Drives Dairy Decline, but Green Bay Water Quality is Silver Lining**
- **HABs Liking it Hot, Hot, Hot**
- **Potato Boom Becoming a Lake Superior Bust**
- **Great Lakes Retain Flyover Status as Investors Target Vancouver**

Overview

The state of the Great Lakes in 2053 is worse than today, but some key players are hoping to reverse that trend. Climate change has allowed agriculture to expand northward and growing seasons to increase. Bumper crops have found an eager global market as Eurasian political instability has strained global food supplies. The Great Lakes and St. Lawrence Seaway has given farmers in the region access to global grain markets that

have sometimes been inaccessible to Mississippi Basin farmers due to low flows in the river and restricted barge navigation. Introductions of new invasive species from increased ballast water exchange from seagoing grain vessels have been minimal, but the threat persists. Investment in Soo Locks upgrades in the 2020s has proven to be prescient in light of the grain shipping boom that has followed.

Along with the agricultural boom, nonpoint runoff has continued to load excess nutrients into Lake Erie, Saginaw Bay, Green Bay, and increasingly to northern waters like Georgian Bay and Lake Superior. Harmful algal blooms that were once common in the lower lakes have gotten worse in the south and grown in frequency and duration in the north due to more nutrient-rich runoff and hotter summers that favor cyanobacteria. As pine and aspen forests have retreated north, potato farming has taken off around Lake Superior and Georgian Bay, and cotton is moving into northern Ohio, Indiana, and Illinois. Increasing irrigation demands have strained aquifers and lowered summer streamflow such that tributary fish populations are suffering, and power grids are experiencing August brownouts in inland areas as cooling water is in short supply for power plants.

The Chicago and Cleveland water crises of 2050 due to unprecedented algal blooms that overwhelmed their drinking water treatment capabilities may have finally pushed long-overdue legislative action on nonpoint agricultural pollution to a decision point. Proposed changes are being considered to the new US Farm Bill and the CWA, including the creation of Great Lakes “Special Protection Areas” (SPAs). After the successes that followed the initial decade of spin-up of the consolidated Canada Water Agency, the US began consideration of a similar change, bringing together parts of USEPA, NOAA, US Geological Survey (USGS), USDA, and civilian elements of the US Army Corps of Engineers.

Key Drivers

The important drivers of this scenario are intensified versions of current drivers, particularly the interplay of climate change and agriculture. The additional driver that is external to the region is global geopolitical food instability, which has driven up demand and prices for Great Lakes products outside the region. The expression of these drivers in the form of localized environmental signature disaster events (HAB-induced water crises), analogous to the Cuyahoga River fire and the Santa Barbara oil spill of 1969, has the potential to make them turning points where something has to be done in terms of environmental legislative action.

Regional Considerations

Lake Superior algal blooms in the western arm of the lake, in Thunder Bay, and along the Apostle Islands and Pictured Rocks National Seashores are becoming almost annual events. Potato farming in the watersheds has delivered nutrients that were previously in short supply to the lake. Climate change migrants are calling for action.

The oil pipeline tunnel in the Straits was finally completed and opposition to the pipeline gradually died down after many spill-free years. Small spills continued at refineries in Indiana, Sarnia, and Toledo, but no major incidents took place and bans on tanker transport of crude oil were maintained in both the US and Canada as energy use shifted more and more to natural gas, and then to renewable onshore and offshore wind and solar power. Reinvigoration of the nuclear power industry in other parts of the country has not penetrated the Great Lakes. The last reactor ceased operation at Bruce Power on Lake Huron in 2028, although land-based shipments of high-level waste outside the basin to centralized interim storage facilities continue.

Toronto's growth slowed in the 2030s but the stable and diversified economic base allowed continued investment in green and resilient infrastructure and environmental equity programs, leading to its designation as the first UN-certified Environmental, Social and Governance (ESG) Platinum Medallion city in North America. Buffalo and Cleveland are playing catch-up. The aging hydropower generation stations at Niagara Falls and on the St. Lawrence are slated for major upgrades and modernization efforts, but the capital has not yet been raised for this.

Key Signposts

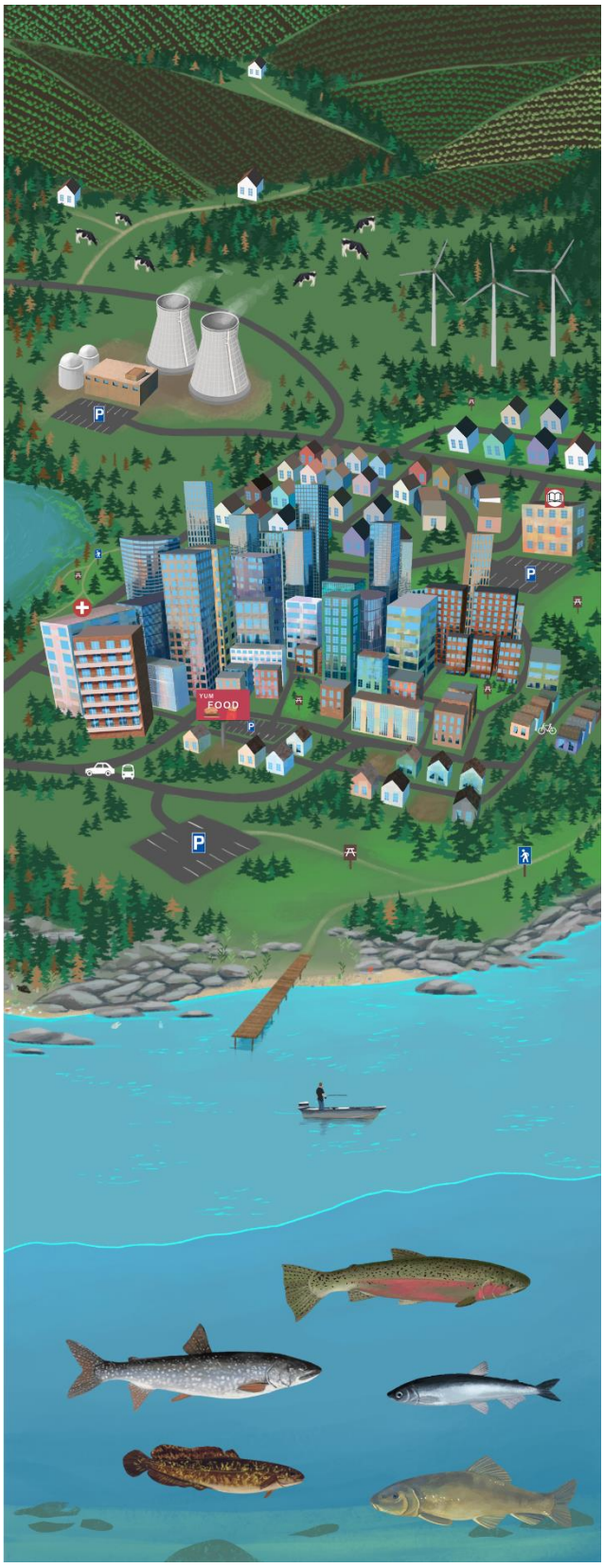
Signposts along the path from 2023 to 2053 related to this scenario including metrics of agricultural production, export and geographic areas of most rapid change, particularly in the north, as well as forest composition shifts and conversion to agricultural use. Although agricultural land use change is typically gradual, market-based drivers can accelerate change so annual patterns should be benchmarked against decadal-scale baselines. Changes that impact watersheds that were previously mostly forested in northern Minnesota, Wisconsin, Michigan, and parts of Ontario around Georgian Bay would be especially important to monitor. The appearance of new crops in the basin or major shifts in relative acreage might also be important to track. Finally, changes in eutrophication-related phenomena like algal bloom abundance, area and persistence or expansion of hypoxic zones would be key indicators of water quality and habitat decline.

Key Uncertainties

In addition to uncertainties about climate, additional driver conditions that are challenging to predict years or decades into the future are national and global market forces that will drive demand for agricultural products outside the Great Lakes. The current war in Ukraine has more than doubled prices for corn and wheat since 2020, while high fertilizer prices have resulted in lower application rates. Beyond these factors, global trade policies, tariffs, transportation challenges, fuel prices, and weather (droughts, floods) all play important roles.

Key Science Gaps

One area of uncertainty related to agricultural expansion and water quality decline is the interplay between climate-related northward shifts in growing season length and the suitability of northern soils for cultivation. Land clearing during the lumbering era in the late 1800s and early 1900s did not ultimately result in widespread conversion to agriculture due to harsh weather conditions, sandy or hydric soils, and loss of fertility due to intense historical fires and burning of organic matter in thin topsoil. Whether modern agricultural approaches to soil amendment, irrigation and drainage modification could result in the conversion of northern forests to productive farmland under altered climate conditions may not be well understood.



Scenario 3: **Better** than Present (improved water, worrying cultural shifts)

Things are Looking Up for the Lakes, but Threats are at the Threshold

2053 Headlines:

- **Close But No Cigar: Agriculture Expected to Dodge Water Regs Yet Again**
- **Climate Migrants are Here to Stay, but Behaving Badly**
- **Provincial Parks May Close as VR Couch Potatoes Camp, Fish in their Basements**
- **US West Unveils GL Thirst Abatement Pipeline Plan (GL-TAPP) – Ottawa Objects**
- **Angler Interest in Growing Sturgeon Fishery Sets new Record**

Overview

The state of the Great Lakes 30 years from now is better than the present state, but not by much. Water quality has gradually improved, although dominant invasives like gobies, mussels, and sea lamprey, appear to be here to stay and Copi (formerly known as Asian carp) have become established in southern Lake Michigan and Green Bay but have not yet made it through the Straits. Restoration of native species like lake sturgeon and lake trout has chugged along, but progress has been slow and climate change poses a continued threat. Societal connections to nature have weakened

as engagement via virtual reality platforms dominates people's daily lives during both work and recreation time. The "no child left indoors" campaign is a distant memory, at best.

Key Drivers

Investments have continued in infrastructure improvements such as CSO control and stormwater management, but political support for these investments has been uneven and progress has been made in fits and starts. Funds that were intended for major upgrades have not kept up with demand, and deferred maintenance has resulted in costly and unplanned repairs to keep systems running, diverting time and funding from enhancements. Some in-migration and slow growth due to outside investment, migrants from climate pressures, and the exodus of remote workers from expensive cities on the salty coasts have boosted tax revenues and innovation. Extreme climate variability, including national headlines about worsening summer heat waves and extreme lake-effect snowfall driven by less winter ice, have kept some would-be immigrants away. Great Lakes residents who are not excited about teaching self-exiled coastal urbanites to love and respect our lakes have not always been eager to roll out the welcome mat, even while their local economies have sometimes struggled. Environmental justice limps along as a low-level concern, but real progress is difficult to demonstrate. Shrinking participation in faith communities has accelerated societal fragmentation and declines in altruism and optimism, along with some loss of a widespread stewardship ethic. Abatement of nonpoint agricultural pollution has continued but at a snail's pace due to political opposition and the increased opportunities presented by longer growing seasons and northward shifts of suitable climate zones.

Regional Considerations

In Lake Superior, shipping through the upgraded Soo Locks for Thunder Bay and Duluth-Superior has increased due to the continued instability of Eurasian grain supplies and frequent droughts that have impacted Mississippi River transportation. The growth has brought investment to the region, but more ocean-going ships have also increased the threat of invasive species introductions through ballast water transport.

Copi have invaded Lake Michigan despite efforts to keep them out, but the cold waters of the northern lake have kept them from passing through the Straits. Waterway restoration and CSO control in the Fox River/Green Bay, Milwaukee, Chicago, NW Indiana, and SW Michigan have resulted in substantial water quality improvements and fewer beach closings due to high *E. coli* counts.

Decommissioning of nuclear reactors on Lake Huron has removed the associated thermal inputs and the threat of radionuclide releases, although waste disposal lingers as a concern. The abundance of new offshore and nearshore wind turbines is not popular with all and poses an ongoing threat to migratory birds, raptors, and bats.

Delisting of all AOCs and major progress on CSO control in the St. Clair-Detroit River System has improved water quality, but recovery of restored habitat has been slower than hoped. Algal blooms, hypoxia and excess macroalgae persist in Lake Erie, and the gradual downward trend that first appeared in the late 2020s has flattened out as nonpoint nutrient management actions have slowed.

Cleanups and CSO control in the Buffalo-Niagara area have improved water quality entering Lake Ontario. Toronto residents are tied much more closely to the lake with the completion of the massive Don Lands redevelopment project, but ongoing population growth and sprawl are stressing stormwater and wastewater management infrastructure in the region.

Key Signposts

Signposts along the path from 2023 to 2053 that would show we are on the "Better" path include the election of more environmentally friendly politicians on average at all levels of government, continued support by voters for conservation measures, stability or growth in outdoor recreation, and steady growth in populations and economies across the region, particularly in relatively clean industries and with low-impact development patterns. Things to watch out for would be slowing progress toward existing timelines for AOC delisting and CSO control, continued erosion of Congressional power for the Great Lakes region with declining US populations, runaway development in Toronto, and growing political support for diversion of Great Lakes water to the West in exchange for short-term financial incentives (Chicago Tribune Editorial Board 2015).

Key Uncertainties

The near-term and longer-term impacts of climate change and population shifts in the region remain the greatest sources of uncertainty in the 2050s and 2060s. Winters have become milder in general, but increased frequencies of extremes (droughts, floods, blizzards, heat waves) are taking their toll. While global political instability is driving migrants and economic opportunities to the Great Lakes, planning is increasingly falling behind the pace of change.

Key Science Gaps

Scientific understanding of the lakes has improved as research and technology have advanced over the last decades. Real-time monitoring is now driving key management decisions. Broader engagement in the technical aspects of lake management by key stakeholders and efficient and timely adaptive decision-making continue to lag. More participation by sociologists, economists and political scientists may help improve these processes.

Scenario 4: **Best** (sustained stewardship, adaptation, shared values)

These Aren't Your Grandmother's Great Lakes

2053 Headlines:

- **Restored Native Fish Keeping the Invaders at Bay**
- **We're Glad You're Here: Climate Migrants Doing Their Share to Protect Lakes**
- **Rewilding of Former Farmland Gets a Boost from Moose, Elk, and Wolf Baby Boom**
- **Fuel Scarcity Fans the Flames of Ecotourism Staycation Trend**
- **Spring Sap Shift Swings Syrup Stocks from South -- Ontario's Maple Tappers Cheer**

Overview

While the trajectory of the Great Lakes has been subject to a range of uncertainties posed by internal and external factors, many of these have also presented opportunities for positive change and growth in the region. Turning these uncertainties into strengths has been a core component of realizing a future for the Great Lakes that centers around supporting and protecting its water resources and ecosystems for the benefit of all. The Great Lakes are fishable and swimmable now and should remain so into the future.

Stewarding the human and ecological systems of the Great Lakes through shifting paradigms has been necessary, as well as co-creating and coordinating water quality strategies that respect Indigenous knowledge and foster shared values amongst all that live within and thrive upon the watershed. More broadly, the complex built, natural, economic and human systems that surround and include the Great Lakes have both developed and prospered under these shared values. Incorporating the concept of "transformative climate adaptation," even without strong federal leadership at times, has been critical for addressing systemic inequities through policy change (Mach and Treuer 2022; Shi and Moser 2021).

The focus on equitable and sustainable economic growth through clean energy and technology and resilient agriculture, infrastructure and natural resources management have been key to success. This approach took advantage of, rather than simply reacting to, climate change. For example, the Great Lakes have led the nation in resilient infrastructure design and operations, such as integrating green design principles into all new construction and repair, innovating in the use of waste to energy, investing in ecosystem services, or shifting to crops that are both higher value and more sustainable under the changing climate. The Great Lakes region has become an international hub for clean energy and technology, pulling in venture capital and investment that drive growth for the region. Climate migration has been a resource rather than a liability and has further fueled this growth.

Importantly, the clean, green and economically prosperous Great Lakes have created greater equity for all. Policies and processes have been enacted to ensure equitable distribution of benefits and any burdens, the inclusion of all voices in decisionmaking processes, and accountability for maintaining equity moving forward. These principles have been a foundational component of all policies that support the Great Lakes in realizing the vision of 2023.

Regional Considerations

Across the Great Lakes region, this has played out in many ways over the last 30 years with important regional distinctions. A few examples include the Lake Superior region, where climate migrants have brought economic development, new ideas, environmental investment, and the creation of more resilient infrastructure and planning to the region. Legacy pollutant cleanup has improved ecosystem health. Around Lake Michigan, population increases from climate-driven migration and immigration more broadly have supported economic growth and environmental investment. Feared population losses did not materialize so restoration efforts were able to continue with financial and political support over the last 30 years. In the St. Clair-Detroit River system and Western Lake Erie, climate refugees brought economic development, new ideas, environmental investment, and more resilient infrastructure and planning to the region. In Toronto, Buffalo and Cleveland, invasive species management methods improved greatly, and the restoration of native species and habitats accelerated as legacy pollutant cleanup costs declined, freeing up resources.

Drivers of Future Change

Achieving these results has required understanding and acting upon drivers of change. From a demographic perspective, population growth supported economic growth, and climate migration more specifically led to enhanced environmental stewardship and investment from a growing population of climate-sensitive and environmentally motivated individuals. The regional economy took advantage of renewable energy investments and the positive impacts of climate change on agriculture. Economic growth resulted from the expansion of the renewable energy sector which further fueled population growth and attracted investment, including from venture and later-stage investors. Science and technology developments from this investment benefitted the region from the solutions they brought as well as the economic growth that they generated. Agricultural shifts to more climate-friendly crops and land use included regenerative and other lower-impact approaches, decreasing riparian habitat impacts, reducing pollutant and sediment loadings and enhancing the quality of receiving waters.

Climate change drove opportunity in the region, as described previously. Rather than waiting for climate vulnerabilities and risks to increase over time, as temperatures warmed, extreme precipitation increased and other climate hazards became more severe and frequent, the region invested heavily early on in resilience and positioned itself as a national leader in climate adaptation. It also protected its economy and population from both the abrupt and gradual impacts of climate change. This meant that water and environmental laws, policies and agreements effectively incorporated future climate projections when enacted or updated. For example, the design of stormwater management upgrades routinely accounted for future storms as combined sewers were phased out and their resulting impacts on receiving water bodies became minimal.

In addition to mitigating CSOs, cleaning up legacy toxins from the environment and controlling nonpoint source pollution supported ecosystem restoration and resilience. Targeted policies, regulations, investments and capacity increases improved invasive species management and led to the restoration of native species biodiversity, fish and wildlife population increases, and expansion of healthy habitats. Environmental restoration brought a wide array of enhanced ecosystem services to the region, leading to economic benefits, greater climate resilience, and gains in well-being.

At the same time, investments in infrastructure accounted for climate change as well as infrastructure condition, age, and deferred maintenance. Proactively replacing, repairing, and redesigning infrastructure based on future needs, rather than on historical ones, set the region ahead of its peers and protected life and property, lower insurance rates relative to other regions. This meant large investments across scales to fix what was already broken, as well as to enhance what was not to account for future needs and hazards. Such investments also prioritized the distribution of benefits and impacts on residents and the environment.

Finally, positive changes in social, cultural, civic and religious participation and engagement supported the improved state of the ecosystem and quality of life in the region over the last few decades as community groups, communication strategies and long-term curricula and

programming continued to support environmental stewardship as a way of life for lifelong and new residents of the region.

Signposts

One of the key ingredients to realizing this scenario is early and intentional action. The climate is already changing, environmental degradation has already occurred and is continuing, and infrastructure is already deteriorating. In many ways, the signposts needed to take action are already here and have been for some time. As such, instead of characterizing those signposts needed to act, a set of narrative signposts can signal if the region is heading toward this "best" scenario.

By 2030, at local to regional levels, the policy environment has shifted to develop the structure to holistically support renewable energy, clean technology accelerators and startups, broad decarbonization efforts, climate-resilient infrastructure and management, including water resources and environmental stewardship more broadly. This shift in the policy landscape to focus more fully on these themes is apparent both through laws and regulations, but also through planning and investment by public and private decision-makers.

By 2040, major investments made in response to the last decade of policy and practice are complete. This means that, for example, aging infrastructure has been or is being replaced or repaired to new standards, new bridges have been built, mass transit systems are redesigned, and energy sources are in transition. This period sees increased economic growth after two decades of investment. At the same time, ecosystems begin to recover after regulations from the prior decade begin to take effect. By 2050, a fuller spectrum of benefits is realized. Water quality indicators improve, AOCs are delisted, insurance rates decline in coastal and riparian areas, incidences of invasive species introductions or range expansions are down, and restoration of native species, such as lake sturgeon, Arctic grayling and coregonines is well underway.

Key Uncertainties

While this scenario is subject to a broad range of uncertainties, there are a few key uncertainties that have the potential to significantly impact its feasibility. Of high importance is the political will to enact the policies and regulations needed. Underlying that political will is public and private support for the ideals that are the focus of this scenario: clean and green investment, climate resilience prioritization and broad valuing of environmental stewardship. Without political will and public and private support for these policies, this scenario will not be realized. In addition, uncertainty around the degree of climate change is also of importance to this scenario. Chiefly, is there a threshold for extreme precipitation, temperature or other hazards beyond which the region cannot adapt? While the ability to adapt depends on available resources (as well as political will), less severe and intense future storms, for example, are easier to adapt to and require fewer resources.

Science Gaps

Beyond the uncertainties related to climate change, fundamental gaps exist in the knowledge of the rates and degree to which highly degraded ecosystems can recover over time. Ecosystem

complexity is such that simply removing major stressors and seeding ecosystems with native plants and animals may not be adequate for their re-establishment and their defense against nonnative invaders. Political support exists for cleaning up the most toxic hotspots but protracted adaptive management of restored habitats and patience with ongoing resource allocation for what appear to be incremental improvements may be lacking.

OVERALL POLICY GAPS

A potential policy gap that is present in all scenarios is the insufficiency of diplomatic authority to control the undue influence of other nations, regions, corporations or individuals who are investing in the Great Lakes. How might these players influence the implementation of the Great Lakes Compact (e.g., invoking the humanitarian diversion exception clause)? How far will cities, states/provinces, and even the US and Canada be willing to go to represent their interests? Concepts quite literally foreign to the region, such as state-owned enterprises hosting free trade zones or partaking in a corporatist structure – commonplace in other parts of the world – could upend norms. The gap might be addressed by stress-testing the roles of corporations and private financing with ensuing self-regulation versus command-and-control forms of investment and decision-making.

Canadian and US environmental policies have remained reasonably well aligned over the last few decades, but political divergence and regression to less effective policies remain threats. External investment and cross-regional or international immigration, although badly needed, will introduce new players who may place a lower priority on the health of the lakes. The prolonged drought in the West and the Mississippi Basin is driving creative thinking about how water for drinking, irrigation, and navigation might find its way from the Great Lakes to other basins, beyond the current diversions. Legal frameworks and policy approaches that protect the sovereignty of Great Lakes governments may need to be strengthened.

A final policy gap is the inadequate management framework for nonpoint source pollution control in both countries, with a special focus on agricultural fertilizer and manure (see Johns 2002). The excess nutrient loading that drives harmful algal blooms, hypoxia and excess macroalgae growth in many Great Lakes embayments at present may be exacerbated by climate change in the future. A more effective policy approach to the management of this problem, which affects many water bodies beyond the Great Lakes as well, is badly needed. Similar conclusions were drawn in decades past as in the 1980 IJC report titled, *Pollution in the Great Lakes Basin from Land Use Activities*.

ENGAGEMENT, MONITORING AND GOVERNANCE STRATEGIES TO PURSUE IN 2023 AND BEYOND

The goal of this project has been to consider ways to decrease the likelihood of negative outcomes and increase the likelihood of positive outcomes for the lakes over the next decades. While shocks from both within and outside the basin may be unavoidable, monitoring will be necessary to recognize trends of concern, watch for signposts, and mobilize mitigation efforts as early as possible so that stresses do not overwhelm and destabilize the system entirely (Table 3). For example, the obsolescence of treaty and compact elements, changes in the balance and concentration of public/private/foreign investment, and the degree of enforcement of checks on political influence should all be tracked over time. Some metrics more typically seen in the international policymaking sphere such as the rule of law, economic freedoms and quality of life might be useful if the course deviates early on from the present trend.

In addition, avoiding the accumulation of stresses may require the Great Lakes to cede some advantages strategically, playing the long game in the sociopolitical sphere, or forming unlikely alliances. For example, coordinating on which energy- or water-intensive crops are grown where (e.g., California versus Plains or Great Lakes) might reduce overall pressures on water systems. Similarly, federal investment packages might steer certain industries into or out of the region to reduce the likelihood of negative economic outcomes. Continued engagement in the fate of other regions as climates change could also blunt some of the potential ill effects of climate migration, for example, by supporting adaptation efforts in the Sunbelt, the Great Lakes may experience less disruption at home.

To ensure continued progress on making the Great Lakes better, sustained and expanded engagement of the greatest breadth of stakeholders possible will be critical. Johns (2002) breaks the categories of environmental motivation into carrots (incentives for positive behavior), sticks (disincentives for negative behavior) and sermons (education, outreach and general encouragement). Regardless of which of the three categories is employed to motivate, engagement at the proper scale or scales is critical. Linking the monitoring of physical, biological, socioeconomic and cultural status and trends into an integrated whole, and acting on the results of the monitoring, remains a challenge at present, but progress is being made at more localized scales. Capturing some of these best practices and examples could be valuable. One model to propagate more broadly might be that of the Regional Conservation Authorities (RCAs) in Canada. Although their role and funding frameworks are evolving and not every RCA is functioning at the same level, the watershed-based organization model could be valuable to propagate into the US, leveraging existing watershed councils and creating new ones where they do not exist. Such a network could be managed with delegated authority by the USEPA under a modified CWA, possibly with a new section specific to the Great Lakes.

Table 3. Signposts and data to monitor.

Scenario	Key Driver and Impact #1: Water Demand Change	Key Driver and Impact #2: Population and Economic Change	Key Driver and Impact #3: Cultural and Social Change	Key Driver and Impact #4: Climate and Infrastructure Change	Key Driver and Impact #5: Biodiversity Change	Key Driver and Impact #6: Pollutant Loading Change
Worst	•Worsening western drought	•Rapid population change (decline or growth)	•Transboundary tensions rise	•Increased flooding and damage	•Multiple new invasive species become established or expand ranges	•Fish consumption advisories expand
	•Continued losses in Congress	•Rapid economic change (decline or growth)	•Sense of place and stewardship ethic decline	•Rising home insurance rates	•Native species and habitat restoration funding declines	•Pollutant loading increases
	•Weakening Great Lakes Compact	•Water quality indicator decline	•Religious participation drops	•Massive influx of climate refugees		•Funding declines for discharge enforcement
	•Less concern with upper Great Lakes in Toronto/Ottawa		•Outdoor recreation declines	•Increasing disputes about Great Lakes protection		•Major new chemicals of emerging concern are identified, with limited management options
Worse to Better	•Little population growth	•Little population growth	•Transboundary relationships stable	•Consistently high variability of Great Lakes water levels and ice cover	•Slow but steady progress with native species restoration and invasives control (e.g., sea lamprey, ballast water management)	•AOC delisting rate slows
	•Little economic growth	•Little economic growth	•Sense of place and stewardship ethic maintained	•Few climate refugees		•Combined sewer overflow investment slows
	•No more lost seats in Congress		•Religious participation stabilizes	•Flat and uncreative infrastructure investment		•Nonpoint source nutrient loads and lake impacts decline slowly
	•Stable western water demands		•Outdoor recreation participation stays consistent			
Best	•Population growth	•Population change (growth or decline)	•Transboundary relationships improve	•Accelerating climate	•Few or no new invasive species	•AOCs delisted
	•Economic growth	•Economic change (growth or decline)	•Sense of place and stewardship ethic strengthened	•Climate migrant trends	•Acceleration of restoration of native species (e.g., lake sturgeon, grayling, coregonines)	•Combined sewer overflows controlled
	•Increasing seats in U.S. Congress	•Water quality indicator improvement	•Religious participation rebounds	•Decreasing coastal and riparian insurance rates		•Nonpoint source nutrient loads and lake impacts decline
	•Water innovation in the West		•Outdoor recreation participation increases	•Infrastructure investments		

RECOMMENDATIONS

To promote positive and improving environmental conditions in the Great Lakes of the future, and to protect against declines, the following actions should be implemented by IJC Commissioners, staff, and board members within three to five years:

- Review the US Clean Water Act (CWA), Canada Water Act, US Farm Bill, and Great Lakes Restoration Initiative Action Plan III, among other legislation and program guidance, with special consideration of ways that the combination of nonpoint nutrient control and climate change can be more effectively implemented and prepare a white paper or policy brief suggesting improvements that are specific to the Great Lakes several decades into the future.

- Develop a plan for integrating and enhancing existing monitoring programs across driver disciplines in and outside the region, where appropriate, on a five-year cycle to identify actionable shifts, accelerations, or decelerations where pressure can be applied to steer trajectories in desired directions. This would serve as a threat analysis companion to other indicator tracking efforts and would target socio-political, cultural, and economic actions to a greater extent than existing efforts, as well as incorporating ecosystem services restoration concepts in prioritization.

- Engage with individuals and groups who are working on innovative technological approaches to support decisions that span the international and inter-regional divides such as transboundary numerical models (e.g., the US National Water Model that spans the Canada border in the Great Lakes) and dynamically track status and trends or rapidly evaluate quantitative future scenarios. Leverage the Great Lakes decadal science planning documents prepared in 2022 by IJC.

- Seek standardization of tributary watershed governance structures across the border, along the lines of Canadian Regional Conservation Authorities or Florida's watershed management districts. Task existing and new bodies like this with developing future scenario documents and mitigation plans.

- Support expansion or realization of new and proposed forward-looking boundary organizations such as the Council of the Great Lakes Region, the Great Lakes Authority, regional environmental think tanks, or disciplinary Centers of Excellence.

- Consider the 30-year horizon explicitly when updating the Canada-US Great Lakes Water Quality Agreement (GLWQA) and other related agreements, treaties and commitments.

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