International Joint Commission
Great Lakes Science Advisory Board
IJC.ORG/SAB

GREAT LAKES SCIENCE STRATEGY **FOR THE NEXT DECADE**

Summary Report

November 2022

A report submitted to
the International Joint Commission by the
Great Lakes Science Advisory Board

Preface

The Great Lakes Science Strategy for the Next Decade (the Science Strategy) summarizes the science gaps and related resource needs identified by hundreds of knowledge-holders convened by the International Joint Commission (IJC). A more detailed description of the surveys, workshops and findings of this project is available in the Great Lakes Science Strategy for the Next Decade report.

This Summary Report provides an overview of the project and integrates findings of the Science Strategy into a broader framework to better define science needs to understand changes in the Great Lakes for the protection of the economic, social and environmental health of the region.

Moving forward from the Science Strategy, additional engagements with knowledge-holders, stakeholders, rights-holders and governments are essential next steps in creating, launching and executing a comprehensive multinational Great Lakes Science Plan.

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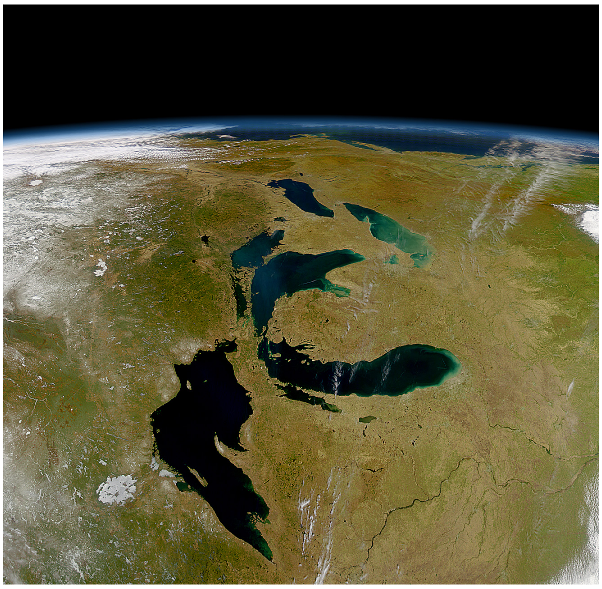
Introduction and Background

The Laurentian Great Lakes represent the largest single source of available freshwater on the planet at a point in time when fresh water is one of the most stressed natural resource on earth. Their impact on the economies of Canada and the United States is immense and the economy of the Laurentian Great Lakes states and provinces is valued at US$6 trillion (CDN$7.5 trillion) per year Gross Domestic Product,[1] the third largest economy in the world.

If spread out, the waters of the Great Lakes would completely submerge both the North and South American continents under more than a foot of water. Yet, despite their size they are surprisingly fragile systems and have been stressed to the breaking point for nearly a century.

The Great Lakes' susceptibility results in large part from the closed nature of these systems, in concert with the economic activity and the human-generated impacts they spurred. The lakes suffered some of the most acute large-scale pollution ever recorded. As recently as the late 1960s, rivers tributary to the Great Lakes caught on fire. Lake Erie, the eleventh largest lake in the world, was declared "dead."



At the same time, these lakes are a source of drinking water for over 38 million people whose health and wellbeing relies upon their availability and untainted cleanliness. Much of the science and study of the Great Lakes resulted from attempting to understand and mitigate these impacts. The predominant research efforts of the last half century hinged on understanding the role, fate and impact of contaminants from excessive nutrients to toxic, bioaccumulating substances like organic chemicals, pesticides and heavy metals.

This research was at the forefront of understanding contaminants globally and drove the comprehension of the adverse nature of these substances and the actions needed to eliminate these impacts. As a result the Great Lakes are far cleaner today yet their susceptibility to change and fragility to disturbance is an increasing risk for Canadian and US water security.

Sequestered hydrologically as isolated systems for thousands of years, relatively simple food chains have been disrupted and re-engineered over the last two hundred years by nonnative species that have been both accidentally and deliberately introduced. Within the last 20 to 30 years the Great Lakes witnessed ecological changes that equal any seen over the last century, driven, for example, by invading nonnative mussels and gobies, a resurgence of massive algal blooms, emerging contaminants and climate variability.

These changes are likely to continue and accelerate. The increasing stress on freshwater resources across other regions—prolonged droughts, wildfires, agricultural productivity losses and aquatic ecosystem collapse—has led many to label the Great Lakes region as a potential climate refuge, almost entirely because of an abundant and reliable supply of freshwater and a temperate climate.

The population of this region and its reliance on the waters of the Great Lakes is only projected to increase. It is in this context that a better understanding of the Great Lakes system is paramount to avoiding historic, catastrophic shocks and their associated social, environmental and economic impacts, and to prepare properly for population growth challenged by new human pressures that are presently poorly understood.

"Within the last 20 to 30 years, the Great Lakes witnessed ecological changes that equal any seen over the last century"

Rationale for the Science Strategy

To date, there has not been a comprehensive assessment of the science needed to understand, predict and anticipate the impact of changes that are coming and, in some cases, that have already occurred. These are complex, highly interlinked forces at play with ripple effects that are extremely difficult to predict, but with implications that are major in terms of human use and vulnerabilities.

The size, complexity and intricate governance of the Great Lakes also confounds their study. They are, in fact, inland seas which are oceanographic in scale, requiring coordinated multinational oceanographic-scaled research programs and infrastructure.

10,000 miles (16,000 kilometers) of freshwater coastline

Geographically, the Great Lakes span a coastline greater than that of the entire marine coastline of the contiguous United States and nearly 12 percent of the coastline of mainland Canada.

A highly variable system

Monitoring a system this large and variable is a challenge. Seasonality is dramatic and changing rapidly, harsh winters exhibit widespread ice cover, storms can generate waves up to 29 feet (9 meters) in height, and the increasing frequency of extreme weather events are playing a major role in restructuring watershed and nearshore dynamics.

Coupled to these natural phenomena, the use of the lakes for the transport and international trade of petrochemicals, grain harvests, coal, iron ore and a wide variety of other commodities, along with recreation, drinking water, waste disposal, fisheries harvest and consumption, and energy production results in an unavoidable set of complex interdependences.

These interdependencies require a much better understanding than currently exists in order to ensure environmental integrity and the economic wellbeing that derives from a sustainably-managed ecosystem.

Questions arise as to whether the present governance structure is optimized for dealing with current and future stressors. Slow management responses to challenges such as ballast water, harmful algal blooms, invasive species and fisheries declines have led to concern about the integration and synergy of the current Great Lakes resource management. Delays in addressing ecosystem injuries result in social and economic injuries of substantial proportions.

Within this context, in 2018 the IJC's Science Advisory Board undertook the development of the first comprehensive, decadal scale science strategy for the Great Lakes, modeled in large part by similar efforts for the oceans including science and technology for America's Oceans: A Decadal Vision [2] and Ocean Science In Canada: Meeting the Challenge, Seizing the Opportunity.[3]

The Great Lakes Science Strategy for the Next Decade represents an initial phase of the development of a forthcoming, detailed Science Plan, and delineates the priorities and challenges facing Great Lakes science. The process involved surveying the Great Lakes science community, resource managers and stakeholders via a series of town hall meetings, online surveys and virtual workshops.

The overall goal of the Science Strategy is to establish a road map for placing the Great Lakes region on a sound scientific footing for ensuring effective management and permanent sustainability of the system.

The Science Strategy calls for a number of investments of time, energy, funding, tools and talent in order to accomplish this goal. The importance of acquiring a fundamental understanding of the functioning of this unique ecosystem is hard to overstate and represents the challenge facing contemporary scientific, resource management and political communities.

But, as the project participants recognized, this challenge is also an opportunity. Science today has numerous new tools that have the potential to unlock many of the questions posed and to fill gaps in our knowledge at resolutions and precisions heretofore unavailable to the study of the Great Lakes. These tools and the practitioners that will wield them can usher in a renaissance of Great Lakes science whose benefits will extend far beyond the next decade.

Development of the Science Strategy

The Science Strategy was developed with the input of hundreds of scientists, engineers, natural resource managers and interested individuals. A primary goal was to identify consensus science priorities and research infrastructure investment in the basin.

A layered approach to identifying science needs began with an online survey of scientists (more than 200 respondents) in the basin, followed by a follow-up survey (over 160 respondents) to further delineate needs. The entire basin was under pandemic constraints for most of the information gathering period. After the online surveys, a series of three virtual workshops were held. The first workshop (100 participants) in April 2021 examined science needs and gaps with a topical, disciplinary focus:

- **Physical processes:** including temperature, currents and shoreline dynamics (e.g., physical hydrodynamics and atmospheric dynamics)
- **Lake and groundwater chemistry:** including nutrients and legacy chemicals (e.g., chemistry and biogeochemical cycles)
- **Food webs and fisheries**
- **Watershed dynamics**
- **Cross-cutting issues:** including social and economic dimensions, human health, ecosystem restoration and governance

The second workshop (75 participants) also held in April 2021 focused on individual Great Lakes and their connecting waters.

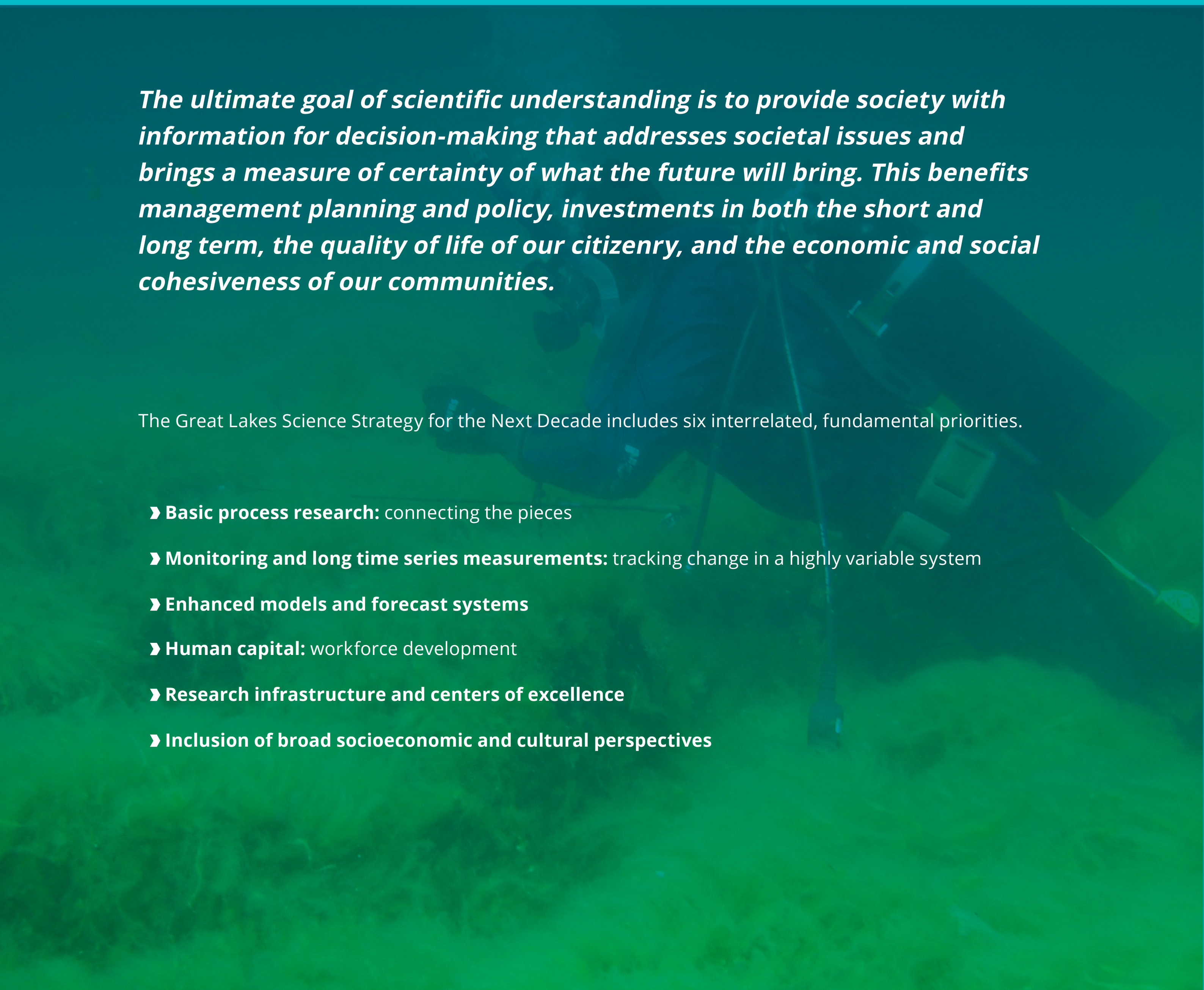
The third workshop (43 participants) held in November 2021 convened primarily with agency research program managers, discussed the preliminary draft contractor report that summarized the previous surveys and workshops and whether they appropriately addressed key science questions gaps and science infrastructure needs.

Following the conclusion of these virtual workshops, a contractor report was developed and reviewed by workshop participants and a 17-member project steering committee consisting of IJC Great Lakes Advisory Board members and major binational science agency and academic representatives.

The draft Great Lakes Science Strategy for the Next Decade report was then reviewed by the IJC Science Advisory Board and finalized by LimnoTech as a contractor's report.

The high-level findings of the surveys and workshops are summarized in the Appendix.

Great Lakes Science Priorities



The ultimate goal of scientific understanding is to provide society with information for decision-making that addresses societal issues and brings a measure of certainty of what the future will bring. This benefits management planning and policy, investments in both the short and long term, the quality of life of our citizenry, and the economic and social cohesiveness of our communities.

The Great Lakes Science Strategy for the Next Decade includes six interrelated, fundamental priorities.

- **Basic process research:** connecting the pieces
- **Monitoring and long time series measurements:** tracking change in a highly variable system
- **Enhanced models and forecast systems**
- **Human capital:** workforce development
- **Research infrastructure and centers of excellence**
- **Inclusion of broad socioeconomic and cultural perspectives**

Priorities of the Science Strategy

1. Basic process research: connecting the pieces

At the heart of the management of any system is the basic understanding of how the parts fit together and interact, how they fluctuate in time and space, and how they respond to internal and external forces. The Great Lakes science community highlighted major perturbations such as toxic contaminants, invasive species, harmful algal blooms, oxygen depletion and fisheries die-offs.

However, there has been no overall framework for science or concerted, interdisciplinary, large scale expeditionary research effort on basic dynamics for over 20 years. The last such programs, the National Science Foundation/National Oceanographic and Atmospheric Administration funded Episodic Events Great Lakes Experiment and the Keweenaw Interdisciplinary Transport Experiment in Superior, were conducted from 1997-2001 with an explicit focus on coastal ocean processes.

The principal recommendation of the Science Strategy is the support of a major program of basic process research studies, aimed at a more complete understanding of the physics, biogeochemistry, food webs, climate forcing and dynamics of the interactions between the lakes and their watersheds. Central to the purpose is predicting future states of the Great Lakes that could jeopardize the economic productivity of the region and social well being by generating deep injuries to the environment.

Revealed by previous experience—for example legacy chemicals like Polychlorinated Biphenyls (PCBs), and invasive species like the sea lamprey—investing in prevention can avoid much more costly remedial efforts later on.

Priorities of the Science Strategy

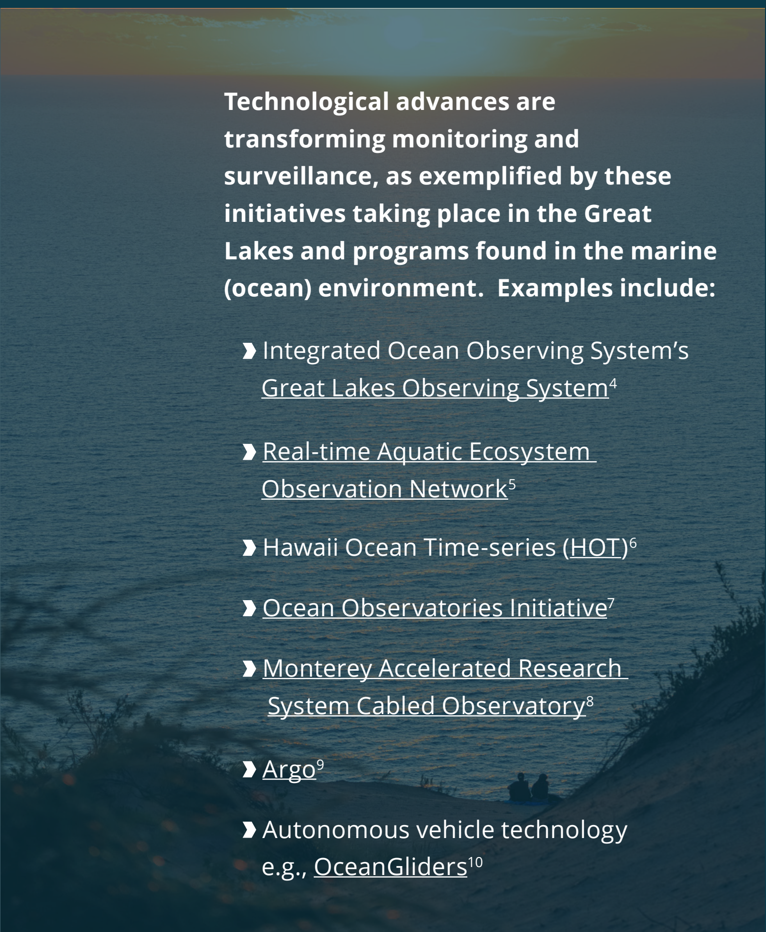
2. Monitoring and long time series measures:
tracking change in a highly variable system

While monitoring the Great Lakes is a priority of current efforts and has provided valuable data, these efforts are geographically sparse, suffer from lack of temporal coverage and are largely limited to measuring state variables (nutrient and contaminant concentrations, fish abundance, etc.) on an annual or biennial basis.

Variability in the Great Lakes is extremely high—a function of their intense seasonality, intimate connection with highly variable atmospheric conditions and driving forces, and non-steady state perturbations induced by elements like invasive species. Consistent winter data is largely absent. Winter research funding is minimal and winter science platforms to support winter science safely or effectively do not exist. Data streams consequently go dark despite the fact that processes occurring during winter and the transitional periods around winter have significant impacts on the structure of the ecosystem including lake level fluctuations, biological production and a myriad of lake effect weather impacts. Climate change projections indicate that changes in winter conditions such as duration, temperature, and precipitation are among the most sensitive to alteration by changing climate and are likely to greatly impact the entire system during all seasons.

Capturing long-term trends, which are often subtle but critical to understand, is virtually impossible in a system with such high variability in the absence of a robust monitoring network consisting of coordinated array of observing platforms that collect data at or near continuous frequencies, and measure variables at depth. Fortunately, the technology for such measurements is now available (see text box, next page).

Priorities of the Science Strategy



Technological advances are transforming monitoring and surveillance, as exemplified by these initiatives taking place in the Great Lakes and programs found in the marine (ocean) environment. Examples include:

- Integrated Ocean Observing System's Great Lakes Observing System[4]
- Real-time Aquatic Ecosystem Observation Network[5]
- Hawaii Ocean Time-series (HOT)[6]
- Ocean Observatories Initiative[7]
- Monterey Accelerated Research System Cabled Observatory[8]
- Argo[9]
- Autonomous vehicle technology e.g., OceanGliders[10]

Observing systems have the capability to bring to the Great Lakes the level of environmental intelligence needed to identify how the system is shifting over time and space, and to provide the level of detail needed to verify and calibrate complex ecosystem models that are predictive of shocks to the system that threaten the well-being of the people of the region. This area of investment would include dedicated lake-specific monitoring arrays and associated data management systems. Year-round process studies would be conducted contemporaneously at a number of such arrays in each lake to link monitoring time series data to studies of the dynamics of critical ecosystem transformations and fluctuations.

3. Enhanced models and forecasting systems

As in previous years, physical modeling continues to be a strong suit of the Great Lakes, as exemplified by the National Oceanic and Atmospheric Administration's Great Lakes Forecasting System.[11] Taking the next step in developing integrated physical-biogeochemical-ecosystem models will provide the capability to project conditions under future scenarios, a key aspect of ecosystem management to protect human health and economic vitality.

With basic process understanding and data for verification, such models can be used as tools to test and design a wide variety of management options, climate change scenarios and sampling strategies. Essential investments include the data management framework and the maintenance and modification of models as they evolve based on ongoing monitoring and process measurements.

4. Human capital:
workforce development

Fostering a vigorous Great Lakes research community and developing a professional workforce is an essential component of a decadal scale Science Strategy and presents job opportunities and economic returns. The region has a distinct advantage in terms of the training of the next generation of practitioners through one of the world's finest assemblages of institutions of higher education.

Encouraging a young, diverse pool of new talent will follow from an investment in research, but should be augmented by programs funding graduate students, post-doctoral fellows and collaborative research coordination networks across these institutions and federal, state, provincial and local management agencies.

Priorities of the Science Strategy

5. Research infrastructure and Centers of Excellence

A principal finding is that the research infrastructure needed to carry out the essential components identified in the Science Strategy was deficient, including the need for development of highly qualified personnel, expanded analytical capacity, improved laboratory facilities, advanced autonomous and remote sensing technologies, and a state-of-the-art research fleet, among others.

While there are approximately 100 active vessels listed on the IJC's Great Lakes Association of Science Ships website,[12] over 80 percent are small craft less than 20 meters (66 feet) in length and half of these are less than 10 meters (33 feet). Only five research vessels exceed 30 meters (98 feet), and only the US Environmental Protection Agency Research Vessel Lake Guardian (55 m/188 ft), the Université du Québec à Rimouski Research Vessel Corolis II (50 m/164 ft), and the Canadian Coast Guard Research Vessel Limnos (45 m/148 ft) would fall within a Regional Class research vessel classification. All were designed based upon research vessel standards that were based on the needs as understood more than 40 years ago.

Priorities of the Science Strategy

In addition, most of these Great Lakes vessels have very specific mission profiles (e.g., fisheries or regulatory monitoring), and are not routinely available for extramurally-funded projects. It was highlighted that winter operations are very limited with virtually no ice class vessels available to researchers on a routine basis. With the exception of Coast Guard icebreakers (e.g., CCGS Griffon, USCG Mackinaw, USCG Neah Bay, vessels that are not characterized as research vessels), the fleet ties up or is deemed unsafe to operate during the winter season.

It was also recognized that many research initiatives will require effort that extends beyond the time frame of an individual project or even a decadal scale effort, and that these also require interdisciplinary groups and networks of professionals working across institutional boundaries.

Fostering our ongoing understanding of the Great Lakes would benefit from the creation of a small, but well supported, number of permanent Centers of Excellence, whose focus would be on long-term, basin-scale, interdisciplinary needs in key evolving areas of research, modeling, socioeconomic analysis, data acquisition, diversity and coordination. Centers of Excellence would also provide a forum to handle cross-cutting issues that may arise in interdisciplinary investigations involving various fields of natural and social science.

Several ideas for physical or virtual Centers of Excellence, collaboratives, innovation clusters or communities of practice have been discussed by contributors to the Science Strategy. These are critical to attracting, developing and aligning talent, and the ability to address interdisciplinary questions.

Such centers need funding to allow for the acquisition of facilities, hiring of coordinators, seed grants for exploratory projects, development of shared repositories of resources and equipment, and interaction with related centers or groups outside the Great Lakes region.

A non-exhaustive and unranked list for topical focus areas for such centers includes:

- Food webs, fisheries and ecosystem services
- Numerical modeling, forecasting, artificial intelligence, and machine learning
- Advanced observing systems and autonomous vehicle operations and applications
- Socioeconomic data collection and analysis
- Indigenous and community knowledge systems
- Diversity, equity, inclusion and justice in Great Lakes science
- Environmental toxicology and human health
- Integrated Great Lakes education facilities including science, engineering, arts, history, geography, culture and public outreach
- Forecasting and Great Lakes early warning system frameworks for ameliorating or avoiding potential future impacts on human and ecosystem health

Priorities of the Science Strategy

6. Inclusion of broad socioeconomic and cultural perspectives

Managing the Great Lakes will require perspectives that extend beyond natural science. The role of Traditional Ecological Knowledge is recognized, but it is also recognized that engaging Traditional Ecological Knowledge will require a concerted effort and investment and that reliance on voluntary contributions will be inadequate.

Economic analysis and system valuation likewise needs directed effort and support. The value of the Great Lakes ecosystem to the regional economy may be difficult to estimate, but it is nonetheless very real and runs into billions of dollars annually.

The Great Lakes commercial, recreational and tribal fisheries alone are collectively valued at more than US$7 billion (CDN$8.75 billion) annually and support more than 75,000 jobs. Drinking water, waste disposal, transportation, electrical power generation, aesthetics and enhanced quality of life are all services provided by the lakes whose value far exceeds the investment in their protection and preservation.

The balance sheet for the Great Lakes is overwhelmingly positive and warrants a quantitative assessment for restoration, protection and preservation, and the benefit those investments will accrue to the future in terms of both cost savings and economic growth.

“The overall goal of the Science Strategy is to establish a road map for placing the Great Lakes region on a sound scientific footing for ensuring effective management and permanent sustainability of the system”

Impact on Restoration

The creation and implementation of a comprehensive decadal scale Science Strategy is timely. Following nearly a century of misuse, the Great Lakes Water Quality Agreement of 1972 and subsequent revisions inspired actions to address eutrophication issues and reduce chemical levels in water, sediment and biota. Yet, impacts have arisen from a host of stressors, invasive species, emerging contaminants, climate change, to mention only a few.

The Great Lakes Restoration Initiative represents the United States' attempt to correct the ills of the past and place the Great Lakes on a path of sustainable protection and preservation. The Canadian corollary, the Great Lakes Protection Initiative (2017), is of smaller magnitude and focused on legacy impacts. Restoring a system as large and complex as the Great Lakes, and with a history of degradation that stretches back decades, is rife with scientific questions and uncertainties. At what point is a system or a functional component of the ecosystem considered restored? We cannot simply turn back the clock.

This system will never be as it once was. How permanent are the restoration activities and will they pass the test of time? What are the most cost effective and impactful actions that can be taken? Have we moved the system toward greater resilience? The answers to these and other important questions can only be attempted if the fundamental nature of how the system functions and how it will respond to change, to intervention and to correction are known. This is the essential role of scientific investigation.

Eventually, this era of restoration should end. This is one of the central recommendations of the 2022 report[13] from the US Environmental Protection Agency's Great Lakes Advisory Board,[14] an independent federal committee tasked with advising the agency on the progress of the Great Lakes Restoration Initiative.

Restoration should be replaced by a new era of sustainable management and protection. The need for scientific inquiry will be undiminished and the role of Centers of Excellence as lasting places of knowledge development and sharing will ensure that closing the loop between fundamental research and adaptive management will become the *modus operandi* of Great Lakes institutions.

Mistakes of the past, often costing billions of dollars to correct, will become a thing of the past, and the billions saved will accrue to future generations.

Investments in Monitoring, Research and Related Great Lakes Management Efforts

The Current Investment

To estimate the current investment in research and monitoring of the Great Lakes by Canada and the United States, approximately 65 organizations were appraised. These included organizations that perform research and monitoring themselves, and major funders of Great Lakes activities including federal competitive funding agencies and private foundations.

The total annual investment defined very broadly in Great Lakes research, monitoring, and associated program administration by Canada and Ontario, the United States and the Great Lakes states, and Indigenous nations, communities and organizations is estimated to be approximately US$250 million (CDN$315 million). Of this amount, approximately 20 percent (US$50 million [CDN$62.5 million]) comes from the Great Lakes Restoration Initiative, 50 percent (US$125 million [CDN$156 million]) comes from US federal sources other than the Great Lakes Restoration Initiative with US Geological Survey and US Environmental Protection Agency the largest contributors (approximately 30 percent and 20 percent respectively), 15 percent comes from Canadian federal and provincial sources, and another 10 to 15 percent comes from US state agencies. While Tribal and First Nation budgets come primarily from federal sources in both countries, in-kind contributions from Indigenous peoples remain incalculable.

The Needed Investment

The Great Lakes Science Strategy for the Next Decade estimates that **the additional investment needed to accomplish the goals and vision over the next decade is approximately US$100 million (CDN$125 million) per year,** two-thirds of which is projected to be invested directly in the research enterprise, via new and enhanced programs in process studies, monitoring, data management and Centers of Excellence.

Updating the Great Lakes research fleet and associated platforms is a high priority and represents approximately one-third of this investment to provide for the addition of purpose built, interdisciplinary, all-season state-of-the art platforms including ice-hardened and regional class research vessels capabilities.

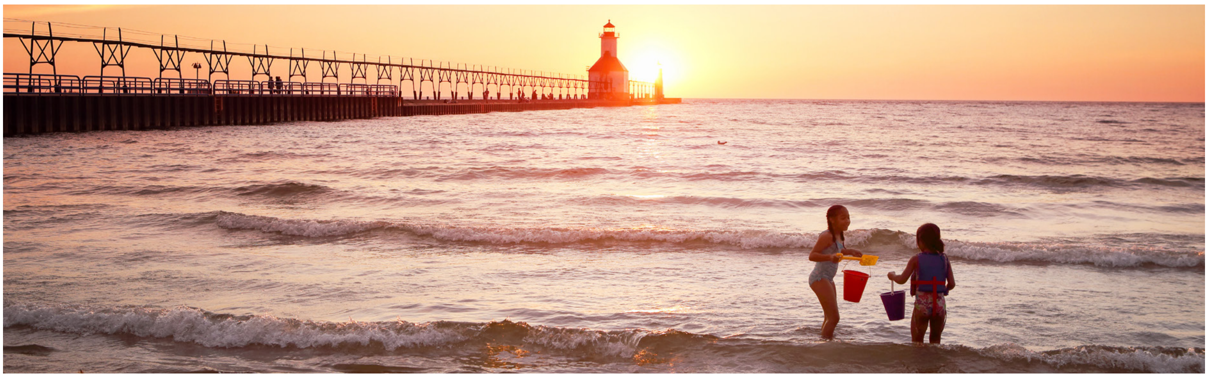
Recommendation: A Road Map to Move the Science Strategy Forward

The size, complexity and diversity of the Great Lakes social, political, and environmental ecosystem present a major challenge for funding, organizing, and implementing an efficient, well-coordinated, and focused, basinwide, transnational, long-term Science Strategy. Questions that arise include:

- What is the mechanism for moving the Science Strategy forward that encompasses the transnational nature of this system and all the partners in the system?
- How will funding be authorized and appropriated and allocated?
- How will coordination across governments, agencies, academia, etc., be facilitated?
- What governance structure will oversee and ensure progress, accountability and efficient, cost-effective use of funding?
- How will the science be judged and reviewed for intellectual merit, broader impacts and value to management?
- How will results be incorporated into planning, management and restoration?

The surveys and workshops held to develop the Science Strategy identified a consensus on broad science questions and gaps, and associated resource needs to address them. Hundreds of professionals contributed to the Science Strategy, but achieving a basinwide Science Plan for a sustainably managed system will require additional engagements and support, as suggested by the US Geological Survey Science Forum Report.[15]

Engaging in partner dialogue and developing consensus on specific science needs, gaps, as well as sustainable management and governance arrangements, is a necessary next step. An efficient, sustainably managed system will require a strong commitment, including funding, to a consensus-based governance structure.



A willing and enthusiastic coalition is needed to build a basinwide Science Plan, communicate science needs, and work with Parliament and Congress to achieve the intimately linked goals of a healthy, protected and sustained regional economy, environment and quality of life.

While complex in terms of the multinational responsibility for the Great Lakes ecosystem, the region has the advantage of a strong history of binational cooperation, as epitomized by the IJC and the Canadian-US Boundary Waters Treaty of 1909, the 1954 Convention on Great Lakes Fisheries, the 1972 Great Lakes Water Quality Agreement, and many strong binational organizations.

The critical next step will be for the IJC to work with partners such as the Great Lakes Commission, the Great Lakes Fishery Commission and Indigenous peoples to take the Science Strategy and use it as a foundational document to collaboratively develop a detailed Science Plan.

In conclusion, the Great Lakes region's characterization as the Rust Belt is rapidly becoming a thing of the past. A revitalization based upon environmental restoration, abundant freshwater and natural resources, coupled with an economic backbone of world class education and research, manufacturing and agricultural prowess, and a historically diverse, multi-sector workforce—anchored in a region recognized as among the most resilient to the stresses of climate change—will project the Great Lakes region into a new era as North America's Fresh Coast.[16]

Ultimately, the Great Lakes Science Strategy for the Next Decade is not about science. It is about ensuring and protecting the health and prosperity of the people. Unlike many freshwater reservoirs around the globe, the Great Lakes will be here a thousand years from now—a perspective that places a decadal strategy within its proper context. Understanding the system is essential for the management, protection and stewardship for the 21st century, a century that augurs to see an unprecedented acceleration in environmental change, technological development and demands on freshwater resources. The Great Lakes Science Strategy for the Next Decade is an important step in acknowledging our responsibility responding to that change and ensuring that the future will be secured.

Footnotes

1. This figure is calculated using the Gross Domestic Products of the Great Lakes-St Lawrence region, including Ontario and Quebec in Canada, along with Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania and Wisconsin in the United States. The US$3.5 trillion figure in the Great Lakes Science Strategy for the Next Decade report is calculated using the gross domestic product of Canadian and US cities in the Great Lakes region, including but not limited to: Chicago, Cleveland, Detroit, Duluth, Milwaukee and Toronto.
2. Accessible at: trumpwhitehouse.archives.gov/wp-content/uploads/2018/11/Science-and-Technology-for-Americas-Oceans-A-Decadal-Vision.pdf
3. Accessible at: cca-reports.ca/wp-content/uploads/2018/10/oceans_fullreporten.pdf
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12. Accessible at: canamglass.org/
13. Accessible at: facadatabase.gov/FACA/apex/FACACommitteeLevelReportAsPDF?id=a10t0000001gzsHAAQ
14. Accessible at: glri.us/glab
15. Accessible at: pubs.usgs.gov/of/2021/1096/ofr20211096.pdf
16. Originally coined by the former mayor of Milwaukee, Wisconsin, Tom Barrett, the term “Fresh Coast” has gained popularity as symbolizing this transformation.

Image credits

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Page 3: MODIS image of the Great Lakes looking eastward, OrbView-2 - SeaWiFS, April 24, 1999. By NASA via NOAA Great Lakes Environmental Research Laboratory Flickr

Page 4: Lake Ontario Scarborough Bluffs aerial panorama shot from above with drone. By Elena Berd via Adobe Stock Image

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Page 19: Cleaning equipment to prevent toxins from migrating. By Great Lakes Mud via Great Lakes Mud

Page 20: ECF walls with a dredging tube at the Randle Reef restoration, summer 2019. By Riggs Engineering via IJC newsletter article " Hamilton Harbour-Randle Reef Restoration Entering Final Phase"

Page 23: St Joseph Lighthouse on Lake Michigan at sunset. By soupstock via Adobe Stock Image

Back cover: Ship on Lake Michigan at sunset, July 2019. By Stephan Cassara via Unsplash

Appendix

Research Priorities and Needs by Discipline

Research Priorities	Science Investment Needs
Physical Hydrodynamics and Atmospheric Dynamics Priorities: Climate change modeling; shoreline dynamics and erosion; and influence and impacts of physical forces.	› More long-term, deep lake monitoring. › New instrumentation for high-resolution observations. › Expansion of the real-time weather and climate buoy network. › In situ and remote sensing measurement of ice cover/thickness. › Better short-term predictions (now casting and forecasting). › Increasing the accessibility, use, and synthesis of Great Lakes data.
Chemistry and Biochemical Cycles Priorities: Identification of the major sources, sinks, and transformations of macro and micro-elements in the five Great Lakes, their patterns in space and time, and their co-dependencies; Great Lakes biogeochemistry responses to anthropogenic activity; status of groundwater in urban and rural communities; and status of legacy chemicals.	› Year-round monitoring at key reference stations. › Standardization of sampling and analytical protocols and binational data management. › Additional scientific staff trained in advanced biogeochemical science, monitoring, analytical methods, modeling, and data management.
Food Webs and Fisheries Priorities: Predicting whole ecosystem responses to physical, chemical, and biological change; understanding annual nutrient dynamics and effects on plankton, benthos, and prey fish communities; and determining how invasive dreissenid mussels and round goby, *Neogobius melanostomus*, are affecting aquatic food webs.	› Institutional framework. › Food web initiative coordinated by a new Ecosystem Monitoring and Modeling Advisory Committee. › Data and modeling Center of Excellence (Brick and mortar). › A new long-term, adaptive, basinwide monitoring and assessment program.

Research Priorities and Needs by Discipline

Research Priorities	Science Investment Needs
Watershed Dynamics Priorities: Develop a better understanding of the hydrologic continuum in the Great Lakes, develop a better understanding of the inter-play among management actions and in-field and beyond-field biogeochemical processes, and their impacts on water quality.	• Monitoring of all tributaries. • Establish multi-scale and/or nested watershed platforms. • Establish Great Lakes Center for Watershed Science, Data, and Modeling Tools.
Cross-Cutting Topics Priorities: Improving understanding of how to realize the benefit of linking experts in Traditional Ecological Knowledge (TEK) with experts in Western science; understanding the socioeconomic factors that drive the establishment of priorities related to the Great Lakes within communities, and how this understanding can be leveraged to accelerate positive change; understanding actions that build and maintain cohesion, resilience, and human flourishing in Great Lakes communities; and evaluating the impact of levels of involvement, engagement, and governance in priority setting and goal setting and how they engender confidence in science and science-mediated outcomes.	• Establish Centers of Excellence, projects of identity, ecosystem services valuation hubs: multidisciplinary facilities, build a more interconnected network of practitioners for the lakes; take advantage of existing gover-nance entities and boundary organizations, pattern approaches after recent US National Science Foundation Coastlines and People solicitations with a focus on multiple nodes sited with consideration of equity, and measurable impacts. • Investment in social dimensions should be at a similar level to natural science inquiry – and social and environmental science inquiry needs to be advanced in an integrated fashion. • Improve understanding of return-on-investment of ecosystem restoration and protection; provide the business case for science and monitoring investments.

Research Priorities and Needs by Lakes and Connecting Waters

Research Priorities	Science Investment Needs
Lake Superior Priorities: Understanding how current and future climate changes are affecting both social and ecological systems in Lake Superior, and evaluate the sources, fate, and bioaccumulation of key toxic chemicals within Lake Superior and its food web.	› Year-round research vessels that are accessible to researchers (both agency and academic scientists) from both the US and Canada. › Increase the number of scientists in the basin. › Improve the network of tributary gauges. › Build new science facilities and improve the wireless communication systems such as wireless buoy data transmission.
Lake Huron and Connecting Waters Priorities: Develop more extensive food web models; better delineate lake-wide conditions; and improve understanding of Lake Huron connecting waters.	› Enhanced monitoring networks that link existing data and networks (e.g., fish telemetry, satellite imaging) with new types of data. › Investment in new research vessels to support year-round operations and monitoring. › The creation of mechanistic fish community models would allow different nutrient management and stocking scenarios to be evaluated in terms of their corresponding impacts on fish communities over time.
Lake Michigan Priorities: Understand the mechanisms that regulate the movement of material in the nearshore zone; research how food web structure and trophic dynamics are responding to various drivers; study lake hydrology and biogeochemistry linkages to watershed properties and processes; and understand the drivers of, and the ecosystem response to, hypoxia in Green Bay, Wisconsin.	› Enhance monitoring programs. › Conduct an updated comprehensive mass balance study. › Develop a modeling community. › Expand capabilities and availability of research vessels. › Invest in people.

Research Priorities and Needs by Lakes and Connecting Waters

Research Priorities	Science Investment Needs
Lake Erie and Connecting Waters Priorities: Winter limnology and meteorology; linkages between the Lake Erie watershed land use changes and in-lake processes; understanding the extent to which climate change is driving changes in biodiversity and fish productivity; and high frequency, real-time, year-round monitoring technology.	› Creation of data management systems for better cross-boundary access, sharing, and integration of data and better integration and coordination of monitoring and research. › A designated Sea Grant-like organization with a funding source for the Canadian side of Lake Erie. › Maintain and expand investments in binational monitoring networks and platforms, with a specific focus on long-term commitments for operation and maintenance (O&M). › Address unmet Lake St. Clair – Detroit River System, and upper Niagara River research and monitoring priorities. › New investments for applying remote sensing tools and other technologies (e.g., satellite and hyperspectral). › Fill gaps and improve the efficiency and flow of information between the research and monitoring efforts and management. A boundary-spanning integrated science-based framework, or a similar mechanism, could secure commitments to improving the flow of information to better guide coordination and collaboration across the system.
Lake Ontario and Connecting Waters Priorities: Nutrient dynamics; social-ecological system research; Ecosystem restoration; human population change; and emerging and legacy contaminants.	› Improved data management systems for the lake and its connecting waters. › Research infrastructure that capitalizes on advances in emerging technologies. › Increased research on nearshore nutrient loading and upwelling processes. › Efforts to restore biodiversity and native species stocks in the lake are hampered by insufficient knowledge of habitat and life cycle of depleted or extinct species, which requires intensive studies to guide restocking programs. › Address unmet upper St. Lawrence River research and monitoring priorities. › Establish metrics to evaluate the effectiveness of the Plan 2014 water level management system.

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