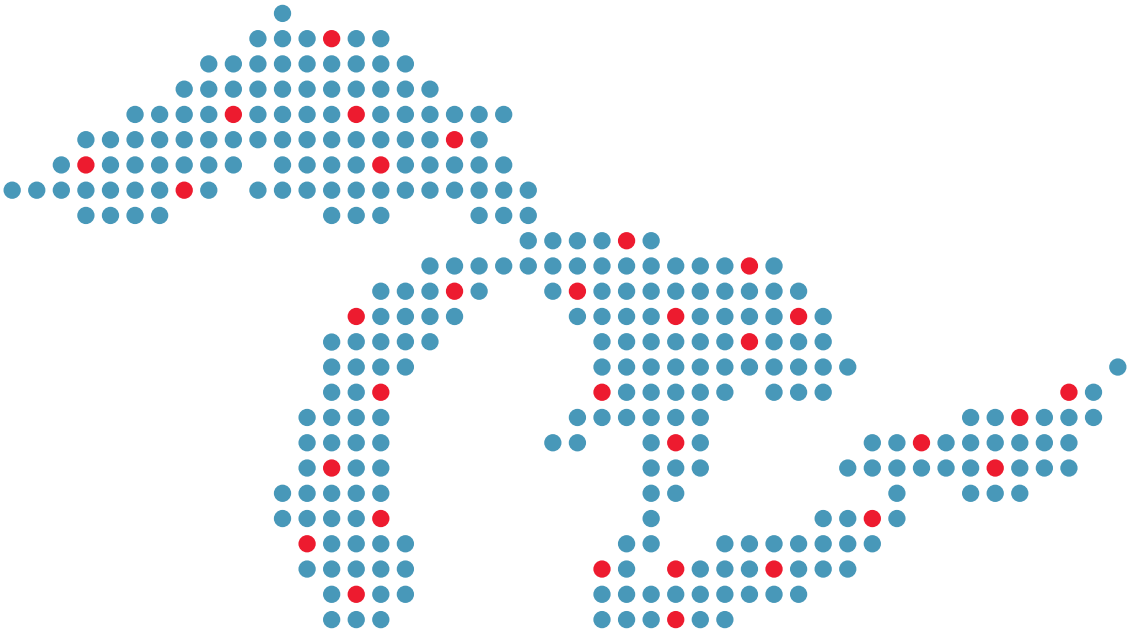

Common Strategy for Smart Great Lakes

Acknowledgments

In 2019, the idea to create a common strategy for using data to make decisions, or Smart Great Lakes, was developed by members of the Great Lakes Observing System, Cleveland Water Alliance and the Council for the Great Lakes Region. The three organizations held several gatherings to present and discuss the idea with a small base of Great Lakes partners, and teams and committees were formed to turn the idea into reality. The Leadership Team, Steering Committee, and Issue Area Strategy Teams began meeting virtually in summer 2020, each with their own charge as outlined in a governance framework and all working towards the development of the Common Strategy for Smart Great Lakes.

We wish to express our gratitude to the various Issue Area Strategy Teams for their input, feedback and time to develop the core content of the Common Strategy. In particular, we would like to thank the Issue Area Strategy Team co-chairs, Dean Alonistiotis, Mary-Claire Buell, Krysha Dukacz, Kat Kavanagh, John Lenters, and JC Nelson for leading the teams throughout this process. The Science, Technology, and Innovation team members include Jay Austin, Andrew Barnard, Laura Bourgeau-Chavez, Shelby Brunner, Steven Cai, Awoke Dagnew, Ngan Diep, Alice Dove, Aaron Fisk, Jennifer Grieser, Max Herzog, Craig Hill, Jeremy Holden, Tom Hollenhorst, Madeline Magee, Benjamin Miller, Joseph Ortiz, Aaron Packman, John Robinson, Ann Rosen, Jeanette Schnars, Bob Sterner, Svetlana Taylor, Chris Vandergoot, Ivette Vera-Perez, Maggie Xenopoulos, and Nathan Zgnilec. The Data and Information team members include Don Arcuri, Vidya Balasubramanyam, Linden Brinks, Terry Brown, Steven Cai, Andy Chartier, Peter Colohan, Awoke Dagnew, Ngan Diep, Carolyn DuBois, Carolyn Foley, Omar Gates, Max Herzog, Craig Hill, Jeremy Holden, Tom Hollenhorst, Katelynn Johnson, John Lenters, Kelly Knee, Clinton Little, Madeline Magee, Guy Meiri, Benjamin Miller, Marylee Murphy, Joseph Ortiz, Elliott Quider, Hannah Ramage, John Robinson, Rick Wilson, and Maggie Xenopoulos. The Policy and Management team members include Don Arcuri, Vidya Balasubramanyam, Joel Brammaier, Jennifer Grieser, Sophia Green, Chad Lord, Madeline Magee, Matt McKenna, Carolyn O'Neill, Tom Rayburn, Katie Rousseau, Laura Rubin, and Ryan Wilson.

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Finally, we respectfully acknowledge and express our gratitude to the waters, lands, and beings of the Great Lakes basin. We give gratitude to the First Peoples of this region, including the First Nations, Tribes, and Métis communities who have cared for the Great Lakes and all their beings since time immemorial. We thank them for their care and for their teachings about the lands, waters, and our relations.

Mark Fisher
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Executive Summary

For the past decade, "smart" technologies have transformed the way society and the world interact. Smartphones and inexpensive sensors have become ubiquitous, allowing us to collect and process far more data than ever before and influencing how we choose to search for, consume, and share information. Technology advancements such as distributed sensing, automation, edge computing, machine learning, data integration, and predictive analysis give us the ability to transform diverse and large datasets into actionable information and sometimes, even direct action. Today, we have the ability to make data-driven decisions in nearly every aspect of our lives—personally and as a region.

Smart Great Lakes Vision:
Advancing technology applications that improve our understanding, management, and use of the Great Lakes.

This notion of using technology to make describing our environment "smarter" inspired the vision for Smart Great Lakes. It catalyzed a network of partners across the Great Lakes region to organize around common goals and priorities to improve the way people learn about and respond to lake events, to inform critical policy, and to direct future science and innovation. Even beyond the current technology-driven interpretation of the term "smart," working smarter means finding ways to improve the quality and methods of doing the work. In this spirit, we seek opportunities through Smart Great Lakes to improve the efficiency, inclusiveness, and impact of our work to ensure the Great Lakes, our immensely valuable shared natural resource, is safe, healthy, and supports thriving communities for generations to come.

As a multinational resource with far-reaching economic, ecosystem, and public health impacts, the Great Lakes region of North America encompasses a diverse set of interests. Smart Great Lakes is about creating a region where people make decisions informed by shared lake data. The Smart Great Lakes Initiative (SGLi) is a consortium that convenes private industry, state, provincial and federal governments, academic institutions, and non-profit partners to lead the development and application of advanced data collection, analytics, and decision-support systems across the Great Lakes. SGLi seeks to improve awareness and response to changes in the Great Lakes, guide, support and apply technological innovation in Great Lakes sensing and data science, and inform critical decision-making across political borders. The Common Strategy's development and implementation through the lens of justice, equity, diversity and inclusion seeks to touch and combine science, innovation and technology, data and information, and policy and management.

What is the Smart Great Lakes Initiative (SGLi)?
A collaborative consortium that is organizing the region's technology ecosystem and network of partners around common policy goals to improve monitoring, data management and analysis, advance research, and spur technology innovation.

From binational commitments such as the Great Lakes Water Quality Agreement to local decision-making by municipalities and water utilities, understanding our relationship with the Great Lakes environment requires the aggregation of data and information to serve as measures of progress toward shared outcomes. While a number of policies encourage integrated, stakeholder-based management, SGLi aims to identify and fill gaps in data collection and interoperability, information dissemination and actionability, and data science education and professional training across all Great Lakes stakeholders. We emphasize common equity in Great Lakes data, and focus on engaging and supporting First Nations, Tribes, Métis, and underserved communities.

As threats and pressures from climate change, invasive species, pollution, and urbanization continue to mount in the Great Lakes region, challenges to region-wide management continue in parallel. Comprehensive and sustainable management relies on critical information infrastructure, including accurate and resilient observing systems, cutting-edge science and research, analysis-ready data and information accessibility, and tools to equip decision-makers with current and relevant information. Capitalizing on the emergence and application of new technologies and partnerships—some of which arose to fill data and information gaps from disruptions due to COVID-19—is critical to keep pace with mounting pressures, challenges, and threats to the Great Lakes. This Common Strategy for Smart Great Lakes is a community-generated set of priorities, strategies, and recommendations for advancing data-driven management and policy in the Great Lakes. It supports systems upgrades to out-of-date monitoring and environmental surveillance structures, and combines resources and energy across the region to better direct capacity, funding, and policy towards combating these pressing challenges.

Expected outcomes of this effort include:

- Advanced information technology and analytics to harness "Big Data" in decision-support applications to improve management, security, and health of the Great Lakes
- Informed performance metrics and measurement strategies to assess the efficacy of Great Lakes policy and management
- Support of private, Indigenous, and public-sector initiatives to acquire, analyze, interpret, and deliver public information products around the Great Lakes
- Identified, promulgated, and supported implementation of best practices for data management and sharing
- Additional investment in crucial observing infrastructure across all Great Lakes agencies and organizations, as well as investment in research and development for emerging monitoring and water treatment technologies.

In addition to the above outcomes for SGLi, priorities presented in the following sections include directing resilient and responsive monitoring systems for Great Lakes-specific systems, empowering data providers to collect and share data in new and more accessible ways, and enhancing both public and private funding opportunities for programming and innovation.

All Common Strategy goals, objectives, and action items are viewed under a dedicated environmental justice lens: each principle is designed and implemented with representation at the forefront, prioritizing equitable access to data, information, and programming, and fostering reciprocity and relationships among rights holders and stakeholders in Great Lakes science and management. SGLi partners will adhere to best practices by including First Nations, Tribes, Métis, and local perspectives to ensure co-creation of new and ongoing projects and that they are valuable for communities affected by them. In addition, data will align with the FAIR Principles (Findable, Accessible, Interoperable, and Reusable) and Indigenous Data Governance Principles: CARE Principles (Collective Benefit, Authority to Control, Responsibility, and Ethics) and OCAP Principles (Ownership, Control, Access and Possession).

Rights holder: An individual or social group that has particular entitlements in relation to specific duty-bearers.
Stakeholder: A person with an interest or concern in something.

The SGLi will lead the development, implementation, and evolution of advanced data collection, analytics, and decision-support systems across the Great Lakes. By coming together as an extensive partnership network, identifying common goals and creating opportunities for shared benefit, we are working smarter to ensure cooperative science and management, or Smart Great Lakes.

Environmental Justice in Smart Great Lakes

To support environmental justice, the SGLi goals will:

- Support community science initiatives
- Improve discoverability of Great Lakes data with different delivery formats and education curricula
- Ensure data collection and management follows FAIR, CARE, and OCAP Principles
- Secure data sovereignty for under-represented communities and include privacy-protecting databases and differential access to sensitive information
- Make decision support tools available to rights holders and stakeholders without reliable internet or smartphone access.

Smart Great Lakes Goals

Science, Innovation, and Technology

Goal 1: Develop novel and interdisciplinary research

Goal 2: Support science, innovation, and technology that improve our ability to identify, assess and respond to stressors and change

Goal 3: Build resilient, adaptable observing systems in support of a swimmable, drinkable, fishable, and equitable future

Data and Information

Goal 4: Improve discoverability of Great Lakes data by increasing findability and accessibility

Goal 5: Foster data compatibility by developing a framework supporting interoperability and reusability

Goal 6: Empower data providers to share and access new data by facilitating reuse and access

Policy and Management

Goal 7: Ensure Smart Great Lakes provides opportunities and resources for the Indigenous Tribes, First Nations, and Métis within the Great Lakes basin through respectful engagement

Goal 8: Strengthen Great Lakes-related policies

Goal 9: Invest in Smart Great Lakes

Goal 10: Accelerate SGLi communication, outreach, education, and engagement

Recommendations

The following recommendations aim to advance SGLi goals:

- Advocate for specific SGLi goals and priorities within other Great Lakes science and policy forums to ensure appropriate consideration for research, monitoring, surveillance, and data sharing (e.g., International Association for Great Lakes Research, Lakeside Action and Management Plans, Healing Our Waters, etc.).
- Develop collaborative basin-wide, lake-wide monitoring and surveillance strategies that leverage existing capacity and address important data gaps (e.g., Smart Lake Erie, Lake Bed 2030).
- Design collaborative information solutions around Great Lakes user communities, especially those that are traditionally underserved and underrepresented (e.g., Indigenous -SGLi, Coastal Climate Signals).
- Enhance the findability, accessibility, interoperability and reusability of Great Lakes data within a process and technical framework that supports Indigenous data governance principles: CARE Principles (collective benefit, authority to control, responsibility, and ethics) and OCAP Principles (ownership, control, access and possession). SGLi will:
    - Compile existing data sources and make metadata discoverable through a central hub (findable), and include the process for getting the data (accessible)
    - Identify and share data standards to enhance data exchanges (interoperable)
    - Identify and support metadata development to ensure data is independently understandable (reusable).
- Support and build communities of practice and iterate these processes to continuously enhance the data framework to meet rights holder and stakeholder needs.

Introduction

The Fresh Coast

The Great Lakes basin houses nearly a quarter of the global supply of surface freshwater and is home to nearly 34 million people or 8 percent of the United States population and 32 percent of that of Canada, including 185 First Nations, Tribes, and Métis communities.[1] More than 30 million residents of the binational region get their drinking water from the Great Lakes system.[2] Viewable by satellite and host to over 17,000 kilometers of shoreline, the Great Lakes basin watershed encompasses over 500,000 square kilometers of land, and is home to an estimated 3,500 unique plant and animal species.[3,4] The region varies widely in topography, climate, and soil, and includes a number of different habitats, including marsh, wetland, pelagic, dune, forest, agricultural, and metropolitan.[5] The lakes themselves provide habitat for more than 170 different fish species, including 61 considered to be threatened or endangered.[6]

The World Bank describes the Blue Economy as sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and ocean ecosystem health.[7] The combined Blue Economy output of Great Lakes basin commercial, recreational, tourism, energy, transportation, forestry, agricultural, and other sectors nears $US 6 trillion annually. If treated as a country, the Great Lakes-St. Lawrence River system's GDP would represent the third largest economy in the world.[8,9] Based on 2018 economic data from the US Bureau of Labor Statistics, over 1.8 million jobs are directly connected to the Great Lakes, generating $82 billion annually in wages.[10] This figure represents roughly a third of combined United States and Canadian economic activity and employment, and has grown by nearly 140,000 jobs since 2009. Within the 83 United States coastal counties bordering the Great Lakes, manufacturing and tourism/recreation have the greatest employment among all sectors, and increased by 8 percent and 10 percent, respectively, between 2009 and 2018. Tourism has experienced a renaissance in the region due to key programs like the US Great Lakes Restoration Initiative, which is estimated to generate $US 3.35 for every dollar spent on the more than 3,600 projects funded between 2010-2017.[11] Maritime industries also have increased significantly in the past decade due to federal investment in Great Lakes vessels, ports, terminals, and other water infrastructure of over $900 million between 2009-2013, and the efficiency of shipping dry-bulk cargo at 6 times less cost than truck transport.

A sustainable future for this unique and bustling region relies on a robust shared information ecosystem. This includes resilient observing systems that produce analysis-ready data as well as cutting-edge research and a wealth of environmental information that is both actionable and readily accessible to decision-makers of all kinds. Through the past several decades, a broad spectrum of monitoring and oversight capabilities have evolved throughout the basin. Given the importance of the drinking water, recreation, maritime shipping, and fishery sectors, much of the critical data collection relates to weather and water conditions as well as ecosystem health. As new technologies

1 Great Lakes Fast Facts | Sea Grant Michigan
2 NOAA Great Lakes
3 EPA | Physical Features of the Great Lakes
4 NOAA | Great Lakes Region Ecosystem-Based Management Activities
5 Great Lakes Regional Collaboration - Great Lakes and St. Lawrence Governors and Premiers
6 GLFC | The Great Lakes Fishery: A world-class resource!
7 World Bank | Blue Economy
8 CGLR | The Great Lakes Economy: The Growth Engine of North America
9 Economic Impacts of Maritime Shipping in the Great Lakes - St. Lawrence Region
10 MI Sea Grant | The Dynamic Great Lakes Economy Employment Trends from 2009 to 2018
11 Assessing the Investment: The Economic Impact of the Great Lakes Restoration Initiative

and capacities emerge, collaborative efforts to collect and disseminate information from a variety of observing, analytical, and community science based platforms will improve preparedness, responsiveness, and resilience of both human and natural ecosystem needs.

The Great Lakes region has historically received less federal attention and resources for baseline science than ocean coasts, despite many comparable physical features. Management and funding are more complex in some ways for the Great Lakes than for marine systems due to multiple binational points of contact, competing regional interests and needs, and differing vulnerabilities. Changing climate, older infrastructure, and regional trends in economic sectors like agriculture and manufacturing have left the Great Lakes region in urgent need of targeted investment. As a region-wide forum for addressing information needs, SGLi seeks to propel advancements in lake monitoring systems and promote accessibility of seamless, high-quality data and information to ensure that the critical public health, economic, and environmental needs of the region are addressed thoroughly and equitably.

To outpace mounting challenges to the region, it is critical to take advantage of new technologies and partnerships and capitalize on streamlined processes that came out of the COVID-19 era. Though the past years have been incredibly damaging in many ways to the region, the jolt to the system caused by the current pandemic and the accompanying natural disasters has resulted in increased clarity about data and information needs, infrastructure vulnerabilities, and more. As a result, many in the region see a need to invest in a vibrant information ecosystem like one the SGLi seeks to create.

Emerging and Pressing Challenges

The Great Lakes are managed by a wide variety of entities and interests, ranging from international commissions to grassroots activism (Figure 1). Important entities in this arena include federal, state, provincial, and municipal agencies, First Nations, Tribes, and Métis as well as binational organizations like the International Joint Commission (IJC; est. 1909) and Great Lakes Fisheries Commission (GLFC; est. 1954). In 2003, the Great Lakes Regional Collaboration (GLRC), a partnership of diverse stakeholders from the United States and Canada, was created by the Great Lakes Governors and Premiers in an effort to provide the leadership and coordination needed to foster restoration, protection, and sustainable use of the region amidst increasing environmental concerns.[12] In 2010, the Great Lakes Indian Fish & Wildlife Commission (GLIFWC; est. 1984) developed a strategic plan guided by anticipated future needs based upon the knowledge, visions and sacrifices of those who have gone before us and provides a foundation for the GLIFWC's work.[13] Subsequently, in 2012, the Canada-US Great Lakes Water Quality Agreement (GLWQA) was updated to better address environmental threats before they cause harm, support work on the existing threats to water quality and ecosystem health, and develop implementation and evaluation metrics. Most recently, an IJC Science Advisory Board report from April 2020 identified the top ten environmental stressor categories plaguing the Great Lakes region, based on "the activities undertaken over the past two decades to quantify and map threats and stressors at the scale of the Great Lakes basin."[14] This report describes the framework to develop a Great Lakes Early Warning System that aligns with goals of the SGLi.

12 Great Lakes Regional Collaboration - Great Lakes and St. Lawrence Governors and Premiers

13 Great Lakes Indian Fish & Wildlife Commission

14 Towards A Great Lakes Early Warning System

10 Broad Stressors in the IJC Science Advisory Report

- Toxic point source pollutants and contaminated sediments
- Invasive species
- Nonpoint pollutants (including agricultural, forestry, and urban sources)
- Altered water level fluxes (often as climate change impacts)
- Climate change
- Shoreline hardening and alterations, aquatic habitat alterations
- Coastal and urban development
- Natural resource use (including water withdrawals)
- Nuisance algae (harmful algal blooms, *Cladophora*)
- Dams and barriers

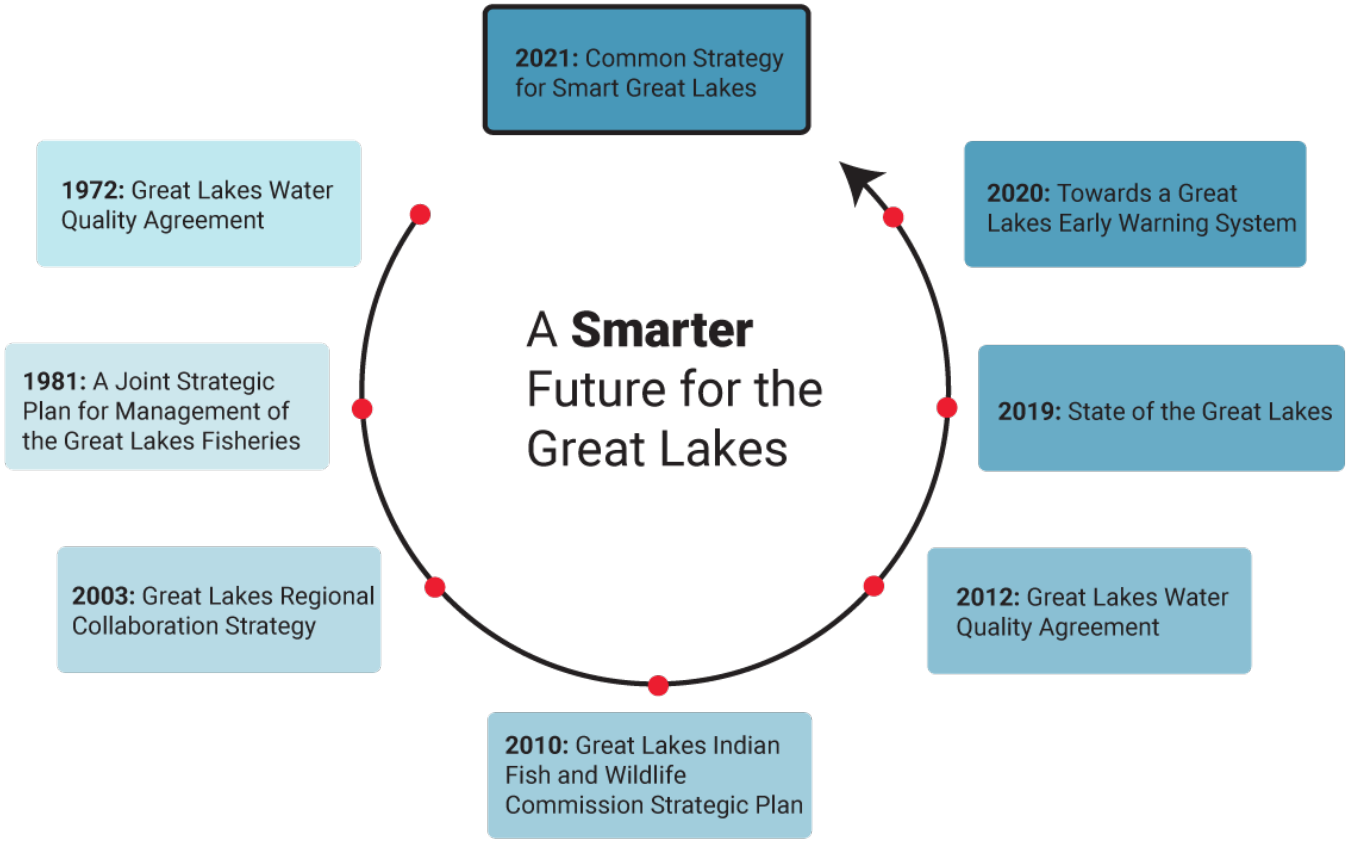


Figure 1: Over the past five decades, several key documents have been published to articulate solutions to emerging Great Lakes challenges, from natural resource management to economic development to climate change.

As issue areas continue to evolve with shifts in climate, land use, harmful algal blooms, and new and emerging observing technology, inter-agency coordination has become increasingly critical to effectively prioritize and address shared challenges. The silo approach to Great Lakes strategy is giving way to a more integrated paradigm, whereby information and insight flow in a multitude of directions among technology innovators, data scientists, policymakers, and the public. This type of collaborative effort is underscored in the 2019 State of the Great Lakes Highlight Report, produced jointly by the US Environmental Protection Agency (EPA) and Environment and Climate Change Canada (ECCC) that assessed nine overarching indicators of ecosystem health as established by the EPA in coordination with ECCC and many other partners.[15] The results of the evaluation identified invasive species as the single area characterized as poor with a deteriorating trend, while other indicators are stable with either a fair or good status.

15 State of the Great Lakes 2019

2019 Assessments of the Nine Great Lakes Indicators of Ecosystem Health

Great Lakes Indicator	Status and Trend
Drinking Water	Status: Good; Trend: Unchanging
Beaches	Status: Good; Trend: Unchanging
Fish Consumption	Status: Fair; Trend: Unchanging
Toxic Chemicals	Status: Fair; Trend: Unchanging to Improving
Habitat and Species	Status: Fair; Trend: Unchanging
Nutrients and Algae	Status: Fair; Trend: Unchanging
Invasive Species	Status: Poor; Trend: Deteriorating
Groundwater	Status: Fair; Trend: Undetermined
Watershed Impacts and Climate Trends	Watershed Impacts: Status: Fair; Trend: Unchanging
	Climate Trends: No Overall Assessment

STATUS

Good Fair Poor Undetermined

While only one indicator is in overall poor status and no other indicators are experiencing deterioration as a whole, the importance and impact of local challenges can be lost when accounting is completed across such a large basin. For instance, habitat and species degradation is occurring within aquatic food webs in most of the lakes for the amphipod *Diporeia*, which is a rich food species that supports whitefish, salmon, trout, and walleye.[16] Another example is the poor, unchanging, or deteriorating status of nutrients, algal events, *Cladophora*, and tributary water quality in Lake Erie. Water insecurity is experienced by many people across the region despite the presence of the Great Lakes, owing to local water quality issues, poor infrastructure, environmental injustices, and governance failures. Additionally, manoomin (wild rice) ecosystems are threatened by degraded riparian and coastal wetland ecosystems. If those resources are lost at the local scale, the well-being of a reliant community is degraded. Coordination along the entire cause-effect trail would provide insight into potential corrective measures to improve conditions at affected sites, and serve as a basis for proactive strategies to address these issues in parallel areas in the future. Ensuring participation, research, and decision-making at the local scale will better represent the true health of the Great Lakes ecosystem.

A Smart, Multi-Pronged Strategy

Technological advancements over the past decade enable far more sophisticated and reliable methods to collect, consume, and distribute data and information than ever before. Improvements in sensor hardware, telecommunications, machine learning and automation, data integration, interoperability, and adaptive and predictive analysis continue to emerge. These technologies enable more thorough, quality-assured, and holistic data capture and distribution, which transform diverse new data into potential actionable information and insights. The SGLi seeks to establish a unified common strategy supporting the integration and implementation of these methods, standards, technologies, and strategies into Great Lakes observations, environmental health and information management.

16 Disappearing Diporeia

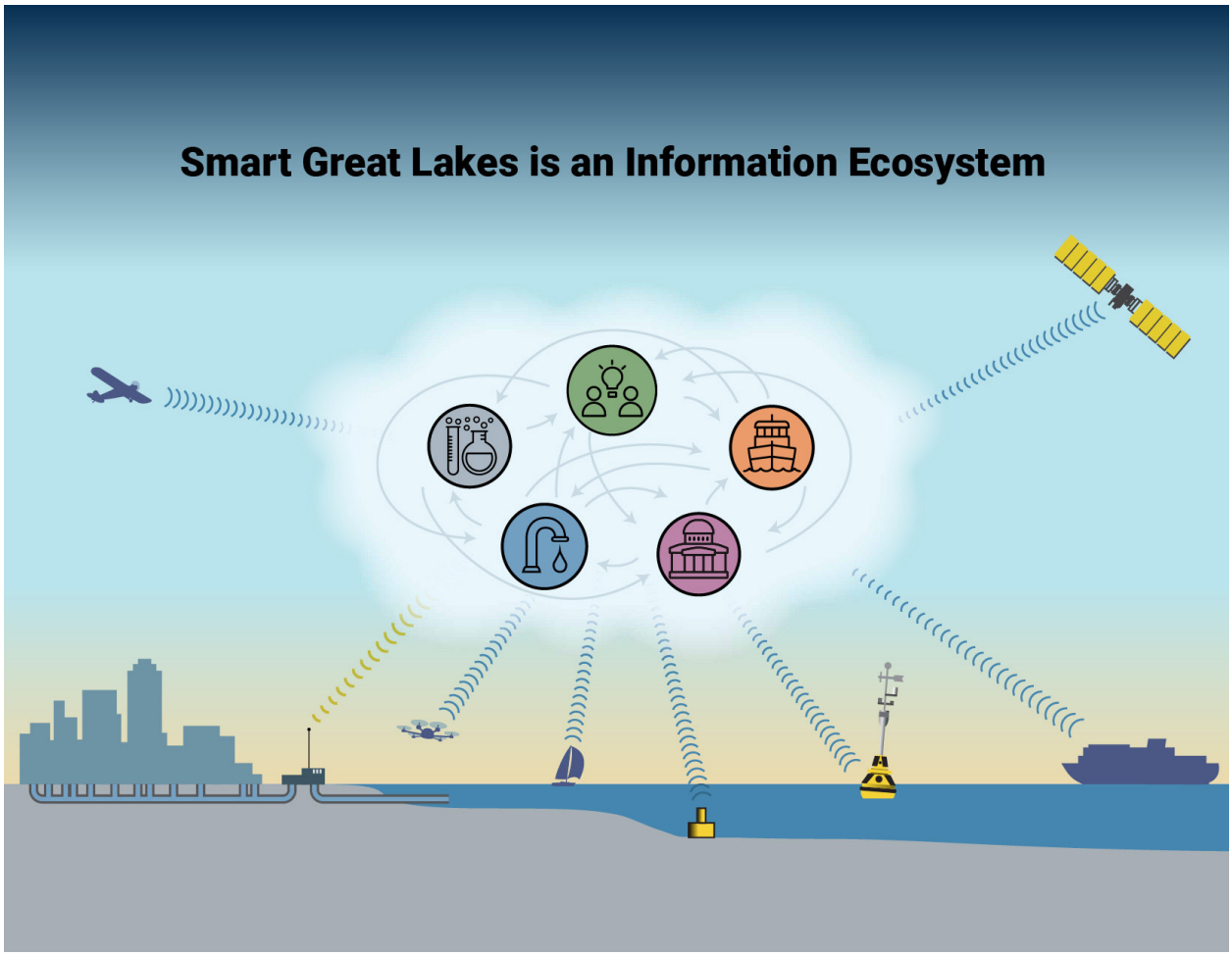
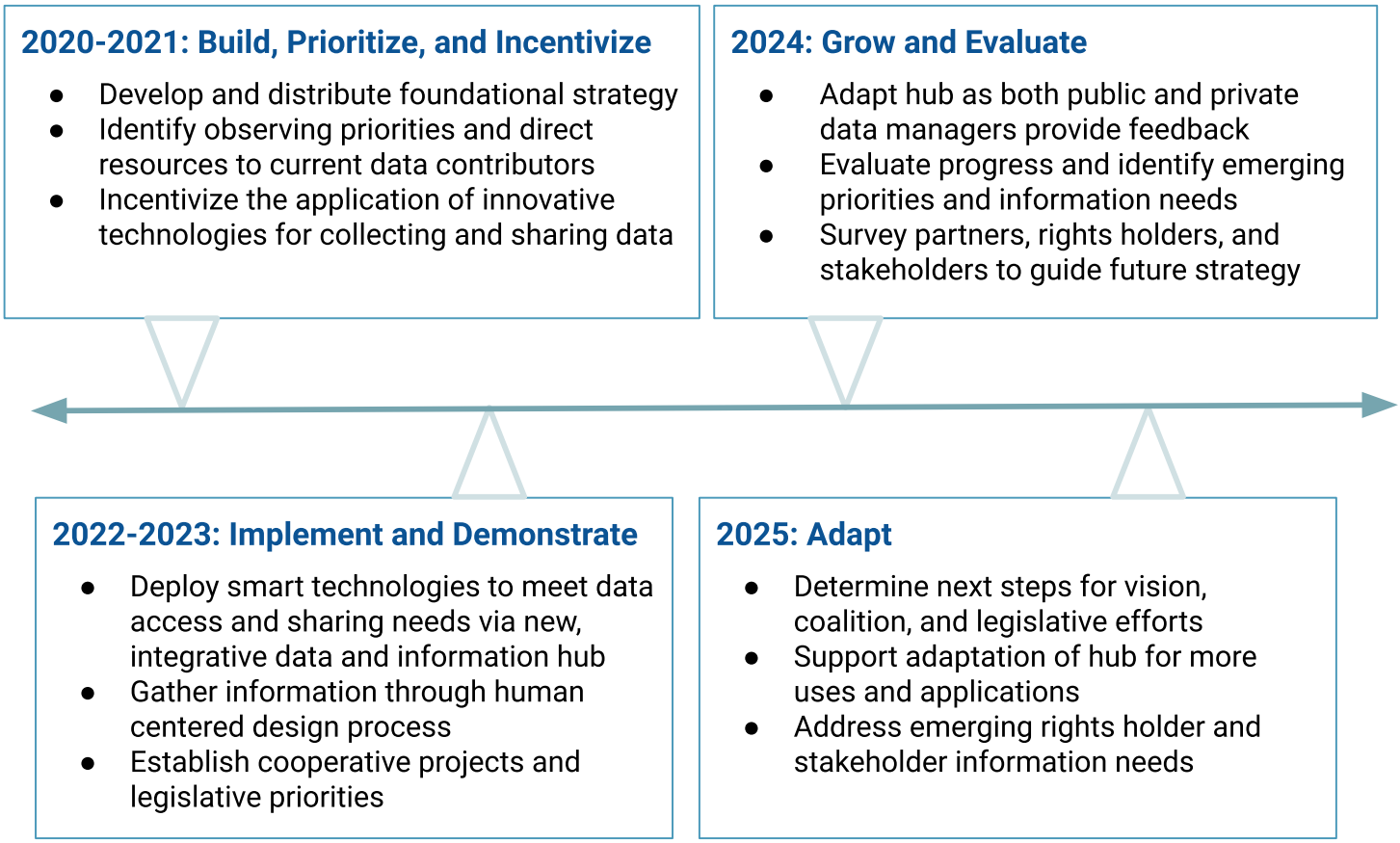


Figure 2: The Smart Great Lakes information ecosystem includes many components. Science, research, water treatment facilities, observation instruments, all levels of government, industry, innovative ideas and people are only the beginning of what is possible.

The SGLi aims to facilitate coordination between data providers and data consumers, and to streamline the transformation of information into accessible and timely insight for rights holders and stakeholders across the watershed including policymakers, business leaders, infrastructure operators, water quality managers, and the public. Over the course of the next five years, the SGLi will follow the steps laid out in the timeline.

Smart Great Lakes Timeline



Effective coordination of regional-scale monitoring requires consideration of the relationship between the following three axes:

I. Science, Innovation, and Technology
II. Data and Information
III. Policy and Management

These three tracks highlight the aforementioned multi-directional flow of information, in which evolving priorities in land management (e.g., of concentrated animal and agricultural operations) and wetland restoration (e.g., for flood reduction and nutrient management) prompt the need for innovative systems that capture and disseminate data in novel ways, particularly to understand interactions between civic engineering, resource management, and ecosystem health. Simultaneously, emerging science and technology trickle into the information landscape (e.g., harmful algal bloom (HAB) forecasting) and policy decisions (e.g., US Coast Guard support for Great Lakes observing systems). The key challenge for a successful modern Great Lakes strategy is establishing a flexible, interdisciplinary approach that emphasizes multilateral information flows to resolve tangible ecosystem and community health problems.

Environmental Justice in Smart Great Lakes

Environmental Justice in the Great Lakes region sweeps broadly across underrepresented groups in many different socioeconomic and geographic areas. Achieving equity, inclusivity, and diversity in Great Lakes agency and decision-making requires not only creating "seats at the table" for underserved groups, but also enabling rights holders and stakeholders to fill these seats and evaluating whether their perspectives have a meaningful impact on agency decisions. Historically, a failure by duty bearers to engage all Great Lakes communities in culturally sensitive and relevant ways has marginalized people of color in urban communities, migrant farm workers, people with low socioeconomic status, and Indigenous communities.

As such, the SGLi Common Strategy strives to ensure equitable participation by focusing this initiative through an environmental justice lens. Each goal and objective has been designed to close gaps in access and participation for Indigenous peoples, communities of color and lower-income communities that meet systemic barriers when forming relationships with the lakes in personal, recreational, management, or many other capacities. Under this framework, all action items are delineated under an umbrella of equitable representation of all rights holders and stakeholders. Some initiatives to improve justice in the more technical issue areas include:

- Support for community-led science initiatives
- Improve discoverability of Great Lakes data with different delivery formats and education curricula
- Ensure data collection and management follows FAIR, CARE, and OCAP Principles
- Secure data sovereignty for under-represented communities, and include privacy-protecting databases and differential access to sensitive information
- Make decision support tools available to rights holders and stakeholders who do not have reliable internet or smartphone access.

Data Principles:
FAIR: Findable, Accessible, Interoperable, Reusable
CARE: Collective Benefit, Authority to Control, Responsibility, Ethics
OCAP: Ownership, Control, Access, Posession

Under the broader justice lens, the SGLi Common Strategy prioritizes engagement of Indigenous communities and environmental justice communities via practices such as reciprocity, human-centered design, and entry barrier elimination. SGLi adopts the Four R's—Respect, Relevance, Reciprocity, Responsibility—as a governing principle and acknowledges that impacted stakeholders have already defined their expectations for how environmental justice communities should be addressed.[17,18] Reciprocity entails ethical research practices, a commitment to listening and acting to include the expressed needs of communities, and often involves dedicated cultural and linguistic training for working with and in communities that have been historically excluded from mainstream research and monitoring efforts. A formalized, multi-national cultural education program led by SGLi will better equip researchers to engage rights holders and stakeholders equitably, ensure reciprocity in knowledge sharing, and include community members impacted by research in each step of the actual work. Human-centered design seeks to ensure that all humans are at the center of access, whether the goal is data collection or distribution, education, public health and safety response, and policy or planning propositions. Lastly, eliminating systemic barriers in access to representation

17 The Four R's - Respect, Relevance, Reciprocity, Responsibility
18 17 Principles of Environmental Justice

requires dedicated investment to incentivize and normalize engagement of underserved populations in Great Lakes activities and governance. Such meaningful engagement leads to changes in governance that address the expressed needs of these communities. Barriers to participation exist for every goal, objective, and action item in the SGLi Common Strategy; as these obstacles are identified in discrete, tangible ways, dedicating resources to overcome systemic under-representation in governance comprises a long-term, overarching mission to achieve equity in currently-underserved communities throughout the Great Lakes region.

Commitment to Indigenous rights and sovereignty in Great Lakes initiatives

Indigenous communities are rights holders in the Great Lakes region; however they are largely under-represented in most Great Lakes initiatives. The entire region exists as Treaty Territories, and as such are the homelands of approximately 185 First Nations, Tribes, and Métis. Indigenous communities have markedly different cultural framing around relationships and interactions with the land, the lakes and their adjacent waters. Vital to the well-being of Indigenous communities within the Great Lakes is their relationship with the Great Lakes waters and lands. The lands and waters are deeply connected to their cultures and support their way of life, including providing sustenance, navigation, and spirituality. Their knowledge and actions with respect to the Great Lakes, sometimes referred to as Traditional Ecological Knowledge (TEK), include observations extending beyond time immemorial, and provides a foundation for their sustainable coexistence with this region. The importance of TEK held by First Nations, Tribes, and Métis has been acknowledged by many Great Lakes initiatives, but is often overlooked when understanding and governing the Great Lakes. Equitable participation by First Nations, Tribes, and Métis in all Great Lakes initiatives is needed in order to ensure that governance of the Great Lakes supports and protects Indigenous rights and relationships with this region.

Science, Innovation, and Technology

Science, innovation, and technology provide the foundation for the "smart" in Smart Great Lakes. The data and information provided to policy and decision-makers originates through research efforts across a variety of sectors with a variety of goals. It is vital that science, innovation and technology capture the diverse perspectives of the many cultures and minority groups throughout the Great Lakes basin. Through this diversity in scientific research and technology development, we can push the status quo.

Diverse perspectives bring diverse and innovative strategies supporting resilience and problem-solving within the Great Lakes. SGLi science, innovation, and technology initiatives will prioritize funding and consulting with researchers, agencies, and communities that have been historically underrepresented. This approach will foster the most innovative approaches in science and technology that ultimately influence Great Lakes governance, actively meet the needs of all communities, and help to ensure an equitable future.

Important components of the goals include establishing ongoing collaborations with experts from all sides of the science-data-management paradigm, leveraging existing knowledge to inform new knowledge creation, and establishing resilient, yet flexible monitoring and research systems that can be used for current and future issues. These components, combined with an overarching goal of an innovative and agile Great Lakes information ecosystem, drive the proposed objectives and actions.

Vision: To create a technologically innovative Great Lakes sensing and data science system that fosters improved awareness and response to changes in the Great Lakes and prioritizes innovation and technology for a swimmable, drinkable, fishable, and equitable future.

Goal 1: Develop novel and interdisciplinary research

Objective 1.1: Create improved linkages from community, field and lab-based data, remote sensing, and modeling to conservation and decision-making in the Great Lakes, and prioritize research that seeks ethical inclusion of TEK and diverse perspectives.

> **Action 1.1.1:** Identify the gaps that exist between existing datasets and models and the needs of decision-makers, including as much detail as possible where available. Understanding where the shortcomings are located will help to inform long-term monitoring and modeling efforts, while making decision-makers aware of all existing data could help to utilize the information that is available.

> **Action 1.1.2:** Develop pilot studies that work across disciplines and captures the diversity around the Great Lakes (i.e., ensuring pilots include projects led by individuals or organizations from the BIPOC (Black, Indigenous and People of Color) communities, rural communities, and others) to demonstrate the ideal continuum of research to management.

Objective 1.2: Understand which tools work for different purposes and their limitations, share resources amongst themselves and provide updates, improvements, and applications in a timely manner on a digital platform.

> **Action 1.2.1:** Provide oversight and evaluation of tools to determine data quality and 'ground truth' their effectiveness.

Action 1.2.2: Create a wiki of tools and methods at various levels of 'readiness' to enable scientists to share knowledge with a community of practice and better understand Great Lakes health.

Action 1.2.3: Create mechanisms that encourage scientists and innovators to collaborate and leverage to create larger-scale opportunities to effect change in the Great Lakes.

Goal 2: Support science, innovation, and technology that improve our ability to identify, assess, and respond to stressors and change

Objective 2.1: Improve assessments of current and future stressors and threats (e.g., climate change), impacts (e.g., fish productivity), and mitigation and adaptation efforts.

Action 2.1.1: Define an initial roadmap for scientific and innovative questions, and provide recommendations that will guide the response actions.

Action 2.1.2: Meet annually to convene scientists and technologists, launch new funded projects, share advancements, prototype new technologies, spark interdisciplinary innovation using novel facilitation methods, and report progress on the roadmap.

Action 2.1.3: Provide targeted funding that ensures diverse representation for scientific inquiry projects and prototype new technologies as well as robust and time-tested tools at a larger scale.

Goal 3: Build resilient, adaptable observing systems in support of a swimmable, drinkable, fishable, and equitable future.

Objective 3.1: Extend physical, biogeochemical, and ecosystem observations temporally to better understand the lakes during winter and the shoulder seasons and spatially to increase the density of observation over the extent of the Great Lakes.

Action 3.1.1: Convene experts to determine how to achieve the biggest impact for increasing observation density on the Great Lakes over time and space.

Action 3.1.2: Provide funding for year-round monitoring, prioritizing winter and shoulder seasons, and encouraging data collectors to share their data in a timely manner.

Action 3.1.3: Co-create communication tools with communities so that results are useful, understandable and respond to local needs.

Objective 3.2: Support new projects with potential for broad implementation or in areas that are under-monitored with mentorship from expert scientists, local perspectives, business experts, and access to funding.

Action 3.2.1: Provide leadership in innovation challenges, connecting entrepreneurs in water to the experts that will deepen their innovation's legitimacy, impact, and reach.

Action 3.2.2: Provide funding that helps to validate and scale quickly when innovations show promise.

Action 3.2.3: Fund interdisciplinary and social solutions that have a social impact rather than an economic one.

Action 3.2.4: Encourage innovators to understand the needs of the local communities by visiting the people and places affected.

Objective 3.3: Facilitate access to a simple data platform that uses best practices for data collection and analysis, with linkages to scientific contributions and decision-making tools.

Action 3.3.1: Engage rights holders and stakeholders in the design process and use the platform at the earliest possible stage. Their feedback on the platform's utility will be incorporated into the final design and in subsequent development of new features.

Action 3.3.2: Seek out and consult on research planning so that TEK and community priorities are included to ensure that program outcomes are equitable.

Action 3.3.3: Establish mechanisms for program co-creation and co-evaluation.

Action 3.3.4: Ensure the utility of the results by providing frameworks for evaluation and seeking feedback for improvement.

Action 3.3.5: Curate and communicate scientific findings and data in formats that can adapt to rights holders and stakeholder's emerging questions.

Overlapping areas

To be successful, scientists' findings and innovators' solutions must be informed and supported by the entire Great Lakes community, including researchers, policymakers, and the public. All science, innovation, and technology efforts require data for assessment, design, and evaluation purposes. Further, data analytics and information infrastructure are needed to inform better decision-making, achieve meaningful action, guide further research, and ultimately improve the health and wellbeing of Great Lakes communities. Without accessible systems to store and share data effectively, or policies and management strategies that drive research priorities and use evidence to inform decision-making, it is not possible to make progress on community and ecosystem goals in the Great Lakes region.

Impact areas

There are great opportunities to fill gaps in scientific knowledge through innovative technologies that will help us protect the Great Lakes ecosystem in the long term. Alongside filling important gaps in scientific understanding, improved information will enable communities and government agencies to respond to the region's and society's most pressing questions. Better information that spans scales from coastal cities to the entire Great Lakes is needed to ensure the sustainability of this critical water resource and respond to immediate and increasing damage caused by climate change and other pressing, regional problems such as invasive species and water quality impairments.

Data and Information

Data and information are critical drivers and determinants of policy and management in the Great Lakes region. Given the complex landscape of jurisdictions, rights holders and stakeholders, coordinating data collection activity is essential to develop a holistic understanding of the lakes and to inform both local and collective actions for overlapping areas of interest and concern. Efforts will focus on promoting data alignment with the FAIR Principles (Findable, Accessible, Interoperable, and Reusable) and Indigenous Data Governance Principles: CARE Principles (Collective Benefit, Authority to Control, Responsibility, and Ethics) and OCAP Principles (Ownership, Control, Access and Possession).

To facilitate this, available data sources across the watershed will be compiled through a central and operational Great Lakes data and information hub to help researchers identify opportunities for collaboration, sharing and efficiencies in data collection and management, and where challenges and gaps exist to direct science and innovation development. The hub will facilitate coordinated and shared responses and contribute to the creation of a community of practice in data collection and management activities that encourages continuous evolution and broad use of the data ecosystem.

Vision: To develop a Great Lakes data and information hub that federates existing data repositories and provides storage for new data producers to facilitate data discovery (findability and accessibility), compatibility (interoperability), and sharing (reusability) by a wide range of cross-border rights holders and stakeholders.

Goal 4: Improve discoverability of Great Lakes data by increasing findability and accessibility

Objective 4.1: SGLi will develop a full understanding of how Great Lakes data are discovered, accessed, and shared, identifying underrepresented groups and culminating in a plan to address identified gaps.

> **Action 4.1.1:** Collect use cases and user stories from rights holders and stakeholders, including federal, state, and provincial agencies, municipalities, nonprofits, and First Nations, Tribes, and Métis governments. Documentation describing how data are currently disseminated and identifying barriers to access will be developed and used to create a plan to support a diversity of communities in connecting with and utilizing SGLi technology, tools, and data.
>
> **Action 4.1.2:** Inventory existing data sources. Through agency partnerships, online exploration, and the information collected through the user cases and stories process, build an initial catalogue of sources of Great Lakes data. A predetermined assessment form will categorize sources in terms of accessibility, quality, ownership, and details of the objective of original collection to aid in the evaluation of fitness for use and facilitate appropriate interpretation of data to support future research.
>
> **Action 4.1.3:** Inventory data and metadata standards of existing data for review and assessment.

Objective 4.2: SGLi partners will create the Great Lakes data and information hub. The data and information hub will house partner data and enable searching of harvested metadata from external repositories as well as the in-house repository.

Action 4.2.1: Building on the data inventory and stakeholder input obtained under Objective 4.1, develop user requirements documentation for the Great Lakes data and information hub, and review the draft documents with rights holders, stakeholder groups and technical experts to prioritize work. Create communities across data types and areas of interest.

Action 4.2.2: Survey data sharing technologies, platforms and policies to develop the technological requirements framework that adheres to FAIR Principles (Findable, Accessible, Interoperable, and Reusable) and Indigenous Data Governance Principles: CARE Principles (Collective Benefit, Authority to Control, Responsibility, and Ethics) and OCAP Principles (Ownership, Control, Access and Possession) including the need to track data versions, citations, and impact.

Action 4.2.3: Create a Great Lakes data and information hub development plan prioritizing high impact areas, working to build in increased automation and ensuring scalability.

Goal 5: Foster data compatibility by developing a framework supporting interoperability and reusability

Objective 5.1: Create a set of best practices for standardization of data and metadata formats.

Action 5.1.1: Develop a guidance document with recommended best practices and share it with new data producers, established data collectors, and others to ensure that relevant and appropriate metadata are collected for interoperability and reuse. The guidance document will identify authoritative data and metadata standards where they exist and encourage non-proprietary formats where possible.

Action 5.1.2: Adapt existing metadata standards from the World Meteorological Organization into a metadata template for the Great Lakes data and information hub to serve as a minimum metadata requirement. The developed threshold for inclusion will be metadata (and supplementary documentation as needed) that provides enough information, such as collection methods, instruments, issues, processing details and error notation, to ensure data are independently understandable, and to facilitate determination of fit and suitability for reuse.

Action 5.1.3: Provide training and tutorials on the adoption and use of metadata templates for new and experienced metadata users.

Goal 6: Empower data providers to share and access new data by facilitating reuse and access

Objective 6.1: Gaps identified in Objectives 5.1.1 and 5.1.2 will be addressed and put into operational action.

Action 6.1.1: Develop a framework of data ownership and sharing that supports managed access and control over the data as required.

Action 6.1.2: Build the Great Lakes data and information hub to address diverse user needs, fill gaps in existing data, and enforce standards for data and its ownership, sharing, and interoperability through policy, procedure, and technical specifications.

Action 6.1.3: Share the framework and Great Lakes data and information hub broadly through SGLi and extended network of partners.

Overlapping areas

Data and information are critical to the policy and management objectives. The comprehensive overview of existing data and ongoing data collection in the Great Lakes region will improve accessibility and usability of data for policy and management decisions, and identify important information gaps that need to be filled. A repository will enhance the accessibility and value of research investments.

Building the data and information hub will reveal inequities in data access and collection, which can then be addressed with targeted investments of funding and attention. Communities that are underrepresented can receive technical input and advice on collecting and using data to build capacity and ensure equitable access to information. Additionally, training in the use of SGLi technology and data will engage diverse communities. The hub will also serve to build knowledge around proper data use and rights.

The data gaps identified through this effort will also impact science, innovation and technology objectives as researchers work to resolve these gaps, and as new innovations enable new data collection and sharing strategies. Areas that will benefit from shared user stories and best practices guidelines include instrumentation, operating procedures, data inputs and outputs, sensor testing, and tool assessment and selection. This sharing of information will help in performing and building processes around software quality assurance and quality control (QA/QC) and generate a common understanding of data of known quality.

Impact areas

The process of developing the Great Lakes data and information hub will produce a comprehensive picture of data production and use in the Great Lakes region. Through engagement with as many rights holders and stakeholders as possible, a platform will be built where data and information coalesce to provide a point of discovery and also a launch pad for new endeavors, including working with underrepresented communities to build capacity in data use and collection, identifying ways to empower under-resourced groups by leveraging tools, and creating synergies where possible. The platform's ongoing development will be iterative, as continual improvement is anticipated as more perspectives and interests are included and represented. The hub will advance data access, usage and discovery of existing data, and point to gaps in access, collection, or equity. Providing support for development may include repository, interoperability, and integration features, technical guidance, data rights education, and highlighting funding opportunities.

Policy and Management

A Smart Great Lakes policy and management framework prioritizes cross-boundary engagement, environmental justice, and communication efforts that mobilize data, convey actionable information, and inspire funding for a variety of efforts such as widely-applicable research, technology innovation, and data infrastructure. Continuous evaluation of Great Lakes policies, programming, and management strategies related to science, technology, and data is imperative to maintain an effective cumulative impact of research and funding security. A main priority of management teams in this region is to set standards and opportunities for research and knowledge-building, as well as for outreach and accessibility. Through a flexible, practical approach, SGLi can actively pursue policy initiatives as they are identified through data gap analyses and partnerships for any existing or future Great Lakes priority.

Vision: To improve existing Great Lakes policies and management by prioritizing cross-sector collaboration, inclusivity, and representation in decision-making. This includes improving data access and information streams that will mobilize informed, actionable strategies. The SGLi vision will approach knowledge creation and sharing that creates inclusive and ethical space[19] for diverse awareness and perspectives to ensure that the entire Great Lakes region and ecosystem are meaningfully represented, and that infrastructure and other management systems can foster health and well-being across all aspects of the lakes.

Goal 7: Ensure Smart Great Lakes Common Strategy provides opportunities and resources for the First Nations, Tribes, and Métis within the Great Lakes basin through respectful engagement

Objective 7.1: Build and maintain ongoing trust and reciprocity with Indigenous communities and partners through authentic engagement with the goal of having equal Indigenous representation and leadership in SGLi.

Action 7.1.1: SGLi will host ethics training through workshops to support those working with or engaging Indigenous communities and TEK for its members and extended network.

Action 7.1.2: Support the creation of an Indigenous-directed sister Smart Great Lakes initiative (I-SGLi) with partner Indigenous scholars and institutions.

Subaction 7.1.2.1: In an environmental scan, review the current landscape of work and initiatives pertaining to Indigenous engagement and information needs associated with the Great Lakes ecosystem.

Subaction 7.1.2.2: Consult with and assess First Nations, Tribes, and Métis interests in and needs to engage in a collective I-SGLi.

Subaction 7.1.2.3: Make recommendations for initial planning and development stages of an I-SGLi to the SGLi for consideration.

Action 7.1.3: Following recommendations made in Subaction 7.1.2.3, seek understanding and opportunities for convergence of the SGLi and I-SGLi.

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Goal 8: Strengthen Great Lakes-related policies

Objective 8.1: Identify and advocate for improvements to Great Lakes policies based on improved data inventories and dissemination practices.

Action 8.1.1: Utilize the results of data gathering activities in Actions 4.1.1 and 4.2.2 to prioritize policy needs and develop a plan to address them.

Action 8.1.2: Incorporate data accessibility and consumability into existing funding requirements, grant deliverables, and reporting to ensure projects and their results are executed by and accessible to diverse communities and user groups.

Goal 9: Invest in Smart Great Lakes

Objective 9.1: Advocate for funding pathways to ensure development and implementation of the Common Strategy for Smart Great Lakes.

Action 9.1.1: Investigate the feasibility of developing a policy for a one-time influx of funding through the US Great Lakes Restoration Initiative or the proposed Great Lakes Science Plan for system-wide improvements in observing assets or data management. In addition, SGLi will develop a report on continued maintenance for observing assets or data management from specific, existing funding streams.

Action 9.1.2: Encourage public-private investment in requests for technology, hacking, design competitions, incubators, and pilot programs that support application of new technologies and diverse usership and ensure funding is channelled to under-represented groups, organizations and businesses.

Action 9.1.3: Advocate for investment in “baseline” data and research as opposed to discrete studies. This could include gaps in nearshore areas, upcoming threats or prevention, and infrastructure of tools or data that people can access for data mobilization.

Goal 10: Accelerate SGLi communication, outreach, education, and engagement

Objective 10.1: Connect data, information, and knowledge with policymakers and community partners in a more timely and effective manner.

Action 10.1.1: Utilizing the results from Action 4.1.1., design a template for data mobilization specifically for policymakers and community partners.

Action 10.1.2: Seek out and foster educational programs around science and technology in the Great Lakes for under-represented groups and their youth to build connections and reduce barriers for participation in Great Lakes governance in the future.

Overlapping areas

The priorities for science, innovation, and technology as well as data and information are threaded throughout policy and management goals and objectives. Infrastructure to disseminate and

communicate information needs from both a top-down and bottom-up framing is critical to ensure effective, sustainable monitoring systems. Management teams help to enable this infrastructure by directing funding for innovative technology development that increases information flow in a year-round, real-time fashion. Outreach and communication tools tailored to specific rights holders and stakeholders will improve access to innovative science and data solutions and the literacies needed to understand them. Policy and management programs build capacity and awareness, and inclusive education and training programs can expand the Great Lakes research, surveillance, and monitoring enterprise.

Impact areas

Smart Great Lakes policy and management seeks to encourage and streamline interactive processes that connect innovative information highways with tangible solutions, and ultimately braid together collective knowledge bases with information needs, technological advancement, and data infrastructure to direct funding and capacity on a large scale. Policy need not necessarily centralize efforts, but rather coordinate awareness and collaboration to identify gaps and overlaps in information generation and mobility, as well as the discrete needs of a diverse array of rights holders and stakeholders. Ultimately, this framework will more cohesively and efficiently address information accessibility, equity, and inclusion, as well as research and restoration opportunities throughout the region.

Recommendations

The following recommendations aim to advance SGLi goals:

- Advocate for specific SGLi goals and priorities within other Great Lakes science and policy forums to ensure appropriate consideration for research, monitoring, surveillance, and data sharing (e.g., International Association for Great Lakes Research, Lakeside Action and Management Plans, Healing Our Waters, etc.).
- Develop collaborative basin-wide, lake-wide monitoring and surveillance strategies that leverage existing capacity and address important data gaps (e.g., Smart Lake Erie, Lake Bed 2030).
- Design collaborative information solutions around Great Lakes user communities, especially those that are traditionally underserved and underrepresented (e.g., Indigenous -SGLi, Coastal Climate Signals).
- Enhance the findability, accessibility, interoperability and reusability of Great Lakes data within a process and technical framework that supports Indigenous data governance principles: CARE Principles (collective benefit, authority to control, responsibility, and ethics) and OCAP Principles (ownership, control, access and possession). SGLi will:
    - Compile existing data sources and make metadata discoverable through a central hub (findable), and include the process for getting the data (accessible)
    - Identify and share data standards to enhance data exchanges (interoperable)
    - Identify and support metadata development to ensure data is independently understandable (reusable).
- Support and build communities of practice and iterate these processes to continuously enhance the data framework to meet rights holder and stakeholder needs.