Great Lakes Indicators – Exploring Alternative Approaches Through Stakeholder Input: A White Paper

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Cover photo: Great Lakes. Credit: NASA, NOAA Great Lakes Environmental Research Laboratory (GLERL))

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Executive Summary

Ecological indicators can be defined as measures of environmental quality that are useful to the scientific and management communities. Over the past three decades, Great Lakes indicators have been developed and refined by U.S. and Canadian government scientists, academic researchers, and other stakeholders, resulting in a comprehensive set of indicators to describe basin-wide status and trends and assess progress towards objectives under the Great Lakes Water Quality Agreement (GLWQA). Throughout this period, there have also been indicator assessment efforts, in particular by the International Joint Commission (IJC), including on approaches to communicating indicators more broadly. As a compliment to these efforts, there is a need for broader stakeholder input on development and use of Great Lakes indicators, including from a wide range of nongovernmental organizations (NGOs), and Tribal, First Nations, Metis, and other underrepresented communities.

In recognition of this need, National Wildlife Federation worked with academic, agency, and private sector colleagues in a project supported by the University of Michigan Cooperative Institute for Great Lakes Research, to gather input on Great Lakes indicators. The input was provided through two fora – a February 2021 virtual expert summit involving stakeholders from diverse sectors, and a June 2021 virtual meeting involving leadership of the Healing Our Waters (HOW) Great Lakes Coalition, which is made up largely of nongovernmental organization (NGO) members. Key objectives of the project included: 1. Identifying strengths and limitations of current Great Lakes indicators and 2. Identifying a process to address shortcomings in current indicators, including considering potential new indicators that meet scientific criteria while also having potentially greater relevance to more diverse stakeholders.

Several key findings from the February 2021 summit included the following:

- Multiple criteria are particularly important, including data availability and resolution across multiple scales, and consideration of human equity and human well-being;
- Stakeholder engagement should occur early on – and throughout – the process;
- Objectives and intended uses of indicators should be informed by both expert and stakeholder involvement, be benchmarked to targets, and be capable of linking to management actions.

Several key findings from the June 2021 HOW Coalition leadership meeting included the following:

- There is particular interest in development and use of other indicators, including socioeconomic, economic, and human health indicators;
- There should be more indicators tying management actions to results, in particular in local communities;
- Indicator development and/or revision efforts should involve more diverse representation, including drawing on local community leadership.

In light of decades of work on indicator development as well as input received through this project, we are proposing a communications framework for assessing (and potentially revising or adding to) Great Lakes indicators. The framework acknowledges ongoing indicator work (in particular basin-wide efforts through the State of the Great Lakes indicators program), the potential for enhanced local and sub-basin or regional work, and the importance of stakeholder involvement at all scales. We offer the following recommendations on processes that should be pursued to implement aspects of the framework:

- The GLWQA Parties should consider adopting the proposed (or an analogous) communications framework to support Great Lakes indicator development and implementation. The process could lead to reevaluation of existing indicators or sub-indicators, and as appropriate, development and implementation of additional Great Lakes indicators. The process should include explicit identification of criteria for indicator selection, as well as stakeholder interests, including those related to socioeconomics and human health.

- As part of the communications framework implementation, the GLWQA Parties should develop a formal structure for both education and outreach as well as obtaining input from a broader range of stakeholders in indicator development and implementation. This work should involve Tribal, First Nations, Metis, and other underrepresented communities, including through umbrella organizations; draw on previous indicator engagement efforts and current institutional arrangements (including through the Science Annex of the GLWQA and Lakewide Action and Management Plans); potential triennial stakeholder workshops; and engagement of community science efforts.

- A Great Lakes Center of Excellence, or a community of practice, should be supported to address multiple issues, including serving as a clearinghouse and resource for indicator development, implementation, and communication efforts. The indicator work of such a center or community could have a focus on development and implementation of local or regional indicators, hosting workshops, and sharing resources. Such a center could be housed at an existing academic, intergovernmental, or other institution, and draw on several current models of collaboration addressing specific Great Lakes threats.

- The research community should increase participation in activities related to indicator development and implementation, building on existing researcher engagement in indicator implementation. Potential areas to address include monitoring program design and trend detection, increasing capacity to track emerging threats, and process-based work that can inform indicator program implementation. There is also a need to continue work on innovative and lower-cost measurement technologies. These efforts would benefit from increased involvement from both natural and social scientists, including as part of enhanced community science engagement in Great Lakes indicator programs.

- Indicator developers and program managers should increase attention to the linkages between management actions and ecological, socioeconomic, and human health outcomes. More concerted efforts at identifying targets or endpoints would aid in making such linkages. In addition, increased use of conceptual frameworks can be particularly helpful in linking existing indicators and identifying potential new indicators, which can aid in both understanding the system overall and helping ensure sound decisions on management actions.

We believe implementation of the proposed framework and specific actions would lead to a suite of Great Lakes indicators that is science-based, descriptive of ecological and relevant socioeconomic and human health conditions, relevant to a broad range of stakeholders – including underrepresented communities, policy-relevant, and can help ensure appropriate management actions are taken to promote effective restoration and protection of the Great Lakes.

Sampling with plankton tow. Credit: LimnoTech

1. Introduction

Environmental indicators have been used for decades to track the status and trends of conditions in the Great Lakes, and the importance of having a comprehensive set of agreed upon indicators has long been recognized (e.g., Bails et al., 2005). Much of this work has involved development of basin-wide physical, chemical, and biological indicators through a process coordinated by the U.S. and Canadian federal governments, initially through the State of the Lakes Ecosystem Conference process (Bertram and Stadler-Salt, 2000; Shear et al., 2003). This work has developed into the current State of the Great Lakes indicators, involving triennial reporting as called for under the Great Lakes Water Quality Agreement (GLWQA) (United States and Canada, 2012). Annex 10 (Science) of the GLWQA notes that in addition to establishing and maintaining science-based ecological indicators, the Parties (the U.S. and Canadian governments) should periodically review and update indicators as necessary (United States and Canada, 2012).

Other developments related to Great Lakes indicators have included assessments and/or development of recommendations on indicators (e.g., through the International Joint Commission (IJC)), as well as independent research efforts. Several IJC projects over the past decade have entailed a comprehensive assessment of changes from 1987-2012 (IJC, 2013), identification of an optimal suite of ecosystem indicators (IJC, 2014), an assessment of congruence with indicators then in use by the Parties to GLWQA objectives (Great Lakes Science Advisory Board, Research Coordination Committee, 2016), and development of recommendations on communication of IJC ecosystem indicators (Great Lakes Science Advisory Board, Science Priority Committee, 2016). A recent effort examined issues around Great Lakes information and its communication more broadly (Great Lakes Science Advisory Board, Science Priority Committee, 2018). Research efforts over the past 15 years have also addressed Great Lakes basin-wide indicators directly or indirectly, including drawing on expert judgment processes (Danz et al., 2007; Allan et al., 2013; Riseng et al., 2018). Other efforts have expanded from a focus on ecosystem indicators to broader consideration of ecosystem services (Steinman et al., 2017). One common theme across many of Great Lakes indicator development and review efforts in the past two decades has been an emphasis on ecological indicators, with less work addressing human health or socioeconomic indicators (see HPAB, 2014 on human health indicators).

In contrast to these research efforts on indicators and related topics related to Great Lakes conditions, many of which used expert judgment for development, there have been fewer assessments directly gauging interest in and/or use of indicators among broader stakeholder groups in the Great Lakes region (e.g., Da Silva and Shear, 2010). At the same time, there has been increasing recognition of the importance of increasing community involvement in Great Lakes governance more broadly (e.g., Krantzberg et al., 2015), including more systematic engagement of Indigenous and other underrepresented communities (e.g., Whyte et al., 2017). Similarly, a 2016 summit addressing ecosystem services highlighted the importance of

increased integration of natural and social scientists to better understand ecosystem services in the Great Lakes (Steinman et al., 2017), and this approach could have value in addressing other important aspects of restoration and protection planning and implementation in the region, including involving indicators.

In recognition of the value of broader engagement on Great Lakes indicators, the National Wildlife Federation Great Lakes Regional Center led a project to obtain stakeholder input on indicators, with support by the University of Michigan Cooperative Institute for Great Lakes Research (CIGLR). Stakeholder input was initially achieved via an expert virtual summit involving scientists, NGO advocates, and others on February 23-24, 2021. The two main objectives of the summit were to 1. Evaluate current approaches to developing and implementing Great Lakes indicators; and 2. Identify alternative approaches to indicator development and implementation that could meet multiple objectives, including being science-based, linking management and ecosystem outcomes to the maximum extent, and otherwise addressing interests of the NGO and other stakeholder communities. Based on discussions at the summit and recognition of the value in further NGO input on these issues, a shorter virtual meeting was organized with leadership of the Healing Our Waters Great Lakes Coalition on June 16, 2021. Objectives of this second meeting were similar, including to gauge current use of Great Lakes indicators, identify other indicators that should receive greater attention, and identify approaches that might engage a broader range of NGO stakeholders in development and use of Great Lakes indicators, including disadvantaged/underrepresented communities. Both meetings entailed use of virtual breakout rooms for more in-depth exploration of charge questions, and were informed by background documents reviewing the development of indicators, including criteria used and current indicators in use.

This white paper provides a brief overview of Great Lakes indicator development and current use, a summary of input received through the two stakeholder meetings, and a communications framework and recommendations for reconsidering Great Lakes indicators in a manner that meets scientific and management criteria while also engaging a broader range of stakeholder perspectives in their development and use. This document should be of particular interest to federal indicator and monitoring program managers in both the U.S. and Canada, including concerning approaches to broader stakeholder engagement in their indicator programs. In addition, we believe this document can also inform other indicator and related work in the region, including led by or involving intergovernmental organizations, Tribal, First Nations, and Metis, other underrepresented communities, NGOs, academic researchers, state and provincial governments, and municipalities.

2. Great Lakes indicators: Development and current use

2.1. Overview of indicator development in the Great Lakes

Tracking conditions in the Great Lakes has been of interest to policymakers, researchers, and others in the region for decades. Assessing conditions in the basin via indicators has been done in various ways, in particular through government programs as well as independent research projects. Government agency interest in indicators increased after the U.S. and Canadian governments (the "Parties") signed the Great Lakes Water Quality Agreement (GLWQA) in 1972. With amendments to the GLWQA in 1987 (United States and Canada, 1987), there was increased emphasis on the "ecosystem approach", as well as significant efforts by the Parties to develop and use ecological indicators. In this period, the role of the International Joint Commission (IJC) concerning indicators changed from directly reporting on indicators (based on government data) to emphasize indicator review and assessments (IJC, 1996). The most recent amendments to the GLWQA in 2012 kept roles regarding indicators essentially unchanged, with the Parties in charge of indicator reporting, and the IJC continuing its review and assessment role, though with the potential to develop and use its own indicators in assessing progress towards GLWQA objectives (United States and Canada, 2012). In addition, there have been multiple efforts by academic and other researchers to develop indicators or otherwise assess conditions of various aspects of the Great Lakes, and similar efforts have been underway elsewhere in the U.S. and Canada (Niemi and McDonald, 2004).

In understanding the historic development, current use, and considerations for any changes of Great Lakes indicators, it is important to have a common understanding of the term. One definition of *environmental indicators* is the following:

> "A measurable feature or features that provide managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality." (ITFM, 1995)

There are multiple considerations in developing and using indicators, issues addressed in multiple IJC reports over the past three decades. Indicators are typically developed with a particular purpose in mind and applied at different levels such as condition of specific species, systems or landscapes (Niemi and McDonald, 2004). A single indicator cannot meet multiple objectives and thus monitoring programs typically incorporate multiple indicators to assess the condition of an ecosystem. As proposed in an earlier report from the IJC (1996), indicators should serve a clear purpose (e.g., assessing the state of the environment and human activities affecting it), be situated within a particular conceptual framework, consider scale, and provide for an assessment of progress towards desired outcomes, which in this case meant meeting ecosystem integrity targets of the GLWQA. In subsequent work, the IJC has noted that scientifically sound indicators applied consistently over time are essential to track changes in Great Lakes water quality. The IJC has also emphasized the importance of using indicators (identified based on specific criteria) to measure progress toward GLWQA objectives (IJC, 1996;

IJC, 2000; IJC, 2006) and noted resource constraints may limit monitoring of specific indicators (IJC, 2002).

The major Great Lakes, basin-wide indicator program following the 1987 Amendments to the GLWQA has been managed by the Parties through the State of the Lakes Ecosystem Conference (SOLEC) forum, which involved a set of science-based indicators referred to as the SOLEC indicators. A slightly reduced suite of indicators was included in the 2016 State of the Great Lakes (SOGL) Report and the indicators were renamed "SOGL indicators". Thus, over time, both SOLEC and SOGL have been used to describe this family of indicators, which is covered in more detail in the following section. Other indicator efforts over the past few decades have included more geographically focused programs, as well as IJC indicator assessments. Most of these efforts have entailed explicit identification of criteria used in developing or reviewing indicators.

Table 1 briefly summarizes key criteria used in developing or assessing Great Lakes indicators. As noted in the table, scientific criteria such as data availability, interpretability (including assessing status and trends), and cost considerations have been relatively common across the indicator development and review efforts. Relevance to management objectives has also been commonly considered in some form in most IJC reviews and assessments. In addition, although understandability has also been a common criterion, understandability by the broader community (including the public) has been less explicitly identified. One exception was a project by the IJC Science Advisory Board, in which filters particularly related to public understanding (compelling story, visible, and easy to understand) were explicitly considered in evaluating IJC indicators (Great Lakes Science Advisory Board Science Priority Committee, 2016). Note Table 1 emphasizes basin-wide, sub-basin, or regional reports or programs; as briefly discussed later, there have been indicator development and implementation efforts in more localized areas, including Areas of Concern (AOCs) (e.g., Steinman et al., 2008).

The value of conceptual frameworks in Great Lakes indicator development has been recognized for several decades, including in the earlier IJC assessment (IJC, 1996). Conceptual frameworks can lead to a more complete understanding of fundamental processes occurring in natural systems. For example, in a simple two-component, stressor-response framework, elevated nutrient loads (due to some human activity) can lead to excessive harmful algal blooms (HABs) in particular areas. Following earlier use of a simpler three-component conceptual framework to help organize SOLEC indicators, USEPA and Environment Canada in 2010 began using the Driving forces-Pressure-State-Impacts -Response (DPSIR) conceptual framework as part of the SOLEC reporting process (Environment Canada and U.S. Environmental Protection Agency (USEPA). n.d. See Fig. 1 on p. 9). In this framework, a major **driver** (such as intensive agricultural activity) can lead to a **pressure** (e.g., elevated phosphorus runoff) which can lead to a change in **state** (e.g., eutrophication in a water body) which in the form of HABs can lead to **impacts** (e.g., cyanotoxins in drinking water) leading to a **management response** (e.g., programs to address fertilizer application on farm fields).

Table 1. Selected Great Lakes Indicator Programs or Reports, and Criteria Used in Indicator Development or Review

Indicator Program/ Report*	Criteria	Reference
Indicators for Evaluation Task Force	Necessary, relevant, scientifically valid, data available, measurable, interpretable, target values, costs, quality, sensitive, timely, anticipatory, integrative, applicable, sufficient, public understandability	IJC, 1996
SOLEC / SOGL (1994-2000)	Initial screening: Necessary, sufficient, feasible Secondary screening: 21 criteria in 7 categories – validity, understandability, interpretability, information richness, data availability, timeliness, and cost considerations	Bertram and Stadler-Salt, 2000; Shear et al., 2003
SOLEC Independent Expert Panel	Data availability, reliability, cost considerations, and political feasibility; evaluation of SOLEC indicators regarding organization, gaps, redundancies via indicator descriptions, data gaps and comparability, funding, coordination, delivery	SOLEC Independent Expert Panel, 2010
SOLEC / SOGL (2011)	Reviewed existing SOLEC indicators based on eight criteria, including ability to assess status and trends, appropriate geographic scales, and an end-point	SOLEC, 2011
16th Biennial Report on Great Lakes Water Quality	Data availability, relevance to the GLWQA or management objectives, ecological importance (e.g., keystone species) availability of experts to contribute information, and data quality	IJC, 2013
Great Lakes Ecosystem Indicator Project	Usefulness, data quality, availability, practicality	Great Lakes WQB, SAB, 2013; IJC, 2014
Future Improvements to Great Lakes Indicators	Overall criteria of providing most useful information while making best use of available resources; More specific criteria used in preceding development of individual IJC indicators	Great Lakes SAB, RCC, 2016
IJC Science Advisory Board, Communication Indicator Workgroup	Initial filters for 16 indicators: Compelling story, visible, easy to understand, direct measure of lake health Prioritization of metrics based on: Comprehensive data across basin, rigorously monitored, regularly monitored, length of monitoring record, calibration and endpoints, owner and cost, communicable, interconnected, useful	Great Lakes SAB, SPC, 2016
State of the Strait	Geographic constraint, availability of data to assess trends	Hartig et al., 2007, 2020
Western Lake Erie Report Card	Science-based, peer-reviewed (preferably) and transparent	UMCES, 2020a

*: SOLEC: State of the Lakes Ecosystem Conference; SOGL: State of the Great Lakes; IJC: International Joint Commission.

The 2010 SOGL program review (SOLEC Independent Expert Panel, 2010) and subsequently an independent IJC assessment (IJC, 2014) both endorsed this general type of framework. However, reporting on indicators currently by the Parties does not include reference to any explicit conceptual framework (ECCC and USEPA, 2021). Nevertheless, the value of conceptual frameworks in restoration and protection planning – including to link management actions to ecosystem outcomes, as measured via indicators – was recently highlighted in a white paper (Murray et al., 2019).

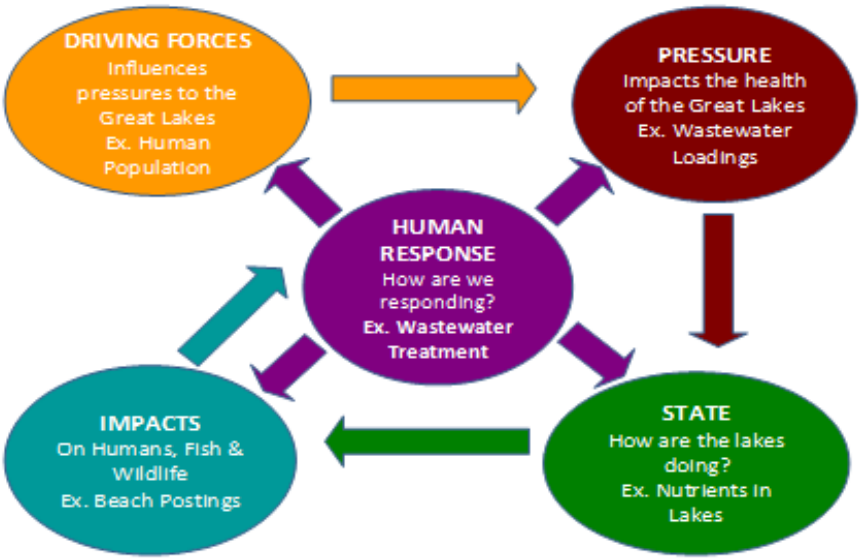

Fig. 1. Driving forces-Pressure-State-Impacts-Response (DPSIR) conceptual framework adopted as part of the SOLEC reporting process in 2010 (Environment Canada and U.S. Environmental Protection Agency, n.d.).

Key Great Lakes indicator programs currently underway that have been developed using criteria identified in Table 1, as well as several research projects that have relevance to indicator development and use, are summarized in the following section.

2.2. Current Great Lakes indicators and related programs

This section briefly reviews current Great Lakes indicator programs (both basin-wide and sub-basin/regional), national (U.S.) programs that include the Great Lakes, and relevant research community efforts. The section concludes with a synthesis of the programs, with an emphasis on key criteria involved, stakeholder engagement approaches, and use of conceptual frameworks.

2.2.1. State of the Great Lakes

Significant indicator development efforts were carried out by the Parties to the GLWQA starting in the 1990s, with reporting in particular through the biennial State of the Lakes Ecosystem Conferences (SOLEC). The conferences involved reporting on status and trends of the Great Lakes and certain stressors, and served as a forum for exchanging information amongst decisionmakers, scientists, and the broader stakeholder community (IJC, 2013). The first State of the Great Lakes (SOGL) report was released in 1994, as prepared by Environment Canada (now Environment and Climate Change Canada (ECCC)) and the USEPA. Indicators were typically referenced as SOLEC indicators until 2016, when "SOGL indicators" was adopted to describe the large subset of indicators that had sufficient data to generate reports for the 2016 SOGL Report (Great Lakes Science Advisory Board, Research Coordination Committee, 2016).

Indicator suites were first introduced in 1998 in order to establish consistent and comprehensive assessments across reporting cycles. Bertram and Stadler-Salt (2000) describe the initial process used for developing indicators. As noted in the previous section, following use of a three-component conceptual framework to help organize SOLEC indicators, EPA and Environment Canada in 2010 began using the DPSIR conceptual framework as part of the SOLEC reporting process. The amended GLWQA of 2012 included Annex 10 (Science), with renewed commitments for the Canadian and U.S. governments to establish science-based ecosystem indicators (United States and Canada, 2012). The Parties' indicator work under the new GLWQA has had a particular emphasis on linking indicators to GLWQA objectives (consistent with recommendations by the IJC (IJC, 2013)), and there have been increasing efforts to tie indicators of the system to management goals and approaches through the Lakewide Action and Management Plans and associated committees and programs (see Lakewide Management (Annex 2), https://binational.net/annexes/a2/).

In addition to the extensive indicator development and implementation work of the Parties, the IJC has continued to be involved in developing and/or assessing indicators and making recommendations to the Parties. A major review effort involving expert workshops resulted in identification of 21 indicators with 51 measures, generally addressing either human health or ecosystem conditions (Great Lakes Science Advisory Board, Research Coordination Committee, 2016). The majority of the indicators were adopted by the Parties for the SOGL 2016 reporting cycle, with lack of available data precluding all indicators from being adopted by the Parties. There remained some differences in measures for certain indicators/sub-indicators, including, for example, an IJC recommendation to assess the quality of source water, vs. treated drinking water that has been adopted by the Parties (Great Lakes Science Advisory Board, Research Coordination Committee, 2016).

The current (as of 2019) SOGL indicator suite of the Parties after refinement now includes 45 sub-indicators organized within nine broad indicators of ecosystem health that correspond with the nine *General Objectives* established by the 2012 GLWQA.

The nine SOGL indicators and their sub-indicators are as follows (ECCC and USEPA, 2020):

1. Drinking Water: Treated Drinking Water
2. Beaches: Beach Advisories
3. Fish Consumption: Contaminants in Edible Fish
4. Toxic Chemicals: Toxic Chemicals in Sediments; Toxic Chemicals in Water; Toxic Chemicals in Great Lakes Whole Fish; Toxic Chemicals in Great Lakes Herring Gull Eggs; Total Chemicals in the Atmosphere
5. Habitat and Species: Coastal Wetland Amphibians; Coast Wetland Birds; Coastal Wetland Fish; Coastal Wetland Invertebrates; Coastal Wetland Plants; Coastal Wetlands: Extent and Composition; Aquatic Habitat Connectivity; Phytoplankton; Zooplankton; Benthos; *Diporeia*; Prey Fish; Lake Sturgeon; Walleye; Lake Trout; Fish Eating and Colonial Nesting Waterbirds
6. Nutrients and Algae: Nutrients in Lakes; Cladophora; Harmful Algal Blooms; Water Quality in Tributaries
7. Invasive Species: Rate of Invasion of Aquatic Non-Indigenous Species; Impacts of Aquatic Invasive Species; Dreissenid Mussels; Sea Lamprey; Terrestrial Invasive Species
8. Groundwater: Groundwater Quality
9. Watershed Impacts and Climate Trends: Forest Cover; Land Cover; Watershed Stressors; Hardened Shorelines; Baseflow Due to Groundwater; Tributary Flashiness; Human Population; Precipitation Amounts; Surface Water Temperature; Ice Cover; Water Levels

Note that some of the sub-indicators listed above are being considered for removal from the list for the 2025 reporting cycle, or for permanent removal based on lack of new data to determine trends, lack of basin-wide relevance, or other factors.

An example of indicator reporting from the State of the Great Lakes 2019 Highlights Report is provided for the invasive species indicator in Fig. 2 (ECCC and USEPA, 2020). Condition information is provided for five sub-indicators for each of the Great Lakes, with information on status (one of four categories) and trends provided, where data are available. Based on aggregating information for the sub-indicators, the indicator overall was assessed as Poor, with a Deteriorating trend.

It should be noted that reporting for individual Great Lakes also occurs through GLWQA Annex 2, Lakewide Action and Management Plans (LAMPs), though there is a major emphasis on using indicators from the SOGL process. For example, the most recent LAMP Annual Report for Lake Erie highlights the current status of the lake against eight GLWQA general objectives as drawn from the SOGL 2019 Highlights report, while also reporting on trends in phosphorus loads to the central basin and trends in the HAB severity index for the western basin (USEPA and ECCC, 2021).

Sub-Indicators Supporting the Indicator Assessment					
Sub-Indicator	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Rate of Invasion of Aquatic Non-Indigenous Species	No lake was assessed separately. Great Lakes Basin assessment is Good and Undetermined.				
Impacts of Aquatic Invasive Species	Deteriorating	Deteriorating	Deteriorating	Deteriorating	Deteriorating
Sea Lamprey	Unchanging	Improving	Improving	Improving	Improving
Dreissenid Mussels	Unchanging	Deteriorating	Deteriorating	Unchanging	Deteriorating
Terrestrial Invasive Species	Deteriorating	Deteriorating	Deteriorating	Deteriorating	Deteriorating

STATUS

Good Fair Poor Undetermined

Fig. 2. Invasive species indicator status and trends in the Great Lakes, from the State of the Great Lakes 2019 Highlights Report (ECCC and USEPA, 2020).

2.2.2. Other indicator efforts: State of the Strait, Lake Erie Report Card

Whereas the State of the Great Lakes indicators were developed to encompass many dimensions of ecosystem integrity and address progress towards binational objectives, some other sets of indicators have been developed to assess change in specific geographic locations and are more granular in terms of the processes and concerns that they address. One example of a regional approach toward indicators in the lakes comes from the State of the Strait (SOS) conferences and status and trends reports, which are focused on the St. Clair-Detroit River System. This conference, and its efforts to summarize indicators in the strait, are closely linked with local stakeholder groups in both Michigan and Ontario. The corridor is among the most severely impacted regions in the Lakes and has a legacy of environmental degradation, evidenced by several Areas of Concern (AOCs) and beneficial use impairments (BUIs) in the waterway and impacts extending into terrestrial habitats and human communities. In 2007 and 2020 this conference released reports summarizing the status and trends of indicators relevant to this region (Hartig et al., 2007; Hartig et al., 2020). The 61 indicators summarized in the 2020 report are not uniformly linked to specific lake objectives, but instead are selected to include both traditional measures of physical, chemical and biological integrity and also related variables in the terrestrial and social communities adjacent to the strait. This approach makes the indicator reports highly diverse in their content, which spans from fish habitat and harvest to nesting bird recruitment and, increasingly, aspects of human health, welfare, and justice. Regional indicators, like those in the SOS reports, may not be applicable to other locations within the basin but can serve as a productive means of identifying issues and areas that warrant further local remediation, investigation, or coordination.

Another geographically focused indicator effort is the recently completed Western Lake Erie Report Card project, funded by Lucas County, OH, City of Toledo, OH, and City of Oregon, OH, with assistance by the Lake Erie Foundation, and carried out by the University of Maryland Center for Environmental Science (UMCES, 2020a). The approach entailed subdividing the watershed and parts of the lake basin into scoring regions, selecting indicators from an existing group, developing new indicators as data allowed (and identifying targets or thresholds), and carrying out scoring, either based on progress towards targets or relative ranking. Expert consensus was used to select (or develop new) indicators. The report cards produced by UMCES are based on indicators that are science-based, peer-reviewed (preferably) and transparent (UMCES, 2020b). One goal of the approach was to create local buy-in through a collaborative development process, and to document the ultimate process used so that a similar approach could be applied in future report card updates by local non-UMCES compilers.

Locally-focused indicator efforts, including for example work at the Muskegon Lake AOC involving delisting targets for beneficial use impairments (Steinman et al., 2008) could be an important resource for NGOs and other concerned parties who have reported that some of the basin-wide indicators do not adequately match their needs (see Section 3). Other localized indicator programs such as watershed monitoring networks involving community science volunteers (e.g., Huron River Watershed Council, 2018; Milwaukee Riverkeeper, 2019) may also be of use to the NGO community. Even if such local efforts are not presently tied to, or nested within, the basin-wide indicator programs, there can still be significant value to local communities, and all involved in indicator development and implementation can be looking for opportunities to link localized to basin-wide indicators (see further discussion in Section 5).

2.2.3. Great Lakes indicators from the research community

The Great Lakes Environmental Indicators (GLEI) projects were funded by the US EPA and NASA to expand the capacity to assess the condition of the entire Great Lakes shoreline based on the relationship between anthropogenic stress gradients and biological conditions represented by indicators. The GLEI projects assessed hundreds of stressors in hundreds of shoreline "segmentsheds" and thousands of watersheds in the US and Canada (Danz et al., 2005, 2007; Hollenhorst et al., 2011). GLEI included indicators for Great Lakes coastal wetlands (riverine, barrier beach protected, and lacustrine), embayments, and high energy beach zones. A total of 14 specific indicators of the U.S. Great Lakes coastal region were identified, along with taxon-specific and multi-taxon indicators including assemblage-specific stress thresholds that identified abundance change points for multiple species of each biotic group (Host et al., 2019).

An anthropogenic stress index for coastal watersheds was used to benchmark these indicators and included measures of population density, road density, urban development, and agricultural development. Aspects of the indicator protocols have been incorporated into the Great Lakes Coastal Wetland Monitoring Program (GLCWMP) since 2010 and are currently a part of the formal EPA coastal wetland monitoring program. Wetland indicators are discussed

in Uzarski et al. (2017) and Cooper et al. (2018). In general, the results of the GLEI investigations indicated that stress related to agricultural activity and human population density/development had the largest impacts on the biotic community indicators.

The Great Lakes Environmental Mapping and Assessment (GLEAM) project developed a coastal risk index (Allan et al., 2013) and mapped a cumulative impact stressor from 34 weighted individual stressors across the Great Lakes open water areas that were identified and prioritized by experts. Eight main categories were considered: aquatic habitat alteration, climate change, coastal development, fisheries management, invasive and nuisance species, nonpoint source pollution, toxic chemicals and water withdrawals. The GLEAM basin-wide risk index includes: the combined influences of industrial ports and harbors, light pollution, tributary dams (altered flow and sediment retention), coastal development, mining, power plants, and road density, recreational fishing, ballast water invasion risk, invasives (fish, sea lamprey, wetland plants, mussels), combined sewer overflows, nitrogen, phosphorus, and sediment loadings, and Areas of Concern. Subsequent analysis developed an index for pelagic and coastal and nearshore areas called the coastal risk index. The GLEAM project also mapped ecosystem services and economic data to inform restoration priorities in the Great Lakes.

Wehrly et al. (2012) developed a landscape risk index that includes the watershed attributes for percentage of area used for agriculture, percentage urban, road density, population density, and dam density. Since the Wehrly et al. (2012) publication, a new set of landscape data has been compiled for the Great Lakes basin as part of the Great Lakes Aquatic Habitat Framework (GLAHF; Wang et al., 2015) along with consistent, basin-wide watersheds referred to as the Great Lakes Hydrography Dataset (GLHD; Forsyth et al., 2016). Using the newly compiled GLAHF binational geospatial database of over 170 data types, the Wehrly et al. (2012) landscape risk index was recalculated for all of the GLHD watersheds and then distributed into the coastal margin and nearshore zones (Riseng et al., 2018).

The Cooperative Science and Monitoring Initiative (CSMI) is a binational effort to coordinate monitoring among agencies and researchers on all five Great Lakes. The CSMI rotates through the Great Lakes on a five-year cycle and is partially intended to collect data on particular indicators, as well as addressing research priorities of LAMPs and management agencies. Planning, field year execution, and reporting cycles bring researchers and managers together to analyze past results and plan future activities that will reduce scientific uncertainty for improved process understanding and informed decision-making in an adaptive management context. Reporting takes the form of presentations at State of the Lake conferences convened by the International Association for Great Lakes Research (IAGLR) that also follow a five year rotation, and often lake-specific CSMI reports and special issues of the Journal of Great Lakes Research (e.g., Watkins et al., 2017; Also see https://www.epa.gov/great-lakes-monitoring/cooperative-science-and-monitoring-initiative-csmi).

2.2.4. U.S. national indicator efforts that include the Great Lakes

The National Coastal Condition Assessment (NCCA) program coordinated by USEPA assesses the conditions of U.S. coastal waters every five years, and starting in 2010 included sampling of 405 sites in the Great Lakes. The assessment encompasses four indices – benthic community, sediment quality, water quality, and fish tissue contaminants. Each index has corresponding thresholds and is made up of multiple individual indicators – for example, water quality (for the Great Lakes) encompasses total phosphorus, chlorophyll a, dissolved oxygen, and water clarity (USEPA, 2016; Kiddon et al., 2020).

The National Oceanic and Atmospheric Administration (NOAA) national Mussel Watch Program, which monitors shellfish contamination along ocean and estuary coasts, initiated monitoring in the Great Lakes in 1992, collecting zebra and quagga mussels at sites ranging from Duluth to Cape Vincent, New York. Chemical analyses of the contaminants in mussel tissue are used to: 1) track the status and trends of 150+ contaminants in the Great Lakes at over 200 sites, 2) track the effectiveness of pollution prevention legislation and remediation programs, 3) assess the environmental impacts in the event of catastrophic environmental disasters, and 4) monitor contaminants of emerging concern (Johnson et al., 2021).

The Fourth National Climate Assessment (NCA) also produced regional analyses, including the most recent Midwest Region chapter with Great Lakes elements released in 2018 (Angel et al., 2018). The Great Lakes content gave special consideration to ice cover, thermal stratification, and biology, including climate change impacts on fish species, invasive species, algal blooms, dissolved oxygen, and coastal wetland habitat, and a Great Lakes case study on climate adaptation.

2.3. Synthesis of Great Lakes indicator efforts

Current and recent indicator efforts of particular relevance to the Great Lakes are summarized in Table 2, showing intended uses or purpose of the indicators, the geographic scope, the high-level description of the indicators included, and the reporting cycle. As noted in the table, the State of the Great Lakes indicators program is the only basin-wide, comprehensive, and regularly reported indicator program currently available (ECCC and USEPA, 2021). As noted above, status and trends reporting for individual lakes also occurs through the LAMP programs (e.g., USEPA and ECCC, 2021), though the reporting draws heavily on information compiled and presented through the SOGL program. The Great Lakes Coastal Wetland Monitoring Program is basin-wide, but focuses on coastal wetland habitat, addressing many aspects of wetland condition, including multiple organism groups (Great Lakes Coastal Wetland Monitoring Program. https://www.greatlakeswetlands.org/Home.vbhtml; Uzarski et al., 2017). The State of the Strait program, focused on the Huron-Erie Corridor, offers arguably the most comprehensive assessment of conditions in a particular area, including a significant number of socioeconomic indicators, though as noted above, it has not been part of a regular assessment or reporting effort (Hartig et al., 2007; Hartig et al., 2020).

Table 2. Summary of Great Lakes and Related Indicator Programs and Assessments.

Indicator Set	Uses/Purposes	Geographic Scope	Indicators/Sub-indicators/Other Measures	Reporting	References
State of the Great Lakes	Fulfills requirement of GLWQA. Referenced by the Lakewide Action Management Plans	Basin-wide & connecting channels	45 sub-indicators organized under 9 high-level indicators: drinking water, beaches, fish consumption, toxic chemicals, habitat and species, nutrients and algae, invasive species, groundwater, watershed impacts and climate trends	Every three years (under GLWQA), with general audience Highlights Report followed by a lengthy Technical Report. The 2019 reports were released in 2020-2021.	ECCC and USEPA, 2020; ECCC and USEPA, 2021
State of the Strait	US Canadian partnerships to compile and interpret long-term data bases for ecosystem indicators from the Detroit River-Western Lake Erie basin	St Clair Detroit River System (including western Erie)	3 categories of indicators: pressure, state, (management) response; 61 indicators in most recent assessment	Comprehensive reporting, including individual indicator reports in two lengthy technical reports (2007, 2020)	Hartig et al. 2007; Hartig et al. 2020
Western Lake Erie 1st Report Card	To develop an ecosystem health report card for western Lake Erie in partnership with local stakeholders for the Lake Erie Foundation	Western Lake Erie Basin	22 indicators across 3 lake categories (water quality, fish, and algal blooms) and 3 watershed categories (water quality, biology, toxic chemicals)	One report (general audience) produced to date (2020)	UMCES, 2020b
IJC Science Advisory Board (2016)	Assess communicability of IJC indicators, prioritize via shorter list; ultimately inform Triennial Assessment of Progress reports	Great Lakes Basin	Selected six high-level indicators (each with one associated metric); narrowed from earlier IJC work identifying 16 indicators with 41 metrics (IJC, 2014)	Stand-alone assessment, informing IJC Triennial Assessment of Progress reports under GLWQA	Great Lakes Science Advisory Board, SPC, IJC, 2016
Great Lakes Coastal Wetland Monitoring Program	Assess and report condition of coastal wetlands basin-wide, providing baseline and temporal trend monitoring of wetland condition, via standardized protocols	All GL coastal wetlands >4 ha connected to the GL.	10-15 metrics (based on wetland vegetation, aquatic macroinvertebrates, fish, birds, amphibians, and water quality measures, etc.) are used to develop Indices of Biological Integrity for each vegetation type	Semi-annual reporting. All sites are sampled over a five-year cycle. Some benchmark sites sampled annually.	Uzarski et al. 2017
National Coastal Condition Assessments	Designed to produce national and regional estimates of coastal condition using rigorous quality assurance protocols and standardized sampling procedures	Basin-wide Nearshore zone (< 30m depth)	Suite of 30 biological, chemical, physical, and recreational indicators to assess ecological integrity and stressors	Every five years, with last available report for 2010	USEPA, 2016; Kiddon et al., 2020

The Western Lake Erie Report Card is more regionally focused, and includes a smaller number of indicators, with a particular emphasis on water quality parameters related to eutrophication and harmful algal blooms (UMCES, 2020a). As a new effort within the Lakes, the Western Lake Erie Report Card provides information of broad interest, though it remains to be seen whether the effort will be sustained. The U.S. National Coastal Condition Assessment covers nearshore sections of the U.S. portion of the Great Lakes, but as indicated above entails sampling carried out every five years, with reporting typically following several years later (USEPA, 2016). Indicators developed through recent IJC efforts are intended to inform the Parties' indicators, as well as IJC review of progress under the GLWQA, but are not part of an independent monitoring program (Great Lakes SAB Science Priority Committee, 2016).

All programs have emphasized a science basis for criteria used in indicator identification, though some programs are more explicit on individual criteria considered (Bertram and Stadler-Salt, 2000; Shear et al., 2003). The Western Lake Erie Report Card included a separate methodology document, and data availability was a central scientific criterion considered in indicator selection (UMCES, 2020b).

Stakeholder engagement in indicator development and implementation has differed in the various programs, though in all cases, subject matter experts have been heavily involved. The SOGL program included stakeholder outreach in earlier development of indicators (e.g., Shear et al., 2003); ongoing outreach is possible, including through GLWQA Annex 10 activities, though it is not clear to what extent such work is occurring. The State of the Strait program includes biannual meetings drawing together resource managers, researchers, NGO representatives and others, though the process of indicator identification or revision is not laid out in the most recent indicator report (Hartig et al., 2020). Development of the Western Lake Erie Report Card, as with other report cards developed by the University of Maryland Center for Environmental Sciences, had as a central goal development of an assessment report that was accessible to the public. The process included multiple stakeholder workshops to gauge interest in particular indicators (including new indicators) for the lake and watershed, as well as to inform the scoring system (UMCES, 2020b). The IJC indicator assessment project noted in Table 2 had as a central purpose identifying improved approaches to communicating (including to the public) on Great Lakes indicators, though as with most other efforts, stakeholder input was mostly through subject matter experts (Great Lakes SAB, 2016).

The ability to link management actions to ecosystem and other outcomes through indicator programs differs between the reviewed programs, including in explicit use of conceptual frameworks. The State of the Strait program groups individual indicators within conceptual framework components (e.g., as a pressure, state, or management response), and in some cases, there may be a clear connection of management actions to outcomes, in particular for state indicators directly related to actions (e.g., coastal wetlands on the Detroit River). In other cases, further work may be needed to consider how a pressure or state indicator are changing in response to management actions (Hartig et al., 2020). As noted in the previous section,

though SOGL indicator development previously utilized a DPSIR conceptual framework, the SOGL program reporting currently does not reference any conceptual framework (ECCC and USEPA, 2021), and consequently complicates efforts to track how indicators of ecosystem health may be changing with management actions. The IJC indicator assessment was part of broader work situated within a DPSIR framework, though further work would still be needed linking indicators to management actions (Great Lakes SAB, 2016). Other indicator programs summarized here similarly do not include explicit conceptual frameworks in reporting or methodology documentation. As noted in Section 2, use of such frameworks can help in assessing progress towards meeting protection or restoration objectives, including via incorporation in Great Lakes indicator programs (Murray et al., 2019), and other papers have highlighted the value of conceptual frameworks in understanding and managing ecosystems (Collins et al., 2011; Potschin-Young, et al., 2018; Schröter et al., 2018; Ives et al., 2019).

The preceding discussion summarizing Great Lakes indicator programs has identified some strengths and limitations of the programs. These types of issues were considered in the two-part stakeholder assessment of current Great Lakes indicators and consideration of alternative approaches to their development and use, as summarized in the following section.

Harmful algal bloom, western Lake Erie, Aug. 10, 2017. Credit: NOAA GLERL

3. Stakeholder perspectives on Great Lakes indicators

Informed by the long history and extensive work developing and implementing Great Lakes indicators through the decades, as summarized in the previous section, this project solicited input from a range of stakeholders on Great Lakes indicators. These efforts aimed to gain insights on the strengths and limitations of current indicators as well as other potential approaches to development and implementation of Great Lakes indicators. Initial input was provided via a virtual 1.5-day summit of Great Lakes experts from multiple sectors on February 23-24, 2021. Based on the expert involvement at the summit, input received, and subsequent considerations, it was decided to obtain further input from NGO representatives, which took the form of a 90-minute meeting with leadership of the Healing Our Waters (HOW) Great Lakes Coalition on June 16, 2021. Key observations from both meetings are summarized here.

3.1. Key observations from Great Lakes indicators virtual summit

The expert summit addressed the following three charges: identifying strengths and limitations of approaches used to develop and implement currently used Great Lakes indicators, identifying alternative processes for developing and implementing Great Lakes indicators, and examining potential approaches to such an alternative process through in-depth exploration of current indicators associated with three case studies (involving toxic chemicals, nutrients and eutrophication, and sea lamprey). Themes and key observations on the first two charge questions from the summit are summarized in Table 3 on p. 20, while Table 4 on p. 21 summarizes input on the third charge question concerning potential alternative approaches to indicator development via three case study topics. (More detailed input from the summit is provided in Appendix B.)

Left: Calf Island, Detroit River International Wildlife Refuge. Credit: Gary Muehlenhardt, U.S. Fish and Wildlife Service, via Wikimedia Commons.

Right: Sea lamprey in Ocqueoc River, MI. Credit: Andrea Miehls, Great Lakes Fishery Commission, USGS

Table 3. Themes and key observations on strengths and limitations of current indicators and potential alternative processes, deriving from February 23-24, 2021 indicators summit.*

Theme	Observations
1. Strengths and limitations of current indicators	
Science aspects, including criteria	● Participants emphasized limitations, current challenges in indicator development; need more time to step back, evaluate, synthesize ● Challenges with some basin-wide indicators being applicable across large, diverse areas ● Limited or missing socioeconomic, economic, and/or programmatic indicators ● Challenges in relying on one set of criteria for indicator selection, given diversity in ecosystem, limited information on some habitat types
Stakeholder engagement/ communication	● Need diverse stakeholder engagement early in process ● Communication issues important, including messaging, consideration of time lags
Objectives/intended use of indicators	● Need to be clear on intended uses, including policy needs, measurement needs ● Conceptual models can aid in ensuring meaningful indicators
2. Identifying an alternative process for developing and implementing Great Lakes indicators	
Engaging broader range of stakeholders/ communities	● Incorporate input from Indigenous communities, traditional ecological knowledge ● Carry out listening sessions, engage NGO scientists ● Consider communication approach, including language ● Increase engagement of underrepresented communities ● Solicit feedback from stakeholders, including on any changes in communication approach needed
Additional objectives/intended uses	● Should capture continuum of evaluation needs, including from process to program to adoption rate to water quality/ecosystem improvement ● Ensure indicator is benchmarked (e.g., to target) ● Expert and stakeholder involvement can ensure objectives and uses best suit needs
Key criteria to consider in indicator selection/refining	● Key criteria include data availability, and linkages to regulatory criteria where available ● Multiple scales (spatial and temporal) important for indicator data collection and reporting ● Consider equity (including human wellbeing) when developing, reviewing, communicating indicators ● Consider indicator weighting as needed, with caveats. ● Multi-purpose indicators can be desirable, e.g., via scaling, nesting ● May need new indicators for emerging issues
Conceptual frameworks	● Important, including in integration of elements from watershed to lake, and management actions to outcomes

*: For the first theme, input from consideration of criteria is combined with input on the science aspects component. For the second theme, input from the component on multiple purposes is coupled here with “Key criteria to consider in indicator selection/refining”.

Table 4. Themes and key observations on potential alternative approaches to indicators via case studies, deriving from February 23-24, 2021 indicators summit.

Theme	Case Study		
	Toxic chemical contaminants	**Nutrients and eutrophication**	**Sea lamprey**
Communities and user groups potentially not having their needs met through current indicators	● Environmental justice, immigrant, Tribal and First Nation communities with potential disproportionate impacts ● Recognize diverse interests, fish consumption patterns	● Verifying whether activities upstream are having resulting impacts downstream in the lake; related to resource expenditures to address problem	● Recognize sea lamprey can affect multiple predator fish
Adequacy of current indicator(s) to meet criteria	● Data availability generally higher for legacy chemicals (e.g., PCBs) than for chemicals of emerging concern (CECs) ● Value in targeted advisories, consumption approach (fillet vs. whole fish)	● More metrics and indicators relating management actions to outcomes ● Account for multiple stakeholder interests ● Account for spatial differences	● Current metrics may underestimate fish mortality ● Limited indication of emerging threats
Other issues to consider in improving the current indicator(s)	● More research needed on exposures, toxicity of CECs (humans and wildlife) ● More information on advisory effectiveness	● More emphasis on considering socioeconomic conditions, under-represented groups ● More emphasis on indicators of program effectiveness	● More consideration of socioeconomic impacts, implications for Tribes/First Nations ● Consider newer data sources, other technologies ● Consider in light of lake ecosystem objectives, other factors ● Dams recognized as tool to help manage lamprey
Other remarks common across case studies/ general discussion	● Feedback from NGO stakeholders should be solicited during preparation and review of indicators, considered when making changes ● Need indicators tied to endpoints for remediation or management (whether from mandates or stakeholder needs)		

As indicated in Tables 3 and 4, summit participants had a broad range of perspectives on current indicators as well as some common elements, with key observations from the meeting overall including the following:

- There are challenges in utilizing one set of criteria to develop and implement indicators covering the entire Great Lakes ecosystem;
- Criteria of interest included data availability, consideration of spatial and temporal variability, linkages to regulatory criteria, and equity and human well-being, while issues of metric weighting and multi-purpose indicators also arose;
- Stakeholder engagement early on – and throughout – the process is important, as is attention to communication, including modifying approaches as needed based on feedback;
- Objectives and intended uses of indicators should be informed by expert and stakeholder involvement, be benchmarked to targets or endpoints, and address the continuum of evaluation needs;
- Some indicators need to be transferable within the Great Lakes basin (e.g., SOGL indicators for each lake) and geographically nested indicators meet this need;
- Multiple objectives, including related to criteria such as relevancy and transparency, and tying management actions to ecosystem, human health, and socioeconomic outcomes can be more easily attained through use of conceptual frameworks.

Observations concerning broader stakeholder engagement was a key factor in the decision to organize the subsequent NGO stakeholder meeting, as described in the following section.

3.2. Key observations from Healing Our Waters Great Lakes Coalition leadership meeting

The June 2021 meeting with leadership of the HOW Great Lakes Coalition on Great Lakes indicators addressed three themes: indicators used by members (and in what manner), identification of other indicators that should receive greater attention by scientists and resource managers, and identification of any approaches that might engage a broader range of NGO stakeholders (and the public) in development and use of Great Lakes indicators, including disadvantaged/underrepresented communities. A summary of key observations from the meeting is provided here, with additional input summarized in Appendix D.

Indicators that have been used by participants include number of combined sewer overflows, harmful algal blooms, *E. coli*, beach closures, mercury and lead in infant blood, wild rice, and BUIs. Key observations from the meeting addressing how indicators are used, perspectives on other indicators, and process to engaging a broader range of stakeholders in indicator development are summarized in Table 5.

Table 5. Themes and key observations on Great Lakes indicators from HOW Leadership meeting, June 16, 2021.

Theme	Observations
How indicators are (or could be) used	● Many limitations with current indicators, including lack of resonance with many local communities, emphasis on ecological rather than socioeconomic conditions, and challenges in addressing on-the-ground conditions in many communities ● Need to consider stakeholder interests/concerns as well as scientific criteria in developing indicators ● Relationship to policy actions and outcomes not always clear ● Current indicators often emphasize state of system, rather than other factors (e.g., stressors) affecting the state
Other indicators that could receive more attention	● Economic and socioeconomic indicators, including related to tourism, recreation, property values, and unemployment rate ● Co-benefits of actions, policies, or change (e.g., associated with green infrastructure) ● Equity and justice, including related to resource allocation, distributive justice, community engagement ● Linkages between ecological, human health, socioeconomic conditions ● Management, including results of actions locally vs. lake-wide, broader consideration of stressors and impacts, and indicators of prevention as well as restoration/cleanup
Process to engage a broader range of stakeholders	● Ensure diverse representation, and increase diversity within NGOs ● Increase involvement of impacted communities in decision-making, provide resources, draw on local leadership ● Addressing socioeconomic indicators should engage broader constituency

As indicated in Table 5 and Appendix D, there were several common themes that arose during discussions on Great Lakes indicators with HOW leadership, including the following:

- Many existing indicators may not resonate with NGO representatives and the broader public, in part due to a general emphasis on larger scale, basin-wide indicators, vs. indicators more reflective of local conditions;
- More development and use of indicators in addition to existing ecological and environmental indicators – including socioeconomic, economic, and human health – would likely engender increased interest in many local communities;
- Significant interest expressed in indicators related to management actions and results – in particular local;
- The combination of more diverse representation in indicator development/revision efforts, drawing on local community leadership, and addressing other indicators would

likely increase interest and support for Great Lakes indicators. In addition, it will be important to engage with social scientists and economists to develop additional socio-economic indicators.

This process of stakeholder input on indicators provided multiple insights in reassessing Great Lakes indicators, both concerning the process for developing, refining, and using indicators, as well as the indicators themselves. Input from both meetings highlighted the importance of identifying goals and objectives at the start of the indicator development process (or as indicators are being reconsidered), in order to ensure potential space for certain indicators that may not otherwise be considered for development. Broader issues involving indicator development and use, drawing on this input, are explored further in the following section, which in turn inform recommendations for the Parties and others in Section 5.

Michigan coastal habitat workshop. Credit: LimnoTech

4. Proposed communications framework for assessing Great Lakes indicators

The multi-decade history of development and use of Great Lakes indicators has provided a systematic and practical approach to providing quantitative measures of the conditions of the Great Lakes. However, as we learned in this project, indicator development and use to date has largely entailed work by subject matter experts within agencies and academia, and there is increasing interest in involving a broader range of stakeholders in the indicator development and implementation process. As part of an approach to this broader engagement, development of nested conceptual models of the natural lake and watershed systems, as well as of linkages with stressors, societal values, and governance structures can help clarify understanding of the systems and the state of knowledge about system components. These models can also be used to identify the particular geographic and topical areas where resources could be applied most effectively to refine indicator suites, reduce key uncertainties, and to shore up outdated, inefficient, or underdeveloped policy.

The virtual summit and NGO stakeholder meeting carried out in this project revealed several high-level themes of interest to stakeholders concerning indicator development and use, including those related to certain technical criteria (including data availability); types of indicators (including socioeconomic and public health); local conditions (including related to equity), and linking management actions to ecological and other outcomes.

In light of these stakeholder perspectives and historic work on indicators, we propose a general communications framework to expand the scope and relevance of indicators in the Great Lakes region, as shown schematically in Fig. 3. In the framework, the current State of the Great Lakes indicators (#1 in the figure) would continue to be used to track status and trends basin-wide, though with potential modifications as needed, including as scientific understanding continues to develop. SOGL indicators (or sub-indicators), which are already in many cases used on a lake-specific basis (including reporting in LAMPs), could also be tied to more localized or other regional indicators, given sufficient data. In addition, there could be continued strengthening of connections to LAMP priorities, rotating State of the Lake meetings convened by IAGLR with management participation, and CSMI planning and execution (#2). Stakeholders (#3) would be a key constituency in informing and using indicators, some of which are already associated with a particular sub-basin or sub-region indicator (e.g., harmful algal blooms in western Lake Erie or Green Bay) (#4). In other cases, there may be particular interest in local or regional-scale indicators, though improved implementation may be contingent on alternative communication approaches for existing indicators (#5). In other cases, stakeholders may be interested in developing or co-developing local indicators that are relevant to their communities but not encompassed in the basin-wide indicators and sub-indicators (#6). For example, in some local areas with elevated eutrophication, there may be interest in tracking the previously used SOLEC indicator mayflies (*Hexagenia* spp.) (EC and USEPA, 2009).

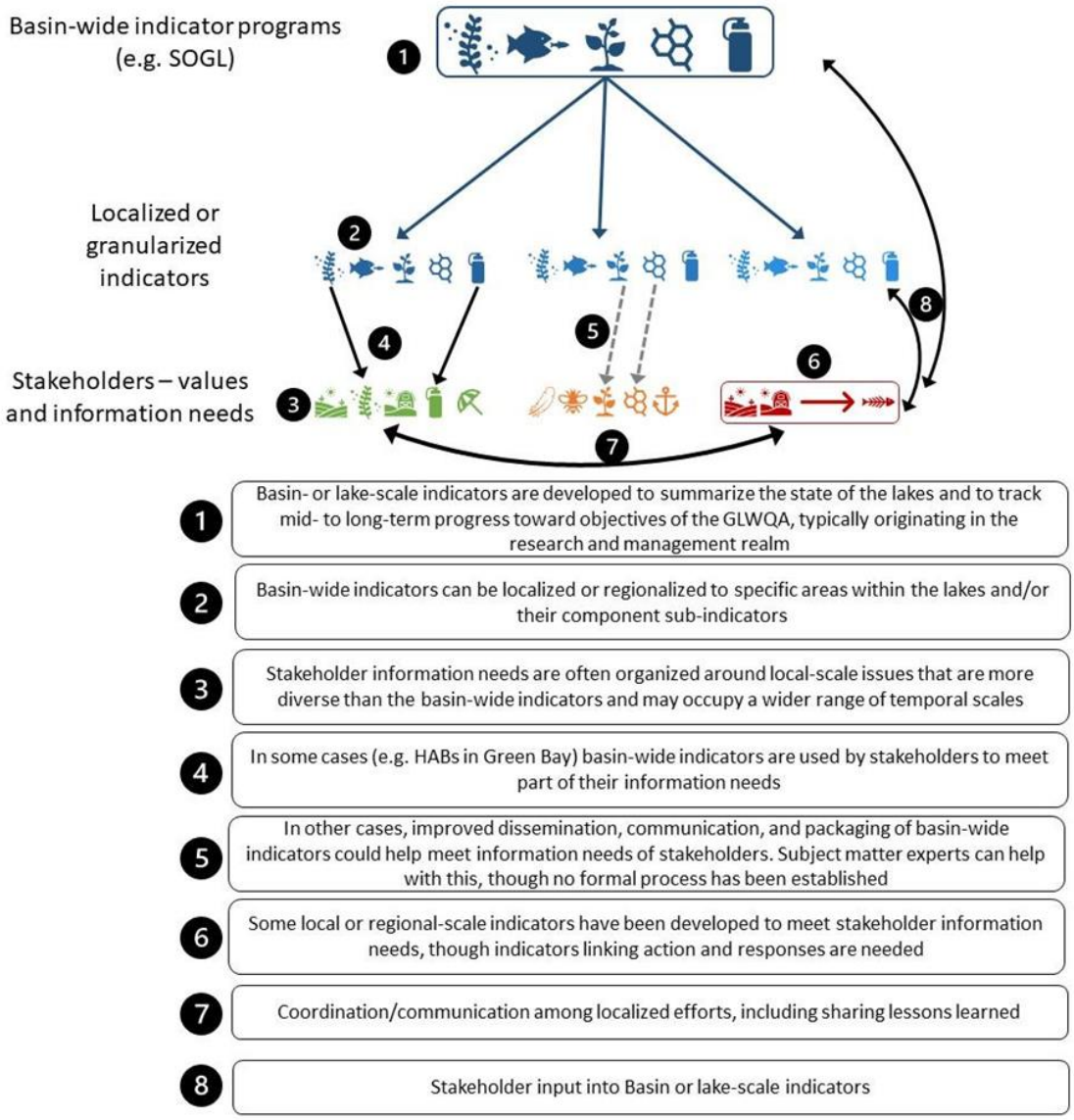

Fig. 3. Proposed communications framework involving development and implementation of Great Lakes indicators. Arrows denote the flow of information (through selecting/matching indicators at each level of the hierarchy) or communication and feedback (bidirectional arrows).

Regarding existing implementation of components in Fig. 3, the two stakeholder meetings in this project have documented that elements 1-4 are occurring presently and that element 5 is also occurring, but to a lesser extent. In general, the current system represents a strongly top-down organization around indicators.

Communication among stakeholders (potentially facilitated through a Center of Excellence or community of practice) could assist in sharing of information and best practices in more local-scale indicator development and use (#7). Such communication could draw on experiences of institutions with existing experience in regional indicator development (as has been done by

the University of Maryland Center for Environmental Sciences, as noted previously). Finally, even with development of some local indicator programs, it will be important to offer broader opportunities for all stakeholders to engage in the indicator selection and development process, including for basin-wide indicators (#8). Such efforts could take several forms, with examples including: a formal public advisory committee to the federal governments in the implementation of the State of the Great Lakes program; a committee or work group within Annex 10 of the Great Lakes Water Quality Agreement; periodic public listening sessions organized by the IJC (e.g., coupled with development of the triennial assessment of progress reports or binational public fora); formally incorporating stakeholder input into indicator-related work within each of the LAMPs; triennial workshops; or some combination of these approaches. One key issue in all of this work is availability of funding for development, assessment, and implementation work. In addition to the potential for funding through larger federal programs (e.g., the U.S. Great Lakes Restoration Initiative), it will be important to consider other innovative approaches, such as earlier work in the Lake Muskegon AOC (Steinman and Ogdahl, 2004), and more recent work in western Lake Erie (UMCES, 2020a).

The proposed framework could serve multiple objectives, including building off decades' work on environmental indicator development while allowing for addition or modification of existing basin-wide indicators (or sub-indicators), addressing local stakeholder interests (including socioeconomic/equity issues), and potentially better linking management actions to ecological and other outcomes, including those of interest to stakeholder communities. As noted previously, conceptual frameworks can be useful in linking management actions and ecological and other responses, and can also be of potential value in linking basin-wide or sub-basin indicators with local indicators which in some cases may be of particular interest to local communities.

Great Lakes Nutrient Adaptive Management Work Group workshop; Credit: L. Wang, IJC

5. Summary and recommendations

Great Lakes indicators have been developed, used, and assessed for more than three decades, and a comprehensive set of ecological indicators are in place addressing basin-wide conditions, with a particular emphasis on assessing progress towards objectives under the Great Lakes Water Quality Agreement. While earlier efforts involved some stakeholders in indicator development, the combination of ongoing and emerging threats to the lakes, increasing interest in a more diverse set of indicators (including socioeconomic and human health), and recognition of the importance of engaging a broader range of stakeholders in indicator development and implementation argues that the time is ripe for reassessing indicators. While the initial emphasis in this project was on indicators of ecosystem condition, multiple stakeholders noted the importance of connections to human health. In addition to several existing indicators relevant to human health within the SOGL program, the IJC Health Professionals Advisory Board developed recommendations on human health indicators (HPAB, 2014).

Conversations on increased stakeholder involvement in Great Lakes management more broadly are gaining momentum, including for example with publication of a recent report on fisheries management noting the importance of involving a broader range of stakeholders – and considering socioeconomic factors – in discussions (Stratos Inc., 2021). The importance of stakeholder perspectives in conservation planning more generally was also highlighted in a recent paper (Liberati et al., 2020).

Drawing on academic, agency and intergovernmental organization, industry, and NGO stakeholder input received in this project, we have several recommendations concerning a framework for communication and key issues to address in development and implementation of Great Lakes indicators going forward. To be clear, we are not arguing for a reset on indicators and starting from scratch, including given the critical historic record for multiple indicators, many of which have served useful purposes for decades. Rather, we are proposing that the Great Lakes community build on the strengths of current indicator programs and explore ways to enhance them (and create new programs, for example in more local areas). This work should entail more intensive work with a broader range of stakeholders, including outreach and education, compiling information on existing indicator programs (including at the local level), work through existing environmental justice advisory councils, and engaging input on all levels of indicators from a broad range of stakeholders.

As indicated below, while the Parties and indicators program managers would play key roles in implementing recommendations, the process would benefit if all stakeholders with a potential interest were engaged as appropriate. Furthermore, there are opportunities to build on historic development of more local or regional indicators in other locations within the Great Lakes region.

Five broad recommendations, with ideas on approaches to more detailed implementation, are as follows:

- **The GLWQA Parties should consider adopting the proposed (or an analogous) communications framework to support Great Lakes indicator development and implementation.** The process could lead to reevaluation of existing indicators or sub-indicators, and as appropriate, development and implementation of additional Great Lakes indicators. The process should include explicit identification of criteria for indicator selection, including scientific/technical criteria (such as data availability and quality, extent of monitoring programs, availability of endpoints (and relevance to objectives of the Great Lakes Water Quality Agreement), as well as stakeholder interests, including those related to socioeconomics and human health. The process should build on work over the past decade on human health indicators, including as carried out by the IJC. Such a process would likely benefit by one or more workshops involving stakeholders across multiple sectors, as noted in the next recommendation.
- **As part of communications framework implementation, the GLWQA Parties should develop a formal structure for both education and outreach as well as obtaining input from a broader range of stakeholders in indicator development and implementation.** The education, outreach, and engagement work should involve Tribal, First Nations, and Metis, and other underrepresented communities. The overall process could draw on approaches used in previous efforts (e.g., SOLEC meetings, IJC workshops), use current institutional arrangements (such as Annex 10 (Science) of the GLWQA, as well as coordinated efforts through LAMPs), and engage with umbrella organizations, such as the Great Lakes Indian Fish and Wildlife Commission and the Chiefs of Ontario, as well as environmental justice advisory councils at the federal and state/provincial levels, in addition to engaging with state and provincial partners themselves. One format that could be fruitful would be triennial stakeholder workshops addressing particular themes, for example related to development of any new human health or socioeconomic indicators. Finally, as part of the process, the Parties should consider the potential to utilize data from community science programs in indicator work, as appropriate.
- **A Great Lakes Center of Excellence, or community of practice, should be developed to address multiple issues, including serving as a clearinghouse and resource for indicator development, implementation, and communication efforts.** Such a center could have a larger mission related to Great Lakes science (e.g., aiding in large-scale planning, developing and implementing conceptual frameworks, documenting ecosystem services, and stakeholder communication), while also addressing indicators, with potential value in particular involving development and implementation of local or regional indicators, hosting workshops, and sharing resources among communities. Such a center could be housed at an appropriate institution, including for example the IJC,

Great Lakes Commission (GLC), a NOAA Great Lakes Sea Grant program, or an academic institution. Indicator work through individual Areas of Concern as well as the recent Lake Erie Report Card are examples of the types of products that could be produced, while institutions with similar missions (e.g., the Great Lakes Integrated Sciences and Assessments program at University of Michigan and Michigan State University, or the University of Michigan Cooperative Institute for Great Lakes Research) could serve as model institutional examples. Other collaborative programs that could serve as models include the Great Lakes HABs Collaborative (GLC) and the Great Lakes Phragmites Collaborative (GLC and U.S. Geological Survey). Regardless of whether a Center or community of practice were developed, sustained institutional support and stable funding would be needed.

- **The research community should increase participation in activities related to indicator development and implementation.** While many scientists are already involved in indicator implementation, there is value in increased research addressing multiple aspects of indicators, including those related to monitoring program design and trend detection, ability to track emerging threats (e.g., as part of an early warning system), and process-based work that can inform indicator program implementation. There is also a need to continue to engage in development of innovative and lower-cost measurement technologies. Furthermore, researchers can work with communities to advance or pilot the development of measurement technologies usable in community science programs, which can potentially contribute to both assessing certain conditions in the lakes as well as providing educational and awareness opportunities for the broader public. Social scientists would also have key roles to play, including in supporting innovative approaches around education and information sharing, as well as engagement through community science programs. Research developments related to all of this work could be highlighted at regular sessions of Conferences on Great Lakes Research (organized by the International Association for Great Lakes Research).

- **Indicator developers and program managers should increase attention to the linkages between management actions and ecological, socioeconomic, and human health outcomes.** In current State of the Great Lakes reporting, linkages to other indicators are noted within sub-indicator sections. However, there are generally not explicit linkages between indicators (or sub-indicators) and management actions, and similarly, limited explicit ties to endpoints. Such linkages may require increased development and use of programmatic or related indicators, and examination of stress-ecosystem response trends. For example, while there are complexities and data limitations in the system, an indicator of harmful algal bloom severity in the western Lake Erie basin would be even more useful if it could be coupled with one or more indicators related to stressors (e.g., spring nutrient loads or tributary discharge) or management actions (e.g., changes in commercial fertilizer or manure application in relevant watersheds). The use of conceptual frameworks that relate stressors (or “pressures”) to ecological or other

impacts will be particularly important in identifying new indicators (or approaches to linking existing indicators), including additional data needs. In general, a more integrated conceptual framework (or series of frameworks) for the Great Lakes can both ensure improved understanding of the lakes as well as direct restoration and protection work in an integrated, robust manner.

We believe implementation of the proposed framework and specific actions would lead to a suite of Great Lakes indicators that is science-based, descriptive of ecological and relevant socioeconomic and human health conditions, relevant to a broad range of stakeholders – including underrepresented communities, policy-relevant, and can help ensure appropriate management actions are taken to promote effective restoration and protection of the Great Lakes.

Herring gull with eggs; Credit: U.S. Fish and Wildlife Service

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Appendices

Appendix A
Indicators Summit: Approach, Agenda, Case Study Descriptions, Summit Participants List

The indicators summit was organized virtually by the National Wildlife Federation, via Zoom, on February 23-24, 2021. The summit involved 23 attendees, including the five Steering Committee members and two representatives from the University of Michigan Cooperative Institute for Great Lakes Research (CIGLR) (see Participants List at end of this appendix). A background document on indicators and the objectives of the summit were provided to participants ahead of the meeting (Murray et al., 2021). The summit consisted of six plenary sessions and three breakout sessions, with the initial session including a welcome by CIGLR Acting Director Tom Johengen, and an overview by Michael Murray of the summit objectives. The breakout sessions addressed three key questions on Great Lakes indicators – concerning strengths and limitations of current indicators, any potential alternative processes for developing indicators, and elaboration on any alternatives through exploration of three case studies. Each breakout session was followed by a plenary, report-out session, and the summit concluded with a brief recap of the meeting and identification of next steps. Each breakout session had a facilitator and notetaker, and breakout discussions were captured by notetakers via Google Slides, with sessions also recorded. The detailed agenda follows.

Agenda

The agenda for the two days is provided below. Note more detailed elements of questions are provided in Appendix B.

Great Lakes Indicators: Exploring Alternative Approaches Through Stakeholder Input
Virtual Summit, February 23-24, 2021

Day 1 – Morning, Tuesday, February 23, 2021

Time	Topic	Facilitator/Notetaker
9:30 - 10:20 am	Plenary 1: Meeting link at start of agenda	
9:30 – 9:45 am	Welcome by CIGLR Acting Director	Tom Johengen (introduced by Michael Murray)
9:45 – 10:00 am	Introductions	Michael Murray
10:00 – 10:20 am	Summit overview and objectives	Michael Murray
10:20 – 10:30 am	Break and Transition to Breakout Rooms	

10:30 – 11:30 am (brief break mid-session)	Breakout Session 1: Identifying strengths and limitations of approaches used to develop and implement currently used Great Lakes indicators	
	Breakout session 1a	Facilitator: Michael Murray
		Notetaker: Ashley Elgin
	Breakout session 1b	Facilitator: John Bratton
		Notetaker: Casey Godwin
	Breakout session 1c	Facilitator: Catherine Riseng
		Notetaker: TBD
11:30 am – Noon	Plenary 2: Meeting link at start of agenda	
	Report-out, summary	Michael Murray, facilitators
Noon – 1:30 pm	Lunch break	

Day 1 – Afternoon, Tuesday, February 23, 2021

Time	Topic	Facilitator/Notetaker
1:30 – 1:50 pm	Plenary 3: Meeting link at start of agenda	
	Alternative indicator development process – overview of issues	Michael Murray, SC
1:50 – 1:55	Break and Transition to Breakout Rooms	
1:55 – 3:10 pm (5-minute break mid-session)	Breakout Session 2: Identifying an alternative process for developing and implementing Great Lakes indicators (questions below)	
	Breakout session 2a	Facilitator: Michael Murray
		Notetaker: John Bratton
	Breakout session 2b	Facilitator: Casey Godwin
		Notetaker: TBD
	Breakout session 2c	Facilitator: Ashley Elgin
		Notetaker: Catherine Riseng
3:10 – 4:00 pm	Plenary 4	
	Report-out, summary, tee up case study session	Michael Murray, facilitators

Day 2 – Morning, Wednesday, February 24, 2021

Time	Topic	Facilitator/Notetaker
9:30 – 9:50 am	Plenary 5	
	Welcome, summary of work from Day 1, goals for Day 2 and case studies	Michael Murray, facilitators
9:50 – 9:55	Transition to Breakout Rooms	
9:55 – 11:10 am (5-minute break mid-session)	Breakout Session 3: Examine potential approaches to alternative process through in-depth exploration of several current indicators as case studies (questions below)	
	Breakout session 3a – Case study 1: Toxic chemical contaminants	Facilitator: Michael Murray Notetaker: TBD
	Breakout session 3b - Case study 2: Nutrients and eutrophication	Facilitator: Casey Godwin Notetaker: Catherine Riseng
	Breakout session 3c - Case study 3: Sea lamprey	Facilitator: John Bratton Notetaker: Ashley Elgin
11:10 am – Noon	Plenary 6	
	Plenary report-out, summary, next steps, including for final report development Adjourn – Noon	Michael Murray, facilitators

Case Study Descriptions

Case study 1: Toxic chemical contaminants

As a stressor group with direct implications for both ecological and human health, toxic chemicals have been addressed through both types of indicators since the inception of State of the Lakes Ecosystem Conference/State of the Great Lakes (SOGL) indicators. Most emphasis to date has been on persistent, bioaccumulative and toxic (PBT) chemicals, including human exposure risks via fish consumption. The current Fish Consumption SOGL indicator has an emphasis on fillet levels of PCBs and mercury. The current Toxic Chemicals SOGL indicator encompasses five sub-indicators (including whole fish and herring gull eggs), addressing PCBs, mercury and other legacy chemicals, and certain chemicals of emerging concern (CECs, e.g.,

PBDEs, PFAS). Overall status and trends in the recent reporting cycle (2019) were mostly fair and unchanging. There are multiple issues to address concerning indicators for toxic chemical contaminants, including legacy vs. CECs; fish consumption vs. other exposure routes (e.g., drinking water); human health and ecological exposures and effects; equity and justice concerns with toxic chemical exposures; and environmental cycling aspects that can complicate linkages to management actions.

Case study 2: Nutrients and eutrophication

Nutrients, and their consequences for algal blooms and food webs, have been targeted by various indicators since the 1970s. Current indicators closely match the updated Lake Ecosystem Objectives and reflect the 'feast or famine' problem of too much phosphorus in certain areas and critically declining phosphorus in large areas offshore. These indicators for nutrients and harmful algal blooms are used to describe responses of the lakes to inputs from the watershed. In areas where excess nutrients lead to harmful algal blooms (HABs) and hypoxia these indicators are designed to be responsive to ongoing management activities and objectives but management options are more limited for abating declines in offshore nutrients. These indicators are an example of a program that has different objectives depending on location and this geographic delineation continues to shift over time.

Case study 3: Sea lamprey

Part of a successful sea lamprey control program with an annual cost of over $28 million is monitoring of adult sea lamprey abundance and impacts (http://www.glfc.org/status.php). Adult sea lamprey population estimates are developed for each lake using mark-recapture studies conducted on index streams. Lake trout wounding or marking from parasitic sea lamprey attachment and trout abundance data are collected annually to generate lake-wide marking rates and population estimates. These indicators are used to independently assess abundance and impacts of sea lamprey, as well as effectiveness of sea lamprey control measures (e.g., lampricide application to streams) and progress of lake trout restoration programs including other measures such as stocking and habitat protection or restoration. This mature indicator program linked to specific management actions can serve as an example of how other indicator programs linked to stressors and associated management decisions can be developed and optimized over time.

Summit Participants List

Participant Name	Affiliation
Todd Brennan	Alliance for the Great Lakes
David Bunnell	USGS Great Lakes Science Center
Amy Holtshouse	The Nature Conservancy
Lucinda Johnson	University of Minnesota-Duluth
Donna Kashian	Wayne State University
Val Klump	University of Wisconsin - Milwaukee
Paul Mathewson	Clean Wisconsin
James McKenna, Jr.	Great Lakes Science Center
Kristy Meyer	Freshwater Future
Mike Ripley	Chippewa Ottawa Resource Authority
Katie Rousseau	Great Lakes Observing System
Lars Rudstam	Cornell Biological Field Station and the Department of Natural Resources
Alan Steinman	Grand Valley State University, Annis Water Resources Institute
Donald Uzarski	Central Michigan University, Institute for Great Lakes Research
Lizhu Wang	International Joint Commission
Chris Winslow	The Ohio State University, Ohio Sea Grant College Program
CIGLR	
Tom Johengen	University of Michigan, Cooperative Institute for Great Lakes Research
Mary E. Ogdahl	University of Michigan, Cooperative Institute for Great Lakes Research
Steering Committee	
Michael Murray	National Wildlife Federation
John Bratton	LimnoTech
Casey Godwin	University of Michigan, Cooperative Institute for Great Lakes Research
Ashley Elgin	National Ocean and Atmospheric Administration, Great Lakes Environmental Research Laboratory
Catherine Riseng	University of Michigan, School for Environment and Sustainability, and Michigan Sea Grant

Reference

Murray, M.W., Bratton, J., Elgin, A., Godwin, C., Riseng, C., 2021. Great Lakes Indicators: Exploring Alternative Approaches Through Stakeholder Input, Background Document.

Appendix B
Great Lakes Indicators Summit: Synthesis of Input in Response to Charge Questions

The February 23-24, 2021 virtual summit entailed six plenary sessions and three breakout sessions, with three breakout groups for each (agenda in Appendix A). Most input at the summit was received during the breakout sessions – on strengths and limitations of Great Lakes indicators, identifying an alternative process for developing and implementing Great Lakes indicators, and examining potential approaches to re-evaluating several current indicators through case studies. Major points captured during the breakout sessions are provided here, integrated among the three breakout groups for the first two sessions, and as distinct contributions for the third breakout session, which was organized around three case studies.

Breakout 1 – Strengths and limitations of Great Lakes indicators

The charge question for the breakout session was as follows:

What are strengths and limitations of various approaches used to develop environmental indicators to date in the Great Lakes (including any not reviewed in the background document), considering factors such as

1. Technical/expert involvement and review
2. Stakeholder engagement
3. Objectives/intended use of indicators
4. Criteria – technical, stakeholder needs, etc.
5. Use of conceptual frameworks

An initial question considered at the summit concerned whether there were other indicator efforts not addressed in the background document that should be considered, and responses are provided first below. Responses from the three separate breakout groups are integrated here, with responses grouped generally by themes identified in the charge question.

Initial Question: Other indicator efforts to consider:

- Coastal wetlands monitoring, including both spatial extent and biotic conditions
- Fisheries, connecting channels, St. Lawrence River, St. Marys River, Detroit River
- Groundwater; also background document could include other 6 major restoration projects

1. Technical/expert involvement and review/science aspects.

- The science of indicator development has stalled
  - We need more indicators that indicate function
  - We are too busy to reflect, synthesize, and innovate
  - May have resistance to change by the management and regulatory community

- Basin-wide indicators have limitations when working across borders and covering broad areas; often Insufficient data to make meaningful, harmonized classifications.
- Socioeconomic and economic indicators absent in existing programs. Work is happening around the lakes in research, but not incorporated; more such indicators could increase relevancy
- Need more indicators for emerging issues/early warning system (viruses, invasives) leveraging technologies that can be applied system-wide (remote sensing, eDNA)
- We lack indicators on the programs themselves (efficiency, gaps, governance, effectiveness, budgets)

2. Stakeholder engagement

- Communication is key
  - Use common language, consistent messaging
  - Manage expectations of the public and managers
- Timing of data collection and reporting
  - Time lags before an ecosystem response following remediation action (messaging challenge)
  - Short term changes can easily be misinterpreted.
- Would have been helpful to include a broader spectrum of backgrounds in this summit
  - More policymakers or end users of indicators
  - Indicator development “experts” (e.g., University of Maryland center) may be able to assist with stakeholder engagement
    - Technically rigorous but communicate via a report about issues that people care about
    - Could be a good process to evaluate for future directions
    - Great Lakes Fishery Commission considering how to similarly adapt fish community objectives; potential source of ideas on broadening involvement in indicator development
- Stakeholder engagement needs to be more inclusive, earlier, sustained in developing indicators. Underserved and underrepresented groups are often asked for input but never hear about it again.

3. Objectives/intended use of indicators

- Clear indication of what needs to be measured and interpreted
  - Why are we using it?
  - Need a clear idea of what it truly indicates.
- It is easier to advocate for policy when the data are available
- Conceptual models can be a starting point for reaching out

4. Criteria – technical, stakeholder needs, etc.

    - One set of criteria for indicator selection does not fit all properties of the ecosystem or issues for the region
    - Redundancy
        - Different groups could have overlap in indicators
        - So many Great Lakes organizations complicates the matter

5. Use of conceptual frameworks
    - Can help public understanding of processes occurring

Breakout 2 – Identifying an alternative process for developing and implementing Great Lakes indicators

The charge for the second breakout session included the following questions:

1. What actions can be taken to engage a broader range of stakeholders/communities in indicator development/review efforts?
2. Are there additional objectives/intended uses that should be considered in selection/refining of indicators?
3. What are key criteria that should go into selection/refining of indicators?
4. Is it desirable to aim for indicators that can meet multiple purposes, including meeting technical criteria and stakeholder interests, vs. developing separate indicators for each purpose as needed?
5. Should indicator selection rely more heavily on consideration of conceptual frameworks, including relating management actions to ecological outcomes, and if so, how should this be done?

Responses from the three separate breakout groups are integrated here, with responses grouped generally by themes similar to those identified in the charge question.

1. Actions to engage a broader range of stakeholders/communities.

    - Engage broader stakeholder group through incorporation of Indigenous/TEK priorities; solicitation of indicator feedback from stakeholders via IJC listening sessions, etc.; and working with "translators" like embedded NGO scientists, Sea Grant Extension staff, and respected environmental reporters; work with citizen scientists; Everglades example of priming stakeholders with draft goals and refining goals and associated indicators
    - After the indicators are developed, assess whether they are being used by the user groups, and if not, may need to repackage the information in a more user-friendly way
    - Consider how to package the outcome for a lay audience - this needs to start early in the process
    - Particularly important in considering the goal of the indicator rather than how to measure that indicator (including individual parameters)
    - Report back to stakeholders to make sure the indicator meets their needs - consider

adaptive management approach
- Use surveys and community engagement to identify underrepresented users

2. Additional objectives/intended uses to consider

   - Objectives/intended uses should capture the continuum of evaluation needs for optimization from process to program to adoption rate to water quality/ecosystem improvement
   - Identify the purpose of developing an indicator, identify the user of the indicator and involve them from the outset
     - Development should include disciplinary experts, social scientists, & as many stakeholders as possible
     - Not every metric is an indicator
     - Challenging to adapt the "canary in the coal mine" utility of an indicator as the lakes undergo transformations
     - What is the indicator benchmarked to and does it capture the gradients we might predict in the future?

3. Key criteria to consider in indicator selection/refining.

   - Key criteria include data availability and linkages to regulatory numeric criteria where available (Wisconsin in-stream phosphorus and Everglades phosphorus examples)
   - Address equity when developing, reviewing, and communicating indicators
     - Many indicators may be more or less resonant depending on: socioeconomics, access to organized representation, resilience of communities to respond to threat/impacts
     - How do we respond to the threats and stressors according to their impacts to different socioeconomic groups?
     - Human wellbeing indicators are already available and increasingly used to look at environment/health impacts; involving stakeholders and social scientists will make such indicators part of the conversation and metrics
   - Consider multiple scales (spatial and temporal) for indicator data collection and reporting out
   - Weighting indicators could be used to highlight indicators that are considered more useful; would have concerns about decisions on weighting, potential interpretation challenges

4. Multiple purposes of indicators vs. additional indicators.

   - Multi-purpose indicators are desirable and one way to do this might be by spatial scaling or nesting of indicators from local to lake (Erie report card example); most stakeholders care more about the state of their local system
   - Need to develop new indicators to address emerging issues, ideally drawing on existing data to extent possible – e.g., Oligochaete Trophic Index, benthic survey data, satellite data

5. Use of conceptual frameworks in indicator selection.

    - Conceptual frameworks are important, including integration of elements from watershed to lake, and management actions to outcomes

Breakout 3 – Examining potential approaches to re-evaluating several current indicators

The charge for the third breakout session was to examine potential approaches to alternative processes of indicator development through in-depth exploration of current indicators associated with three case studies, considering the following questions/topics:

1. Any individuals who have had experience working on some aspect of this case study issue (or a related issue) involving indicators can provide a very brief verbal summary.
2. Which communities/user groups are potentially not having their needs met through current indicators? And what might that mean for purposes or objectives of the indicator(s)?
3. How well does current indicator(s) meet criteria, including data availability, management-ecosystem linkages, use of conceptual frameworks, and ability to address emerging threats?
4. Are there other issues to consider in improving the current indicator(s) - e.g., new metrics, incorporating citizen/community science - and what general process might best address them?

The three case studies were toxic chemical contaminants, nutrients and eutrophication, and sea lamprey control, each the focus of a single breakout group (i.e., 3a, 3b, 3c). Key points below derive from discussions within each breakout group, where responses are grouped by above questions as appropriate.

<u>Group 3a (toxic chemical contaminants)</u>

1. Existing experience on case study

    - Fish consumption advisories in Detroit River and consumption advisories; PFAS in mussel tissue; PAHs in fish in Milwaukee area; earlier IJC projects on environmental indicators involved contaminants

2. Communities/user groups potentially not having their needs met through current indicators, and implications for purposes or objectives of the indicator(s)

    - Consider experiences of environmental justice communities, immigrant populations, Tribal/First Nations, and subsistence fishing communities
    - Need to recognize diverse interests – e.g., subsistence anglers, fisheries managers, charter boat industry, etc.; may have different perspectives w/r fish consumption advisories
    - Recognize different consumption patterns – e.g., some immigrant groups consuming whole fish rather than fillets, though advisories typically based on latter

- New IJC project partnering with Great Lakes Fishery Commission is examining fish advisories and binational, multiple jurisdiction waters involving indigenous communities

3. Extent to which current indicator(s) meets criteria, including data availability, management-ecosystem linkages, use of conceptual frameworks, and ability to address emerging threats

   - Data availability generally higher for legacy chemicals (e.g., PCBs) than for chemicals of emerging concern (CECs); same issues for toxicity information (e.g., related to triggers leading to advisories)
   - Consider level of advisories needed – e.g., targeted, vs. basin-wide; whole fish vs. fillet; targeting different communities. Pros and cons of various approaches
   - Conceptual frameworks can help inform management actions needed to address toxic chemicals; simple example may be in an Area of Concern

4. Are there other issues to consider in improving the current indicator(s) - e.g., new metrics, incorporating citizen/community science - and what general process might best address them?

   - More work needed on CECs, microplastics
   - Citizen (or community) science: Complicated for toxic chemicals (e.g., do not want to risk exposure for participants). But there may be limited roles like recruiting anglers to catch fish for sampling.
   - Lot of unknowns regarding health risks and levels of concern for CECs
   - Issues of advisory outreach, are people paying attention/understanding advisories, how best to effectively communicate
   - Consider geographic scope – e.g., to what extent should inland issues be incorporated with Great Lakes indicator development

<u>Group 3b (nutrients and eutrophication)</u>

1. Existing experience

   - Significant research experience among group members (collecting data related to nutrient sources and impacts), as well as user groups using output of research community
   - In some cases, needs are addressed by metrics and other information, rather than indicators

2. Communities/user groups potentially not having their needs met through current indicators, and implications for purposes or objectives of the indicator(s)

   - Significant interest in verifying whether activities upstream are having resulting impacts downstream, in lake
   - Related issue of resources being provided upstream (e.g., agricultural operators), vs. in downstream communities potentially suffering impacts (harmful algal blooms (HABs),

drinking water impairments, etc.); some interest in cost-benefit analysis of these types of expenditures

3. Extent to which current indicator(s) meets criteria, including data availability, management-ecosystem linkages, use of conceptual frameworks, and ability to address emerging threats

   - Some interest in more metrics and indicators relating management actions to impacts
   - Need to account for challenges with multiple stakeholders and interests – e.g., generally higher nutrients means higher productivity (and more fish), but potential for increased HABs; related to consideration of indicators of well-being, including resulting from management actions, and ensuring indicators are still useful as system (including socioeconomic conditions) changes
   - Need to consider spatial differences, including in watersheds and water bodies (e.g., western Lake Erie, Green Bay)
   - Communication important, including considering newer approaches (e.g., via apps), while being cognizant of digital divide

4. Are there other issues to consider in improving the current indicator(s) - e.g., new metrics, incorporating citizen/community science - and what general process might best address them?

   - Recognize some data processing challenges. For example, in some cases (e.g., waves), data are provided essentially real-time, but for nutrients, there is a lag between collection, processing, and data availability.
   - More emphasis on considering socioeconomic conditions, underrepresented groups, including interests, and potential for indicators to address
   - More emphasis on indicators of program effectiveness, cost-benefit analysis

<u>Group 3c (Sea lamprey)</u>

1. Existing experience

   - Extensive experience, including by Tribes/First Nations in addressing sea lamprey. Indicator and metrics (e.g., wound rates) tie in directly to management actions

2. Communities/user groups potentially not having their needs met through current indicators, and implications for purposes or objectives of the indicator(s)

   - Even though significant concern with sea lamprey is impacts to larger predator fish (e.g., lake trout), other large fish species can still be affected by sea lamprey, so relevant in Lake Erie (even without substantial lake trout populations)
   - Recognize that dams can be helpful in managing sea lamprey

3. Extent to which current indicator(s) meets criteria, including data availability, management-ecosystem linkages, use of conceptual frameworks, and ability to address emerging threats

    - Current metrics may underestimate fish mortality
    - Need to consider stakeholder perspectives on different species (e.g., lake trout, salmon)
    - Need to recognize inherent link of indicators to existing monitoring programs, which may limit consideration of emerging threats

4. Are there other issues to consider in improving the current indicator(s) - e.g., new metrics, incorporating citizen/community science - and what general process might best address them?

    - Consider newer data sources and technologies (e.g., eDNA, telemetry, autonomous vehicle surveys, information from GLATOS)
    - Climate change and increasing interest in dam removals may require adjustment of approaches, indicators
    - More consideration of socioeconomic impacts, which is clear need for Tribes/First Nations
    - State of the Great Lakes (SOGL) indicator thresholds and management goals may be out of synch with current state of system, lake ecosystem objectives (through Great Lakes Fishery Commission)

Appendix C
Healing Our Waters Meeting: Approach, Agenda, Meeting Participants List

Based on input at the February 2021 summit, a decision was made to obtain further input on indicators from the Great Lakes NGO community, with a focus on input from the Healing Our Waters (HOW) Great Lakes Coalition, given its breadth of members and extensive involvement in Great Lakes issues. We worked with the HOW Coalition Director (Laura Rubin) in reaching out to HOW leadership, and organized a 90-minute virtual meeting (via Zoom) with HOW leadership on June 16, 2021, to gain additional input on Great Lakes indicators. Nine HOW leaders and four Steering Committee members took part in the meeting. The conversation was organized around several questions – current use of Great Lakes indicators, other indicators that should receive greater attention by scientists and resource managers, and identification of any approaches that might engage a broader range of NGO stakeholders in development and use of Great Lakes indicators, including disadvantaged/underrepresented communities. There was a single breakout session to consider these three questions, with a facilitator and notetaker for each breakout group, and notes captured via Google Slides.

Agenda

The agenda for the HOW meeting is provided below. Note more detailed elements of questions considered in the breakout session are provided in Appendix D.

Great Lakes Indicators & Alternative Approaches:
Input from Healing Our Waters Great Lakes Coalition Leadership
Virtual Meeting, June 16, 2021, 3:00 – 4:30PM (EDT)

Time (EDT)	Topic	Facilitator/Notetaker
Plenary 1		
3:00 – 3:10 PM	Welcome and introductions	Michael Murray, all
3:10 – 3:20 PM	Overview of Great Lakes indicators	Michael Murray
		Notetaker: Casey Godwin
Breakout Sessions		
3:20 – 4:10 PM	Breakout Session A	
		Facilitator: Michael Murray
		Notetaker: Laura McNeil
	Breakout Session B	
		Facilitator: Catherine Riseng
		Notetaker: Casey Godwin
Plenary 2		
4:10 – 4:30 PM	Report-out, summary, next steps	Michael Murray, facilitators
		Notetaker: Catherine Riseng

HOW Meeting Participants List

Participant Name	Affiliation
Ameer Abdullah	Junction Coalition
Joel Brammeier	Alliance for the Great Lakes
Andrea Densham	Shedd Aquarium
Joe Fitzgerald	Milwaukee Water Commons
Erma Leaphart	Sierra Club
Alexis Lopez-Cepero	National Parks Conservation Association
Janet Pritchard	Milwaukee Water Commons
Laura Rubin	National Wildlife Federation & Healing Our Waters Great Lakes Coalition
Andrew Slade	Minnesota Environmental Partnership
Steering Committee Attendees	
Michael Murray	National Wildlife Federation
John Bratton	LimnoTech
Casey Godwin	University of Michigan, Cooperative Institute for Great Lakes Research
Catherine Riseng	University of Michigan, School for Environment and Sustainability, and Michigan Sea Grant

Reference

Murray, M.W., Bratton, J., Elgin, A., Godwin, C., Riseng, C., 2021. Great Lakes Indicators: Background and Overview for a HOW Coalition Leadership Meeting.

Appendix D
Healing Our Waters Meeting: Synthesis of Input in Response to Charge Questions.

The following are insights that were collected from participants at the Healing Our Waters Great Lakes Coalition meeting that took place virtually on June 16, 2021. The discussion was structured around three guiding charge questions:

1. What indicators do you use and how do you use them?
2. Are there other indicators (e.g., socioeconomic and/or human wellbeing indicators, programmatic) that should receive greater attention by scientists and resource managers?
3. What approaches would engage a broader range of NGO stakeholders (and the public) in development and use of Great Lakes indicators, including disadvantaged/under-represented communities?

The notes have been grouped according to these questions, with responses to the first question separated out into two components below. Discussions took place in two virtual breakout rooms, and input is integrated below.

1a. Indicators currently used

- Number of combined sewer overflows; water quality generally; harmful algal blooms (HABs; *E. coli*; beach closures (and ties to nutrient and other runoff); mercury and lead in infant blood; wild rice; beneficial use impairments (BUIs)

1b. How indicators are (or could be) used

- Limitations in current indicators
  - Do not resonate with many local communities
  - Historic emphasis on cleanup, rather than prevention
  - Historic emphasis on ecological indicators, rather than socioeconomic indicators, and disconnect between social, public health, ecological indicators
  - Inherent limitations in comprehensively addressing situation on the ground in many areas; indicators can be location-, agency-, organization-dependent
- Consider changing baselines
- Want to be able to use in policy, but not always straightforward connection with simple indicator; Sometimes anecdotes can get more attention (by NGOs, media)
- In addition to considering science and what it can say about the state of the water, need to listen to stakeholders in identifying indicators – what do they care about?
- Begin with the end in mind, i.e., a target - what is the goal we want to attain (particular state, etc.)? BUIs are good example: goal is removal of the BUI
- Need assessments of whether indicators are having desired effect; whether or not they are useful
- Many indicators emphasize only current state of system, rather than why (e.g., drivers, stressors) system is in that state

2. Other indicators to receive more attention

- Property values (though can have limitations)
  - Blue economy (tourism, recreation, etc.)
- Climate change
- Unemployment rate
- Co-benefits (e.g., broader local impacts of green infrastructure, beyond water mgmt.)
  - These are of interest to NGOs but often not part of the discussion and reporting on indicators
- Indicators of community engagement
- Indicators of distributive justice, resource allocation/equity
- May have data/information gaps, preventing tracking of important issues
- Better tie ecological, human health, & socioeconomic indicators together
- Include thinking about causal relationships between stresses and impacts
- Consider indicators that can highlight prevention efforts, rather than indicators emphasizing cleanup/restoration
- Consider time scale - i.e., varying length of time in which changes may result from interventions
- Consider manageability - e.g., feasibility of impacts of management actions in local area vs. broader, lake-wide changes
- Indicators tie in with resource allocation - consider phenomena monitored, equity and justice concerns

3. Engaging a broader range of stakeholders

- Addressing socioeconomic benefits will engage more individuals, communities
- Representation important, as well as considering messenger of indicator information
- Increase diversity, including within NGOs
- Increase involvement of impacted communities in decision-making
  - Recognize existing leadership within communities, and consider community leaders' roles in indicator development and decision-making
  - Empower organizations within impacted communities: more resources, encourage development of their own indicators
  - Query impacted communities, youth, including via nontraditional means (such as oral histories) - what do you value in the environment, the Great Lakes?