**Great Lakes Indicators: Exploring Alternative Approaches Through Stakeholder Input**
**Background Document**

Prepared by the Great Lakes Indicators Summit Steering Committee Members
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In recognition of the continuing importance of tracking conditions in the Great Lakes, and interest in having optimal indicators to do so, the National Wildlife Federation Great Lakes Regional Center is working with colleagues in organizing a virtual expert summit February 23-24, 2021, supported by the University of Michigan Cooperative Institute for Great Lakes Research. The goal of the summit is to evaluate current approaches to developing and implementing Great Lakes indicators and identifying any alternative approaches to indicator development and implementation that meet multiple objectives. This background document provides context for the summit, including via a brief introduction addressing rationale for the summit, an overview of approaches to development of Great Lakes indicators to date and summary of key indicators, a brief review of recent indicator assessments, and identification of questions to address in consideration of any alternative approaches to indicator development or refining in the Great Lakes.

## 1. <u>Introduction</u>

Environmental indicators have been used for decades in the Great Lakes, and as is the case in other large aquatic ecosystems, the importance of indicators is widely recognized in tracking the status and trends of key aspects of the system. Earlier efforts involving multiple scientists across diverse disciplines have led to the current State of the Great Lakes indicators utilized by the U.S. and Canadian federal governments in reporting on progress towards objectives under the Great Lakes Water Quality Agreement (GLWQA). Ecosystem indicators and their reporting are specifically referenced in Annex 10 (Science) of the current GLWQA, where it is noted that while the Parties (the U.S. and Canadian governments) are charged with establishing and maintaining science-based indicators, the indicators should be periodically reviewed and updated as necessary (GLWQA, 2012).

The International Joint Commission has in the past decade through several work group efforts assessed and developed recommendations on both ecological and human health indicators for the Great Lakes. In addition, academic and other researchers have developed and applied environmental indicators or carried out relevant assessments in several projects. In spite of the extensive work on Great Lakes indicators, and that many have had significant stakeholder development, it is not clear to what extent the broader policymaking and nongovernmental organization (NGO) communities closely track and utilize indicators in planning and decision-making. At the same time, there is growing interest in ensuring restoration and protection efforts address equity and justice concerns, including through broader stakeholder engagement in these efforts.

The National Wildlife Federation Great Lakes Regional Center is addressing these needs by assembling scientists, advocates, and others for a virtual expert summit February 23-24, 2021, supported by the University of Michigan Cooperative Institute for Great Lakes Research (CIGLR). The goal of the summit is to evaluate current approaches to developing and implementing Great Lakes indicators and identifying any alternative approaches to indicator development and implementation that can 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. This goal is being addressed through three sessions at the summit: 1. Reviewing existing Great Lakes indicator development, including criteria used; 2. Identifying any alternative approaches and criteria that should be considered in any new or revised indicators; and 3. Applying any alternative approach identified to three indicator case studies. The remainder of this document provides more background concerning Great Lakes indicators and their development as well as discussion questions to consider at the summit.

## 2. Great Lakes indicators review

### 2.1 Process of indicator development, criteria used

The Great Lakes Water Quality Agreement (GLWQA) is a commitment between the United States and Canada to restore and protect the waters of the Great Lakes by identifying binational priorities and implementing actions that improve water quality. The signing of the original GLWQA in 1972 highlighted the need for indicators of the condition of the Great Lakes, including to assess progress towards meeting objectives of the Agreement. Reporting was initially done largely through the International Joint Commission (IJC), based on data from the Parties (the U.S. and Canadian governments, via the federal environmental agencies). Amendments to the GLWQA in 1987 shifted reporting responsibility to the Parties. The amended GLWQA of 1987 also included an emphasis on the "ecosystem approach", which was followed by significant efforts by the Parties to develop and use ecological indicators. At the same time, following the changed charge, the IJC shifted to indicator review and assessment work (IJC, 1996). The amendments to the GLWQA in 2012 kept the roles of the Parties and IJC regarding indicator development, implementation, and assessment essentially unchanged. 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 relevant efforts have been underway elsewhere in the U.S. and Canada.

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)

It has been recognized that indicators are utilized in a broader context. An earlier IJC report noted the importance of indicators serving a clear purpose (e.g. on the state of the environment and human activities affecting it), being situated within a particular conceptual framework, considering scale, and providing for an assessment of progress towards desired outcomes, which in this case meant meeting ecosystem integrity targets of the GLWQA (IJC, 1996). 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). As will be summarized below, the indicator development efforts to date in the Great Lakes have varied in the degree to which they have explicitly considered criteria in establishing ecological indicators. This section briefly summarizes multiple programs, including use of criteria or other elements important in the development of Great Lakes ecological indicators.

#### 2.1.1. Earlier indicator efforts

Following the 1987 amendments to the GLWQA, the IJC established the Indicators for Evaluation Task Force to assess the IJC data and information needs and identification of indicators to evaluate GLWQA progress. In addition to addressing the broader context in which indicators are used (noted above), the task force identified the importance of assessing both programmatic progress as well as conditions in the lakes, both of which were called for in the amended GLWQA (IJC, 1996). The effort utilized a pressure/state/effects/ (human) response conceptual framework, utilized over one dozen science-related criteria, and noted the importance of "criteria for public understandability", though no specific, separate criteria were noted (see summary in Table 1 below) (IJC, 1996). Indicators themselves were organized around desired objectives of the GLWQA (e.g., drinkability, swimmability, fishability, biological community integrity and diversity), with multiple indicators for each objective (IJC, 1996).

#### 2.1.2. State of the Great Lakes indicators

Significant indicator development efforts were carried out by the Parties starting in the 1990s, with reporting in particular through the biennial State of the Lakes Ecosystem Conferences (SOLEC). 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 U.S. Environmental Protection Agency (USEPA), with reporting and indicators typically referenced as SOLEC reports and indicators (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. The process used for developing indicators to that point is shown in Figure 1 below.

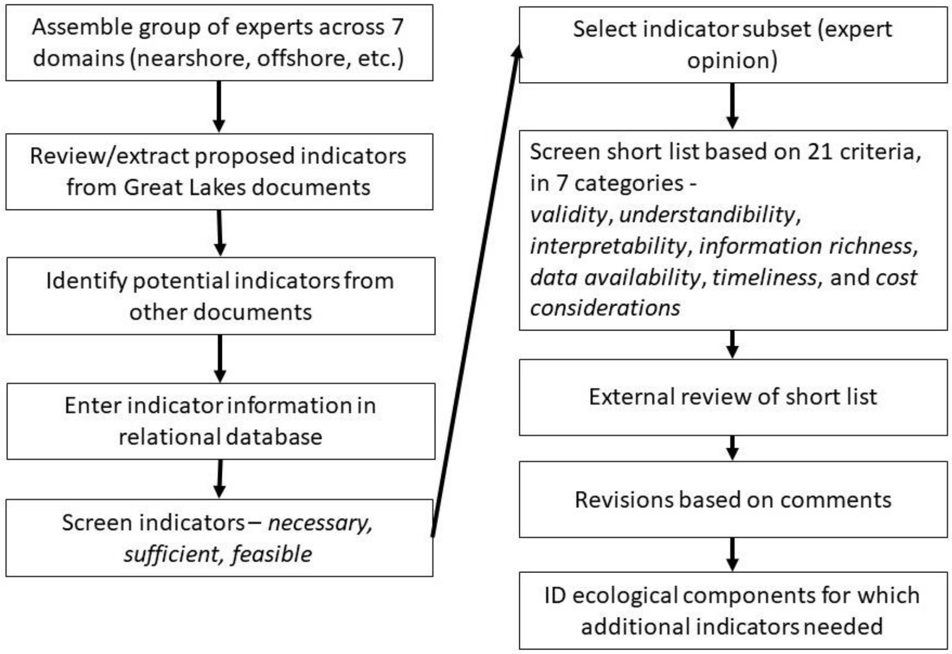


**Figure 1.** Process for indicator development for Great Lakes reporting, pre-1998 (adapted from Bertram and Stadler-Salt, 2000).

Following earlier use of a simpler conceptual framework to help organize SOLEC indicators, EPA and Environment Canada in 2010 began using the Driving forces-Pressure-State-Impacts - Response (DPSIR) conceptual framework as part of the SOLEC reporting process in 2010 (see Figure 2 below).

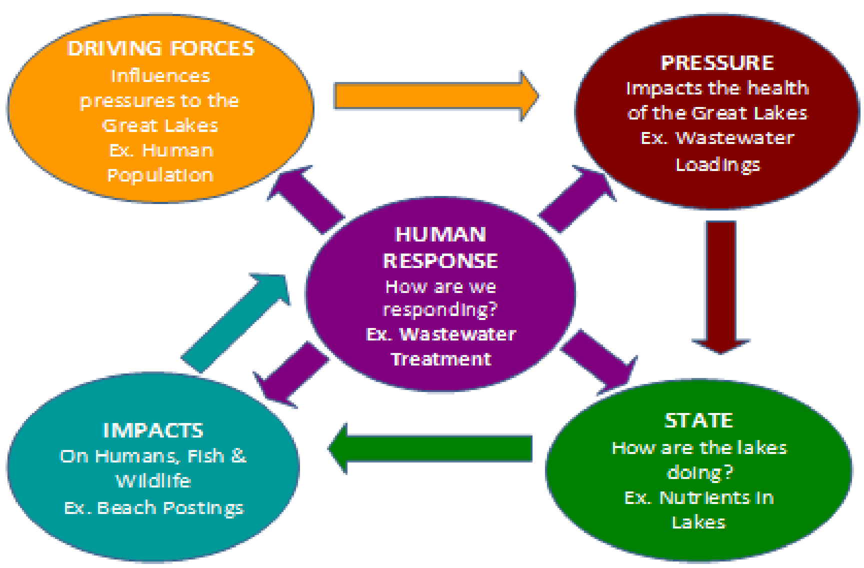


**Figure 2.** Driving forces-Pressure-State-Impacts-Response (DPSIR) conceptual framework adopted as part of SOLEC reporting process in 2010 (Environment Canada and U.S. Environmental Protection Agency. n.d.).

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 (Government of Canada and Government of the United States of America, 2012). The Parties' indicator work under the new GLWQA has had a particular emphasis on linking indicators to GLWQA objectives.

In addition to work of the Parties on indicators, the IJC has been involved in several indicator efforts in the past decade. A multi-Board work group tasked with assisting in assessment of programs and monitoring for the amended GLWQA produced a technical report reviewing various government efforts to develop and use indicators (including criteria in their selection), emphasized indicator framing in support of objectives of the GLWQA, and also endorsed the use of the DPSIR framework utilized up to the signing of the new GLWQA in the Parties' indicator implementation work. Based on consideration of criteria across four categories (usefulness, data quality, availability, practicality), 16 ecosystem indicators were identified, including indicators of chemical (5), physical (6), and biological (5) integrity, and accompanied by 41 measures. The final IJC report noted that the criteria utilized led to a bias towards existing indicators with available data, though new indicators could still be proposed (IJC, 2014).

A subsequent assessment effort by the IJC noted that most of these recommended indicators (and separate human health indicators) were adopted in the Parties' indicator program, with relatively close agreement between IJC indicators and measures, and the Parties' high-level indicators and sub-indicators, all of which were tied to the GLWQA General Objectives. The assessment also examined data availability and gaps for IJC indicators, and identified future indicators that should be pursued by the Parties, including recommendations on specific sub-indicators (Great Lakes Science Advisory Board, Research Coordination Committee, 2016).

A parallel project involved developing recommendations to improve the communication potential of the IJC indicators. The effort included an assessment and prioritization of the 16 ecosystem indicators, and identification of a smaller set of indicators that can both assess progress towards GLWQA objectives and best inform the public. The initial step was to use four filters (compelling story, visible, easy to understand, direct measure of lake health) and a ranking process to reduce the 16 indicators to six that ranged across indicator types and were readily communicated. Then the 28 metrics associated with the six indicators were prioritized based on seven filter categories (see Table 1), ultimately resulting in one priority metric for each of the six indicators. (Great Lakes Science Advisory Board, Science Priority Committee, 2016).

The current 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. See Section II.C.1 for a list of the indicators and sub-indicators. The SOGL reports are produced approximately every three years by ECCC and USEPA; they are just now starting the process for the 2022 SOGL reporting cycle.

### 2.1.3. Great Lakes indicators from the research community

Great Lakes Environmental Indicators (GLEI)

The purpose of the GLEI projects was to expand the capacity to assess the condition of the entire Great Lakes shoreline based on the relationship between anthropogenic stress gradients and biological condition represented by indicators. GLEI-I funded by the US EPA and NASA (2001-2006) focused on developing initial biotic indicators calibrated against a stress index for the U.S. Great Lakes coastline. GLEI-I summarized 207 anthropogenic stressors in the basin divided into 762 spatial units known as “segmentsheds” (Danz et al. 2005, 2007). GLEI-II funded under the GLRI (2010-2015) extended the stress index to include the Canadian shoreline and simplified the representation of stress while capturing the majority of the variation in a landscape development gradient summarized for a set of 5971 watersheds comprising the entire Great Lakes basin, excluding islands (Hollenhorst et al. 2011). GLEI-I (*SumRel*) and GLEI-II (*AgDev*) stress gradients represent landscape stress delivered to the coastal areas via a hydrologic network.

GLEI-I identified and GLEI-II refined a set of biological indices that can be used to characterize the biological condition of biotic communities of amphibians, birds, diatoms, fish, macroinvertebrates, and wetland plants as well as indicators of polycyclic aromatic hydrocarbon (PAH) photo-induced toxicity. Both GLEI-I and II focused on indicators for Great Lakes wetlands (riverine, barrier beach protected, and lacustrine), embayments, and high energy beach zones. These metrics were ranked with respect to their relevant spatial extent, stressor sensitivity, ease of collection, analysis, interpretation, and communication, as well as cost-effectiveness (Brazner et al. 2007a,b). A total of 14 specific indicators of the U.S. Great Lakes coastal region were identified. A fish IBI was calibrated to the GLEI I stress index (Bhagat et al. 2007), macroinvertebrate community (functional) metrics were calibrated to the GLEI II ( (Kovalenko et al. 2014), and change points were calibrated to specific GLEI II stress scores for wetland macroinvertebrates, fish, birds and amphibians (Host et al. 2018). Also developed was a multi-taxon indicator that combined sensitivities of all organisms collected at a site to a scaled stressor gradient termed the Biotic Response.

In addition to these analyses, assemblage-specific thresholds were identified where changes in abundances of multiple species of each biotic group reflected stress or change points (Host et al. 2018). These change points can be used to identify those areas of the basin that are near the boundary of the reference condition, and potentially at risk of falling outside the reference condition. Congruence of responses to anthropogenic stress in community thresholds were reported for macroinvertebrates, fish, birds and diatoms and aquatic plants (Kovalenko et al. 2014). This protocol is currently used by the Great Lakes Coastal Wetland Monitoring Program for monitoring birds and amphibians (Howe et al. unpublished). In general, the results indicated that stress related to agricultural activity and human population density/development had the largest impacts on the biotic community indicators

Both the GLEI-I and Coastal Wetland Monitoring groups identified biotic indicators of condition for Great Lakes wetlands (c.f., Niemi et al. 2007; Uzarski et al. 2017). Although they are important ecosystems that contribute disproportionately to the delivery of ecosystem services, wetlands occupy less than 10% of the shoreline length in the Great Lakes.

Great Lakes Environmental Mapping and Assessment (GLEAM)

The Great Lakes Environmental Mapping and Assessment (GLEAM) Coastal risk index (Allan et al. 2013) developed and mapped a cumulative impact stressor from 34 individual stressors across the Great Lakes open water areas. Great lakes experts identified 50 anthropogenic stressors that were subsequently reduced to 34 stressors that had sufficient data and were most influential within eight main categories: 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. Individual stressors were standardized and then weighted to reflect their relative impact on ecosystem condition based on expert knowledge. The expert opinions were used to derive a single integrative weight for each stressor on a 0–1 scale that were able to account for disparities in the ecological impact of different stressors in different habitats of different lakes. The Cumulative Stress index combined the spatial data on individual stressors with the relative weights of those stressors derived from Great Lakes experts. 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. To identify restoration and conservation projects GLEAM first used agency reports, citizen science, and social media as data sources to quantify the spatial distribution of five recreational elements of cultural ecosystem services—sportfishing, recreational boating, birding, beach use, and park visitation—across the Great Lakes. The evidence for the economic benefits of service delivery was then tested using Economics: National Ocean Watch (ENOW) gross domestic product data for the tourism and recreation sector, which provide consistent data on the economic importance of cultural ecosystem services. Finally, a service delivery index was developed and compared with the estimated cumulative environmental stress.

Wehrly et al. Landscape Risk Index

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 – see below; 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 data, the Wehrly et al. landscape risk index was recalculated for all of the GLHD watersheds and then distributed into the coastal margin and nearshore zones. To distribute the values into the aquatic zones, the risk index value was multiplied by the area of the watershed, and then from a pour point (or shoreline segment) decays with distance and weighted by depth (Riseng et al., 2018). The newly calculated Wehrly et al.(2012) landscape risk index was rescaled to the maximum value by lake, and five log breaks were set (i.e., 1, 0.1, 0.001, 0.0001, and 0.00001) based on the data distribution.

Spatial Geodatabase and Framework: Great Lakes Aquatic Habitat Framework (GLAHF)

The Great Lakes Aquatic Habitat Framework is a publically accessible, bi-national collection of authoritative, fundamental geospatial data; a raster geodatabase to manage aquatic ecosystem data; and an aquatic ecological classification system. GLAHF provides a standardized system for data collection, analysis and visualization of nearshore and coastal zone habitat across the Great Lakes. The GLAHF project consists of a GIS framework linked to a geospatial database and a hierarchical classification system for the Great Lakes Basin. The framework is a set of nested spatial grid cells covering the entire Great Lakes Basin at 30m, 1800 m and 9000m resolutions. The hierarchical structure allows the user to aggregate cells into larger units or to partition larger units into smaller units based on user-specified criteria. Each cell has a unique ID linked to the spatial data available for that location. Spatial data include the best available physical, chemical and biological data (over 170 variables) including unique data developed by GLAHF that have been harmonized for continuous coverage across the U.S. and Canada. Other spatial data developed as part of GLAHF include a harmonized set of Great Lakes watersheds, the Great Lakes Hydrography Dataset (Forsyth et al. 2012) and an ecological classification for the Great Lakes ecosystem based on four key variables: depth, thermal regime, hydraulic and landscape variables (Riseng et al. 2018). GLAHF was funded by the Great Lakes Fishery Trust with support from the Michigan Department of Natural Resources, the Great Lakes Basin Fish Habitat Partnership, and the University of Michigan.

### 2.1.4. Other Great Lakes indicator efforts

State of the Strait and other Geographically-Specific Indicators

Whereas the State of the Great Lakes indicators were developed to encompass many dimensions of ecosystem integrity and address progress towards bi-national 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 (SOTS) conferences, which are focused on the waterway connecting Lake Huron, Lake St. Clair, and western Lake Erie. This corridor is among the most severely impacted regions in the Lakes and has a legacy of environmental degradation. 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 Lake Objectives, but instead are selected to include both traditional measures of 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 SOTS 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. The approach entailed 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. Detailed criteria used to select (or develop new) indicators are not provided, though report cards are to be based on indicators that are science-based, peer-reviewed (preferably) and transparent (UMCES, 2020a).

### 2.1.5. National indicator programs

The National Coastal Condition Assessment program coordinated by USEPA assesses the conditions of U.S. coastal waters (including the Great Lakes for the first time in the 2010 assessment year), including the relative importance of key stressors. The assessment encompasses four indices – benthic community, sediment quality, water quality, and fish tissue contaminants. Each index 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. The 2010 Great Lakes assessment including sampling at 405 sites across the basin. Thresholds are used in the rating system for indices (e.g., good, fair, poor) (EPA, 2016). Indicators had been developed earlier in the EPA national coastal assessment programs, with indicators refined or added as needs arose (Kiddon et al. 2020).

The National Oceanic and Atmospheric Administration (NOAA) national Mussel Watch Program 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, 2) track the effectiveness of pollution prevention legislation and remediation programs, and 3) assess the environmental impacts in the event of catastrophic environmental disasters.

After expanding its monitoring to Great Lakes Areas of Concern with previous Great Lakes Restoration Initiative (GLRI) support, Mussel Watch is now focusing on contaminants of emerging concern in Great Lakes fish and wildlife. New emphasis is now being placed on evaluating exposure and effects of emerging contaminants to mussels co-located with other projects that address contaminants of emerging concern. More information is available at the NOAA NCCOS Great Lakes Mussel Watch website (https://coastalscience.noaa.gov/data_reports/great-lakes-mussel-watch-assessment-of-contaminants-of-emerging-concern/).

The Fourth National Climate Assessment also produced regional analyses, including the most recent Midwest Region chapter with Great Lakes elements released in 2018 (https://nca2018.globalchange.gov/chapter/21/). 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.

## 2.2 Summary of Approaches to Great Lakes Indicator Development to Date

Table 1 below summarizes approaches to development of indicators in several efforts in the Great Lakes, including the scale of application, any conceptual approach incorporated, and criteria used in selecting indicators and/or metrics. There are common elements across indicator efforts, including application typically at least at a sub-basin or lake scale. Concerning use of conceptual frameworks, most indicator programs document use of a framework (often DPSIR-type or a simpler design). For the State of the Great Lakes indicators, the Parties previously utilized conceptual frameworks, but in recent reporting following the amendments to the GLWQA, there is no formal reference to conceptual frameworks, but rather implicit links to GLWQA objectives. Concerning criteria used in selecting indicators, efforts have included lengthy lists of technical criteria, and in some cases, greater emphasis on accessibility to the broader public (e.g. IJC SAB, 2016; UMCES, 2020b).

**Table 1. Selected Great Lakes Indicators and Approaches to Development**

| Indicator Program/ Report | Scale/Conceptual Approach | Criteria | Reference |
|---|---|---|---|
| IJC (1996) | • Basin, whole lake, sub-basins<br>• Pressure/state/effects/(human) response framework<br>• Organize around 5 stresses (invasive species, nutrients, toxic chemicals, physical alterations, human activities and values) | Necessary<br>Relevant<br>Scientifically valid<br>Data available<br>Measurable<br>Interpretable<br>Target values<br>Costs<br>Quality<br>Sensitive<br>Timely<br>Anticipatory<br>Integrative<br>Applicable<br>Sufficient<br>+ Public understandability | IJC, 1996 |
| SOLEC/SOGL (1994-2000) | • Basin, whole lake, sub-basins<br>• State/pressure/(human) response framework | Initial screening:<br>Necessary, Sufficient, Feasible<br>Secondary screening:<br>+ 21 criteria in 7 categories (Figure 1) | Shear et al., 2003; Bertram and Stadler-Salt, 2000 |

| | | | |
|---|---|---|---|
| SOLEC /SOGL (2011-present) | • Basin, whole lake, sub-basins<br>• DPSIR framework initially (prior to reporting under amended GLWQA) | Reviewed existing SOLEC indicators based on eight criteria | SOLEC, 2011 |
| IJC (2014) | • Basin<br>• DPSIR framework | Usefulness<br>Data quality<br>Availability<br>Practicality | Great Lakes WQB, SAB, 2013; IJC, 2014 |
| IJC Science Advisory Board (2016) | • Basin<br>• DPSIR framework (previously agreed to (IJC, 2014) | Initial filters for 16 indicators:<br>Compelling story<br>Visible<br>Easy to understand<br>Direct measure of lake health<br>Prioritization of metrics based on:<br>Comprehensive data across basin<br>Rigorously monitored<br>Regularly monitored<br>Length of monitoring record<br>Calibration and endpoints<br>Owner and cost<br>Communicable, interconnected, and useful | Great Lakes Science Advisory Board, IJC, 2016 |
| State of the Strait (2007, 2020) | • Sub-basin and connecting channel<br>• State/pressure/response framework | Geographic constraint, availability of data to assess trends | Hartig et al., 2007; Hartig et al., 2020 |
| Western Lake Erie Report Card | • Western Lake Erie basin<br>• No explicit framework, though linked to existing indicators, data | Indicators that are science-based, peer-reviewed (preferably) and transparent | UMCES, 2020a. |

A recent paper by scientists from The Nature Conservancy on use of indicators in conservation planning more generally identified issues relevant to alternative approaches to developing and using Great Lakes indicators. The authors recommended a structured process for developing indicators, following the PrOACT approach, with identification or consideration of the Problem (including the intended use of indicators), Objectives (i.e., criteria against which indicators are compared), Alternatives (with conceptual models assisting), Consequences (how well indicator alternatives meet selection criteria), and accounting for Tradeoffs (wherein alternatives do not uniformly meet objectives). The authors suggested multiple types of criteria (including technical and socioeconomic) could be grouped in one of six high-level categories, as summarized in Table 2. Different indicator alternatives would then be scored against the criteria, and the values would be weighted (based on relative importance of the six criteria, determined separately), leading to a total "consequence" score that could inform indicator selection. The authors noted value in the greater rigor and objectivity of the approach, including consideration of factors such as stakeholder/community interests and indicator selection biases (Liberati et al. 2020).

**Table 2. Criteria for Selecting Indicators in Conservation Planning (adapted from Liberati et al. 2020).**

| Criterion | Definition/Elaboration |
|---|---|
| Relevant | Indicator connection to conservation program's goal(s) or conservation projects being implemented |
| Resonant | Indicator importance to community members potentially impacted by conservation program or projects |
| Responsive | Indicator able to signal changes in the environmental or social systems, in manner to inform decision-making |
| Confidence | Confidence among experts in assessments (or scoring) of other criteria for specific indicators |
| Data availability | Availability of long-term datasets and with data at resolution suitable for the decision-making context |
| Realism | Existing sustainable monitoring protocols and a sustainable monitoring program at reasonable costs |

## 2.3. Current Great Lakes indicators

### 2.3.1. State of the Great Lakes indicators

The 45 sub-indicator reports, as grouped within the nine SOGL indicators are as follows:

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 several of the listed sub-indicators are being considered for removal from the list for the next assessment 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 Figure 3 below. 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 the trend Deteriorating.

| 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

**Figure 3**. Invasive species indicator status and trends, from the State of the Great Lakes 2019 Highlights Report (U.S. Environmental Protection Agency and Environment and Climate Change Canada, 2020).

### 2.3.2. State of the Strait indicators

The 61 indicators in the 2020 report were grouped within 3 categories aligning to the pressure-state-response model.

1. Pressure Indicators- Air pollution and environmental justice in southwest Detroit, Michigan; Detroit River phosphorus loads to Lake Erie; Human population growth and distribution in southeast Michigan; Human population growth and distribution in the Windsor Census Metropolitan Area; Land use change in southeast Michigan; Oil pollution of the Detroit and Rouge rivers; Phosphorus loads and concentrations from the Maumee River; Trends in sediment contaminant concentrations in the Huron-Erie Corridor; Transportation in southeast Michigan; Wayne County's carbon emissions.

2. State Indicators- Atmospheric temperature changes in the Western Lake Erie Climate Division; Bald Eagle reproductive success; Benthic macroinvertebrates in the Rouge River watershed; Changes in ice cover in Lake Erie; Chironomid abundance and deformities; Common Tern breeding colonies in southeast Michigan; Conservation of Black Terns – A Michigan Species of Special Concern; Conservation of common five-lined skink in Point Pelee National Park; Contaminants in colonial waterbird eggs – Detroit River; Detroit River coastal wetlands; Dissolved oxygen levels in the Rouge River; Fall raptor migration at Holiday Beach Conservation Area, Amherstburg, Ontario; Fall raptor migration at the Detroit River Hawk Watch; Harmful algal blooms in western Lake Erie; Hexagenia density and distribution in the Detroit River; Invasive species; Lake level changes in Lake Erie; Lake sturgeon population; Lake whitefish spawning; Lead poisoning in Detroit, Michigan; Management of common reed (Phragmites australis) at Erie Marsh Preserve; Mercury in Lake St. Clair walleye; Oligochaete densities and distribution; Osprey nesting success in southeast Michigan; Peregrine Falcon reproduction in southeast Michigan; Plankton communities in western Lake Erie; Precipitation changes in Western Lake Erie Climate Division; Projected bird impacts of climate change; Walleye population of Lake Erie; West Nile virus.

3. Response Indicators- Canadian habitat restoration in the Detroit River; Canadian laws and policies to address algal blooms; Climate change adaptation in Windsor, Ontario; Combined sewer overflow controls in southeast Michigan; Connecting United States and Canadian greenways; Contaminated sediment remediation in the Canadian portion of the Detroit River; Contaminated sediment remediation in the River Raisin Area of Concern; Contaminated sediment remediation in the U.S. portion of the Detroit River; Detroit's leadership in establishing municipal greenhouse gas reduction targets and an action agenda to address climate change; Detroit River-Western Lake Erie Cooperative Weed Management Area – The 7-year evolution of an effective partnership in invasive species surveys and treatment; Green infrastructure in southeast Michigan; Greenway trails in Windsor, Ontario; Growth of the Detroit River International Wildlife Refuge; Phosphorus discharges from the Great Lakes Water Authority's water resource recovery facility; Soft shoreline along the Canadian side of the Detroit River; Soft shoreline along the U.S. Detroit River shoreline; The legacy of bicycles in Detroit, Michigan: A look at greenways through time; The need for a multi-national climate change adaptation plan;

Transbounday conservation in the Detroit River-Western Lake Erie region; Treaty responsibilities between settler and Indigenous Nations in the western Lake Erie-Detroit River ecosystem; U.S. habitat restoration under the Detroit River Remedial Action Plan.

### 2.3.3. Other Great Lakes indicators

The Great Lakes Coastal Wetland Monitoring Program, funded by GLRI since 2010, applies a statistical design to optimize both one-time and repeat sampling of approximately 1,000 known coastal wetlands greater than >4 hectares in size with a surface water connection to the Great Lakes. Indicators for wetland condition are based on amphibian, bird, invertebrate, fish, and plant community data and water quality parameters collected according to 16 protocols (Great Lakes Coastal Wetland Monitoring Program. https://www.greatlakeswetlands.org/Home.vbhtml).

Development of a report card for Western Lake Erie and its watersheds (introduced in section 2.1.3 above) was led by the Integration and Application Network at the University of Maryland Center for Environmental Science. The desire for such a report card arose in part from a view that NGOs and county or city governments did not have synthesized information on the state of their part of Lake Erie and its watersheds at sufficient resolution to make informed decisions about investments in restoration and related policies, programs, and legislation. Indicators selected based on engagement with stakeholders and experts, as well as on data availability, included total phosphorus, dissolved phosphorus, total nitrogen, nitrate+nitrite, chlorophyll *a*, fish populations of three species (Walleye, Yellow Perch, and Emerald Shiner), algal bloom index, source water cyanotoxin concentration for drinking water, and recreational water cyanotoxin concentration (University of Maryland Center for Environmental Science, 2020a). Data were primarily from 2018 and benchmarks were based on regulatory or management guidance. The report card was released in August 2020 (Figure 4) and future report cards following similar analysis methods and reporting formats will be developed by the University of Toledo.


**Figure 4**. Figure showing status (via grade scales) for western Lake Erie basin watersheds and lake regions, from the Western Lake Erie 1st Report Card (UMCES, 2020b).

A similar report card approach has been developed for the Milwaukee River Basin. Annual report cards have been released by the Milwaukee Riverkeeper organization since 2010. The latest report card is based on eight water quality parameters from 88 sites and a benthic macroinvertebrate index. Much of the monitoring and sampling activity in the network is carried out by volunteers (Milwaukee Riverkeeper. https://www.milwaukeeriverkeeper.org/category/report-cards/).

### 2.4. Summary of current Great Lakes programmatic indicators

Table 3 below summarizes information presented above for several ongoing indicator reporting efforts, including high-level indicators or categories, indicators or sub-indicators, and approaches to reporting. As indicated, the current indicator reporting programs have some commonalities and differences. For example, the three programs all have some type of high-level indicators or categories with underlying sub-indicators. Differences include that two of the programs are focused on more specific geographic areas, and only one (the State of the Strait) explicitly addresses a conceptual framework, at least concerning categorization of indicators. The State of the Strait and SOGL technical reports go into greater depth for individual indicators or sub-indicators that cover a wider range of stressors or conditions in the lakes, while the Lake Erie 1$^{st}$ Report Card emphasizes a smaller number of indicators, including several of significant researcher interest and public concern currently. The recent State of the Strait report is the only effort of the three with significant emphasis on programmatic (or response) indicators.

**Table 3. Current Great Lakes Indicators**

| Indicator Set | High-Level Indicators or Categories | Indicators or Sub-indicators | Reporting | Reference |
|---|---|---|---|---|
| State of the Great Lakes | Nine high-level indicators: drinking water, beaches, fish consumption, toxic chemicals, habitat and species, nutrients and algae, invasive species, groundwater, watershed impacts and climate trends | 44 sub-indicators, ranging from one each in drinking water, beaches, and groundwater, to 17 in habitat and species | Triennial reporting (under GLWQA), with Highlights Report (geared to more general audience) followed by lengthy technical report | USEPA, ECCC, 2020 |
| State of the Strait | Three categories of indicators: pressure, state, (management) response | 61 indicators across the three categories | Biennial conferences, but more limited comprehensive reporting, including individual indicator reports as part of two lengthy technical reports (2007, 2020). | Hartig et al. 2007; Hartig et al. 2020 |
| Lake Erie 1st Report Card / Lake Erie Foundation/ UMCES | Three categories of indicators: Lake: Water quality, fish, and algal blooms<br>Watershed: Water quality, biology, toxics | Lake: Five indicators (water quality) and three each (fish, algal blooms)<br>Watershed: Five indicators (water quality), three each (biology, toxics) | One report (general audience) to date (2020) | UMCES, 2020b |

### 2.4.1. Assessments/critiques of Great Lakes indicators from literature

There have been multiple efforts through the decades to review or assess Great Lakes indicators, and several key reviews over the past three decades include the following:

- Indicators of the Condition of the Great Lakes Basin Ecosystem (IJC, 1998): A binational workshop convened by the IJC Indicators Implementation Task Force that included a wide-ranging discussion on Great Lakes indicators, including across scales and from ecological to socioeconomic domains (IJC, 1998).
- Environmental Indicators (GAO, 2004): Though not focused on the Great Lakes, a Government Accountability Office (GAO) report included an overview of SOLEC indicators. The report included several recommendations on indicators more broadly, including the importance of being able to link management actions and program activities to environmental responses (GAO, 2004).
- Review Report of the SOLEC Independent Expert Panel (Barr et al., 2010): An outside expert panel reviewed SOLEC indicators and reported multiple findings, including lack of clarity on the scope and purpose, lack of clarity on specificity and detail of existing indicators, and lack of endpoints. Recommendations included identification and use of conceptual frameworks to help guide the overall process, development of an ecologically based and hierarchically nested, geographic framework(s) and classification systems to facilitate greater consistency in reporting, and increased coordination (including concerning monitoring, data analysis, and development of a science-based strategy) (Barr et al. 2010).

## 3. Elements to consider in alternative approaches to indicator development and use, and approach at the summit.

As noted in the review above, there are a plethora of environmental indicators that have been developed in the Great Lakes, including as part of binational coordination by the federal governments (SOGL); through academic, agency, and other stakeholder contributions (State of the Straits); non-profit, local agency, and academic collaboration (Western Lake Erie 1$^{st}$ Report Card); and research-driven efforts (e.g., GLEI, GLEAM, Great Lakes Aquatic Habitat Framework). While the research-driven efforts have typically provided significant details on approaches to developing indicators or other metrics of ecological condition, the agency program efforts have not always provided such details in any readily available format. Although a number of such cases involved stakeholder efforts, increased transparency/documentation would assist in better understanding the approach to developing indicators. The importance of addressing issues such as stakeholder concerns, broader socioeconomic considerations, and selection biases in indicator development in conservation programs has recently been highlighted (Liberati et al. 2020).

In light of the review in this document, multiple questions arise concerning approaches to selecting Great Lakes indicators, including the following:

- Are there additional purposes of indicators that need to be considered, beyond for example assessing progress towards meeting Great Lakes Water Quality Agreement objectives? Are there restoration targets (e.g., within the Great Lakes Restoration Initiative and the Canadian Great Lakes Protection Initiative) not necessarily addressed by the GLWQA that should be considered in selecting indicators?
- What are the most important criteria for selecting indicators, including technical and socioeconomic/stakeholder interest?
- What actions are needed to engage a broader range of stakeholders in indicator development efforts, including communities often disproportionately affected by environmental hazards or not equitably realizing environmental benefits?
- 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?
- Should indicator selection rely more heavily on consideration of conceptual frameworks, including relating management actions to ecological outcomes, and if so, what approach should be taken to do so in current indicator programs?
- How can Great Lakes indicators be developed or refined to track emerging threats – whether in the form of entirely new stressors or changes (e.g. via climate) to existing stressors?

These types of questions will be addressed at the February 23-24 summit, including on the second day through consideration of case studies on three topics: toxic chemical contamination, nutrients and eutrophication, and sea lamprey management.

Coming out of the summit we hope to have recommendations on a general approach to Great Lakes indicator development and implementation that can be carried out in subsequent stakeholder efforts. Ideally the approach will include multiple components, including reference to strengths of existing Great Lakes indicators, and identification of key purposes and criteria important in selecting (or refining) indicators; efforts needed to engage a broader range of stakeholders; approaches to incorporating conceptual frameworks in the process; and approaches to better address emerging threats to the Great Lakes ecosystem.

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