Towards A Great Lakes Early Warning System

A report submitted to the
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Great Lakes Science Advisory Board

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List of Acronyms

GLEWS	Great Lakes Early Warning System
IJC	International Joint Commission
SAB	Great Lakes Science Advisory Board
USEPA	US Environmental Protection Agency
WQB	Great Lakes Water Quality Board

Executive Summary

The Great Lakes Water Quality Agreement (the Agreement) charges the International Joint Commission (IJC), supported by its Great Lakes advisory boards, with several responsibilities including identification of emerging issues facing the Great Lakes. To help fulfil this responsibility the IJC's Great Lakes Science Advisory Board (SAB) undertook this first phase of Great Lakes Early Warning System (GLEWS) development, focusing primarily on the development of a GLEWS organizational framework. Six different organizational models were examined through an expert workshop, and the project work group identified a preferred organizational framework.

The work group recommends that the IJC create a GLEWS that would operate as an entity reporting to the Great Lakes Water Quality Board. The IJC would be responsible for GLEWS oversight and ensure that the IJC Commissioners are aware of emerging issues. To function appropriately, a GLEWS requires highly qualified personnel and resources to assemble, assess, rank and report on emerging threats that the Parties (e.g., the governments of Canada and the United States) have available in their agencies. Therefore, the GLEWS should be supported by subject matter experts provided by the Parties. The IJC would serve the role of oversight by convening additional highly qualified personnel to evaluate the effectiveness of the GLEWS.

This report and its associated contractor analysis also reviews current knowledge and approaches used by other environmental early warning systems, describes necessary components of a GLEWS, and identifies topic areas of stressors and threats that could be considered through the identified organizational framework. A second phase of the project will be advanced by the SAB to develop the analytical techniques and risk management approaches that could be applied through the recommended organizational framework.

The Great Lakes science and management community has successfully remediated many established Great Lakes stressors. Those resource-intensive experiences have highlighted the prudence of anticipating and preventing stressors before they become established. The SAB hopes that the analysis contained in this report provides a useful description of the elements of an effective Great Lakes Early Warning System and its associated organizational framework.

1.0 Introduction

The Laurentian Great Lakes are a globally significant resource, holding 20 percent of the world's surface fresh water, and deliver a significant set of services provided to humans in the form of source drinking water, food, waste disposal, energy production, recreation, shipping and cultural significance. But, the delivery of those services and the quality of these fresh waters are threatened by a vast array of waterborne and airborne substances resulting from human activities within and outside the Great Lakes basin. Exacerbating these disturbances are climate-driven changes in precipitation intensity and temperature extremes, as well as land use changes, particularly in the coastal areas of the basin. These Great Lakes have undergone a remarkable transformation over the last six decades as a result of introductions of a myriad of contaminants and nutrients, as well as aquatic invasive species that have upended the food webs, altered geochemical cycling and degraded critical habitats.

The nature of the Great Lakes basin makes it difficult to manage environmental change due to the geographic scale of the region and the numerous agencies responsible for environmental management. Had an appropriate monitoring and response framework been in place in the early phases of human activity, many of these disturbances causing significant changes in the basin could have been anticipated and perhaps mitigated. Given the tremendous inherent value of this freshwater system, it is notable that the region lacks a single, comprehensive Great Lakes Early Warning System (GLEWS)[1] that monitors and tracks the entire array of emerging threats and stressors, including their interactions, and translates outcomes into recommended resource management actions.

The Great Lakes basin is home to an expansive and complex array of governmental agencies, multiple levels of communities ranging from villages to megacities, research institutions, stakeholder organizations and water-dependent industries. Many such entities are currently engaged in some form of monitoring and response activities associated with one or more threats and stressors central to their mission and business interests. In some cases management and regulatory agencies are unable to anticipate accurately some emerging threats. In other cases problems are anticipated but, because of competing priorities or limited resources, agencies determine that the risk does not warrant preventive action. Regardless of the cause, governments and other entities have had to devote significant resources to correct or remediate damage to the Great Lakes ecosystem for decades. Examples include newly introduced chemicals that caused unforeseen impacts, the arrival of invasive species that altered the aquatic food web, and the

[1] This report examines early warning systems as distinct from early detection systems. Early warning systems examine slow onset stressors and threats that are expected to take many months or years to materialize and are expected to affect large geographic areas (e.g., one or more of the lakes). For example, early detection of an invasive species can be considered a component of an early warning system due to the potential far-reaching impacts of a new invader. In contrast, early detection systems are in place to address rapid onset stressors and threats that take minutes, hours or days to materialize and are of smaller spatial scale. An example of an early detection system includes real-time water quality monitoring to alert drinking water plant operators about the presence of contaminants moving towards plant intakes so that appropriate adjustments to treatment processes can be applied.

sharp increase in runoff of bioavailable phosphorus that, in part, is an unintended consequence of policies that promote large-scale livestock operations and which, in turn, have contributed to an unexpected rise in nuisance and harmful algal blooms. Responding to these and other threats once the damage has occurred usually requires expensive and lengthy remediation.

While some individual jurisdictions—and even those jurisdictions that collectively span entire lakes—have appropriate data and information to anticipate certain types of threats, there are common threats that are faced by all of the Great Lakes. Furthermore, there are complex interactions and interdependencies in the system that may make a threat visible at a basin level long before it becomes evident at a local level. Therefore, creation of a basinwide warning system offers not only operational efficiency but also the potential to identify threats that may be undetectable at a local scale, thereby increasing effectiveness. Currently some early warning systems are in place for the Great Lakes to address, for example: invasive species (Great Lakes Aquatic Nonindigenous Species Information System), contaminant spills (Huron to Erie Drinking Water Monitoring Network), hypoxia and harmful algal blooms (Experimental Lake Erie Hypoxia Forecast; Harmful Algal Bloom Early Warning System), and beach bacteria (various local and regional health departments). While these systems are valuable resources, there is a need for an umbrella early warning system that consolidates data and information, identifies potential tipping points and has a plan of action for communicating and responding to risks.

Foreseeable problems that affect the Great Lakes have often been forecasted or detected but not addressed until they become crises. To identify emerging threats, a US Environmental Protection Agency (USEPA) Science Advisory Board report recommended that the agency create a "look-out panel" with members from both inside and outside government to provide USEPA and the nation with an early warning of environmental issues that may emerge in the future (USEPA 1995). Other studies and documents have highlighted the need for greater anticipatory capacity to protect the Great Lakes through prevention (Gee and Stirling, 2003; Creed et al. 2016; Science for Environment Policy 2016).[2] Environmental horizon scanning is recommended as a systematic approach for detecting potential threats and opportunities that are currently not well recognized (Sutherland and Woodroof, 2009). There is little doubt that a more ecologically responsible and economically effective alternative to remediation is to prevent emerging stressors and threats from becoming established in the first instance.

Prevention and precaution are two principles outlined in the 2012 Protocol to the Great Lakes Water Quality Agreement (the Agreement). The Agreement was first established in 1972 and revised several times, most recently in 2012. The Agreement's purpose is to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes. The Agreement charges the International Joint Commission (IJC) with several responsibilities that include identification of emerging issues and recommendation of strategies and approaches to the federal governments to address these issues. The Agreement also prescribes an important role for the IJC's advisory boards to provide advice to the IJC on this topic. Further, independent scholars

[2] Prevention is a principle and approach included in the Great Lakes Water Quality Agreement and is defined as "anticipating and preventing pollution and other threats to the quality of the Waters of the Great Lakes to reduce overall risks to the environment and human health" (Canada and United States, 2012).

have suggested that the IJC should take a more active role on emerging issues (Grover and Krantzberg, 2015). Complementing this directive is a growing body of literature that recognizes the need for early warning systems to address an array of ecological issues and document the performance and attendant benefits of such a system.

To help fulfil the obligation of the IJC in the Agreement to address emerging issues, the IJC's Great Lakes Science Advisory Board (SAB) undertook this Phase 1 GLEWS project to:

(i) evaluate current knowledge and approaches used by other environmental early warning systems and evaluate their applicability to the Great Lakes,
(ii) develop a GLEWS organizational framework, and
(iii) explore and identify topic areas of stressors and threats that could be considered through the identified organizational framework.

Although it was originally intended that the project develop an analytical framework to identify and evaluate emerging stressors and threats, that activity was not undertaken in detail and is the focus of a planned second phase of the project.

To carry out the project, the SAB formed a multidisciplinary workgroup that was supported and informed by a contractor to carry out three activities. First, background information on the global experience with early warning systems was gathered through a literature review, responses from 15 experts to a detailed online survey and the completion of interviews with eight of the survey respondents. Second, a two-day workshop was held in May 2018 with 30 participants (plus the contractors and IJC staff) to discuss a preferred GLEWS organizational framework and identify stressors and threats that could be evaluated further. Third, the outcomes of the project were synthesized in a report by the contractor.[3]

This report provides a summary of the project findings and recommendations to the IJC. Section two summarizes the current state of knowledge on Great Lakes stressors and threats and reviews existing early warning systems and their operational mechanisms. Section three presents the GLEWS organizational framework developed by the workgroup and refined through the workshop, while section four identifies the next step to operationalize GLEWS by developing analytical approaches for identifying emerging stressors and threats in the Great Lakes. The conclusions and recommendations of this project are included in section five.

The Great Lakes science and management communities have successfully remediated many established Great Lakes stressors. Those resource-intensive experiences have highlighted the prudence of anticipating and preventing stressors before they become established. The SAB hopes that the analysis contained in this report provides a useful description of the elements of an effective GLEWS and its associated organizational framework.

[3] The contractor report, completed in 2018 by LimnoTech and AECOM, provides source material for this report. The report is accessible at: ijc.org/sites/default/files/2019-10/SAB-SPC_GLEWSReport_Appendix.pdf.

2.0 Current State of Knowledge

Underpinning a Great Lakes Early Warning System is the fundamental need to understand key concepts and the current set of both threats and stressors that affect the system. Definitions of threats and stressors vary widely. *Stressors* are defined by the USEPA as any physical, chemical or biological entity that can cause an adverse effect (USEPA 2018). There is no standard definition of a *threat*, thus in this report we define 'threat' as any natural or anthropogenic event or condition that leads to or otherwise facilitates a stress on the ecological integrity of the ecosystem.

Many of the threats and stressors affecting the Great Lakes are well known and are explicitly addressed in the annexes of the 2012 Agreement. Others are poorly understood and can be considered *'emerging' threats*, such as effects of nanoplastics and microplastics, fluorinated chemicals, novel pharmaceuticals and complex interactions among known or novel stressors. Different types of threats and stressors require different detection techniques, monitoring methods, indicators and benchmarks, in addition to responsive actions. Detection of *slow onset stressors*, such as eutrophication, invasive species establishment,[1] contaminant accumulation in sediment or climate-driven temperature extremes pose serious problems when they exceed a threshold and affect the ability of an ecosystem to recover adequately from disturbance. Detection of these disturbance types requires systematic monitoring of specific indicators with known stress-response patterns, backed by a solid scientific underpinning of the relationships between a given stressor and the physicochemical environment. In contrast, *rapid onset stressors*, such as contagious diseases, contaminant spills, terrorist actions and natural disasters, are generally identified through detection systems or informal warnings. However, other stressors, such as onset of hypoxia and harmful algal blooms, are now predicted through modeling efforts and warning systems for these are under development (e.g., Experimental Lake Erie Hypoxia Forecast[2] and Harmful Algal Bloom Early Warning System[3]).

It is worthy to consider two issues explicitly, e.g., detection of a stressor (or potential stressor), and detection of a system response (or disturbance). For example, a new nonnative species could be a potential stressor and a sensitive technique could identify its presence in the Great Lakes. However, detecting a response to the stressor might come later and detecting that would entail a broader understanding (e.g., stressor-response relationship) in order to know what response to look for. It is also possible that a potential stressor (e.g., a nonnative species) is detected, but it will never be considered a *bona fide* stressor in the lakes (e.g., for various reasons, many nonnative species introduced in the Great Lakes are not considered invasive).

Understanding and responding to unknown threats is a genuine challenge. Active horizon scanning that includes all of the above approaches is required to address unknown threats.

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[1] Some of the better examples of existing early warning systems in the Great Lakes have been developed for aquatic invasive species. The Great Lakes Aquatic Nonindigenous Species Information System provides a useful clearinghouse of information and can be accessed at glerl.noaa.gov/glansis/.
[2] Accessible at: glerl.noaa.gov/res/HABS_and_HypoxiaWarningSystem.html.
[3] Accessible at: glos.us/projects/habs.

Because the Great Lakes basin is large, geographically diverse, and managed by a complex set of political entities and their associated agencies, the detection of unknown and rapid onset stressors is a particular challenge. A precautionary approach should inform choices regarding monitoring methods to detect newly detected or potential stressors.

2.1 Necessary components of a GLEWS

A GLEWS that provokes a response to an identified threat or potential stressor should consist of four discrete components: a framework for anticipating possible futures and assessing risk, a monitoring and warning system (including indicators), a dissemination and communication plan, and a response plan (United Nations Office for Disaster Risk Reduction 2018). GLEWS depends upon foresight and appropriate indicators embedded in a solid framework designed to collect appropriate data, assess status and trends of key indicators, identify triggers for action, disseminate data and information to appropriate parties, and initiate appropriate responses.

Risk knowledge: An early warning system requires an ability to anticipate possible futures and develop responses to eliminate or mitigate negative impacts identified in those futures. An example might be programs that are in place to detect new invaders to the Great Lakes (e.g., Great Lakes Aquatic Nonindigenous Species Information System). Risk assessment identifies the potential hazards and vulnerabilities by means of a systematic process (United Nations Office for Disaster Risk Reduction 2018). Horizon scanning is an important component of an early warning system and may include interviews, issues trees (a graphical breakdown of a question that dissects it into its different components vertically and horizontally), reviews, expert workshops, open fora and scenario planning. Horizon scanning is a systematic way of improving foresight of otherwise unexpected environmental issues (Sutherland and Woodroof, 2009). Regardless of the foresight technique applied, environmental models should be employed and should reflect potential state changes in order to avoid the risk of locking in assumptions about the system that are not supportable going forward (Beck 2005).

Monitoring: The core of an early warning system is data collection to assess status and trends and predict future hazards (and the effects of current hazards). Monitoring programs must include appropriately calibrated indicators, or metrics that provide pertinent information and can be used to infer or represent the state of a system. The most useful indicators are linked to endpoints that are familiar and relevant to the public and managers and are appropriately benchmarked to a response that is meaningful (Jackson et al. 2000). Such benchmarks provide the basis for triggering a warning that is communicated to appropriate members of the community to initiate action in response to the threat. Scientifically sound indicators applied consistently over time are essential to track changes in Great Lakes ecosystems (IJC 2013). The State of the Great Lakes Report (Environment and Climate Change Canada and the US Environmental Protection Agency, 2017) describes the status and trends of indicators related to the objectives of the Agreement. Most indicators cover the status or condition of various resource values (e.g., wetlands) or stressors (e.g., aquatic invasive species). Such indicators are useful towards developing a GLEWS but more is needed to implement an early warning system.

A review of previously prioritized groups of environmental stressors (Smith et al. 2015) identified ten broad stressor categories for the Great Lakes:

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

These categories of environmental stressors are consistent with the activities undertaken over the past two decades to quantify and map threats and stressors at the scale of the Great Lakes basin, and the methods developed therein could prove useful for benchmarking future threats. The Great Lakes Environmental Indicators project mapped five categories of watershed threats and stressors and over 180 individual metrics across the US side of the basin (Danz et al. 2005). A refinement of that analyses resulted in an online map tool that identifies tributary watersheds that are 'at risk' from mainly urban and agricultural stressors (Host et al. 2019). Allan et al. (2013) subsequently mapped 32 types of stressors and threats to the lakes themselves. These stressors included anthropogenic activities such as shoreline hardening, point source pollution, fishing, boating, nutrient loading, as well as climate change and water level fluxes. The methods used in these analyses could provide a potential baseline for assessing future threats to the Great Lakes.

Recently there has been much interest in the application of signal analysis techniques to detect system changes. Generic early warning signals have been posited to exist for a wide class of systems and can indicate a critical threshold is approaching (Scheffer et al. 2009). For example, a change in variance in a response variable (also referred to as 'flickering' expressed as rising variance coupled to decreasing autocorrelation and skewness) can sometimes indicate that a critical threshold is approaching. Thus, both status and trends data derived from monitoring systems are an important component of an early warning system program. That said, many ecological systems may not show such indication of regime shifts. It follows that, while early warning indicators may point to critical transitions in certain cases, such indicators yield best information when applied to well-understood systems. Key processes, appropriate monitoring and modeling may further improve outcomes in those instances (Gsell et al. 2016).

In general, environmental tipping points (where small perturbations trigger large responses) represent opportunities for anticipating and responding to a new stressor (Lenton 2013). Loss of ecosystem resilience can facilitate a switch to an alternative state; therefore sustainable management should focus on the maintenance of ecosystem resilience (Scheffer et al. 2001). The European Union anticipates that future environmental changes will generally be preceded by a signal that may be discernable through foresight approaches, monitoring technology, citizen science, online media and rate change theory (Science for Environment Policy 2016). Such

approaches, including traditional ecological knowledge, should be considered part of the GLEWS.

Communication and dissemination: Once a threat is recognized a mechanism must be in place to transmit information to the appropriate responders. Rapid onset threats, such as accidental chemical spills or extreme weather events in general, have well-defined response protocols embedded within agencies with emergency management responsibility, although there may be gaps in areas that cross jurisdictional boundaries (Personal communication, Dr. Carolyn Johns, Ryerson University, February 2020). However, slow onset threats are a challenge and, except for specific situations (e.g., detection of a new invasive species), responses can range from no attention to highly protective. Slow onset threats such as drought may require short-term policy actions to reduce water consumption. Other threats (e.g., water quality degradation due to nonpoint source pollution such as nitrate loading from agriculture fields and other deforested regions) may require a broad range of local to regional management practices and policies. Communication strategies must be designed to address each specific type or category of threats.

Response: Coordination among the appropriate responders is critical for successfully addressing the threats identified by an early warning system. While coordination among agencies within countries associated with emergency response organizations is known to be improving, it is not clear that a structure for identifying the range of slow onset threats has been identified. The GLEWS would provide a mechanism for such an organization. For a GLEWS to be effective it should have the following characteristics.

The GLEWS must be:

- *practical: readily designed and implemented, with user-friendly features designed for an array of interested parties;*
- *pragmatic: focused exclusively on Great Lakes threats and stressors, with a clear linkage to actions and mechanisms to respond to them;*
- *effective: an objective, science-based service able to capture the array of current, emerging and evolving threats and stressors;*
- *efficient: taking full advantage of existing early warning system mechanisms, organizations and associated resources;*
- *affordable: designed, staffed and operated in a manner consistent with current and anticipated financial resources;*
- *accessible: to all relevant rights holders and organizations with a stewardship role, responsibility and interest in the Great Lakes-St. Lawrence River basin;*
- *supportable: by key Canadian and US governmental jurisdictions, policy makers, researchers, resource managers and other rights holders and stakeholders; and*
- *sustainable: able to be maintained over the long term to provide a data base and historical repository of current, emerging and evolving threats and stressors, actions taken to address them, and the outcomes of those actions.*

3.0 Development of the Framework for a Great Lakes Early Warning System

3.1 Components of the GLEWS framework

An institutionalized GLEWS would require the development of a governance structure and organizational approach by which different stressors and threats would be characterized and activities prioritized. At present, the IJC's Great Lakes Water Quality Board (WQB)[1] is required to report emerging issues to the Commission who then report to the governments per Article 8.3.(b) of the 2012 Agreement: by "identifying emerging issues and recommending strategies and approaches for preventing and resolving the complex challenges facing the Great Lakes" (Canada and the United States, 2012). Such a horizon scanning operates currently as the WQB becoming aware of emerging issues through its membership. Although there are also ongoing interactions between WQB and the IJC's SAB,[2] a formal system between the boards to identify and report on emerging issues has not been established. In recent years, the SAB has indeed held annual special sessions at the International Association for Great Lakes Research conference to invite academic and agency researchers to share their views and concerns about emerging issues and threats to the Great Lakes ecosystem in a broad sense. One of the objectives of this project is to identify a governance and organizational structure for an effective GLEWS.

3.2 Governance and operation of the GLEWS: considerations of six alternative GLEWS structures by workshop

The following is a summary of the various proposed governance and organizational structure alternatives for a GLEWS considered by the project workshop participants,[3] highlighting the salient features of each. Note that options two through six presented below are what could be put in place; they do not exist today. The alternatives are listed in the order from the current least-structured entity to the most independent entity.

Option 1) Status quo: GLEWS is not a formally constituted entity. The importance of identifying current, emerging and anticipated threats and stressors is recognized within the resource management and research communities. Stressors and threats continue to be identified through various research initiatives and citizen science activities, at conferences and during policy

[1] The Water Quality Board (WQB) is the principal advisor to the Commission and assists the Commission by reviewing and assessing progress of the Parties in implementation of the Agreement, identifying emerging issues and recommending strategies and approaches for preventing and resolving the complex challenges facing the Great Lakes, and providing advice on the role of relevant jurisdictions to implement these strategies and approaches.

[2] The Science Advisory Board (SAB) provides advice on research and scientific matters to the Commission and to the WQB.

[3] For further information on the workshop and its participants, see the contractor report. This report is accessible at: ijc.org/sites/default/files/2019-10/SAB-SPC_GLEWSReport_Appendix.pdf.

deliberations. A short-term outlook is prevalent as the emphasis is on threat and stressor response rather than anticipation and prevention. This alternative does not require additional funds, nor does it require any institutional adjustments. However, it does not address the inadequacies of current approaches to identify and respond to emerging and anticipated threats and stressors in a timely coordinated manner (beyond the mandate of the WQB to notify the IJC).

Option 2) Periodic GLEWS conference: A conference focusing on current, emerging and anticipated threats and stressors to be held on an annual or semiannual basis, and concerted outreach occurs as meeting outputs. The event would feature formal technical and resource management presentations, as well as opportunities for input by citizens and stakeholders. The conference would be followed by broad distribution of a proceedings document that includes both research outcomes and practical and pragmatic resource management actions; this will emphasize involvement of all entities with a responsibility for and interest in current, emerging, and anticipated threats, stressors and their impacts. Structural requirements include a steering committee and a sustainable funding source. The regularly scheduled conference could be a component of an existing conference (e.g., International Association for Great Lakes Research). Operations should be overseen by a steering committee and one or more sponsoring entities with a science-based focus (e.g., university, federal, state, provincial, First Nations, tribal agency, or nongovernment organizations). Funding sources would be required to offset costs. Such an inclusive GLEWS conference can provide an organized, regularly scheduled event focused specifically on current, emerging and anticipated threats and stressors and prospective responses. Yet, this conference-based alternative lacks a specific mechanism for follow-up, and does not adequately respond to time-sensitive threats that will be identified and acted upon by appropriate entities.

Option 3) GLEWS subcommittee within the IJC: Under the auspices of the SAB, the subcommittee would be composed of a broad, multidisciplinary array of stakeholders with special expertise in identifying, researching and responding to current, emerging and anticipated threats and stressors. Assisted by an IJC staff scientist, the subcommittee can increase the capacity of the SAB to focus on current, emerging and anticipated threats and stressors, as well as facilitate prospective responses. This alternative is consistent with the responsibilities assigned to the IJC under the Agreement. However, this subcommittee would feature a system of experts that relies largely on existing research and other early warning system mechanisms, and it encourages, but does not set in place, additional capacity and technologies for research and identification of threats and stressors. Additionally, modest budgeting to staff the new subcommittee and support its operations would be required, given that identifying, researching and responding to threats and stressors will require substantial time and expertise.

***Option 4) A formal GLEWS within the IJC with dedicated IJC staff support*:** An SAB subcommittee focusing on the science and policy dimensions of a GLEWS would be established, as in the preceding alternative. It would have a pronounced emphasis on securing appropriate representatives (e.g., government, public, private, nongovernment organizations) with a designated responsibility for identifying and addressing current, emerging and anticipated threats and stressors within their jurisdiction and area of responsibility. The full-time service of an IJC scientist (with additional assistance as needed) should be dedicated to this effort, given that each

class of threats and stressors requires a distinct approach for detection and analysis. This alternative would also entail the development and promotion of new processes and technologies to advance the science and application of early warning systems. This alternative can move beyond informal efforts to coordinate existing efforts to identify threats and stressors. It incorporates all the positive attributes of the preceding alternatives and formalizes the involvement of multiple parties with responsibilities for identifying and responding to current, emerging and anticipated threats and stressors. A formal GLEWS within the IJC structure would require additional IJC resources to support staff and subcommittee activities as well as active support and involvement of multiple public, private sector and nongovernmental entities with relevant roles and responsibilities.

***Option 5) Assignment to another existing entity*:** The previously identified structural and operational components would remain intact. However, associated responsibilities would be incorporated into another existing Great Lakes entity with a binational focus (e.g., Great Lakes Commission). A new source of funding (or reallocation of existing resources) would be required to support GLEWS functions. Functions can be similar to those that would be undertaken by the IJC (Option 4 above), although operations might be influenced by the nature of the organization. This alternative can embody all the positive features of the preceding alternatives. The primary issue associated with this alternative is the prospective difficulty in finding an appropriate binational home for GLEWS. There is uncertainty as to whether any non-IJC entity has a truly binational, ecosystem objective and science-based approach to identifying threats and stressors and is willing to take on the additional responsibilities and resource requirements of a GLEWS.

***Option 6) A new, independent organization*:** A newly constituted entity (governmental or nongovernmental) would be responsible for GLEWS management, with the IJC serving as one of many interested parties. A new source of funding could operationalize and maintain the new organization. Functions of this new, independent organization would be similar to those undertaken by the IJC. As a new organization, it would be dedicated exclusively to the development and implementation of GLEWS. Further, constraints and limitations that might be associated with a host entity would be avoided. The primary challenge associated with this alternative is the difficulty setting up a new and independent organization given concerns over redundancy and sustainability. In addition to creating more complexity on the institutional landscape, this alternative would also require coordination with and funding from the relevant jurisdictions.

Summary: Most workshop participants preferred Option 3 (GLEWS subcommittee within the IJC) or Option 4 (A formal GLEWS with dedicated IJC staff support), with fewer preferring Option 2 (Periodic GLEWS conference) and Option 5 (Assignment to another existing entity), and none of the workshop participants expressed a preference for either of Option 1 (Status quo) or Option 6 (A new, independent organization).

3.3 Approach and criteria for identifying stressors and threats

Any effective GLEWS would require a process and criteria for identifying, assessing and prioritizing different stressors and threats. Stressors and threats include those that can be

transmitted spatially (e.g., from southern US states to states bordering the Great Lakes), have cumulative effects (e.g., cause 'spill through' effects on part of the Great Lakes ecosystem), interact synergistically or antagonistically (e.g., have effects greater than, or less than, the additive effects of the individual stressors), be stochastic or unpredictable in nature, and be unintentionally neglected. Although this project initially intended to develop a GLEWS process and criteria as well as an organizational framework, it focused primarily on the latter. The process by which stressors and threats would be identified, assessed and priortitized is understandably complex for the reasons listed above. Accordingly, a proposed primary effort in the next phase of the GLEWS project will be to develop and refine the process to incorporate stressor and threat identification, assessment and actions into GLEWS.

3.4 List and explain the identified classes of stressors and threats

Table 1 (on the next page) lists the top 25 topic areas of public concern in the Great Lakes basin, as determined by public consultation by the IJC as a component of its First Triennial Assessment of Progress on Great Lakes Water Quality (International Joint Commission 2017). These topic areas were discussed during the 2018 GLEWS workshop and voted on by the workshop experts as topics that should be addressed as top threats and stressors to the ecological integrity of the Great Lakes and should therefore be included in the GLEWS. The workshop experts also identified threats and stressors such as changes in land use and habitat loss, intensified human activity, demographic changes and harmful spills as topics in addition to the top public concerns. It was also acknowledged that there are 'unknown unknowns' and that vigilance is required to recognize these once they emerge.

Table 1: Top topic areas of public concern in the Great Lakes basin based on IJC 2016-2017 public meetings.[1]

Rank	Topic Area	Votes
5	Toxic contamination and other pollutants	10
8	Nutrients, agricultural runoff and best management practices	7
15	Climate change	4
17	Aquatic invasive species	4
19	Asian carp (linked to Aquatic Invasive Species)	4
6	Proposed United States funding cuts to Great Lakes programs	4
23	Ballast water controls (linked to Aquatic Invasive Species)	4
24	Lack of government action/mismanagement	4
12	Citizen activism, public participation and education	3
1	Safe drinking water	2
10	Infrastructure and wastewater treatment plants	2
21	Combined sewer overflows	2
13	Areas of Concern	1
3	Nuclear plants/nuclear waste	1
4	Proposed Lake Huron nuclear waste repository	1
18	Harmful algal blooms (linked to Nutrients)	1
20	Safe beaches/closures	1
22	Environmental justice	1
7	Radionuclides as a chemical of mutual concern	0
2	Recreation and tourism	0
9	First Nation/Tribe/Métis involvement	0
11	Draft TAP report content and findings	0
14	Enbridge Line 5 pipeline	0
16	Mandatory regulations for CAFO operations	0
25	Bottled water withdrawals	0

[1] Note: These topics were derived from the public consultation by the IJC as a component of its First Triennial Assessment of Progress on Great Lakes Water Quality (International Joint Commission 2017) and were ranked 1-25 by frequency of mention throughout the TAP public engagement process. The votes are the total number of times these topic areas were considered by the GLEWS workshop participants as suggesting inclusion in a Great Lakes Early Warning System.

4.0 Next Steps

4.1 Operationalizing a GLEWS

This report focuses mainly on the development of the potential governance structure of a GLEWS and explored identification of the threats and stressors affecting the Great Lakes. It did not focus on the process and criteria for identifying, assessing and prioritizing different stressors and threats to the extent originally intended. However, such work is not complete without consideration of the analytical underpinnings and data requirements for a successful GLEWS. As a next step, the work group will focus on the development of operational procedures and analytical frameworks for identifying and prioritizing threats and stressors to be included in the GLEWS, including a set of preferred risk assessment protocols and analytical tools for evaluating potential threats, and the data and information (including indicators) required to address both known and unknown stressors. Models and scenarios will be assembled (or developed) to allow forecasting under future climatic and socioeconomic conditions. Hindcasting exercises for selected stressors such as harmful algal blooms, mussels, and chemicals such as polychlorinated biphenyls may provide insights into how the trajectory of responses can be modified for future (but similar) threats.

The effort to develop a process for identifying and prioritizing threats and stressors will start with knowledge gained from the IJC's Information Coordination and Flow project (International Joint Commission Great Lakes Science Advisory Board 2018) and the ongoing Stressor Interactions project to assess the probable effects of a set of different classes of known and unknown threats. A risk analysis approach will identify the likelihood and severity of potential stressors and threats, and identify priorities. The outcome will be a framework for identifying the appropriate threat data and response variables for different classes of threats to the physical, chemical, and biological integrity of the Great Lakes ecosystem. Since some threats require rapid policy actions, it is important to include perspectives from decision makers in this exercise.

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5.0 Summary and Recommendations

Following a careful review and analysis of the contractor's interview, survey, literature search and workshop outcomes, the framework for a recommended GLEWS organizational structure was developed.

To ensure that action occurs and that responses are timely and effective, data collection through sustained and enhanced monitoring and surveillance of the Great Lakes ecosystem are needed to provide the information flow necessary to trigger alarm in response to chosen thresholds of selected threats, both known and unknown.

The construct of a GLEWS envisions facilitated information management and sharing to improve knowledge, accessibility and exchange of relevant Great Lakes information in order to enhance effectiveness of this early warning system. The evaluation of threats and stressors during the expert workshop, compared to the issues of greatest public concern summarized through IJC public engagement, highlights the disconnect between public perception and experts' views of risk (**Table 1** previously). An institutionalized GLEWS must remain connected to public interests and those of rights holders and stakeholders throughout the basin.

Recommendation: **the IJC should create a GLEWS that would operate as an entity reporting to the Great Lakes Water Quality Board, a hybrid of options 3 and 4 presented in Section 3.2 of this report.**

The IJC would be responsible for GLEWS oversight and ensure that the IJC Commissioners are aware of emerging issues, per Article 8.3 (b) of the 2012 Agreement, through the action of the WQB. To function appropriately, a GLEWS requires highly qualified personnel and resources to assemble, assess, rank and report on emerging threats, which the Parties have available in their agencies. Therefore, we recommend that GLEWS be supported by subject matter experts provided by the Parties (e.g., the governments of Canada and the United States). The IJC would serve the role of oversight by convening additional highly qualified personnel to evaluate the effectiveness of the GLEWS.

The precedent for a similar functioning group is the current Great Lakes-St. Lawrence River Adaptive Management Committee. The Great Lakes Adaptive Management Committee undertakes monitoring, modeling and assessment needed to support ongoing evaluation of the regulation of water levels and flows in the Great Lakes-St. Lawrence River system. Accordingly, the Great Lakes Adaptive Management Committee reports to the Lake Superior Board of Control, Niagara Board of Control, and International Lake Ontario-St. Lawrence River Board.

Alternately, an option for formalizing a GLEWS would be via an additional annex (Annex 11) to the Agreement that specifically prescribes the responsibilities and activities of a GLEWS. This approach could be realized through an exchange of letters between the Parties pursuant to the Boundary Waters Treaty of 1909 that created by reference, the Great Lakes Water Quality Agreement (Canada and the United States, 2012).

Through its analysis, the IJC's Great Lakes SAB found that the scope of a GLEWS is understandably very large, yet justified, considering the enormous costs incurred once a new pervasive threat becomes established. Temporal and spatial aspects of a large system with existing stressors, such as the Great Lakes, challenges any governance system to anticipate and assess threats. This project report identified a recommended GLEWS organizational framework and several classes of threats that should be considered.

A second project phase will be advanced by the SAB to develop the analytical techniques that could be applied through the recommended organizational framework. The SAB provides analysis towards an improved capacity to identify and respond to emerging issues, threats and stressors facing the Great Lakes.

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