Toward a Great Lakes Early Warning System

FINAL REPORT

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Prepared for:

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Executive Summary

The Science Advisory Board (SAB) of the International Joint Commission (IJC) commissioned the development of a framework for a Great Lakes Early Warning System (GLEWS), a means to allow the Great Lakes scientific and management communities to “get ahead of the curve” in addressing emerging and anticipated issues before they threaten the ecological integrity of the Great Lakes - St. Lawrence River Basin. Toward that end, a multi-faceted approach consisting of a literature review, interviews, survey and Experts Workshop was taken to 1) identify and prioritize emerging and anticipated threats and stressors; and 2) develop a conceptual framework for a GLEWS to characterize these threats and stressors and link them to response actions.

Project outcomes included the identification and prioritization of several dozen “threats” to ecological integrity, notably aquatic invasive species (AIS), harmful algal blooms (HABs), hypoxia, chemicals of emerging concern, nanoparticles, natural disasters, spills, airborne contaminants, bioaccumulative contaminants, habitat degradation, surface water availability, microplastics, emerging diseases, endocrine disruptors, groundwater quantity and quality, water chemistry, water born illnesses and “unknown unknowns”. Identified stressors included climate change, nutrients, population growth, land management, unsustainable waste disposal practices, infrastructure failure, legacy contamination, and terrorism. Complementing these ecological stressors are social stressors that include apathy, complaceny, disincentives, economic drivers, lack of resources, policy decision making and short-term thinking, lack of vigilant detection of ecosystem change, and lack of outreach.

On the basis of the threats and stressors analysis, and a review of the continuum of alternative frameworks for a GLEWS, a recommended alternative was selected and developed for consideration by the SAB and IJC. The recommended framework calls for the initial development of a distinct and formalized entity, namely, a subcommittee of the SAB within the IJC structure, supported by one or more IJC staff, and responsible for the following five functions:

1. Identifying and monitoring current, emerging and evolving threats and stressors;
2. Prioritizing the threats and stressors on the basis of anticipated/ demonstrated ecological and socio-economic impacts;
3. Recommending response actions designed to avoid, mitigate or otherwise address the identified threats and stressors;
4. Documenting response actions taken and associated outcomes; and
5. Addressing (and offering recommendations concerning) gaps and unmet needs that compromise the ability to identify, characterize and prioritize the array of current, emerging and evolving threats and stressors in the Great Lakes - St. Lawrence River Basin.

Recommended next steps include establishing a two-year pilot project that entails:

- GLEWS Formation (the detailed development of GLEWS structure and operation (Months 1-6);
- GLEWS Operation (the design and implementation of assigned functions (Months 7-19); and
- GLEWS Evaluation and Refinement (Months 20-24).

Recommended deliverables include:

- Quarterly meetings of the GLEWS membership;
- Quarterly updates;
- Sponsorship of one or more conference sessions dedicated to identifying threat and stressors and associated response actions;
- Identification of gaps and unmet needs and formulation of recommendations; and
- An annual report to the IJC summarizing activities and outcomes to date.

I. Introduction

A. Issue Overview

The International Joint Commission (IJC) and its Science Advisory Board (SAB) have long recognized the need for strategies and approaches to prevent and resolve complex challenges facing the Great Lakes. They also recognize that the early identification and monitoring of both emerging and prospective threats and stressors can facilitate timely, effective and cost-efficient responses. By applying a science-based approach to such an initiative, the IJC and SAB can make a valuable contribution to Great Lakes resource management efforts.

The challenge is a daunting one, given the array of current and prospective threats and stressors that include (among many others) chemical substance impacts, invasive species, climate change, and HABs in the Western Lake Erie Basin and Great Lakes embayments. An additional challenge is that of developing a Great Lakes Early Warning System (GLEWS) that is practical and pragmatic, affordable, sustainable, acceptable to all relevant organizations on a binational basis, and sufficiently flexible to accommodate and address a complex and dynamic system.

The primary impetus for developing a GLEWS is found in the 2012 Protocol to the Great Lakes Water Quality Agreement, which calls upon the IJC to identify emerging issues and recommend strategies and approaches to address them. Complementing this directive is a growing body of literature that recognizes the need for an Early Warning System (EWS) to address an array of ecological issues, and documents the performance and attendant benefits of such a system, once implemented.

The Great Lakes - St. Lawrence River Basin is home to an expansive and complex array of governmental agencies, research institutions, stakeholder organizations and water-dependent industries. Many such entities are currently engaged in some form of monitoring and response activity associated with one or more threats and stressors central to their mission and business interests. However, the region lacks a single, comprehensive EWS with the ability to monitor and track the entire array of threats and stressors, including their interactions, and translate outcomes into recommended resource management actions.

B. Project Goal and Objectives

The SAB has embraced this challenge with the goal of developing an approach that will allow members of the Great Lakes scientific and management communities to “get ahead of the curve” by addressing emerging and anticipated issues before they become serious problems that threaten the ecological integrity of the Great Lakes - St. Lawrence River Basin. Two objectives support this overall goal: 1) identify and prioritize emerging and anticipated threats and stressors; and 2) develop a conceptual framework for a GLEWS to characterize these threats and stressors and link them to response actions.

C. Methodology

The project methodology centered on four primary tasks, as follows:

Task 1: Assessment of Existing Approaches. Existing approaches and mechanisms to characterize and respond to emerging and anticipated ecological threats and stressors were reviewed and assessed for relevance to a GLEWS framework. A comprehensive approach to this task featured three primary activities:

- *Literature Search and Analysis*: A search process was conducted, yielding over 100 documents (peer-reviewed and government reports) exploring the merits, applications and performance of various EWSs throughout North America and beyond. Those determined to be particularly relevant were abstracted with "best practices" and "lessons learned" documented for prospective application in development of a GLEWS framework. An array of ecological issues was captured in the search including, among others, water quality, algal blooms, drinking water, AIS, habitat stressors, extreme weather events, epidemiology, and food security.

- *Survey Administration*: A detailed survey was developed and administered to approximately 20 carefully selected individuals (both within and beyond the Great Lakes - St. Lawrence River Basin) to elicit input on both threats and stressors of priority concern, and desired elements of a GLEWS capable of identifying and addressing them.

- *Subject Matter Expert (SME) Interviews*: Eight SMEs, drawn primarily (though not exclusively) from the Great Lakes - St. Lawrence River Basin's scientific and management communities, were interviewed to elicit input on approaches and factors to consider in analyzing/reviewing existing frameworks with prospective GLEWS relevance. The SMEs were selected on the basis of their familiarity with EWS mechanisms and needs, and were drawn from various governmental agencies, citizen stakeholder organizations and water-dependent industries and associations.

Task 2: Experts Workshop. Approximately 40 individuals, drawn largely from the SME interviews and survey recipients, convened for a two-day workshop in Windsor, Ontario in May 2018. Through invited presentations and facilitated small group discussions, participants generated lists of stressors and threats, as well as elements of a GLEWS framework. Background materials (literature review, survey response summaries, interview outcomes, alternative GLEWS frameworks) were provided in advance.

Task 3: Refinement of Priority Threats/Stressors and a GLEWS Framework. Outcomes from the preceding tasks collectively yielded a list of priority threats and stressors as well as the key components of a GLEWS framework. These outcomes reflected two key principles embraced by the IJC: the prevention principle, wherein reduction of overall risks to the environment and human health by anticipating and addressing issues is sought; and the precautionary principle, whereby exhibiting a willingness to prevent environmental degradation through cost-effective actions even in the absence of scientific certainty is required. The GLEWS framework was developed specifically to accommodate and address the science-based identification and prioritization of potential threats and stressors and (as previously noted), to provide a practical and pragmatic mechanism that is affordable, sustainable, acceptable to all relevant organizations, and sufficiently flexible to accommodate and address a complex and dynamic system.

Task 4: Technical Report Preparation and Submittal. Outcomes of the preceding tasks were reviewed, analyzed and subsequently incorporated into this report. Sections include an Executive Summary; Introduction; Current State of Knowledge: Threats, Stressors and Early Warning Systems; Alternative Frameworks for a Great Lakes Early Warning System; Experts Workshop; Recommended Framework for a Great Lakes Early Warning System; Next Steps; and a Bibliography. Appendices include A: Survey Outcomes; B: Interview Notes; and C: Workshop Agenda and Participants.

This four-step methodology was performed with the following understandings and assumptions:

- Deliverables would include a binational Experts Workshop (i.e., planning, organizing, facilitating, reporting); and interim, draft and final technical reports that include recommendations on priority threats and stressors, and on the key components of a conceptual GLEWS framework;
- Existing data and information (as accessed via the literature search, interviews, survey and Experts Workshop) would form the basis for the deliverables;
- SAB leadership, with assistance from the IJC Great Lakes Regional Office, would be actively engaged in project design and conduct; and
- The project consultants would exercise best professional judgment in developing a recommended GLEWS framework, drawing from the literature review, survey, interviews, Experts Workshop and their own experiences and expertise.

II. Current State of Knowledge: Threats, Stressors and Early Warning Systems

As means to enhance understanding of threats and stressors, as well as the theory and practice of EWSs, a literature search and analysis was performed, followed by SME interviews, a survey, and the Experts Workshop.

A. Literature Search and Review

The literature review was performed using Google Scholar (https://scholar.google.com) and the DeepDyve research database (https://deepdyve.com), initially by using combinations of the terms "Great Lakes", "water quality", and "early warning system". Additional terms of interest were identified during review of sources yielded in the initial search, including "tipping points", "foresight", and "indicators"- all leading to expansion of the search boundaries. Items found in the original and extended searches were reviewed to confirm relevance, as were items suggested by survey respondents, interviewees, and workshop participants. For many relevant items, abstracts were collected and summary descriptions prepared.

The literature review process identified several dozen relevant documents for consideration. Perusal of these documents confirmed that there is active consideration across the international scientific and governmental community of the need for effective EWSs to support better decision-making in the environmental arena. Many EWSs exist for rapid-onset threats and stressors (e.g., tsunamis, tornados, hurricanes), but there is also recognition of the importance of slow-onset threats, such as deforestation or climate change. A summary of relevant literature search outcomes is presented below.

Great Lakes Threats and Stressors

The definitions of threats and stressors vary widely in the literature. The U.S. Environmental Protection Agency (USEPA) defines a "stressor" as any physical, chemical, or biological entity that can cause an adverse effect (USEPA, 2018). While there is no standard definition of a "threat", for the purposes of this report we refer to any natural or anthropogenic event or condition that leads to or otherwise facilitates a stress on the ecological integrity of the ecosystem.

In the Great Lakes, a wide range of stressors has been identified:

- Basin-wide, anthropogenic stressors (e.g., agriculture, atmospheric deposition, human population, land cover, point source pollution) impact water quality, especially the western shore of Lake Michigan, the western basin of Lake Erie, and southeast Lake Ontario;
- Chemical contamination, shoreline development, non-native invasive species, habitat loss, wetland loss and degradation, and forest fragmentation are major Lake Superior stressors;
- Lake Michigan is stressed by pathogens, aquatic nuisance species, sedimentation, habitat destruction, nutrients, and various chemicals (USEPA, 2000);
- Lake Huron stressors include climate change, coastal pollution, N impacts on water quality, Hg and Cu in sediments, and PCBs;
- Lake Erie stressors are similar to Lake Huron, plus invasive species and P-related algal blooms;

- The IJC Nearshore Framework (IJC, 2016) looks at nearshore impacts of algae and other stressors (including chemical contaminants, habitat loss, invasive species, and climate change);
- Agriculture, development, and reductions in wetland area are basin-wide wetland stressors; and
- The Great Lakes water resource region ranked 5th highest out of 18 US regions based on sediment, nutrient and toxics threats associated with housing density, road density, cultivation, livestock grazing, confined animal feeding, mining land cover, potentially toxic mines, potentially damaging wildfire, and atmospheric deposition in its watershed (Brown and Froemke, 2012).

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

- 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 impact);
- Climate change;
- Shoreline hardening and alterations, aquatic habitat alterations;
- Coastal and urban development;
- Natural resource use (including water withdrawals);
- Nuisance algae (HABs, Cladophora); and
- Dams and barriers.

In the same review (Smith et al., 2015), experts rated 50 key stressors and concluded that those related to invasive and nuisance species (e.g., dreissenid mussels, ballast invasion risk) and climate change had the greatest potential adverse impacts, a shift away from perennial concerns with persistent bioaccumulative toxics, and nonpoint source nutrients.

Early Warning Systems

The four key components of an EWS are identified by the United Nations (UNISDR, 2017) as risk knowledge; technical monitoring and warning service; communication and dissemination of warnings; and community response capability. EWSs are sometimes considered part of preventive management of biological invasions – likened to natural disasters - where the EWS is coordinated with information access, training, and response (Ricciardi et al., 2011).

Data and information from long-term ecosystem research and monitoring provides a basis for change detection, and can increase confidence and alacrity in decision-making (Parr et al., 2003). Further, socioeconomic trajectories may predict migration of conditions to a particular geography (Garnier et al., 2015). For example, future conditions in the upper Great Lakes may be foreshadowed by Lake Ontario’s current state – perhaps aided by perceived misalignments between the long-term time frame of lake changes and short-term, election cycle-driven thinking by governments (CGLI, 2016).

Another key component of an EWS (i.e., community response capability) was found to be improved by trust built through community engagement (Arias et al., 2015). Also, it was determined that the overall efficacy of an EWS can be predicted from accuracy, event threshold, timeframe, and previous severity (Girons et al., 2017). It is also noted that stakeholder strategies and perceptions of risk should inform characterization of, and response to risk (Ceccato et al., 2014).

Foresight. EWSs depend on anticipation of possible futures and development of responses to negative impacts identified in those futures. Science and technology foresight provides a set of appropriate tools for identification of impacts and development of responses with adequate lead time for societal preparation and strategic response (Smith and Saritas, 2011). Horizon scanning may include interviews, issues trees, reviews, expert workshops, open fora, and scenario planning; it is a systematic way of improving foresight of otherwise unexpected environmental issues (Sutherland and Woodroof, 2009). Scenario planning often appears as a recommended approach to inform resource management decisions while addressing the uncertainties inherent in the interaction of simultaneous ecosystem changes (Rowland et al., 2014).Regardless of the foresight technique applied, environmental models should reflect structural change in order to avoid the risk of locking in assumptions about the system that are not supportable going forward (Beck, 2005). It is further suggested by Beck that the risk can be tempered by “discovering our ignorance at the earliest possible moment.”

Indicators. Deciding what to watch for as a means to identify a potential impact has been a topic of much research. For example, monitoring of relative abundance and community composition for zooplankton has been shown to detect lake acidification and recovery (Marmorek and Korman, 1993), while algae respond rapidly and predictably to a wide range of pollutants and, therefore, may provide useful early warning signals of deteriorating conditions (McCormick and Cairns, 1994). Parasites may serve as effective monitors of pollutant effects on marine species, as they are more numerous, may have multiple differing life cycle stages, and may be sensitive in free-living transmission stages (Mackenzie, 1999). Further, research-based studies of wildlife in the Great Lakes - St. Lawrence River Basin suggest that health effects monitoring of sentinel wildlife species may provide human health benefits (Fox, 2001). In general, bioindicators provide a signal of an ecosystem’s biological condition, and simple bioindicators that respond to generalized stress could support citizen monitoring, with potential benefits for community engagement (Linton and Warner, 2003).

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 that indicate a critical threshold is approaching (Scheffer et al., 2009), although many ecological systems may not show typical leading indicators of regime shifts because they are described as systems without smooth potential, resulting in regime shifts with no apparent warning (Hastings and Wyham, 2010). However, a regime shift may have been signaled a year in advance of complete food web transition in a lake destabilized by introduction of top predators (Carpenter et al., 2011). Similarly, flickering (rising variance coupled to decreasing autocorrelation and skewness) has been observed 10-30 years in advance of transition to eutrophic conditions in a lake (Wang et al., 2012). Early-warning indicators may point to critical transitions in certain cases, but such indicators are best focused on well-understood systems and key processes; increased monitoring and modeling may 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 addressing a given system (Lenton, 2013). Loss of ecosystem resilience was seen to facilitate a switch to an alternative state, which suggests that sustainable management should focus on the maintenance of resilience (Scheffer et al., 2011). 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 Environmental Policy, 2016).

Characteristics. While EWS technologies and approaches have had well-documented mixed results, their capacities and strengths warrant consideration. To start with, a successful EWS requires long-term sustained action, strong political commitment, continued support and coordination, and the participation of diverse stakeholders. EWSs should be people-centered to maximize implementation, and their development should include community-based involvement, public education, mock exercises, and a warning dissemination strategy (Pulwarty and Sivakumar, 2014).

The scientific and data foundations for EWSs must include best available technology to maximize their utility, and effective EWSs should include hazard and vulnerability mapping, employment of early warning science and technology (e.g., GIS, remote sensing, statistical and mathematical models), along with an Internet portal for natural hazards, risks and warnings (Anderson et al., 2001). The design and operation of EWSs for a broad array of applications (e.g., water security, flood control, disaster mitigation, sustainable water utilization, water quality management) warrants consideration of systems dynamics through a qualitative and quantitative simulation and analysis methodology for system integration (Jacks et al., 2010). Various models can be employed (e.g., Fuzzy Comprehensive Evaluation Model) to evaluate water stress in terms of water supply and demand balance, socio-economics, agricultural production and ecology, thereby shaping the structure and operation of an EWS to characterize and respond to those stresses.

Establishment of an EWS focused on water quality and other ecological considerations requires researchers to consider meteorological considerations, land use, land management, population distributions and other regional factors. Its development should begin with a conceptual model that entails a retrospective analysis of past extreme events, systems and impacts. Development should also recognize that strong observational capabilities are critical to an EWS, as observations must capture the severity of extreme events, their impacts, and key variables for assessing the links to climate change or other stresses (Quansah et al., 2010).

The EWS must be capable of detecting ecosystem stresses such as changes in energetics, nutrient cycling, or community structure and function. In addition, it should recognize and address “tipping points”; critical transitions that reflect either a “slowing down” of a system or an increase in a property that causes the system to recover slowly from small impacts (Bestelmeyer 2006, Groffman et al. 2006, Huggett 2005, Scheffer and Carpenter 2003). The EWS must also be capable of recognizing and addressing a “flickering” phenomenon, described earlier in this report as rising variance coupled to decreasing autocorrelation and skewness (Wang et al., 2012). In addition, the system should be sensitive to reduced resilience or increased external fluctuations in an ecosystem, perhaps by detecting asymmetry in time series data and, hence, a prospective regime shift such as a substantial, long-term reorganization of a complex system (Scheffer and Jeppesen 2007). However, although regime shift theory is increasingly well-developed, there is not yet a common understanding on drivers, mechanisms, and characteristics of abrupt changes in ecosystems (see Bestelmeyer 2006 for further discussion).

The use of indicators in EWSs is critically important, as they can be used to detect impending regime shifts with sufficient time for effective management intervention. Long-term observations continuously accumulated over many years are typically necessary for the operation of an EWS, suggesting the need for mathematical and computational data analyses. Carefully selected indicator species will enhance the value of monitoring efforts associated with an EWS, provided that many species representing various taxa and life histories are included in the monitoring program; their selection is primarily based on a sound quantitative database; and interpretation of population trends is accomplished carefully to distinguish actual signals from variations unrelated to the deteriorating ecological integrity (Pulwarty and Sivakumar, 2014).

Effective use of an EWS - in conjunction with immediate access to critical information, specialized personnel training, and rapid-response strategies - can support preventive action in place of mitigative reaction. Prevention is preferable to mitigation, as it lessens or avoids expensive impacts.

In the particular instance of an EWS to address threats and stressors associated with toxic substances, key elements (based on review of numerous peer-reviewed articles listed in the bibliography) are:

- Structure-activity correlations to predict environmental characteristics of the stressor;
- Trends analysis of stressor production, import, and use;
- Review of environmental testing results; toxicological research;
- Maintenance of tissue banks and sediment to allow for retroactive analysis to establish trends;
- Monitoring to characterize the presence and significance of chemical residues;
- Development and use of mathematical models to predict consequences of stressor loading rates;
- Development of a data bank to store information on physical and chemical properties, toxicology, use and quantities in commerce of the stressor(s);
- Development of data and models to evaluate loadings of stressors;
- Development and use of reproduction, physiological and biochemical measures in wildlife, fish and humans as health effects indicators; and
- Establishment of a database to store, retrieve and interpret the data.

The focus on toxic substances, as provided in the literature review, is complemented by a focus on other categories of threat and stressors (e.g., invasive species, climate change) during the survey, interview and Expert Workshop components of the study.

B. Survey and Interviews

An online survey was developed and distributed to approximately 20 individuals willing to share their perspectives on ecological threats and stressors, and on EWSs. The survey asked for brief responses (i.e., no more than a few sentences or paragraphs) to the following questions:

- Based on your experience and expertise, what are the essential components of a Great Lakes Early Warning System framework?
- What are the top 5 to 10 stressors/threats you think should be addressed by a Great Lakes Early Warning System?
- Please provide examples of Early Warning Systems you believe can be applied to the Great Lakes. Include, where possible, reference material such as websites, reports and contacts.
- Is there anything else you would like to add, or other experts you recommend we consult?

Potential survey respondents were introduced to the project- and provided with survey access- via email correspondence. Survey responses received are presented in Appendix A. The responders included a mix of agency, academic, indigenous, private sector, and non-governmental organization (NGO) representatives from both Canada and the United States.

Survey responses were instrumental in informing the selection of eight SMEs for interviews, including representatives of indigenous peoples, commercial interests, academia, and provincial and state authorities from both Canada and the United States.

Each subject was interviewed via telephone; five questions (listed below) provided a starting point for additional discussion:

- What processes have you and others used to identify emerging ecosystem stressors as a means facilitate a response by resource managers?
- In your experience, what primary ecosystem stressors (and associated issues) speak to the need for an Early Warning System in the binational Great Lakes-St. Lawrence River Basin?
- Are you aware of any systematic processes (e.g., Early Warning Systems) -either at the conceptual or operational stage- that may offer “lessons learned” or “best practices” applicable to the Great Lakes? They can pertain to any geography or topical area(s) as long as they provide insights for design of a Great Lakes Early Warning System.
- What characteristics are most important in designing a Great Lakes Early Warning System, both in term of structure (e.g., organization, staffing, level of authority) and operation (e.g., funding arrangements, functions)?
- What are the primary opportunities and obstacles that need to be addressed to move a Great Lakes Early Warning System from the conceptual to operational stage?

A summary of survey and interview findings is provided below, with additional detail found in Appendices A (Survey Outcomes) and B (Interview Notes).

Threats and Stressors

Threats and stressors identified via the survey process and personal interviews can be grouped into the five categories identified below. This list is complemented by additional factors or events that are largely unanticipated at this time yet may have major adverse impacts on the system.

Chemical threats and stressors include emerging chemicals (i.e., as compared to chemicals of emerging concern); impacts of nanoparticles on biological integrity; microplastic impacts; familiar chemical pollutants such as phosphorus and organochlorine contaminants; hormones and pharmaceuticals; radioactive waste stored along the Great Lakes; oil spills from various sources (e.g., pipelines, ships); and water pollution due to urbanization and agriculture.

Nutrient threats and stressors include changes in agricultural methods and fertilizers leading to phosphorus and nitrogen loading; HABS and cyanobacteria blooms; and internal resuspension of phosphorus.

Climate Change threats and stressors include extremely low precipitation years (e.g., summer drought, low winter snowpack accumulation); lake warming; increased frequency of flooding events (which can increase nutrient influx and erosion rates); lake chemistry, water levels and water supply impacts; and, in general, climate change impacts that exert additional/new pressures on the resource (e.g., water diversion, population growth and shifts).

Biological threats and stressors include aquatic diseases; invasive species; loss of critical habitat for native species that could become species at risk; and intensified benthification of large areas of the Great Lakes due to the presence of dreissenid mussels, possibly aggravated by round goby and increased external controls on phosphorus loading.

Other threats and stressors identified in the survey and interview process can be categorized under **Human Impacts**, and include the distribution of the human population in the Great Lakes - St. Lawrence River Basin; failure and capacity limitations of grey infrastructure; power outages; terrorist threats to water quality (i.e., ecoterrorism); hydrologic alterations following construction of dams; and continuing chronic loss of shoreline and coastal habitat that exacerbates coastal and nearshore water quality and water resources problems.

Early Warning System

Survey and interview participants offered an array of suggestions and recommendations regarding a GLEWS framework. Components of such a framework, as identified by multiple respondents, can be conveniently organized under the three categories provided below.

Membership and Stakeholder Involvement

Interview subjects and survey respondents agreed that all relevant stakeholders and sectors of interest should be aware of and involved in the design of a GLEWS, and have ready access to outcomes once it is operationalized. In addition to broad representation from relevant Canadian and United States agencies and organizations, indigenous peoples (i.e., Tribes and First Nations) should be involved in GLEWS design, as they offer "on-the-ground" observations of natural systems, a long history of monitoring natural processes, and a basin-wide network. It was also noted that demonstrating the relevance of threats and stressors to industry interests can facilitate their engagement in a GLEWS (e.g., impact on regulatory regimes, impact of climate change-related low water levels on cost of commercial transportation).

In sum, an inclusive approach to GLEWS design will provide a common platform to deliver data and information to wide range of users. Coupled with an emphasis on transparency, an empirical approach, and unbiased data and information, inclusiveness will also position GLEWS as a highly credible source of threat and stressor impacts.

Building upon other Efforts. It was also emphasized that GLEWS should build upon existing detection and EWSs (e.g., contaminants, AIS, hypoxia, HABs) that are in various stages of development and operation. While gaps and unmet needs do exist, connecting GLEWS to such monitoring and response systems will maximize available resources and the use of available techniques and innovations relative to data acquisition and management, including remote sensing technologies.

GLEWS Functions. Interview subjects and survey respondents identified a number of critical functions for incorporation into a GLEWS framework including: employment of monitoring protocols to address key parameters and indicators across space and time (and in sufficient detail to establish variability around the mean); establishment of "triggers" to identify threats and stressors that warrant response activity; and employment of both expert opinion and modeling in a balanced manner to provide informed advice and guidance. Expert opinion, however, should not be limited to the physical, chemical and biological sciences; it was noted that the social sciences have much to offer with regard to threat and stressor identification, assessment and response. Further, experiences in related fields (e.g., disease surveillance and response) can offer valuable best practices and lesson learned for application to a GLEWS.

Adaptive management was also an important consideration identified through the interview and survey processes. It was noted that threats and stressors evolve rapidly given the dynamic nature of the Great Lakes - St. Lawrence River Basin, and that political priorities also evolve given governance changes in Basin jurisdictions. Thus, it was recognized that a GLEWS needs to adapt accordingly; its structure and operation needs to be periodically assessed and revised, as needed, to avoid short-term thinking and provide reliable service that focuses on the long-term. This will enhance the ability of GLEWS to anticipate and address extreme unpredicted threats (i.e., "unknown unknown" or "black swan" events). It was also noted that engagement of early-career agency staff in long-term efforts such as a GLEWS can contribute to its success through the development of highly qualified personnel. In sum, "form must follow function"; the structural characteristics of a GLEWS must be sufficiently flexible and adaptable to maximize responsiveness to current, emerging, evolving and anticipated threats and stressors.

III. Alternative Frameworks for a Great Lakes Early Warning System

A. Introduction

In preparation for the aforementioned Experts Workshop, six alternative frameworks for the organization structure of a GLEWS were developed and provided to workshop invitees. The intent was not to provide an exhaustive and definitive array of alternative organizational structures from which to select, but to provide a continuum of prospective alternatives to promote creative thinking among the participants. Ranging from the “status quo” to a highly structured framework dedicated exclusively to an Early Warning System, each of these alternative frameworks was briefly described in terms of structural and operational characteristics, followed by the “pros” and “cons” of such an arrangement. A facilitated process was employed during the workshop to seek input and consensus, where possible, on a preferred framework that could be selected from among the six alternatives, consist of a hybrid of two or more of the identified frameworks, or be an entirely new framework that emerged from workshop discussions.

B. Alternative Frameworks Presented at the Experts Workshop

Six alternative organizational frameworks, as presented to workshop participants, are presented below. Their development was influenced, in part, on the basis of literature review, interview and survey outcomes. They were designed to offer an illustrative continuum of alternative frameworks to provide workshop participants with a starting point for their discussions.

1. Status Quo

Structure: GLEWS is not a formally constituted entity or system. Rather, the importance of identifying current, emerging, and anticipated threats and stressors continues to be recognized within the resource management and research communities. Various research initiatives, conferences and policy deliberations will continue to focus on such issues, with a decided emphasis on recognized threats and stressors that demand immediate attention.

Operation: GLEWS is not formally constituted in this alternative; operations include informal, opportunistic activities associated with various ongoing research and resource management initiatives, as well as networking that occurs at conferences.

Pros: This alternative does not require additional funds, not does it require any institutional adjustments. Rather, it relies on the interests and capabilities of the existing research and resource management communities.

Cons: This alternative does not address the inadequacies of current approaches to identifying and responding to emerging and anticipated threats and stressors. The emphasis is on threat and stressor response rather than anticipation and prevention. Further it does not provide for a defined clearinghouse or repository for current, emerging, and anticipated threats.

2. Periodic GLEWS Conference

Structure: A conference focusing on current, emerging, and anticipated threats and stressors is held on an annual or semi-annual basis, forming the centerpiece of this alternative. The event features formal technical and resource management presentations, and is followed by broad distribution of a proceedings document that includes both research outcomes and practical and pragmatic resource management actions. An emphasis is placed on involving all Great Lakes entities with a responsibility for and interest in current, emerging, and anticipated threats, stressors and their impacts. Structural requirements include a steering committee, one or more sponsors that may be permanent or rotating, and a reliable, sustainable funding source.

Operation: The regularly scheduled conference is a discrete component of an existing conference (e.g., International Association for Great Lakes Research; or State of the Lake conferences) or a new, "stand-alone" event. Operations are 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, non-governmental organization). Funding sources are secured to offset costs. Conference sponsors prepare and widely distribute conference proceedings and may also manage a web site to post information deserving of immediate attention.

Pros: A periodic GLEWS conference provides an organized, regularly scheduled event focused specifically on current, emerging, and anticipated threats and stressors and prospective responses. It also provides for inclusive activity with prospective participation by the various research, resource management, and non-governmental communities. In addition, it produces a proceedings document that encourages additional attention to issues.

Cons: A substantial commitment of multiple parties (i.e., time, effort, funding) is required for conference design, conduct and proceedings preparation/distribution. Fundraising would likely be required on a continuing basis. The conference alternative also lacks a specific mechanism for follow-up, and does not set in place (although it may encourage) additional EWS capabilities/processes. In addition, this strategy does not consider how time-sensitive threats will be identified and acted upon by appropriate entities. For example, published proceedings are not likely to be read by busy managers; if there is an urgent threat, what is the best way to disseminate information to the stakeholders?

3. GLEWS Subcommittee within the International Joint Commission (IJC)

Structure: The IJC establishes a GLEWS Subcommittee under the auspices of the SAB. The subcommittee is composed of a broad, multi-disciplinary array of stakeholders with special expertise in identifying, researching and responding to current, emerging and anticipated threats and stressors. With the assistance of an IJC staff scientist, and reliance on data and information gathered, the subcommittee provides the SAB and IJC with reports and advice, and responds to any inquiries the governments may have.

Operation: This is a formal standing body that meets on a regular basis and is responsible for providing the SAB/IJC with reports and advice. Modest funding is made available through the IJC, as it is for other boards/committees.

Pros: Maintaining a GLEWS subcommittee within the IJC will increase the capacity of the SAB to focus on current, emerging and anticipated threats and stressors at the binational level, as well as facilitate prospective responses. This alternative also provides an ongoing process featuring regular meetings, reports, and practical/pragmatic advice to the SAB and ultimately, the IJC and the two governments. It is not necessarily a "stand alone" alternative and can complement other GLEWS alternatives such as the preceding "periodic GLEWS conference." Further, it relies on existing IJC staff capacity with minimal additional costs. Finally, this alternative is consistent with the Great Lakes Water Quality Agreement (GLWQA), thereby requiring minimal "institutional energy" to establish.

Cons: This alternative features a "system of experts" that relies largely on existing research and other EWS mechanisms; 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.

4. A Formal Great Lakes Early Warning System with Dedicated IJC Staff Support

Structure: An SAB subcommittee focusing on the science and policy dimensions of an EWS is established (as with the preceding alternative), but with a pronounced emphasis on securing appropriate representatives of the various entities (i.e., public, private, non-governmental) 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 time services of an IJC scientist (with additional assistance, as needed) are dedicated to this effort, given that each class of threats and stressors would require a distinct approach for detection and analysis.

Operation: A full-time staff scientist at IJC, with the assistance of administrative support, is responsible for staffing the subcommittee, organizing and conducting an annual (or semi-annual) GLEWS conference, and leading the design and operation of a formal EWS that features the coordinated efforts of relevant public agencies, private sector interests, and non-governmental organizations. This alternative also entails the development and promotion of new processes and technologies to advance the science and application of EWSs.

Pros: This alternative provides a formal structure and enhanced professional staff support, thereby moving beyond informal efforts to coordinate existing efforts to identify threats and stressors, and promote EWS innovations and technologies. It incorporates all the positive attributes of the preceding alternatives, and also formalizes the involvement of multiple parties (binational) with responsibilities for identifying and responding to current, emerging, and anticipated threats and stressors.

Cons: A formal GLEWS within the IJC structure requires additional IJC resources to support staff and subcommittee activities. It also requires the active support and involvement of multiple public, private sector, and non-governmental entities with relevant roles and responsibilities.

5. Assignment to another Existing Entity

Structure: The previously identified structural and operational components (e.g., formally constituted body, regularly scheduled meetings and conferences, proceedings preparation, interagency coordination, GLEWS design/operation/refinement) remain intact. However, associated responsibilities are incorporated into another existing Great Lakes entity with a binational focus (e.g., Great Lakes Commission, Great Lakes Observing System). The IJC is an interested party but not in a leadership or coordinative role. A new source of funding (or reallocation of existing resources) will support GLEWS functions.

Operation: Functions are similar to those that would be undertaken by the IJC (per previous alternatives), although operations would be influenced by the nature of the organization (e.g., legal status, authority, mission, strategic plan, priorities, financial and staffing resources). This will result in opportunities and constraints differing from those under an IJC-led arrangement.

Pros: This alternative embodies all the positive features of the preceding alternatives. By being assigned to an existing entity (other than the IJC), cost and time delays associated with organization start-up are avoided, and scientific expertise and a staffing structure would be largely in place. In addition, constraints and limitations associated with the structure and operation of other entities (e.g., IJC) or a new entity (given unknowns and uncertainties) are avoided.

Cons: 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 other entity 1) has a truly binational, objective and science-based approach to identifying threats and stressors and 2) is willing to take on the additional responsibilities and resource requirements that GLEWS operation would require. Additionally, “buy-in” by affected jurisdictions may be uncertain depending upon the entity housing GLEWS.

6. A New, Independent Organization

Structure: The previously identified structural and operational components (e.g., formally constituted body, regularly scheduled meetings and conferences, proceedings preparation, interagency coordination, GLEWS design/operation/refinement) remain intact. However, there is one significant exception; a newly constituted entity (governmental or non-governmental) is responsible for GLEWS management, with the IJC serving as one of many interested parties. A new source of funding operationalizes and maintains the new organization.

Operation: Functions of this new, independent organization are similar to those that would be undertaken by the IJC (per previous alternatives), although operations are influenced by the nature of the new organization (e.g., legal status as a governmental or non-governmental entity, bylaws/charter, financial and staffing resources). This will result in opportunities and constraints differing from those under an IJC-led arrangement.

Pros: Establishing a new and independent organization allows GLEWS to embody the various “pros” identified in previously described alternatives. Additionally, as a new organization, it will be dedicated exclusively to GLEWS development and implementation. Further, constraints and limitations that might be associated with a "host" entity would be avoided.

Cons: The primary challenge associated with this alternative is the difficulty setting up a new and independent organization given concerns over redundancy and efficiency, funding reliability and sustainability, and political will and support. Cost and time requirements for forming and operationalizing a new binational organization (particularly if it is formally constituted under a binational compact, convention or Memorandum of Understanding) would be substantial and with an uncertain outcome. In addition to creating more complexity on the "institutional landscape", this alternative would also require "buy-in" and active support by the various affected jurisdictions- an additional uncertainty.

IV. Experts Workshop

A. Purpose

The goal of the Experts Workshop was to advance the development of a GLEWS framework by meeting two objectives:

1. Identifying and prioritizing current/emerging threats and stressors that can adversely affect the ecological integrity of the system; and
2. Identifying preferred structural and operational characteristics of an EWS able to detect and facilitate a response to those threats and stressors.

Coupled with outcomes of the preceding literature review, personal interviews and survey, the workshop yielded the informed input of multiple parties and helped shape project recommendations regarding a preferred GLEWS framework. Workshop materials and a list of participants are provided in Appendix C.

B. Approach

The Workshop was preceded by the selection of approximately 50 invitees, of which approximately 40 were able to participate. Invitees consisted of individuals with expertise in (and responsibility for) monitoring and responding to current and anticipated ecological threats and stressors. Invitations were extended to individuals from both the Great Lakes region and beyond, and included academic/research institutions, governmental agencies at various levels, indigenous peoples, and industry.

Held in Windsor, Ontario (May 14-15, 2018), the initial day of the workshop focused on the identification of current and emerging threats and stressors, the reason for their selection, and their relative priority. Following an opening panel of guest speakers (identified later in this section), multiple breakout sessions were held, composed of approximately 6-8 (randomly selected) workshop participants as well as pre-assigned facilitators, recorders and rapporteurs. The second day of the workshop was also preceded by an opening panel of guest speakers, with breakout sessions focused on the identification of a preferred GLEWS organizational framework and key structural and operational characteristics.

A modified “Nominal Group Technique” was employed in all breakout sessions to encourage contributions by all participants. Plenary sessions for “reporting out” were held each day to share input and provide for discussion by all participants.

1. Primary Threats and Stressors

As noted above, the first day of the Experts Workshop was dedicated to a facilitated discussion of current and emerging threats and stressors in the binational Great Lakes-St. Lawrence River Basin. A panel offered framing thoughts prior to two breakout sessions organized around the following items:

- Identify your “top three” emerging threats/stressors and explain why they were selected.
- As a group, prioritize the threats and stressors as “high”, “medium” or “low” for tracking by an Early Warning System.

The panelists offered perspectives on the use of remote sensing, in-situ observations, and models to support the Lake Erie hypoxia EWS and HABs detection system at NOAA's Great lakes Environmental Research Laboratory (Stephen Ruberg – Group Leader, Marine Instrumentation Lab, NOAA – GLERL); the ability to statistically discern loss of stability in systems nearing a tipping point, potentially leading to opportunities to prevent or mitigate (Ryan Batt – Post-Doctoral Fellow, National Academy of Sciences); and the importance of integrating observing and monitoring systems to support ecosystem forecasting to improve decision-making and reduce risks (Stephen Brandt – Professor, Oregon State University and Chair, Delta Independent Science Board). The ensuing discussion emphasized the importance of routine, long-term research to support warning and forecast systems; noted the difficulty of working with biological observations as compared to physiochemical observations; and touched on the (in)adequacy of the historical data record to meet new analytical needs.

The breakout portion of the workshop asked attendees – divided into four groups – to first identify top threats and stressors to the ecological integrity of the Great Lakes, and then prioritize them as candidates for tracking within an EWS. The four groups each identified between 10 and 17 threats or stressors, and ordered them as shown in Table 1 below.

Group 1		**Group 2**		**Group 3**		**Group 4**	
1	Nutrients	1	Habitat loss/degradation	*H/H*	Nutrient change - > HABs/Hypoxia	*H*	*AIS*
2	*AIS*	2	Nutrients	*H/H*	Climate change -> flooding	*H*	Economic drivers
2	Waste disposal	3	*AIS*	*H/H*	*AIS*	*H*	Climate change
4	Intensified human activity	3	Land cover/management chnages	*H/M-H*	Offshore oligotrophication	*H*	Nutrient inputs
5	*CECs*	4	Climate change	*H/M-H*	Emerging chemicals/PFAS	*M*	Bioaccumulative contaminants
6	Climate change	5	Unustainable practices	*H/M-H*	Habitat loss	*M*	Water amount and rate (hydrology)
6	Short-term thinking	6	Policy decisionmaking	*H/M-H*	Irreversible land use change	*M*	Land use change (med high)
8	Lack of resources	7	Hydrologic disruption	*H/L*	Plastics	*M*	Complacency (med high)
9	Pollutants from new tech	7	Chemical toxicity	*L/H*	Infrastructure failure	*M*	Unexpected catastrophes
10	Spills	9	Disincentives	*L/H*	Waterborne illnesses	*M*	Legacy contamination
11	Terrorism	10	Population growth	*L/M-H*	Endocrine disruptors	*L*	Temperature changes
		10	Groundwater	*M/M*	Airborne contaminants	*L*	Airborne
		12	*CECs*	*L/H*	Emerging diseases	*L*	Major ions in water
		12	Apathy	*M/L*	Demographic changes		
		12	Complacency	*L/M*	Spills		
		12	Spills	*L/M*	Power outages		
		12	Microplastics	*L/?*	Water diversion		

AIS = Aquatic Invasive Species
CECs = Constituents of Emerging Concern
HABs = Harmful Algal Blooms
PFAS = Per- and polyfluoroalkyl substances

H = High, M = Medium, L = Low, ? = unknown
H/H (e.g.) = High probability of occurrence/high consequence

Table 1. Stressors and threats as identified by breakout groups. Groups 1 and 2 ranked based on numerical scores, while groups 3 and 4 ranked categorically (High, Medium, or Low).

Several threats and stressors with a social dimension were identified by groups during the breakout sessions and/or in the subsequent plenary discussion. These included apathy; complacency; disincentives; economic drivers; lack of outreach; lack of resources; lack of vigilant monitoring/change detection; short-term thinking; and the uncertainties associated with policy decisions.

Attendees agreed that these items were potentially important factors, but are perhaps outside of the aegis of the SAB; it may be more appropriate for other entities to address them. It was also noted that

EWSs for several of the identified threats (i.e., AIS, HABs/hypoxia, natural disasters, and spills) presently exist in some form, and have the potential to contribute to a GLEWS.

2. Desired Elements of a Great Lakes Early Warning System

As noted above, the second day of the Experts Workshop was dedicated to a facilitated discussion of alternative organizational frameworks for a GLEWS. It began with a panel session composed of Phyllis Green (Superintendent, Isle Royal National Park, National Park Service), Lewis Linker (Modeling Coordinator, Chesapeake Bay Program Office), and Gavin Christie (Division Manager, Fisheries and Oceans Canada). Phyllis Green and Gavin Christie focused largely on AIS-related issues to discuss the opportunities, challenges and applications of EWSs, while Lewis Linker shared his experiences in establishing EWS functions focusing on the Chesapeake Bay. With this as a basis, two questions were directed to each of four facilitated breakout groups to elicit thoughts and perspectives.

- Based on the prioritized threats/stressors and the “alternatives” handout, what is your preferred GLEWS framework (or hybrid thereof), and the rationale for your selection?
- Which GLEWS framework (or hybrid thereof) is preferred by the group, by consensus, and what additional details on key components and functions can be recommended?

Given the far-reaching discussion that ensued, responses are conveniently organized under four headings: Preferred Organizational Framework, Key Structural Components, Key Operational Functions and Activities, and Additional Advice and Recommendations.

Preferred Organizational Framework: Most workshop participants preferred Alternatives 3 (GLEWS Subcommittee within the IJC) or 4 (A Formal GLEWS with Dedicated IJC Staff Support), with fewer preferring Alternative 2 (Periodic GLEWS Conference) and Alternative 5 (Assignment to another Existing Entity). None of the workshop participants expressed a preference for either of the “extremes” on the continuum of formality – Alternative 1 (Status Quo) or Alternative 6 (A New, Independent Organization).

Key Structural Components: Workshop participants identified a number of desired structural components they would like to see embodied in a preferred alternative. They envisioned a GLEWS framework that is flexible and nimble, able to evolve as issues evolve. Suggestions included the prospective formation of a new Annex 10 subcommittee that could either evolve into an IJC board over time, or could be “piloted” by the IJC and then “handed off” to the USEPA and Environment and Climate Change Canada (ECCC).

The structure should be multi-faceted and employ a mix of activities (e.g., IAGLR sessions, workshops, dedicated conferences, literature reviews, contracted reports, scoping, social media, and input from an array of government, academia, industry and other sectors including water-based industry, transportation and insurance). Well-defined roles and responsibilities for staff and members are critical, as the entity must have credibility and respect. Staffing arrangements should be adequate to provide for all necessary data gathering, analysis and modeling functions, as well as coordination, reporting and related requirements. While the IJC staff can lead and coordinate the development of analytical and reporting procedures, the structure should provide for collaboration with other entities (e.g., federal, state, provincial) with monitoring, processing and analysis capabilities. As a membership-based entity, GLEWS membership should be sufficiently diverse to accommodate all key binational interests, yet be comparatively small to ensure functionality. The members should include representatives of agencies and organizations with the authority and capacity to respond, ass appropriate to priority threats and stressors.

Key Operational Functions and Activities: From an operational standpoint, workshop participants envisioned a GLEWS framework as an “action-oriented” central clearinghouse for coordinating, acquiring and analyzing data and information, prioritizing threats and stressors of concern, and facilitating responses by appropriate agencies and organizations. Core functions supporting these activities include monitoring, knowledge-sharing, data synthesis and integration, warning, and advising. Workshop participants envisioned GLEWS operations to build upon existing, disparate efforts; to serve as a “network of networks” that takes full advantage of existing EWS capabilities; and to provide for a practical, pragmatic and affordable EWS mechanism.

“Horizon scanning” and “scenario planning” were identified by workshop participants as useful mechanisms to identify emerging/evolving threats and stressors for subsequent triage to quantify vulnerabilities, differentiate between cumulative and acute threats and stressors, and determine those that warrant attention via GLEWS. Complementing these prospective activities are a range of other activities that include regularly scheduled workshops and other functions; close coordination with IJC boards and other relevant entities; and full engagement with a large and rather disparate community of researchers, managers and decision makers with an interest in some subset of the universe of relevant threats and stressors.

With regard to the identification of priority threats and stressors, workshop participants emphasized the importance of paying attention to scale (i.e., both geographic and temporal), including the need to differentiate between the short term (to determine acute response), the medium term (for research), and long term (for projections).

Additional Advice and Recommendations: In providing perspectives on the preferred structural and operational elements of a GLEWS, workshop participants noted that it is important to glean “best practices” and “lessons learned” from EWS experiences elsewhere (e.g., Chesapeake Bay, Danube River Early Warning System, International Union for the Conservation of Nature) as well as issue-specific response systems (e.g., AIS, oil and hazardous material spills). It was also noted that prospective incorporation of GLEWS into the IJC structure (i.e., informally or as a subcommittee) should recognize that the IJC is adept at studies, coordination and warnings, but less so with regard to timely response actions. It was also noted by one participant that dedicated IJC staff may not be viewed by some as sufficiently independent to manage an EWS.

V. Recommended Framework for a Great Lakes Early Warning System

A. Criteria to Guide Framework Development

Following a careful review and analysis of the interview, survey, literature search and workshop outcomes, the framework for a recommended GLEWS organizational structure was developed with the following eight fundamental criteria as guidance. The GLEWS must be:

1. *Practical*……readily designed and implemented, with “user-friendly” features designed for an array of interested parties;
2. *Pragmatic*……focused exclusively on Great Lakes threats and stressors, with a clear linkage to actions and mechanisms to respond to them;
3. *Effective*…… an objective, science-based service able to capture the array of current, emerging and evolving threats and stressors;
4. *Efficient*…..taking full advantage of existing EWS mechanisms, organizations and associated resources;
5. *Affordable*……designed, staffed and operated in a manner consistent with current and anticipated financial resources;
6. *Accessible*……to all relevant organizations with a stewardship role, responsibility and interest in the Great Lakes-St; Lawrence River Basin;
7. *Supportable*……by key Canadian and US governmental jurisdictions, policy makers, researchers, resource managers and other stakeholders; and
8. *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.

B. Structure and Operation

The above criteria, coupled with outcomes of the literature review, interviews, survey and Experts Workshop, informed development of recommended structural and operational components of a GLEWS. The recommended organizational framework consists of a distinct and formalized entity within the IJC structure supported by one or more IJC staff. Initially, GLEWS can most readily be formed as a subcommittee of the IJC SAB where it can complement the Emerging Issues Work Group of the IJC’s Water Quality Board (WQB). As the GLEWS framework evolves and, as the GLWQA and the parties allow, GLEWS may assume a more independent status as a standing board or distinct IJC program.

The recommended GLEWS structure features multiple appointees from science-based Canadian, US and indigenous peoples entities (e.g., public agencies, academic units, research organizations) that are collectively responsible for 1) identifying and monitoring current, emerging and evolving threats and stressors; 2) prioritizing these threats and stressors on the basis of anticipated/demonstrated ecological and socio-economic impacts; 3) recommending (and undertaking, as appropriate) response actions designed to avoid, mitigate or otherwise address the identified threats and stressors; 4) documenting response actions taken and associated outcomes; and 5) addressing (and offering recommendations concerning) gaps and unmet needs in EWS capabilities that compromise the ability to identify, characterize and prioritize the array of current, emerging and evolving threats and stressors. Associated

IJC staff responsibilities include overall GLEWS support; sponsorship of special GLEWS sessions at new and established events (e.g., International Association for Great Lakes Research conference, Areas of Concern conference, State of the Lakes conferences); data base development/maintenance; and annual report development (tracking threats and stressors, response recommendations and actions, and gaps and unmet needs to be addressed).

1. Legal Status

As an SAB subcommittee, GLEWS formation must be consistent with GLWQA provisions. As such, this will first require approval by the SAB membership, followed by that of the IJC commissioners. The latter will ultimately be responsible for establishing GLEWS structural and operational guidance and periodically reviewing performance.

2. Membership/Participants

As envisioned, GLEWS will be a membership-driven entity with a strong focus on coordinating current and anticipated EWS functions of existing, science-based entities. Among others, this will include selected Canadian and US agencies (i.e., federal, state, provincial, local), indigenous peoples organizations, regional organizations, academic units, research institutes and industry/user groups that regularly identify, monitor, and respond to threats, stressors and relevant ecological processes. It is further anticipated that members and participants will include current IJC SAB and WQB members, both as a means to benefit from their individual expertise and to ensure coordination and collaboration with the standing IJC boards.

While identification of prospective GLEWS members is beyond the scope of this framework, it is anticipated that the core GLEWS membership will be in the range of 24-30 individuals, with "associate membership" arrangements for additional participants being an option to ensure that special projects, topics and/or focus areas have ready access to relevant expertise.

3. Functions

As noted above, GLEWS will have five primary functions, as follows:

A. *Identifying and monitoring current, emerging, and evolving threats and stressors.* The GLEWS will benefit from ongoing efforts of the Great Lakes - St. Lawrence River Basin community to gather and analyze data, track national and international developments of relevance (via literature review and other means), and sponsor and/or participate in existing and new events designed to identify and explore the range of threats and stressors and their ecological and associated socio-economic implications. The GLEWS will serve as a clearinghouse for this data and information, and as a mechanism for translating it into actionable information. This function will benefit from the threats and stressors identified over the course of this project.

B. *Prioritizing the threats and stressors on the basis of anticipated/demonstrated ecological and socio-economic impacts.* Once identified, the GLEWS will be responsible for characterizing the threats and stressors to determine status (i.e., current, anticipated, evolving; low, medium, high risk); spatial and temporal attributes; type and magnitude of prospective impacts (i.e., ecological, socio-economic); and actions taken to date (if any). Based upon this characterization, the various threats and stressors will be prioritized for prospective action by responsible parties. This can be accomplished through designations that include High Priority (i.e., those that require immediate and concerted response actions); Medium Priority (i.e., those that require near-term response actions); and Low Priority (i.e., those of potential concern that require ongoing monitoring and characterization).

C. *Recommending response actions designed to avoid, mitigate or otherwise address the identified threats and stressors.* With a primary focus on threats and stressors identified as High Priority, the GLEWS will share the outcomes of its monitoring, coordination and characterization activities with the IJC, SAB and WQB (as appropriate) via regularly scheduled presentations, complemented by the preparation of a detailed annual report and quarterly updates, all with an online presence for ease of access. Advice provided will be based upon the outcomes of regularly scheduled GLEWS meetings and associated analysis of identified threats and stressors, their interactions, and recommended responses. An emphasis will be placed on the latter, with specific, action-oriented recommendations directed to the boards and IJC for prospective presentation to the parties.

D. *Documenting response actions taken and associated outcomes.* The aforementioned annual report and quarterly updates will provide running documentation of identified threats and stressors (i.e., High, Medium, or Low Priority), recommended responses, actions taken, and the status/outcomes of such actions. This will provide a connection between identification, prioritization and response activities and, collectively, contribute to an overall characterization of the state of the Great Lakes-St. Lawrence River Basin.

E. *Addressing (and offering recommendations concerning) gaps and unmet needs that compromise the ability to identify, characterize and prioritize the array of current, emerging and evolving threats and stressors in the Great Lakes-St. Lawrence River Basin.* The GLEWS membership, with staff assistance, will identify gaps and unmet needs with regard to overall capabilities to identify, monitor, characterize, prioritize and respond to threats and stressors. Recommendations to eliminate or otherwise address those gaps and unmet needs will be included in advice contained in the annual report, quarterly update and other relevant mechanisms.

4. Relationship to Existing Mechanisms

As designed, GLEWS is a collaborative mechanism fundamentally dependent upon the full participation of entities with some EWS capability to identify, characterize and respond to one or more threats and stressors in the Great Lakes - St. Lawrence River Basin geography (or a component thereof). As such, GLEWS will showcase, advance and strengthen such mechanisms rather than compete with or replace them.

5. Resource Requirements

At the minimum, GLEWS subcommittee support will require the full-time services of at least one IJC staff member, with administrative and technical support for report production and meeting/event assistance.

Further, periodic assistance of IJC staff assigned to support SAB and WQB functions will be required to ensure internal coordination. Additional resource requirements include support for periodic meetings of the GLEWS membership (e.g. two in-person and two via teleconference annually), participation of GLEWS co-chairs in IJC meetings, and support for periodic conference participation (e.g., GLEWS-related session at conferences of the International Association for Great Lakes Research, GLEWS-specific conference). The resource requirements associated with any IJC actions in response to GLEWS recommendations will be determined on an issue-specific basis.

VI. Next Steps

As noted in the Experts Workshop discussion- as well as in outcomes from literature review, interview and survey activities- GLEWS must be able to adapt to evolving conditions as dictated by threats and stressors, as well as by resource management procedures and priorities. For these reasons, a two-year pilot project is recommended, composed of the following:

GLEWS Formation: Based on the recommended structural and operational framework described above, GLEWS will be formed in detail through an IJC directive (similar to that prepared for other GLWQA entities) that presents mandate, functions, membership, member competencies, co-chair and member responsibilities, and operational aspects (e.g., meetings, work planning and reporting, liaison with GLWQA boards and the IJC). During the formation period, GLEWS personnel will work with the SAB to develop an initial shortlist of threats and stressors for focused consideration during the pilot project. This shortlist will provide the basis for a case study demonstration of how data can be translated into actionable information to identify a threat, quantify the risk, and propose potential actions. Necessary funds to support subcommittee activities will be secured as well. *(Months 1-6).*

GLEWS Operation: Assigned functions will be designed and implemented, with a concerted effort to publicize services, coordinate with other GLWQA entities, secure the active involvement of the Great Lakes-St. Lawrence River Basin community (specifically including entities positioned to deliver the various components of an EWS for relevant threats or stressors), and document outcomes and associated benefits. At the minimum, this initial pilot project will include development of a draft protocol for prioritizing threats and stressors; quarterly meetings of the GLEWS membership; quarterly updates; sponsorship of one or more conferences/sessions dedicated to identifying threat and stressors and associated response actions using the draft protocol; communication of recommended response actions to the IJC; identification of/recommendations concerning gaps and unmet needs; and an initial annual report to the IJC that summarizes activities and outcomes to date. *(Months 7-20).*

GLEWS Evaluation and Refinement: The preceding 14-month operational phase will be evaluated in detail based upon feedback from GLEWS members, contributors, users, other GLWQA entities and the IJC. Adjustments to GLEWS structure and operations, including the prioritization approach, will be made accordingly, and in light of evolving threats, stressors and resource management priorities. Recommendations will be made to the IJC with regard to the future status of the GLEWS. *(Months 21-24).*

Bibliography

Anderson, D.M., P. Andersen, V.M. Bricelj, J.J. Cullen, and J.E. Rensel. 2001. Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters, APEC #201-MR-01.1, Asia Pacific Economic Program, Singapore, and Intergovernmental Oceanographic Commission Technical Series No. 59, Paris. https://www.whoi.edu/fileserver.do?id=24193&pt=10&p=19155

Arias, Paola A., Juan Camilo Villegas, Jenny Machado, Angélica M. Serna, Lina M. Vidal, Catherine Vieira, Carlos A. Cadavid, Sara C. Vieira, Jorge E. Ángel, and Óscar A. Mejía. "Reducing Social Vulnerability to Environmental Change: Building Trust through Social Collaboration on Environmental Monitoring." Weather, Climate, and Society 8.1 (2015): 57-66.

Bae, M.J. and Y.S. Park. 2014. "Biological early warning system based on the responses of aquatic organisms to disturbances: a review." *Science of the Total Environment*, Vol. 466, pp 635-649. https://doi.org/10.1016/j.scitotenv.2013.07.075

Batt, R.D., S.R. Carpenter, J.J. Cole, M.L. Pace and R.A. Johnson. 2013. Changes in ecosystem resilience detected in automated measures of ecosystem metabolism during a whole-lake experiment. Proceedings of the National Academy of Sciences 110: 17398-17403.

Beck, M.B. "Environmental foresight and structural change." Environmental Modelling & Software 20.6 (2005): 651-670.

Bestelmeyer, Brandon T. 2006. "Threshold Concepts and Their Use in Rangeland Management and Restoration: The Good, the Bad, and the Insidious". Restoration Ecology, 14 (3), pp 325-329. https://doi.org/10.1111/j.1526-100X.2006.00140.x

Brown, Thomas C. and Pamela Froemke. "Nationwide Assessment of Nonpoint Source Threats to Water Quality." BioScience 62.2 (2012): 136-146. https://doi.org/10.1525/bio.2012.62.2.7

Butitta, V. L., S. R. Carpenter, L. C. Loken, M. L. Pace, and E. H. Stanley. 2017. Spatial early warning signals in a lake manipulation. Ecosphere 8:e01941

Carignan, V. and M.A. Villard. 2002. "Selecting indicator species to monitor ecological integrity: a review." *Environmental Monitoring and Assessment*, Vol. 78, Issue 1, pp 45-61. https://doi.org/10.1023/A:1016136723584

Carpenter, S. R., J. J. Cole, M. L. Pace, R. Batt, W. A. Brock, T. Cline, J. Coloso, J. R. Hodgson, J. F. Kitchell, D. A. Seekell, L. Smith, and B. Weidel. 2011. Early Warnings of Regime Shifts: A Whole-Ecosystem Experiment. Science 332:1079-1082.

Carpenter, S. R., W. A. Brock, J. J. Cole, and M. L. Pace. 2014. A new approach for rapid detection of nearby thresholds in ecosystem time series. Oikos 123:290-297.

Carpenter, S.R. and W.A. Brock. 2006. "Rising variance: a leading indicator of ecological transition." *Ecology Letters*, Vol. 9, pp 311–318. doi:10.1111/j.1461-0248.2005.00877.x

Ceccato, Pietro, Katia Fernandes, Daniel Ruiz, and Erica Allis. "Climate and environmental monitoring for decision making." Earth Perspectives 1.1 (2014): 1-22.

Contamin, R. and A.M. Ellison. 2009. "Indicators of regime shifts in ecological systems: What do we need to know and when do we need to know it." *Ecological Applications*, Vol. 19 pp 799–816. doi:10.1890/08-0109.1.

Conversi, A., V. Dakos, A. Gårdmark, S. Ling, C. Folke, P.J. Mumby, C. Greene, M. Edwards, T. Blenckner, M. Casini, and A. Pershing. 2015. "A holistic view of marine regime shifts." *Philosophical Transactions of the Royal Society B*, Vol. 370, Issue 1659. http://dx.doi.org/10.1098/rstb.2013.0279

Council of Great Lakes Industries. January 26, 2018. "Commentary: Predicting, Preventing, and Addressing Long-Term Threats to the Great Lakes." http://cgli.org/2016/04/commentary-predicting-preventing-and-addressing-long-term-threats-to-the-great-lakes/.

Dai, L., D. Vorselen, K.S. Korolev, and J. Gore. 2012. "Generic indicators for loss of resilience before a tipping point leading to population collapse." *Science*, Vol. 336, Issue 6085, pp 1175-1177. http://science.sciencemag.org/content/336/6085/1175

Danz, Nicholas P., Gerald J. Niemi, Ronald R. Regal, Tom Hollenhorst, Lucinda B. Johnson, JoAnn M. Hanowski, Richard P. Axler, Jan J. H. Ciborowski, Thomas Hrabik, Valerie J. Brady, John R. Kelly, John A. Morrice, John C. Brazner, Robert W. Howe, Carol A. Johnston, and George E. Host. "Integrated Measures of Anthropogenic Stress in the U.S. Great Lakes Basin." Environmental Management 39.5 (2007): 631-647. https://doi.org/10.1007/s00267-005-0293-0

Donhyug Kang, Hansoo Kim, Seungwon Jung, and Mira Kim. 2016. "Development and Field Application of Early Warning System for Harmful Algal Blooms (Red-Tide)- Early Warning Using Ultrasound Wave, Korea"- in The Journal of the Acoustical Society of America 140, 3242. https://doi.org/10.1121/1.4970253

Environment and Climate Change Canada. "Compendium of Canada's Engagement in International Environmental Agreements: Great Lakes Water Quality Agreement." February 2017. http://www.ec.gc.ca/international/EB6F1B1B-7408-48A5-A108-6295839AB42C/C12%202017%20IEA%20Factsheet%20GLWQA%20EN%20Final.pdf

Fox, G.A. 2001. "Wildlife as sentinels of human health effects in the Great Lakes--St. Lawrence basin." *Environmental Health Perspectives*, Vol. 109, Suppl. 6, pp 853–861. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240620/

Garnier, Josette, Luis Lassaletta, Gilles Billen, Estela Romero, Bruna Grizzetti, Julien Némery, Thi Phuong Quynh Le, Chiara Pistocchi, Najla Aissa-Grouz, Thi Nguyet Minh Luu, Lauriane Vilmin, and Jean-Marcel Dorioz. "Phosphorus budget in the water-agro-food system at nested scales in two contrasted regions of the world (ASEAN-8 and EU-27)." Global Biogeochemical Cycles 29.9 (2015): 1348-1368.

Girons Lopez, M., G. Di Baldassarre, and J. Seibert. "Impact of social preparedness on flood early warning systems." Water Resources Research 53.1 (2017): 522-534.

Groffman, Peter M., Jill S. Baron, Tamara Blett, Arthur J. Gold, Iris Goodman, Lance H. Gunderson, Barbara M. Levinson, Margaret A. Palmer, Hans W. Paerl, Garry D. Peterson, N. LeRoy Poff, David W. Rejeski, James F. Reynolds, Monica G. Turner, Kathleen C. Weathers, and John Wiens. 2006. "Ecological Thresholds: The Key to Successful Environmental Management or an Important Concept with No Practical Application?" Ecosystems, 9 (1), pp 1-13. https://link.springer.com/article/10.1007%2Fs10021-003-0142-z

Group on Earth Observations. "Harmful Algal Bloom (HAB) Early Warning System"- 2017-2019 Work Programme- Group on Earth Observations, Geneva Switzerland. https://www.earthobservations.org/activity.php?id=97

Gsell, Alena Sonia, Ulrike Scharfenberger, Deniz Özkundakci, Annika Walters, Lars-Anders Hansson, Annette B. G. Janssen, Peeter Nõges, Philip C. Reid, Daniel E. Schindler, Ellen Van Donk, Vasilis Dakos and Rita Adrian. Evaluating early-warning indicators of critical transitions in natural aquatic ecosystemsPNAS 2016 113 (50) E8089 - E8095; published ahead of print November 22, 2016, doi:10.1073/pnas.1608242113

Guttal, V. and C. Jayaprakash. 2008. "Changing skewness: an early warning signal of regime shifts in ecosystems." *Ecology Letters*, Vol. 11, pp 450–460. doi:10.1111/j.1461-0248.2008.01160.x

Hastings, A. and D.B. Wysham. 2010. "Regime shifts in ecological systems can occur with no warning." *Ecology Letters*, Vol. 13, pp 464–472. doi:10.1111/j.1461-0248.2010.01439.x

Howard, B.F. May 2007. "Real Time Monitoring Program: Protecting the Drinking Water Source in the Huron to Erie Corridor." State of Michigan Department of Environmental Quality. http://www.michigan.gov/documents/deq/deq-wb-wws-BrockHowardCIPRTMtalk5-30-07_237078_7.pdf

Huggett, Andrew J. 2005. "The concept and utility of 'ecological thresholds' in biodiversity conservation". Biological Conservation, 124 (3), pp 301–310. http://frst411.sites.olt.ubc.ca/files/2015/01/Huggett_BioCon2005.pdf

International Joint Commission. 2016. "The Great Lakes Nearshore Framework". Lakewide Management Annex Nearshore Framework Task Team, September 2016. https://binational.net/wp-content/uploads/2016/09/Nearshore-Framework-EN.pdf

International Joint Commission. 2018. "Annex 12 – Persistent Toxic Substances". *The GLWQA Review Great Lakes Water Quality Agreement.* http://www.ijc.org/en/activitiesX/consultations/glwqa/agreement_3.php#ann12

Jacks, Elliot, Jim Davidson, and H. G. Wai. "Guidelines on early warning systems and applications of nowcasting and warning operations." World Meteorological Organization.

Juech, Claudia, and Evan S. Michelson. "Innovation in horizon scanning for the social sector: an introduction to the Searchlight function." foresight 14.6 (2012): 439-449.

Kumar, Arun and Suchendra M. Bhandarkar. 2017. "A Deep Learning Paradigm for Detection of Harmful Algal Blooms". Applications of Computer Vision (WACV), IEEE Winter Conference, March 24-31, 2017. http://cobweb.cs.uga.edu/~csc/

Lenton, T.M. 2011. "Early warning of climate tipping points." *Nature Climate Change*, Vol. 1, pp 201–209. doi:10.1038/nclimate1143

Lenton, Timothy M. "Environmental Tipping Points." Annual Review of Environment and Resources 38 (2013): 1-29.

Linton, Dulcie M., and George F. Warner. "Biological indicators in the Caribbean coastal zone and their role in integrated coastal management." Ocean & Coastal Management 46.3 (2003): 261-276.

Mackenzie, K. November 1999. "Parasites as Pollution Indicators in Marine Ecosystems: a Proposed Early Warning System." *Marine Pollution Bulletin*, Vol. 38, Issue 11, pp 955-959. https://doi.org/10.1016/S0025-326X(99)00100-9

Marmorek, D.R. and J. Korman. 1993. "The use of zooplankton in a biomonitoring program to detect lake acidification and recovery." *Water, Air, & Soil Pollution*, Vol. 69, Issue 3, pp 223-241. https://doi.org/10.1007/BF00478160

Marti, CL and Imberger, J. A Real-Time Management System For The Perth Coastal Margin, Western Australia; E-proceedings of the 36th IAHR World Congress 28 June – 3 July, 2015, The Hague, the Netherlands

McCormick, P.V. and J. Cairns. 1994. "Algae as indicators of environmental change." *Journal of Applied Phycology*, Vol. 6, Issue 5-6, pp 509-526. https://doi.org/10.1007/BF02182405

Michalak, A.M. 2016. "Study role of climate change in extreme threats to water quality." *Nature*, Vol. 535, Issue, 7612, pp 349-352. https://www.nature.com/news/study-role-of-climate-change-in-extreme-threats-to-water-quality-1.20267

National Science Foundation. April 28, 2011. "A Tale of Two Lakes: One Give Early Warning Signal for Ecosystem Collapse." *National Science Foundation*, URL: https://www.nsf.gov/news/news_summ.jsp?cntn_id=119359

Odum, E.P. August 1, 1985. "Trends Expected in Stressed Ecosystems." *BioScience*, Vol. 35, Issue 7, pp 419–422. https://doi.org/10.2307/1310021

Organisation for Economic Co-operation and Development OECD. January 26, 2018. "Schooling for Tomorrow Knowledge Base › Futures Thinking › Overview of Methodologies" Paris, France. https://www.oecd.org/site/schoolingfortomorrowknowledgebase/futuresthinking/overviewofmethodologies.htm

Pace, M. L., R. D. Batt, C. D. Buelo, S. R. Carpenter, J. J. Cole, J. T. Kurtzweil, and G. M. Wilkinson. 2017. Reversal of a cyanobacterial bloom in response to early warnings. Proceedings of the National Academy of Sciences 114:352-357.

Parr, T.W., A.R.J. Sier, R.W. Battarbee, A. Mackay, and J. Burgess. "Detecting environmental change: science and society—perspectives on long-term research and monitoring in the 21st century." Science of the Total Environment 310.1 (2003): 1-8.

Peter, Marc K., and Denise G. Jarratt. "The practice of foresight in long-term planning." Technological Forecasting and Social Change 101 (2015): 49-61.

Presner, J. December 6, 2017. "How to Predict the Future(s)." *Huffpost (Oath, Inc*.), *THE BLOG,* May 4, 2015, https://www.huffingtonpost.com/jeremy-pesner/how-to-predict-the-future_1_b_6979736.html

Pulwarty, Roger S. and Mannava V. K. Sivakumar. 2014. "Information systems in a changing climate: Early warning and drought risk management." Weather and Climate Extremes 3:14-21. https://doi.org/10.1016/j.wace.2014.03.005

Quansah, Joseph E., Bernard Engel, and Gilbert L. Rochon. 2010. "Early warning systems: A review." Journal of Terrestrial Observation 2.2. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1072&context=jto

Rapport, D.J., R. Costanza and A.J. McMichael. 1998. "Assessing ecosystem health." *Trends in Ecology & Evolution*, Vol. 13, Issue 10, pp 397-402. https://www.ncbi.nlm.nih.gov/pubmed/21238359

Ricciardi, A., M.E. Palmer, and N.D. Yan. 2011. "Should biological invasions be managed as natural disasters?" *BioScience*, Vol. 61, Issue4, pp 312-317. https://doi.org/10.1525/bio.2011.61.4.11

Rowland, E., M.S. Cross, and H. Hartmann. 2014. "Considering Multiple Futures: Scenario Planning To Address Uncertainty in Natural Resource Conservation." U.S. Fish and Wildlife Service, Washington, D.C. www.fws.gov/home/feature/2014/pdf/Final%20Scenario%20Planning%20Document.pdf

Samarasundera, Edgar, Anna Hansell, Didier Leibovici, Claire J. Horwell, Suchith Anand, and Clive Oppenheimer. "Geological hazards: From early warning systems to public health toolkits." Health And Place 30 (2014): 116-119.

Scheffer, M., J. Bascompte, W.A. Brock, V. Brovkin, S.R. Carpenter, V. Dakos, H. Held, E.H. van Nes, M. Rietkerk, and G. Sugihara. September 3, 2009. “Early-warning signals for critical transitions.” *Nature* Vol. 461, pp 53–59. doi:10.1038/nature08227

Scheffer, M., S. Carpenter, J.A. Foley, C. Folke, and B. Walker. 2001. “Catastrophic shifts in ecosystems.” *Nature*, Vol. 413 Issue 6856, pp 591-596. doi:10.1038/35098000

Scheffer, Marten and Erik Jeppesen. 2007. "Regime Shifts in Shallow Lakes". Ecosystems, 10 (1), pp 1-3. https://link.springer.com/article/10.1007/s10021-006-9002-y

Scheffer, Marten and Stephen R. Carpenter, 2003. "Catastrophic Regime Shifts in Ecosystems: Linking Theory to Observation". Trends in Ecology and Evolution, 18 (12), pp 648-656. http://dx.doi.org/10.1016/j.tree.2003.09.002

Science for Environment Policy. March 2016. “Identifying Emerging Risks for Environmental Policies.” *Future Brief 13.* Produced for the European Commission DB Environment by the Science Communication Unit, UWE, Bristol. Issue 13. http://ec.europa.eu/environment/integration/research/newsalert/pdf/emerging_environmental_risks_early_warnings_FB12_en.pdf

Storey, Michael V., Bram van der Gaag, and Brendan P. Burns, Advances in on-line drinking water quality monitoring and early warning systems, In Water Research, Volume 45, Issue 2, 2011, Pages 741-747, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2010.08.049.

Sutherland W.J., M. Clout, I.M. Côté, P. Daszak, M.H. Depledge, L. Fellman, E. Fleishman, R. Garthwaite, D.W. Gibbons, J. De Lurio, A.J. Impey, F. Lickorish, D. Lindenmayer, J. Madgwick, C. Margerison, T. Maynard, L.S. Peck, J. Pretty, S. Prior, K.H. Redford, J.P.W. Scharlemann, M. Spalding, and A.R. Watkinson. 2010. “Horizon scan of global conservation issues for 2010.” *Trends in Ecology & Evolution*, Vol. 25, Issue 1, pp 1-7. https://www.cbd.int/doc/emerging-issues/2010-TREE-horizon-scan-conservation.pdf

Sutherland, W.J. and H.J. Woodroof. 2009. “The need for environmental horizon scanning.” *Trends in Ecology & Evolution*, Vol. 24, Issue 10, pp 523-527. http://www.cpsg.org/sites/cbsg.org/files/2013_AM/Sutherland%20&%20Woodroof%202009.pdf

Tapinos, Efstathios. "Perceived Environmental Uncertainty in scenario planning." Futures 44.4 (2012): 338-345.

Third International Conference on Early Warning (EWC III). 2006. “Developing early warning systems: A checklist.” Bonn, Germany. https://www.unisdr.org/2006/ppew/info-resources/ewc3/checklist/English.pdf

U.S. Environmental Protection Agency. “Lake Michigan Lakewide Management Plan.” April 2000. https://www.epa.gov/sites/production/files/2015-11/documents/lake-michigan-lamp-2000-458pp.pdf

U.S. Environmental Protection Agency. “Watershed Web Academy: Watershed Ecological Risk Assessment.” https://cfpub.epa.gov/watertrain/pdf/modules/wshedecorisk.pdf

UNEP: Early Warning Systems: A State of the Art Analysis and Future Directions http://www.zaragoza.es/contenidos/medioambiente/onu/newsletter12/883_eng.pdf

United Nations Office for Disaster Risk Reduction. 2017. "Early Warning System." Terminology. https://www.unisdr.org/we/inform/terminology

Van Brenik, Debora. "Great Lakes stressed out." The London Free Press December 19, 2012. https://lfpress.com/2012/12/19/great-lakes-stressed-out/wcm/08e43e3b-ea9f-738f-8936-1d8c45580840

Vaseashta, Ashok. "Advanced sciences convergence based methods for surveillance of emerging trends in science, technology, and intelligence." foresight 16.1 (2014): 17-36.

Villagrán de León, Juan C., Inés Pruessner, and Harold Breedlove. 2013. "Alert and warning frameworks in the context of early warning systems: A comparative review." Intersections No. 12 Bonn: United Nations University Institute for Environment and Human Security. http://www.droughtmanagement.info/literature/UNU-EHS_alert_warning_frameworks_ews_2013.pdf

Wang, Hangzhou, Faisal Khan, and Salim Ahmed. 2015."Design of Scenario-Based Early Warning System for Process Operations". Industrial Engineering and Chemistry Research, 54 (33), pp 8255–8265. http://pubs.acs.org/doi/abs/10.1021/acs.iecr.5b02481

Wang, R., J.A. Dearing, P.G. Langdon, E. Zhang, X. Yang, V. Dakos, and M. Scheffer. December 20, 2012. "Flickering gives early warning signals of a critical transition to a eutrophic lake state." *Nature*, Vol. 492, pp 419–422. doi:10.1038/nature11655

Wilhite, Donald A., M. V. K. Sivakumar, and Deborah A. Wood. 2000. "Early warning systems for drought preparedness and drought management." Proceedings of an Expert Group Meeting held in Lisbon, Portugal, 5-7 September 2000. Geneva, Switzerland: World Meteorological Organization. http://www.wamis.org/agm/pubs/agm2/agm02.pdf

Wilkinson, G. M., S. R. Carpenter, J. J. Cole, M. L. Pace, R. D. Batt, C. D. Buelo, and J. T. Kurtzweil. Early warning signals precede cyanobacterial blooms in multiple whole-lake experiments. Ecological Monographs DoI 10.1002/ecm.1286

Appendix A. Survey Outcomes

A total of 15 survey responses were received. Responses to Questions 1 and 2 are summarized below. Responses to Questions 3 (Provision of Examples) and 4 (Other Information) were helpful in identifying relevant reference material as well additional SMEs to interview. Outcomes of those questions are incorporated into the bibliography, literature search, and interview notes.

Question 1: Based on your experience and expertise, what are the essential components of a Great Lakes Early Warning System framework?

Survey respondents suggested many essential components/attributes for a GLEWS, including the following:

- Selection and monitoring of appropriate parameters and indicators across space and time sufficient to establish variability around the mean;
- Integration across sectors and stakeholders;
- Triggers for action;
- Plans for action;
- Periodic reassessment;
- Remote sensing;
- Involvement of resource scientists and managers;
- Transparent, empirical, unbiased approaches;
- Science-driven and research-based;
- Data management;
- Expert opinion and modeling balanced;
- Stakeholders engaged, including indigenous peoples;
- Implement as a common platform delivering information to wide range of users;
- Communications skills;
- Long-term commitment from leaders for sustainable resources over many years;
- Appropriately connected to existing emergency response systems; and
- Start with goals/outcomes then identify and rank potential threats/risks.

Question 2: What are the top 5 to 10 stressors/threats you think should be addressed by a Great Lakes Early Warning System?

The responses to Question 2 are synthesized into several categories, as noted below.

- Chemical
  - Emerging chemicals: as compared to chemicals of emerging concern;
  - Impacts of nanoparticles of biological integrity;
  - Microplastic impacts;
  - Familiar chemical pollutants such as phosphorus and organochlorine contaminants; and
  - Hormones and pharmaceuticals.
- Nutrients
  - Nitrogen contributions to cyanobacteria and Lake Erie's demise (and possibly Lake Ontario); and
  - HABs.
- Climate Change
  - Years of extremely low precipitation, both summer drought and low winter snowpack accumulation;
  - Lake warming;
  - Increased frequency of flooding events (which can increase nutrient influx and erosion rates); and
  - Lake chemistry, and water level and supply impacts.
- Biological
  - Aquatic diseases;
  - intensified benthification of large areas of the Great Lakes as a results of dreissenid mussels, possibly aggravated by round goby and increased external controls on phosphorus loading
  - Invasive species; and
  - Loss of critical habitat for native species that could become species at risk.
- Humans
  - Human population and its distribution in the GL watershed;
  - Continuing chronic loss of shoreline and coastal habitat because of human development which also exacerbates nearshore water quality and water resources concerns;
  - Grey infrastructure system failure and capacity limitations;
  - Power outages;
  - Terrorist threats to water quality (i.e., ecoterrorism);
  - Geo-political instability or pressures attributable to climate change in North America (and possibly beyond) that exert new pressures on the Great Lakes - St. Lawrence River Basin (e.g. water taking from outside the basin; rapid population growth);
  - Water pollution from urbanization and agriculture;
  - Radioactive waste stored along the Great Lakes;
  - Changes in agricultural methods and related fertilizers;
  - Hydrologic alterations following construction of dams; and
  - Oil spills from various sources (e.g., pipelines, ships).
- A largely unanticipated factor or event that has major impacts on regional water resources or lake ecology.

Appendix B. Interview Notes

Note- These summaries present selected items from the SME interviews. Since they were open, free-flowing conversations generally guided by the prepared questions, these bulleted points are not organized under specific questions. By design, responses are not attributed to individual interview subjects.

Interview #1

Summary Notes

- Numerous EWS mechanisms exist within the indigenous community, such as the Assembly of First Nations (at the macro/large scale level), the Chiefs of Ontario in Canada and the Northeast Tribes organization in the US (at the Great Lakes-specific level), and the USEPA Tribal Science Committee.
- Indigenous peoples and communities talk to one another, and notify each other when concerns arise.
- Consult http://greatlakes.akwesasne.ca for a relevant web site. It is a map of recognized First Nations; non-recognized will be added in the future.
- The only connections these groups have with the US and CA governments (fed/state/provincial level) tend to be on a case-by-case, issue-specific basis. What is lacking is a coordinated, large-scale system view- they tend not to look at the "big picture."
- In the US, dating back to the Carter Administration, Executive Orders have been in place to compel federal agencies to work with tribal authorities. Funds have been available to the tribes to assist with environmental monitoring, but there are issue-specific "silos" that preclude a "big picture" view.
- In Canada (federal/provincial) there is "almost no funding" available to First Nations.
- There are new justice principles in Canada (federal level) that require federal agencies to work with the First Nations. It would be advantageous to have a Great Lakes EWS that this new process can feed into.
- Indigenous peoples are always looking for indicators of emerging issues. Items of current concern include (among others), lake levels, climate change, extreme weather events, fisheries, AIS, and threatened and endangered species. This is knowledge that reflects the hunter/gatherer culture, and information is passed to the Akwesasne Environment Department.
- Use governance to fulfill responsibilities to the environment, although this process differs from group to group. Some details:
    - Thunder ceremony (our grandfathers speak to us though thunder). Welcome back in June/July in the past, bon voyage in August → March to December
    - South Carolina practices (e.g., termite barrier, plant Carolinian trees) for climate change adaptation

  - The Public Infrastructure Engineering Vulnerability Committee (PIEVIC) process (Natural Resources Canada and Engineers Canada) is being adapted to First Nations practices. A Technical Services Group is assembling this as a toolkit.
- The insurance/assurance industry needs to be brought into the conversation, as they closely monitor trends.
- The Remedial Action Plan process has evolved into a community-based process that has been effective in raising awareness of environmental issues and concerns.
- Social media can be an effective means of gathering and processing environmental monitoring/ early warning data and information. (For example, twitter and Facebook communications regarding the Lake Ontario levels issue has been extensive and informative.)
- This interviewee is participating in “ecumenical councils” that review/discuss prophecies relative to environmental conditions, trends, and issues. Ecumenical councils look to their prophecies and see what’s coming true. “Someday in the future we will see the trees dying from the top down; this foretells the doom of the world”.
- Funding availability is always an issue regarding the design and establishment of a GLEWS.
- The upcoming workshop on GLEWS can be of great assistance in moving this idea forward, and it will be important to have a representative sampling of indigenous peoples present for the event. Candidates include Tony Davis of the Akwesasne, Kathleen Padulo (Chiefs of Ontario), and/or Rod Whitlow (Assembly of Ontario).
- The interviewee is pleased that the GLEWS initiative is moving forward.

Interview #2

Summary Notes

- In this age of artificial intelligence, we should be able to develop technologies and equipment to advance EWS capabilities. Don't forget that at the end of the day it's the human mind that synthesizes and decides.
- The focus must be on research- both basic and applied.
- Many forward-looking issues are generated by young researchers; we need to cultivate that.
- We tend to deal with questions and issues after they occur (i.e., after the fact) as opposed to identifying and addressing emerging issues. It's difficult to understand and identify problems before they occur. However, research is an effective way to do this by deepening our understanding of the system.
- We need knowledgeable research teams to identify and attack problems.
- Prioritizing current and emerging issues is a challenging task.
- We need to strengthen our research culture and provide additional funds, as research is the key to identifying and addressing emerging issues.
- We need to strengthen existing monitoring programs to detect ecosystem changes and identify stressors.
- Our tendency is to focus on legacy (i.e., previously identified) stressors.
- Reduced funding for basic and applied research over the last decade has been problematic.
- An example of reduced research capability is the Freshwater Institute in Winnipeg, which was once a leading research organization for freshwater lake eutrophication, and now has very little freshwater focus. It was established in 1968 and became "fully an entity" 1971. It housed an experimental lakes program and was a leader in eutrophication research into the 1980s.
- NSF and NCERC are major funding sources but, historically, they have viewed Great Lakes research as a primary responsibility of state/provincial/federal agencies due to the binational character of the resource. It is, therefore, unlikely that Great Lakes researchers will enjoy much success pursuing those avenues.
- The Great Lakes Restoration Initiative is focused largely on issues we already know about.
- Political will is a limiting factor in securing the funds needed for research that will drive an EWS; members of the Great Lakes Congressional Delegation need to take a more pronounced leadership role.
- A good example of an EWS is found in Australia (Center for Water Research). The focus is on instrumentation and water quality (primarily drinking water). It is linked to real-time monitoring networks. It has some applicability to the Great Lakes, but it does focus on a much smaller system (i.e., reservoir). Also, it is directed at identifying and addressing issues before they become major problems.
- See the American Society of Limnology and Oceanography (ASLO)-sponsored symposium (approximately 1968) that focused on an EWS capability as related to eutrophication.

- We have institutions in the Great Lakes that we did not have in 1968; their capabilities and focus need to be enhanced to place more emphasis on both basic and applied research.
- Basic and applied research has become a political issue in the US and Canada.
- A strong plea (from the IJC to the federal governments) for enhanced funding for basic and applied research would be a significant means to advance GLEWS development.
- Existing monitoring programs need to be strengthened to better anticipate and address issues.
- With regard to fisheries issues, resource managers don't want to hear about new and emerging issues because they are focused on existing ones. It will require a significant amount of convincing to broaden their focus.
- Public involvement is the key to making a case for more and better-funded basic and applied research.

Interview #3

Summary Notes

- This interviewee has 20 years' experience in working on issues of ecosystem stability and resilience.
- Theoretical and whole-lake experiments can identify stressors. Statistical properties of time series data change in predictable ways when resilience is declining and the ecosystem is vulnerable to shifting.
- Some time series data are easy to measure and they change in predictable ways when a system is declining.
- This interviewee is now working on spatial indicators to complement temporal indicators in assessing and measuring resilience of ecosystems.
- These indicators could be an EWS element, particularly if the system is found to be highly vulnerable to stressors.
- There is work underway in Lake Erie to predict algal blooms- see the NOAA web site for details.
- Primary threats and stressors include (among others) nutrients (this has been a stressor for over 50 years); invasive species (aquatic and terrestrial); toxic contaminants (e.g., mercury, halogenated hydrocarbons, DDT, PCBs, Furan); acidification of water bodies (not presently a leading issue but still important); the carbon dioxide threat (measurable effects in the ocean, and needs to be further examined in the Great Lakes); Dissolved Organic Carbon/Dissolved Inorganic Carbon (DOC/DIC) vs. productivity, new AIS; release of new chemicals; and water level fluctuations and other climate-induced changes.
- This interviewee co-chaired a group that developed alternative futures (i.e., scenarios) - not focused on the Great Lakes but still relevant. A diverse, multi-disciplinary group engaged in scenario planning for that effort, and this approach could be adapted for the Great Lakes.
- The Millennium Ecosystem Assessment project took place from 2000-2005. It had a global focus, with a significant freshwater component. The Great Lakes system was not "singled out" but the approach taken could have relevance provided that the "right" questions were asked.
- The political science literature relating to "future search" and "horizon planning" may be of interest.
- This interviewee has done a substantial amount of scenario planning, involving simulation models and a multi-disciplinary approach.
- A scenario planning project (supported by the National Science Foundation) focused on Wisconsin lakes and entailed the conduct of interviews with knowledgeable people with diverse perspectives. The interviews were structured to identify hopes and fears for the system, to determine what makes the system robust, and to identify risks. Multi-disciplinary workshops were then conducted, entailing the development of stories about the future of the system and identification of popular themes. A smaller group was then engaged to condense themes and write a story around them to generate alternative futures. A modeling team then refined those alternatives based on plausible future conditions and assumptions (e.g., climate change impacts, government interests) associated with an array of ecosystem services. The multi-disciplinary

group involved in the exercise included (among others) scientists, storytellers and artists, with the latter illustrating the scenarios.

- Some success is realized when social science organizational tools are brought together with simulation modeling grounded in the natural sciences.
- There is an extensive base of literature on normative scenarios that may be of relevance to this project.
- This interviewee indicated that he is not knowledgeable about political frameworks, but noted that a prospective GLEWS should have binational “buy-in” and the involvement of the many relevant parties (e.g., Sea Grant programs) that can add value to the effort. Engage key users early. IJC is in a good position to lead this effort.
- We tend to know less about the Great Lakes than the oceans or small inland lakes; a limitation that needs to be addressed. The lack of Great Lakes research makes it difficult to design, operate or modify a GLEWS. Increased availability of time series data would be very helpful.
- Adaptive approach: assess, learn, apply.

Interview #4

Summary Notes

- This interviewee focuses on future conditions such as climate change impacts. She identifies issues, threats, trends, and related sensitivities, and then prioritizes measures to detect them.
- Among others, she focuses on sedimentation, the movement of contaminants (over land and riverine), changes in algal bacterial assemblages, ice cover impacts of those assemblages, and invasive species.
- She examines physical processes to better understand impacts, potential consequences, when these events occur, and monitoring required to assess them.
- As one example, stream flow is an issue; a tool employed by the U.S. Army Corps of Engineers (USACE) involved the application of a statistical test to determine abrupt ecosystem changes and then manage stream flow accordingly.
- This interviewee also focuses on sea level changes, with requisite monitoring data provided by tidal gauge data.
- It is difficult to detect changes until they occur; it is necessary to have historical data to detect a change.
- This interviewee focused primarily on "big picture" and "over the horizon" thinking.
- USACE undertakes vulnerability assessments (e.g., watershed-level) that are reliant upon indicators and employ a weighted average methodology. Such tools are largely for internal use at USACE and are performed consistent with established USACE guidance that requires watershed vulnerability to be considered when determining appropriate actions to address a given problem. The tool can be updated, as needed. There is an interest in making the tool publicly available although that has not yet happened.
- USACE undertakes "horizon planning" and "scenario planning" in the interest of complying with its Principles and Guidelines. There is a strong emphasis on Cost/Benefit Analysis in this process.
- The USACE vulnerability assessment tool has been under development since 2011 and has entailed reaching out to academics, other agencies, and consultants. This was a particularly valuable aspect of the exercise. Some 600 indicators were originally identified and ultimately narrowed down to 27.
- This interviewee will make available two relevant journal articles by sending the links. She will also provide a user manual that relates to the vulnerability tool.
- It would be valuable to establish a GLEWS under the auspices of the IJC. The system should have multi-agency and academic involvement, employ one or more specific tools, be guided by a handbook, and produce published "futuring" information.
- This interviewee will provide time series information that may be of relevance.
- In developing a GLEWS, build on established practices and solicit long-term support and involvement of states and provinces as well as federal agencies.
- USACE maintains (internally) a "sea level tracker" tool that yields future change scenarios. This may be of some relevance to the development of a GLEWS.
- Interviewee has been involved in writing agency guidance relative to Great Lakes water levels.

- Key indicators of issues, threats, and trends may include, among others, air and water temperature, precipitation, ice freeze/thaw processes, dissolved oxygen levels, PH changes, growth kinetics, time horizons over which changes occur, fires in the Great Lakes basin (i.e., relative to drought), and the presence/types/populations of invasive species.
- The behavioral economics literature focuses, in part, on means to determine interventions to address emerging stressors; citations for articles by Richard, Falor, Kaversky and Sundstein are relevant and will be provided.
- Early interventions are more effective than addressing issues and threats after they occur.
- A case can be made that a GLEWS is necessary. The system is complex and there is a need for suites of indicators to know when a change in state occurs.
- A set of rules is needed (e.g., if a certain set of conditions are met, then we are seeing a change).
- “It’s OK not to have all the answers, but we need adaptive management.”
- The building blocks are out there for a GLEWS- there is a substantial amount of indicator-based literature. See the “wicked problems” literature from the 1970s.
- Information on stressors is needed to reach broad conclusions about system changes.
- USACE embraces the “co-production” of science; consensus papers produced by groups of scientists drawn from various agencies, academic institutions and others.
- “Co-production” is a similar notion to a “research brokerage” function; it entails a means to review and interpret available data and information by multiple parties in the interest of producing actionable findings by decision makers and resource managers.
- Consider consulting with David Behar regarding the work of San Francisco Public Utilities.
- This interviewee will provide her talking points relative to presentations she has given on communicating science.
- There are presently no funds within USACE to develop and operate a formal EWS for the Great Lakes or any other basin. The National Science Foundation and the National Academy of Sciences may have funding for such an initiative.
- A GLEWS should be “component based and modular” to easily update information; provide for open access on the Internet; be legally and scientifically sound (i.e., peer reviewed); be staffed by technically competent and objective individuals who care about the outcomes; and feature a multi-agency staffing arrangement to yield a more diverse and “solid” product. An EWS may also need an “authority figure”.
- Multiple disciplines should be involved in the development and operationalization of a GLEWS, including (among others) computer specialists (i.e., coders), data interpreters, and communications specialists. Administrative/overhead staff should be kept to a minimum. Staff members and operations should be nimble, agile, and cost-effective. If public funds are to be pursued for development and operations, the relevance of the EWS to agency missions must be clearly and convincingly explained (in the US) to the Congress and to the federal Office of Management and Budget.
- As far as operations are concerned, build on established practices and solicit long-term support and involvement of states and provinces as well as federal agencies. Perhaps look to young professionals who have enthusiasm and seek experience.

Interview #5

Summary Notes

- This interviewee is a social scientist whose research focuses, in part, on governance systems.
- Examining the public administration literature can be valuable, as it includes an examination as to how well systems are governed. It also provides insights into the ability to anticipate and respond to stressors.
- Much of the literature is backward-looking, but we need to focus on looking forward by examining indicators that can be employed to identify issues and trends and perhaps signal how well a system is being governed.
- Claudia Pahl-Wostl has undertaken a comparative analysis of 28 transboundary water systems; this may be of relevance to our project.
- Another academic (US) that may be worth contacting is Anita Milman- her research may also be relevant.
- This interviewee is not aware of any examples of water systems or other governance arrangements that have a formal EWS in place.
- There is a Northern Emergency Management Assistance Compact in the northwest between various states and provinces; it maintains a strategic plan for responding to issues and stressors. While it is not anticipatory, the compact may have some relevance to this project.
- There is a substantial body of data and information on the Great Lakes that focuses on threats and stressors, but it lacks a forward-looking focus.
- A GLEWS is needed. It may push policy makers and public servants to look beyond the current three to five year time frame.
- The Great Lakes governance system (e.g., IJC, Great Lakes Commission, Great Lakes St. Lawrence Cities Initiative) should be supportive of a GLEWS. The various layers of Great Lakes governance operate distinctly, but such an EWS could pull them all together.
- The IJC is a logical candidate to lead, coordinate, and house such an initiative.
- Since many threats and stressors have a local dimension, it is best that any EWS have a strong local component.
- In order to establish and maintain an effective and sustainable EWS, governments must exhibit the requisite level of political will, as well as the funds required to operate and maintain such a system.
- This interviewee is not aware of any EWS at a basin level but, on a global scale, there are examples of such systems as related to earthquakes, floods and other natural disasters.
- The USEPA (Office of Water) has published a paper on EWSs that will be relevant to this project.
- There have been various workshops in other basins to look for, and at emerging issues and threats.
- A large number of published articles focus on what an EWS should look like; they range from those with a citizen science focus to those with high-level science platforms.
- Engaging key players within the Great Lakes governance arena will be key to success; the IJC is in a good position to lead and manage this effort.

- No one else is currently focusing on the development of a GLEWS.
- In addition to its design, a key challenge will be to operationalize such a system. The Great Lakes Observing System, along with other entities, should be engaged. The best approach is to start small, engaging 5-10 experts for input and then developing a framework through a scalable demonstration.
- Examine the Organization for Economic Co-operation and Development (OECD) as a prospective entity for identifying "best practices." Thirty six governance indicators have been developed, and follow-up on 12 principles is underway. Details will be published in a March 2018 article and presented at the upcoming World Water Forum.
- There is presently a group within the IJC looking at adaptive management and governance; it may be worthwhile to examine those efforts.

Interview #6

Summary Notes

- This interviewee manages a science program at Environment Canada that focuses, in part on AIS. This is a good example of the unintended impacts of such species and the visioning required to anticipate and prevent problems.
- "The Binational Rapid Response Plan for Aquatic Invasive Species" prepared by M. Donahue (with extensive involvement of Gavin Christie and others) has a number of elements relevant to the development of a GLEWS.
- There is a role for "Traditional Knowledge" (i.e., indigenous peoples) in the development of a GLEWS. Environment Canada's Arctic Science Program is a good example of this, particularly as it relates to "co-management" of the resource.
- The "Traditional Knowledge" approach is one of "looking forward by looking back."
- It is important to think on a large scale (e.g., climate change impacts) to maximize the value of an EWS. Annex 9 of the GLWQA was noted.
- The AIS issue is a good example of the prospective value of an EWS; fisheries management offer many examples of stressors and associated issues. Fisheries managers have a strong reliance on science-based advice associated with total allowable catch. Management issues are difficult due to the array of resources users (e.g., recreational, commercial, aboriginal).
- Changes in prey species abundance and the nutrient regimes are examples of important indicators, and can assist in management decision-making.
- We need to identify future stresses to facilitate a response to large-scale regime shift. Examining changes in one lake (e.g., Lake Huron) can provide insights into management approaches in another lake (e.g., Lake Ontario).
- The fisheries management community does not engage in as much forward-looking thinking as it should; they tend to focus on the problems at hand as opposed to looking "over the horizon."
- The Strategic Great Lakes Fisheries Management Plan developed by the Great Lakes Fishery Commission (GLFC), as well as the GLFC's committees (e.g., Lake and Technical), are good examples of how science and management can be connected to inform decisions.
- The AIS issue is a good example as to how a problem "pathway" can be identified, and how probabilities can be assigned to certain scenarios.
- The "shiny penny" problem is in play as far as current and emerging issues are concerned. Politicians, in particular, tend to focus on the priority problem of the day as opposed to focusing on longer term, emerging issues.
- The work that M. Donahue did for the IJC in developing a "Binational Rapid Response Plan for Aquatic Invasive Species" is a good example of an EWS approach to a Great Lakes issue. As a second line of defense (i.e., rapid response if prevention fails), it has merit and applicability to the formation and operation of a GLEWS.
- Climate change researchers and managers are trying to relate temperature and system variability to ecosystem function changes.

- In establishing a GLEWS, key considerations include building on the advantages and successes of ongoing shared efforts; looking to the IJC as a prospective candidate (among others) to house a GLEWS function; addressing and resolving the “tension” between federal, state and provincial efforts; carefully considering tools, systems and structures to engage the thoughts and ideas of a large array of interested parties (including municipalities); and undertaking a thorough risk assessment of emerging issues (e.g., microplastics).
- A “blue ribbon panel” is one approach that could be used in establishing and operating a GLEWS.
- The IJC boards under the GLWQA have the potential to perform some prospective EWS functions but “have not taken it further.”
- We should look to other disciplines (e.g., technology development, medicine, other areas of science) to study how they approach this topic and see if lessons can be gleaned for prospective application.
- The National Academy of Sciences and the Royal Society of Canada may be good models for how review panels should be established and operated.
- Consider also the “Canadian Scientific Advice Secretariat” (possibly under the Department of Fisheries and Oceans) as a prospective model for how science and management can connect to inform the decision-making process.

Interview #7

Summary Notes

- The Council of Great Lakes Industries (CGLI) has addressed this matter in the past; conversations with the IJC took place several years ago.
- This interviewee consulted with selected members of her organization in preparing her responses.
- CGLI members are used to dealing with changes in the Great Lakes, such as fluctuating lake levels, various seasonal cycles, and other established and/or evolving issues. These issues are typically accommodated in company business plans.
- Key areas of concern include trends and developments in the regulatory, legal and policy arenas that impact company operations (e.g., 315(b) rule, impingement/entrainment, invasive species and their impacts). Other issues include such matters as the current review of the water diversion compact managed by the Great Lakes governors and premiers.
- It is important to take a "systemic" view of the Great Lakes when identifying and analyzing emerging issues; a stressor in one part of the system may impact another part of the system.
- Climate change is a stressor for industry, but in a long-term sense.
- Specific impacts associated with climate change, however, are of heightened concern, such as climate-induced lake level fluctuations that raise concerns about the resiliency of industry located on the coast or dependent upon water access.
- While the development of a GLEWS should be focused primarily on the water resources in the binational region, accommodations must be made for land-based issues as well as the human system.
- A primary challenge is one of predicting and responding to issues and trends that are on (or beyond) the horizon (i.e., those that have not yet become problems).
- "An Early Warning System for things we expect is not as valuable as an Early Warning System for the things we do not expect."
- The insurance industry is quite adept at focusing on trends and future prospective issues and problems; that perspective should be accommodated in this project.
- CGLI members believe there is a wealth of data and information on conditions, issues and trends that should be sufficient to provide the basis for a GLEWS. There are also perceptions that research/monitoring activities and outcomes are not adequately connected to resource managers. Emphasis should be placed on "connecting the dots" among existing efforts rather than developing new mechanisms for detecting and responding to issues and threats. "If we did what we are doing now a little better, we would have an Early Warning System."
- Timeliness is an issue; real-time information is necessary to facilitate industry response to emerging issues and threats.
- Industry "can do better" with long-term thinking.
- With regard to obstacles and opportunities, "many of the pieces are out there" but need to be better integrated.

- It is important to demonstrate relevance and "bottom line" impact to keep industry engaged and supportive. For example, the Cleveland water utility likes the Great Lakes Observing System because it finds value in the value of a data/information gathering buoy in its vicinity.
- It is a challenge to organize businesses around a given initiative due to diverse interests and priorities.
- An EWS that features information on regulatory issues and trends would be of particular interest to CGLI members.
- Some stressors have a strong connection to industry (and the personal interests of industry representatives) while others are of little immediate interest. Demonstrating broader relevance is critical.
- CGLI members primarily represent land-based, heavy manufacturing companies with a water connection. It is recognized that other sectors of Great Lakes industry (e.g., recreational fishing, water-based tourism) will have other interests in the types of threats and stressors that an EWS might address.

Interview #8

Summary Notes

- This interviewee had previously worked with the IJC on a project to harmonize data between Canada and the United States.
- The lack of standardized data is a problem; a system to address this is needed.
- Noteworthy threats and stressors include algal blooms (at the top of the list), E.coli, other "standard" public health indicators, and issues of current/emerging concern.
- There is no standard process relative to identifying current and emerging issues and threats on a resource-specific basis.
- Highly visible issues, such as algal blooms, rely in part on public notices.
- Surveillance data is typically available in sufficient detail to identify some trends. However, data access is a big issue that limits the ability to methodically identify many others.
- We often have a data-rich environment, but access is often not complete.
- The Great Lakes region has some great academics and researchers but their work is rarely informed by practitioners; this limits their focus on current and emerging issues. The extent of this limitation is a function of area and context.
- Disease surveillance is a good example of the strengths and limitations of our ability to identify current and emerging issues. Acute illnesses with a high risk of spreading (e.g., measles) have a sophisticated tracking process that is set up to run continuous algorithms as new data comes in, facilitating identification of conditions that require public health alerts. Such a system is in place for Ontario's 36 regional health authorities.
- There is a real challenge in establishing and operating an EWS for environmental data because such data are often collected on an infrequent basis (e.g., annually). In contrast, public health data are often collected every few hours. Therefore, we need a real-time approach for environmental data as well.
- The "essential components" of a GLEWS include sufficient standardized and harmonized data, adequate staffing with a high level of expertise, and a well-connected, well-coordinated multi-disciplinary team.
- One potential model is the public health system in Ontario; the provincial Ministry of Environment and the local health units communicate on a regular basis.
- Given the differences between public health and environmental data and, specifically, the variation in the frequency of data collection, expanding the existing public health surveillance program to include environmental data is not advisable. However, linking the public health web sites with the online component of a prospective GLEWS, where possible, has merit.
- An additional challenge is the fact that public health data in Ontario are largely proprietary and not readily available to the public.
- Rules and regulations differ between Canada and the United States relative to the proprietary nature of public health data. However, there is more flexibility relative to environmental data.

- Long-term thinking is desirable in identifying and evaluating both chronic and acute impacts of environmental stressors. This also intersects with long-term planning decisions for commercial operations.

Appendix C. Workshop Materials and Participants

WORKSHOP AGENDA

Purpose: *A select, multi-disciplinary group of experts will assist the International Joint Commission in developing the framework of a Great Lakes Early Warning System, and identifying a preliminary list of emerging ecosystem threats and stressors.*

May 14

1:00 pm	Welcome and Introductions	*Michael Twiss and Lucinda Johnson, Work Group Co-chairs, IJC Science Advisory Board*
1:05 pm	Project Purpose and Background	*Michael Twiss and Lucinda Johnson*
1:10 pm	Workshop Objectives and Methodology	*Mike Donahue and Tad Slawecki, Project Principals*
1:15 pm	Progress to Date	*Mike Donahue and Tad Slawecki*
1:30 pm	Panel Session: Perspectives on Emerging Ecosystem Threats and Stressors	*Moderator: Tad Slawecki*
	Stephen Ruberg, Group Leader, Marine Instrumentation Lab, NOAA - GLERL *Ryan Batt, Post-Doctoral Fellow, National Academy of Sciences* *Stephen Brandt, Professor, Oregon State University, Chair, Delta Independent Science Board*	
2:30 pm	Break	
2:45 pm	Charge to Breakout Groups and Introduction to The Nominal Group Technique	*Mike Donahue*
3:10 pm	Facilitated Small Group Discussions: Identifying Emerging Great Lakes Threats and Stressors	*Small groups to be assigned; each with a facilitator, recorder and reporter*
	1. Each individual identifies their "top three" emerging threats /stressors and explain why they were selected? *2. The group prioritizes the threats/stressors as "high", "medium" or "low" for tracking by an Early Warning System.*	
4:30 pm	Plenary Session - Reporting Out	*Assigned Reporters- Small Groups*

4:55 pm	Summary and Preview of Day Two	*Mike Donahue, Tad Slawecki*
5:00 pm	Adjourn	
6:30 pm	Dinner at Rock Bottom Bar & Grill	3236 Sandwich Street, Windsor (Directions to be provided at meeting)

May 15

8:00 am	Day One Recap and Day Two Focus	*Mike Donahue, Tad Slawecki*
8:10 am	Introducing Alternative Frameworks for a Great Lakes Early Warning System	*Mike Donahue*
8:20 am	Panel Session: Perspectives on the Design and Operation of Early Warning Systems	*Moderator: Mike Donahue*

Phyllis Green, Superintendent, Isle Royal National Park, National Park Service
Lewis Linker, Modeling Coordinator, Chesapeake Bay Program Office
Robert Hirsch, Research Hydrologist, US Geological Survey
Gavin Christie, Division Manager, Fisheries and Oceans Canada

9:20 am	Break	
9:35 am	Charge to Breakout Groups	*Mike Donahue*
9:40 am	Facilitated Small Group Discussions: Selecting a Preferred GLEWS Framework	*Small groups to be assigned; each with a facilitator, recorder and reporter*

1. *Based on the prioritized threats/stressors and the "alternatives" handout, each individual identifies a preferred GLEWS framework (or hybrid thereof) and presents their rationale.*

2. *The group selects, by consensus, a preferred framework and offers additional detail on key components and functions of that framework.*

11:15 am	Plenary Session – Reporting Out	*Assigned Reporters – Small Groups*
11:50 am	Summary and Next Steps	*Mike Donahue and Tad Slawecki*
11:55 am	Closing Remarks	*Michael Twiss and Lucinda Johnson*
12:00 pm	Adjourn	

WORKSHOP PARTICIPANTS

Workgroup Chairs

Michael Twiss	Clarkson University
Lucinda Johnson	University of Minnesota-Duluth

Contractor Staff

Mike Donahue	AECOM
Tad Slawecki	LimnoTech

IJC Staff

Matthew Child	International Joint Commission
Li Wang	International Joint Commission
Glenn Benoy	International Joint Commission
Michael Mezzacapo	International Joint Commission
Victor Serveiss	International Joint Commission
Mark Burrows	International Joint Commission

Panelists

Steve Ruberg	NOAA-GLERL
Steve Brandt	Oregon State University
Ryan Batt	Rensselaer Polytechnic Institute & Rutgers University
Gavin Christie	Fisheries and Oceans Canada
Phyllis Green	U.S. National Park Service
Lew Linker	U.S. Geological Survey

Other Participants

Val Klump	University of Wisconsin-Milwaukee
Al Steinman	Grand Valley State University
John Livernois	University of Guelph
Kathryn Buckner	Council of Great Lakes Industries
Jan Ciborowski	University of Windsor
Dale Phenicie	Council of Great Lakes Industries
Kathryn Friedman	University of Buffalo
Jon Hortness	U.S. Geological Survey
Craig Stow	NOAA-GLERL
Carol Miller	Wayne State University
Bob Hecky	University of Minnesota-Duluth
Ian Campbell	Agriculture Canada
Norm Grannemann	U.S. Geological Survey (retired)
Mike Murray	National Wildlife Federation
Bogdan Hlevca	Ontario Ministry of Environment
Abdullah Alotaibi	Ryerson University
Fred Luckey	U.S. Environmental Protection Agency
Pam Joosse	Agriculture Canada
Daniel Jobin	Kije Sipi
Merrin Macrae	University of Waterloo
Gust Annis	The Nature Conservancy
Patricia Chambers	Environment Canada

Note: In addition to the agenda provided in Appendix C, Expert Workshop materials also included an "**Abbreviated Literature Review Summary**", a summary of "**Survey Responses**", and a descriptive inventory of **"Alternative Organizational Arrangements for a Great Lakes Early Warning System".** These items are included in the main body of the report (Section II.A, Appendix A, and Section III.B, respectively) and therefore are not included here.