Information Coordination and Flow in the Great Lakes Basin

Prepared by the
Great Lakes Science Advisory Board
Science Priority Committee
Information Coordination and Flow Work Group

Submitted to the International Joint Commission

January 2018

Acknowledgements

The Science Advisory Board's Science Priority Committee acknowledges the excellent efforts of the Information Coordination and Flow Work Group and the extensive work of the contract team from the Great Lakes Commission and LimnoTech. The team's report provided the basis for this report and its recommendations. Thanks also to all individuals who provided their valuable input through their participation in the workshop, surveys and interviews for this project.

Primary Authors

Scott Sowa (Work Group Co-Lead), The Nature Conservancy
Lucinda Johnson (Work Group Co-Lead), University of Minnesota

Work Group Members

David Allan, University of Michigan and US EPA Great Lakes Advisory Board Science and Information Subcommittee Liaison
Steve Cole, Blue Accounting
Norm Granneman, US Geological Survey - Retired
Henry Lickers, Annex 10 Traditional Ecological Knowledge Work Group Liaison
David Lodge, University of Notre Dame
Chris Metcalfe, Trent University
Carol Miller, Wayne State University
Kelli Paige, Great Lakes Observing System
Dale Phenicie, Environmental Affairs Consulting
Jen Read, Annex 10 Data Management and Sharing Subcommittee
Jeff Ridal, St. Lawrence River Institute of Environmental Sciences
Christina Semeniuk, University of Windsor
David Ullrich, Great Lakes St. Lawrence Cities Initiative

Contract Team

John Bratton, LimnoTech
Samuel Molnar, Great Lakes Commission
Victoria Pebbles, Great Lakes Commission
Michael Polich, Great Lakes Commission
Tad Slawecki, LimnoTech

IJC Staff

Antonette Arvai, International Joint Commission (Great Lakes Regional Office)
Matthew Child, International Joint Commission (Great Lakes Regional Office)
Victor Serveiss, International Joint Commission (US Section)
Glenn Benoy, International Joint Commission (Canadian Section)

Executive Summary

In 2014, the International Joint Commission (IJC) asked the Great Lakes Science Advisory Board's Science Priority Committee (SPC) to identify a subset of the 16 ecosystem indicators that could tell meaningful and compelling stories to decision makers and the public about the status of water quality in the Great Lakes. This charge to the SPC was generally referred to as "identify the fewest that tell us the most." The SPC formed a Communications Indicator Workgroup (CIW) to address this charge, which developed an objective, repeatable process to assess the "communicability" of these indicators. Using this process, the CIW identified eight of the 16 indicators that should be the focus of communicating progress toward the Great Lakes Water Quality Agreement (GLWQA) objectives to the public (SAB-SPC, 2016).

However, the CIW found that it is impossible to tell meaningful and compelling stories with only ecosystem indicators because they provide a small, but important, component of a much larger story. Consequently, the CIW recommended that future Triennial Assessments of Progress (TAP) by the IJC focus on telling more *complete* stories around these eight ecosystem indicators by bundling them with related stressor, program and socioeconomic (e.g., human health) indicators in a manner that helps to answer all facets of the following question: "How are our investments and management programs doing to address the key stressors and help to maintain or restore the ecological and socioeconomic conditions associated with the GLWQA objectives?" The CIW recommended that the assessment process be applied to these other types of indicators. Finally, the CIW found that much more attention has been given to proper collection of data compared to the proper management and delivery of relevant information to decision makers and the public, and recommended immediate steps be taken to address this lack of attention. The Information Coordination and Flow Workgroup (ICF) and the project covered in this report grew directly out of these findings and recommendations.

The purpose of this project was to assess the flow of information to decision makers in the Great Lakes, identify barriers to the flow of this information, and provide recommendations to the IJC and the Parties to address these barriers. The goal of our project was to develop and apply methods of assessing and identifying barriers to the flow of information needed to a) assess programs and progress towards GLWQA objectives and b) support resource allocation decisions that seek to help achieve the objectives of the GLWQA. The specific objectives of our project were to:

1. Identify and assess programs and efforts that manage and deliver information to Great Lakes decision makers
2. Develop and apply an information flow assessment process for two GLWQA objectives

3. Assess opportunities and approaches to include traditional ecological knowledge (TEK) of indigenous peoples into the information available for Great Lakes decision makers.

There are many Great Lakes agencies and organizations responsible for the collection, management and delivery of data and information related to the general objectives of the GLWQA. To address Project objective 1, we compiled a general inventory of these programs for each of the major indicator categories (i.e., ecosystem, socioeconomic, stressor and program) and used it to assess the level of emphasis placed on each of the six major components of information flow:

1. planning and goal setting
2. data collection
3. data management and sharing/delivery
4. data analysis and reporting
5. knowledge management and delivery
6. information management and delivery

We also conducted a workshop that sought to bring together representatives from these programs to increase the collective understanding of information management and delivery, to foster greater communication and collaboration among these Great Lakes programs, and to conduct group exercises that complement the analyses based on the inventory.

For Project objective 2, we developed an information flow assessment process that consisted of three complementary activities: an online survey, interviews, and information flow assessments for specific indicators and metrics. The surveys and interviews focused on Great Lakes resource professionals and attempted to identify information needs of these individuals and the challenges, solutions, and success stories for meeting these information needs. Due to time and resource limitations, the tabular assessment used a much simpler process than the assessment of communicability developed by the CIW. We also determined that it was only feasible to assess barriers to information flow for two of the nine general objectives of the GLWQA. General objective ii and vii of the GLWQA were ultimately selected based on interest and activity of IJC and annex workgroups. These two general objectives state the Great Lakes should:

- Objective ii: “allow for swimming and other recreational use, unrestricted by environmental quality concerns” and
- Objective vii: “be free from the introduction and spread of aquatic invasive species (AIS) and free from the introduction and spread of terrestrial invasive species that adversely impact the quality of the Waters of the Great Lakes.”

For this report, we generally refer to these two general objectives as "issues" or more specifically AIS and recreational use.

Finally, for Project objective 3, we conducted a literature review and expert interviews to identify approaches for incorporating traditional ecological knowledge into the information available to and used by Great Lakes decision makers.

Results from the analyses conducted on the program inventory and at the workshop showed that we dedicate most time and resources to the collection, management and analysis of data and much less attention to delivery of information to decision makers. In fact, we were unable to find a single example of a regional or basinwide decision maker who had access to the necessary information for assessing programs and progress to accomplish GLWQA objectives and making well-informed resource allocation decisions. However, there are some programs that come close to meeting this high standard of information delivery and can serve as models, such as the Great Lakes Fisheries Commission sea lamprey control reports (http://www.glfc.org/pubs/slcp/annual_reports/ANNUAL_REPORT_2015.pdf), and Environment and Climate Change Canada's environmental sustainability reports (http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=47F48106-1). We also found that the Great Lakes is a relatively data rich region, with monitoring programs that routinely collect ecological, socioeconomic and threat/stressor data that could be integrated to tell more complete, meaningful and compelling stories for many of the general GLWQA objectives. The lack of collaboration among these monitoring programs is the primary barrier to the integration of these data that must be addressed. We also found that decision makers are rarely asked about their information needs and even when the relevant data are available, they are often difficult to find or in unusable formats.

From Project objective 2, we found that lack of sustainable funding was a consistent problem affecting programs and efforts associated with all six components of information flow. We also found that local decision makers consistently had a more complete set of relevant data upon which to make decisions, compared to regional and basinwide decision makers who must rely on the aggregation of local datasets to generate information at their scale of interest. We found some major strengths and weaknesses when looking at each component of information flow.

A strength of the planning and goal setting component was that general goal statements were consistently developed for both issues in the basin for all three scales we assessed (i.e., local, regional, and basinwide). These general goals provide the foundation for good information flow and decisions. General goal statements were most consistently developed for ecological conditions; however, there were also instances where they were expressed for socioeconomic conditions and program operations. A weakness in this component was the lack of specific

metrics and indicators to measure progress toward these general goals, and also a lack of specific goals or benchmarks for these indicators when they did exist.

A strength of the data collection component was the availability of good data for generating relevant metrics and indicators for threats/stressors, ecological condition, and socioeconomic conditions at all three spatial scales. Data for program metrics and indicators are much scarcer. Fragmentation of data collection efforts and a lack of collaboration and collection standards among those efforts were consistently cited as two of the biggest barriers to the aggregation and delivery of data within this component of information flow. All findings are consistent with findings from Project objective 1.

For the data management and delivery component we found several good online databases that provide easy access to relevant data for both issues, such as the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS), Open Data Canada, BeachGuard, and Beach Advisory and Closing Online Notification (BEACON). But we also found many weaknesses in this component, such as the lack of data sharing and licensing agreements, inability to share sensitive data, and incompatible data formats that were barriers to aggregate local datasets for nearly all the indicators we assessed.

Despite the barriers mentioned above, the data analysis and reporting component of information flow is an area of strength for both general objectives. We found many excellent examples of analysis and reporting for both issues that covered all three spatial scales and occurred on regular annual or longer-term cycles. These include the State of the Great Lakes (SOGL) and TAP reports of the Parties and the IJC, respectively, state and provincial annual AIS and water quality reports, and many municipal and tribal reports. However, we also found a lot of variation in the content and quality of the reports. Some reports were largely narrative and qualitative, others were highly quantitative but lacked context, while others provided a mix of these two aspects. Most of these reports focus almost exclusively on ecosystem indicators, but a few also cover the other major indicator categories. Another interesting finding was that most reports are still delivered as PDFs on the US side of the basin, whereas interactive online reports are more prevalent in Canada.

Knowledge management and delivery is another area of strength for both general objectives. We found abundant online resources and excellent networking among education and outreach programs for both issues, particularly related to educating key members of the public and training resource professionals in best management practices.

Similar to Project objective 1, we were unable to find an example of a decision maker who is receiving appropriate information on integrated assessments across the relevant threat/stressor, program, ecological and socioeconomic indicators to help them assess progress and make well-

informed resource allocation decisions for either issue. There are emerging programs and initiatives, like Canada's Results and Delivery Program that grew out of the recently established Policy on Results and the Blue Accounting initiative, which resulted from a recommendation by the Council of Great Lakes Governors and Premiers that aspires to deliver this more complete set of information to decision makers. However, it is too early to make an informed assessment of the success of these efforts.

For Project objective 3, we understand that the underlying concepts of knowledge differ between indigenous and non-indigenous groups. Traditional ecological knowledge (TEK) is a relational process for indigenous peoples that is built through experience and relationships that are difficult to incorporate into non-indigenous information systems and decision frameworks. We found that current information flows to Great Lakes decision makers allow for limited use of TEK for governance and planning; thus, TEK is mainly used to supplement and validate data collected through traditional scientific methods. Some key barriers to transmission of TEK to non-indigenous agencies and scientists include concerns regarding commodification of knowledge focused on topics having spiritual value (e.g., sturgeon or wild rice) or divulging information that might be used to exploit a critical resource (e.g., genetic material, distribution maps of wild rice). The governments of both countries have made commitments to include the perspectives of indigenous peoples in decision making; it is now incumbent upon program leaders to develop the appropriate protocols for including indigenous people in decision making bodies. This will require consideration of cultural sensitivities and patience on the part of all involved, including development of ongoing mutual relationships that exhibit reciprocity and respect.

There were many important findings not necessarily associated with any specific objective of the project. First, we found our project to be very timely. There has been a recent surge of interest in the areas of accountability, information delivery, and monitoring a broader set of indicators to provide decision makers and the public with more complete and meaningful stories. Individuals continually expressed the need and an interest to foster collaboration among these efforts to support shared learning and minimize unnecessary duplication of effort. Despite this increased interest, we found the topic of information management and delivery and the terms in Appendix A of this report are still unfamiliar to many resource professionals in the Great Lakes.

We also found a lack of real-world examples or case studies to demonstrate the value of integrating data across complementary metrics and aggregating these data across scales that support well-informed regional and basinwide decisions. There are data gaps that must be addressed before we can create robust case studies; however, this project did find some hope for creating these real-world examples in a relatively short time period, particularly with regard to integrating ecological and socioeconomic metrics.

Finally, the most important lesson we learned was that paying attention to all six components of information flow is an essential but extremely complex process that will require a long-term commitment and must be broken down into manageable pieces and steps. This is essentially what the IJC and the Parties did from the 1970s to early 2000s by largely focusing on ecosystem indicators rather than the broader set of indicators. The amount of time, money and effort that has gone into putting in place the governance and funding structures to do the science, planning, monitoring and reporting for ecosystem indicators has been staggering and the progress has been phenomenal. But our project and the CIW project collectively found that by focusing on ecosystem indicators we have, by analogy, essentially built all components of a car except the dashboard and steering wheel. The following recommendations center on how we begin to build these last two key components of the "car" and continually design new and improved models over time.

Recommendations

1. ***The IJC and the Parties should take steps to more equitably invest time and resources in all major components of information flow.*** We believe addressing the subsequent recommendations go a long way toward fully addressing this first recommendation.

2. ***The IJC and the Parties should make a long-term commitment to improving information flow to decision makers and the public.*** Effective information management and delivery is a persistent challenge that requires constant attention and a goal of continual improvement. The most important lesson we have learned from this and other projects is that performing "information flow audits" and developing sound information management and delivery strategies is unfamiliar territory to most Great Lakes natural resource professionals. To address this challenge, we believe the IJC should:

    a. Support development of a binational forum that fosters a regular dialogue among relevant programs and efforts (e.g., Annex 10 Data Management and Sharing Task Team, Blue Accounting, Canada's Policy and Results program, Global Earth Observation System of Systems (GEOSS), Great Lakes Advisory Board (GLAB) Science and Information subcommittee, Great Lakes Observing System (GLOS), and others) focused on generally improving information flow in the Great Lakes.
    b. Convene a regional discussion to define the entity or entities that are best positioned to facilitate information management and delivery related to the specific goals of the GLWQA.

3. ***The IJC and the Parties should support and build upon existing efforts to track and report on relevant threat/stressor, program, and socioeconomic metrics and indicators.*** The IJC's efforts to identify human health and program indicators were important steps in improving information flow across the Great Lakes. However, these efforts need to be more focused by

identifying relevant metrics and indicators related to each of the general objectives of the GLWQA, especially those socioeconomic and program indicators that are viewed as a priority by decision makers. The IJC should support and foster collaboration among complementary efforts that are addressing these types of metrics and indicators, such as Canada's Results and Delivery Program and Blue Accounting. The IJC should also encourage those responsible for SOGL reporting to collaborate with these complementary efforts in order to focus these reports on status and trends in ecosystem indicators and enable them to be integrated into the broader sets of indicators. This will provide more comprehensive assessments and reports to decision makers and tell more complete, meaningful and compelling stories in future TAPs.

4. ***The IJC and the Parties should immediately take steps to address barriers to information flow.*** There are some obvious and/or relatively easy steps the IJC could take or promote to improve the flow of information to decision makers. These include:

    a. implementing already identified data collection and sharing policies needed to aggregate datasets for individual ecosystem metrics up to regional and basinwide scales. We believe the Annex 10 Data Management and Sharing Task Team should take the lead on prioritizing these relevant policies as they relate to specific sets of drivers-pressures-state-impact-responses metrics tied to each general objective of the GLWQA.
    b. encouraging collaboration of the Parties and IJC staff and boards with representatives of state, provincial and federal agencies that collect, track and report on socioeconomic metrics, such as the US Census Bureau, US Centers for Disease Control and Prevention, Statistics Canada and the Public Health Agency of Canada. Starting these collaborations is an important step toward making the integration of ecological and socioeconomic data routine.
    c. encouraging the Annex 4 and 6 work groups and task teams to address the specific barriers to information flow identified in Project objective 2. Specifically, we believe these work groups should review the detailed findings and recommendations laid out in the contractor's report provided in Appendix C of this report.

5. ***The IJC should ask the Parties to facilitate information flow assessments for each of the general objectives in the GLWQA using the recommended approach provided in this report***. Identifying barriers to information flow is a complex process. Breaking down the assessment of information flow into manageable steps will lead to a more efficient and effective means of identifying and addressing barriers to information flow. This approach is likely to lead to tangible case studies that demonstrate how specific barriers to information flow (e.g., Table 4, section 2.4 of this report) can be addressed to more efficiently and effectively deliver relevant information to decision makers. This work could be conducted

through existing groups such as the Annex Committees, Lake Committees, or other issue-specific partnerships such as Great Lakes Aquatic Nuisance Species Panel, Great Lakes Beach Association, Great Lakes Source Water Initiative or the Great Lakes Coastal Wetlands Working Group. We believe these groups are best suited to identify the specific sets of metrics and indicators for assessing barriers to the delivery of information to decision makers. Effort should be made to constantly improve the recommended assessment process to make it more objective, repeatable and scientific. The information flow audit should:

a. document the data and information needs of Great Lakes decision makers especially as they relate to setting priorities and making investments to achieve the objectives of the GLWQA.
b. identify data gaps and identify barriers to information flow that inform decision making for each of the general objectives of the GLWQA using the framework laid out in section 4.4.8 and Table 9 of this report.
c. identify specific policy solutions (see Table 4 and Appendix C) and processes to assess progress towards addressing gaps and barriers to information flow. These can be included in future Triennial Assessment of Progress reports or other special reports.

6. ***Traditional ecological knowledge (TEK) should be incorporated into all facets of information flow assessments and efforts to improve the flow of information to decision makers.*** To benefit from TEK, indigenous groups, non-indigenous agencies and scientists must establish ongoing mutual relationships that exhibit reciprocity and respect, and all parties must be included in all six components of information flow. Consideration should be given to cultural sensitivities in the way that different types of information are used in knowledge and governance systems and should embrace the concepts of free, prior and informed consent when entering into agreements. Both Parties have recognized the importance of TEK and the governance systems of native people that support this; the Parties must now implement principles and protocols for delivering information and knowledge in an appropriate manner.

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

Accountability and adaptive management are two of the core principles of the Great Lakes Water Quality Agreement (GLWQA, 2012). For several decades, the IJC, the Parties and many other stakeholders in the Great Lakes have invested significant time and resources to ensure adherence to the principle of accountability. Most of these investments are aimed at fulfilling the obligations laid out in Article 3 of the GLWQA. Article 3 specifies the agreed upon general objectives, the requirements for creating specific objectives, and the associated monitoring and reporting procedures needed to assess progress towards these objectives (IJC, 2014). Most recently, the IJC and the Parties have focused significant attention on identifying the right set of *ecosystem indicators* to assess progress towards these general and specific objectives (IJC, 2014; ECCC and USEPA, 2017) and more effectively communicate progress to the public (SABSPC, 2016). The IJC and the Parties are commended for this persistent emphasis on accountability to ecosystem objectives.

The IJC and the Parties have invested much less time and resources into adhering to the principal of adaptive management. This is understandable given the fact the information needs for adaptive management are a bit more complex and challenging even under the more simplistic definitions (Walters, 1986; NRC, 2004; Stankey et al., 2005; Williams and Brown, 2014) (Table 1).

Table 1. Basic steps in the adaptive management process as used in this project

1. Identify challenges and set general goals/objectives
2. Develop strategies to guide investments in policies and programs that seek to get the right management practices to the right places in the right amount at the right time to achieve the goals/objectives
3. Identify performance metrics and indicators with goals to help track and assess progress towards short and long-term outcomes
4. Implement strategies
5. Monitor and analyze the performance metrics and indicators on a regular basis
6. Deliver relevant information in desired formats to decision makers so they can assess collective progress and their respective contribution/progress
7. Adapt goals and strategies as necessary
8. Share relevant knowledge throughout the process so all stakeholders can properly interpret the relevant data/information and make informed decisions

At the heart of adaptive management are many resource allocation decisions that seek to achieve the four Rs, i.e., get the *right practices* to the *right places* in the *right amount* at the *right time* to achieve your objectives (Williams and Brown, 2014; Fales et al., 2016). Making these decisions

requires a broad set of related performance metrics and indicators that allow decision makers to collectively assess status and trends across these indicators so they can answer some fundamental questions (Table 2) and make informed resource allocation decisions (Salafsky et al., 2002; Tear et al., 2005; Sowa et al., 2016).

Table 2. Examples of questions answered by retrospective and forward-looking assessments, with example metrics or indicators used to answer those questions

Indicator Type	Retrospective (Status and Historic Trends)	Forward Looking (Potential Future Trends)
Threats/Stressor	What have been the most pressing problems (threats/stressors) facing the Great Lakes?	In the future, what will likely be the most pressing problems (threats/stressors) facing the Great Lakes?
Threats/Stressor	What problems (threats/stressors) have we/I been trying to address?	In the future, what problems should we/I focus on?
Program	How much have I/we invested collectively in trying to address all of these problems?	In the future, how much should we/I be investing to collectively address these problems?
Program	How much have I/we invested in trying to address each of these problems?	In the future, how much should I/we be investing into addressing each of these problems?
Program	What specific policies, programs and practices have I/we invested in and how much?	In the future, what specific policies, programs and practices should I/we be investing resources in and how much?
Program	Where in the Great Lakes have I/we invested resources and how much?	In the future, where in the Great Lakes should I/we be investing resources and how much?
Ecological	What are the status and trends in the overall ecological health of the Great Lakes?	What are the projected future trends in the overall ecological health of the Great Lakes?
Ecological	What are the status and trends in particular components of ecological health of the Great Lakes?	What are the future trends in particular components of ecological health of the Great Lakes?
Ecological	Where are ecological conditions improving and declining?	Where are ecological conditions projected to improve and decline?
Socioeconomic	What are the status and trends in the overall socioeconomic health of the Great Lakes?	What are the projected future trends in the overall socioeconomic health of the Great Lakes?
Socioeconomic	What are the status and trends in particular components of socioeconomic health of the Great Lakes?	What are the projected future trends in particular components of socioeconomic health of the Great Lakes?
Socioeconomic	Where are socioeconomic conditions improving and declining?	Where are socioeconomic conditions projected to improve and decline?

The Parties are committed to using the Driver, Pressure, State, Impact and Response (DPSIR) model (Borja et al., 2006; EC and USEPA, 2014; IJC, 2013) for assessment and reporting (Figure 1). They even developed a draft list of indicators that covered these categories that were reviewed at the 2004 SOLEC meeting (US EPA and EC, 2004).

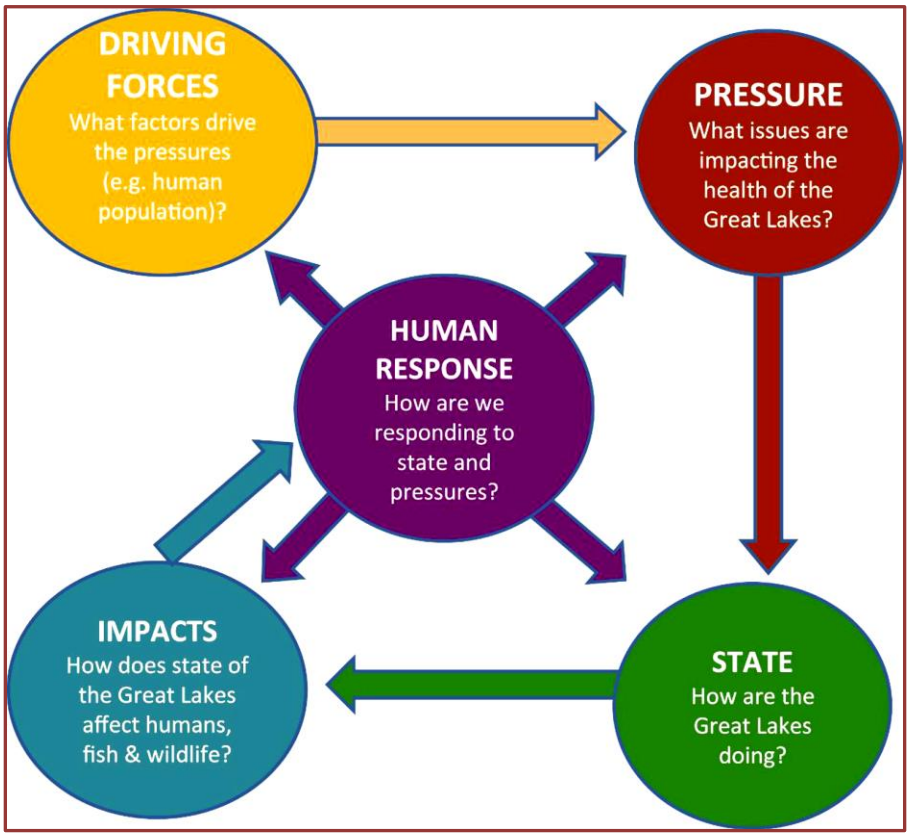

Figure 1. The DPSIR framework for monitoring and assessment to provide decision makers with useful information to assess progress and make informed resource allocation decisions.

If adhered to, reporting across related sets of DPSIR metrics would help decision makers answer questions like those laid out in Table 2 (Oesterwind et al., 2016). However, in 2011 the Parties decided that the scope of State of the Great Lakes (SOGL) reports would not specifically address all the questions that the DPSIR monitoring model would normally allow decision makers to answer (EC and USEPA, 2014). The Parties defined the scope of future SOGL reports as follows:

1a. The State of the Great Lakes Ecosystem Conference (SOLEC) and State of the Great Lakes reporting will continue to provide environmental indicators and data in a meaningful way for

decisionmakers working to improve and protect the health of the Great Lakes ecosystem in support of the Great Lakes Water Quality Agreement.

1b. The SOLEC and State of the Great Lakes reporting will continue to answer the following questions:

- How are the Great Lakes doing (status and trends)?
- How are humans impacting the Great Lakes?

1c. The SOLEC and State of the Great Lakes (SOGL) reporting will continue to contribute to, but not aim to
answer the following questions:

- Are the Parties to the GLWQA achieving their program commitments?
- What achievements can be attributed to agency investments?
- Are the Great Lakes basin resources being used sustainably?

1d. Conditions of the Great Lakes themselves will continue to be the focus of reporting. Watershed
related indicators (e.g. land use) will continue to be included to explain how human activities are related to conditions in the Great Lakes. Indicators will continue to be reported on a basinwide and individual lake basin scale. A recent endeavor to report on the status of the lake's open waters and the lake's nearshore waters will be enhanced.

The problem with this stated scope is that status and trends in human disturbance and ecological indicators (i.e., item 1b) provide decision makers with limited information with which to make policy and management decisions (Tear et al., 2005). So, the questions remain as to whether, where and how decision makers are getting the information they need to answer questions like those in Table 2 or listed under item 1c above. Evidence suggests that in many instances they are not getting this more robust set of information (Heinz Center, 2008; Steinman et al., 2017). Some of this evidence comes from the consistent and growing demands for better data management and information delivery systems to support adaptive management decision making for the Great Lakes and other ecosystems (CGLGP, 1985; IJC, 2000; Heinz Center, 2008; Barr et al., 2010; USGAO, 2013; CRS, 2013; Seelbach et al., 2014; Steinman et al., 2017).

Despite these demands, responsibility for the collection, analysis and delivery of the data and information needed for development of key environmental policy and decision making is still highly fragmented, resulting in a profusion of insufficiently coordinated and inefficient federal, state, local and nongovernmental efforts (Heinz Center 2008). For instance, the 2009 SOGL report was prepared by 139 authors from 43 government and nongovernment organizations, with an additional 111 contributors formally recognized by the authors (EC and USEPA, 2014). Over 180 government and nongovernment Great Lakes scientists and other experts participated in the development of the most recent SOGL report to generate the 44 sub-indicator reports (ECCC and

USEPA, 2017). Given these immense logistical challenges of monitoring, assessing and reporting on status and trends, for just ecological (i.e., state) indicators, is it not surprising the Parties have taken steps to reduce the number of reported ecological indicators and avoid further expanding their numbers (EC and USEPA, 2014). Still, the questions listed in Table 2 and many other questions that rely on a broader set of indicators will always be a challenge to decision makers unless steps are taken by the Parties, IJC and/or other Great Lakes stakeholders to fill those gaps.

Recently, the IJC has taken steps to identify and possibly expand the set of indicators included in the SOGL and Triennial Assessment of Progress (TAP) reports to include impact and response indicators through work groups focused on human health and program indicators (HPAB, 2014; IJC, 2014). A recent report by the IJC's Science Priority Committee's Communication Indicators work group (2016) recognized the importance of potentially broadening the suite of reported indicators, as this was an essential first step toward addressing this work group's main recommendation:

"…the Parties and IJC should begin taking steps toward telling complete and compelling stories by collecting, analyzing, integrating and delivering the necessary data for a complementary set of ecological, socioeconomic and program metrics to help decision makers and the public answer 'How well are our investments and management actions leading to our desired ecological and socioeconomic outcomes for the Great Lakes?'"

However, the recommendations of this work group go beyond just expanding the set of metrics and indicators. In their analyses of the IJC's 16 ecosystem (state) indicators, they found very little attention had been given to the management and delivery of these indicators to decision makers. They recommended that the IJC and the Parties focus more attention on this problem in the future, implementing the programs and policies that will assess and improve the flow of information to decision makers (SAB-SPC, 2016). The current project covered in this report grew out of this recommendation.

1.1 Importance and value of incorporating traditional knowledge into the adaptive management process

Cultural norms and styles differ between indigenous and non-indigenous peoples, which can pose challenges to joint decision making with respect to methods, pace and reliance on technology. However, both the United States and Canadian governments have recognized the importance of incorporating traditional knowledge (TK) in governance issues affecting indigenous peoples and have developed guidelines and protocols for its use. These include, for example, multiple Executive Orders by US Presidents, beginning in 1969 through 2009; a United Nations "Declaration on the Rights of Indigenous Peoples"; and several Canadian Federal Government directives including "Principles Respecting the Government of Canada's

Relationship with Indigenous Peoples." Thus, it is important to consider and incorporate traditional knowledge in decision making, first and foremost because it is embedded in the legal frameworks in both Canada and the United States. But perhaps more importantly, indigenous people have a long and deep understanding of natural systems that extend the time frame and depth of traditional science data sets; their knowledge systems are fundamentally based on information about natural systems; and because indigenous peoples have different methods of communication that flows through hierarchies of peoples, their knowledge contributes important and unique information about the Great Lakes system. In the context of adaptive management, these knowledge systems are continuously refreshed and add unique perspectives and information that are gathered outside the framework of most science-based data gathering programs.

2.0 Project Background

The International Joint Commission (IJC) was formed through the Boundary Waters Treaty of 1909 to prevent and resolve disputes related to the use and quality of the boundary waters of the United States and Canada. Under the Great Lakes Water Quality Agreement (GLWQA) one of the responsibilities of the IJC is to provide advice and recommendations to the governments on matters related to the water quality of the Great Lakes and approaches and options that governments may consider to improve effectiveness in achieving the purpose and objectives of the GLWQA. The Great Lakes Science Advisory Board (SAB) serves in an advisory capacity to the IJC. The SAB provides advice on scientific matters and research and is comprised of two standing committees: the Science Priority Committee (SPC) and Research Coordination Committee (RCC).

In 2014, the IJC identified a suite of 16 ecosystem indicators composed of 41 metrics to assess progress towards achieving the objectives of the 2012 GLWQA (IJC 2014). Although the IJC agreed that this set of ecosystem indicators provides good coverage of the Agreement's objectives and annexes with the smallest number of indicators possible, they also believed that 16 indicators and over 40 metrics were simply too many to clearly communicate progress to the public. Consequently, the IJC asked the SPC to identify a subset of the 16 ecosystem indicators that could tell meaningful and compelling stories to decision makers and the public. This charge to the SPC was generally referred to as "identify the fewest that tell us the most."

The SPC formed a Communications Indicator work group (CIW) to address this charge, which developed an objective, repeatable process for assessing "communicability" of these indicators. Using this process, the CIW identified eight of the 16 indicators as those that should be the focus of communicating progress toward GLWQA objectives to the public (SAB-SPC 2016). However, the CIW found that it is impossible to tell meaningful and compelling stories with only ecosystem indicators because they provide a small, but important component of a much larger

story. Consequently, the CIW recommended that future IJC Triennial Assessments of Progress focus on telling more *complete* stories around these eight ecosystem indicators by bundling them with related stressor, program, and socioeconomic (e.g., human health) indicators in a manner that helps to answer all facets of the following question: "How are our investments and management programs doing to address the key stressors and helping to maintain or restore the ecological and socioeconomic conditions associated with the GLWQA Objectives?" The CIW recommended that the assessment process they develop be applied to these other types of indicators. Finally, the CIW found that much more attention has been given to proper collection of data compared to the proper management and delivery of relevant information to decision makers and the public and recommended steps be taken to address this lack of attention. The Information Coordination and Flow work group and the project covered in this report directly grew out of the CIW's findings and recommendations.

In 2015 the SPC formed the Information Coordination and Flow (ICF) work group, which undertook a project to identify and assess programs and platforms that collect, deliver and use data and information in the Great Lakes to support management and policy decisions and help to improve the flow of this data and information to decision makers. The ICF work group was comprised of members of the SPC and representatives from the IJC's RCC and Water Quality Board (WQB). Also, since there were several groups and organizations working on issues associated with data management and information dissemination, it was important to include representatives of these groups as expert members on the ICF work group. Finally, a contractor team of the Great Lakes Commission and LimnoTech were selected through a competitive bidding process to assist the ICF work group in carrying out this project. This report is based upon and incorporates much of the work and reporting that was done by the Great Lakes Commission and LimnoTech.

2.1 Purpose, Goal and Objectives

The purpose of this project was to assess the flow of information to decision makers in the Great Lakes, identify barriers to the flow of this information, and provide recommendations to the IJC and the Parties for addressing these barriers. The goal of our project was to develop and apply methods for identifying barriers to the flow of information needed to a) assess programs and progress towards GLWQA objectives and b) support resource allocation decisions that seek to achieve the objectives of the GLWQA. More specifically, our goal was to assess our ability to answer the following questions:

- How well are our investments and actions helping us address the problems facing the Great Lakes and to achieve the objectives of the GLWQA?
- Do we need to change course?
- If so, what are the best alternative courses of action?

The specific objectives of our project were to:

1. Identify and assess programs and efforts that manage and deliver information to Great Lakes decision makers to help answer these questions
2. Develop and apply an information flow assessment process to determine how well we can answer the above questions for two GLWQA objectives
3. Assess opportunities and approaches to include traditional ecological knowledge of indigenous peoples into the information available for Great Lakes decision makers

2.1.1 Project Deliverables

The contract team of the Great Lakes Commission (GLC) and LimnoTech assisted the ICF work group in achieving the project objectives through the submission of a series of deliverables, including:

- **Interim Report**: includes an inventory of data and information resources and a summary of workshop proceedings
- **Final Report**: includes information flow assessment tables for the two GLWQA objectives and recommendations for improving information flow to support adaptive management decisions associated with the GLWQA in general, and specifically for objective ii (recreational waters) and objective vii (invasive species)

Throughout the project the ICF work group provided technical guidance and reviewed all project deliverables. The ICF work group then augmented and built upon the completed work of the contractors. The additional work undertaken by the work group included: an updated general inventory of data and information providers; a more detailed inventory of data and information providers relevant to objective vii (invasive species); a Prezi presentation that complements the updated general inventory; and prioritization of findings and recommendations. This additional work is discussed below.

Updated Inventory

The material from the contractor-created inventory was augmented by including fields such as jurisdiction covered, lake basin and scale, in addition to those completed by the contractor (e.g. organization description, website). The data from the inventory and updated fields were then used to create a database to allow the data that could be queried by attribute.

Detailed Inventory of Recreational Waters and Invasive Species

The contractor conducted an information flow assessment for two of the GLWQA objectives (ii- recreational waters and vii- invasive species), which resulted in tables that provided a narrative/qualitative view of gaps across six categories of information flow for specific metrics within five indicator categories (socioeconomic, management activities, human stressors, habitat and biological). Additional work was undertaken to augment the tables created for objective vii

(invasive species) by building complementary spreadsheets that illustrate the data available for each component of information flow. The spreadsheets contain a list of organizations, broken down by three scales (local, state/provincial, lake basin, and basinwide), with links to their respective websites and/or documents. The database provides a snapshot of organizations working across the information flow continuum on the specific issue of invasive species.

Prezi Presentation

The information from the general inventory as well as the more specific inventory for objective vii (invasive species) was used to develop a Prezi presentation (built upon an existing IJC presentation). The Prezi presentation illustrates the inventory data in a more condensed form that shows who the players are and where there are gaps along the information flow continuum.

Prioritization of Findings and Recommendations

The contractor's final report provided many findings and recommendations to improve the flow of information to support management decisions to achieve GLWQA objectives. The work group rated the importance of each finding and recommendation as a means of prioritizing those that should be included in the work group's final report. Based on the ratings and work group member discussion, recommendations of a similar nature were combined to develop a discrete set of actionable recommendations.

Final Report

The culmination of the work undertaken by the contract team and the work group are presented in this report. The report also provides a consolidated set of recommendations for improving the flow of information in the Great Lakes basin for the consideration by the IJC.

2.2 Scope of project

Countless management decisions are made that influence our ability to achieve the objectives of the GLWQA, which makes a comprehensive assessment of the information flow associated with each decision impossible. However, in a more general sense, there are relatively similar types of decisions associated with different timeframes. These timeframes have two dimensions (e.g., long term vs real time) pertaining to the time step of the data needed for the decision and the timeframe of analysis to generate the data (e.g., past, present, future) (Figure 2).

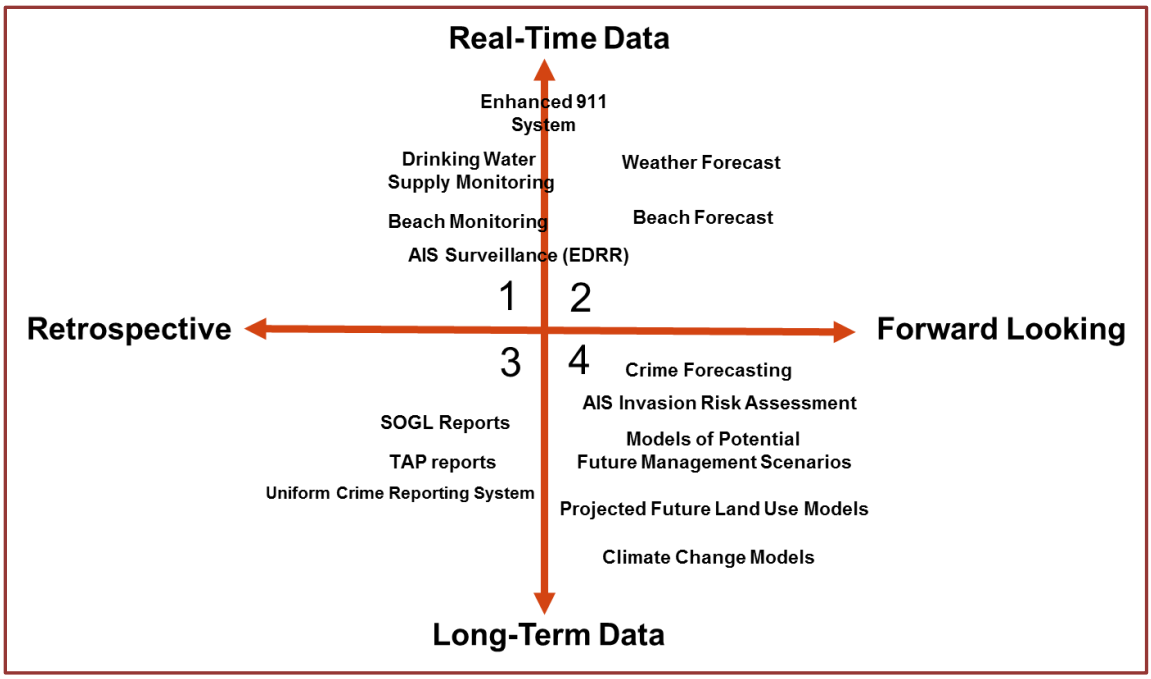

Figure 2. Two important timeframes of decision making and examples of the types of data, analyses and reports used to inform decisions falling within four relatively distinct quadrants of decision making.

The scope of this project largely focused on decisions that rely on longer-term assessments of information that help decision makers make informed decisions to strategically allocate limited resources. We focused most attention on retrospective assessments and associated decisions (see quadrant 3 of Figure 2), which complements the current assessment and reporting done through the SOGL and TAP reports. This simplified the scope of our project because such retrospective assessments require the same major types of information, with specific metrics pertinent to each issue (Table 3).

Table 3. Examples of the types of metrics that could be used to answer the questions in Table 2 specifically as it pertains to meeting general objectives ii (recreational waters) and vii (invasive species) of the GLWQA

Issue	Threats/Stressors	Investments	Management Actions	Ecological Metrics	Socioeconomic Metrics
Aquatic Invasive Species (AIS)	Relative risk of new invasions for each invasion pathway	Total expenditures on AIS prevention and control	Percentage of Early Detection Rapid Response (EDRR) surveillance sites monitored	Detections of new species	Total estimated economic costs of AIS
	Potential increased risk of new invasions under future climate	Actual and percentage of total AIS expenditures by each source	Number and extent of AIS eradication and control efforts	Rate of invasion for established species (Existing SOGL Ecosystem Indicator)	Estimated economic costs of AIS by sector (water supply, tourism, etc.)
		Actual and percentage of total AIS expenditures by management action	Research expenditures into new risk assessment, surveillance and control techniques	Presence/total number of invasive species overall and by major taxonomic group	
		Public expenditures in AIS prevention and control as percentage of total public expenditures	Number of regulatory violations issued for illegal possession and transport	Geographic extent of distribution of invasive species (Existing SOGL Ecosystem Indicator)	
			Number of management professionals trained in AIS detection and control	Number of high risk invaders (Existing SOGL Ecosystem Indicator)	
			Percentage of AIS education and outreach objectives achieved		
			Number of people receiving education and outreach on AIS		

Table 3 (*Continued*) Examples of the types of metrics that could be used to answer the questions in Table 2 specifically as it pertains to meeting general objectives ii (recreational waters) and vii (invasive species) of the GLWQA

Issue	Threats/Stressors	Investments	Management Actions	Ecological Metrics	Socioeconomic Metrics
Recreational Use	Percentage of beach closings caused by each contaminant source	Total expenditures on management actions to restore or maintain quality of nearshore waters	Percentage of combined and sanitary sewer overflows separated	Concentration of *E. Coli* (proposed HPAB metric)	Incidence and duration of beach closings
	Potential increased risk to nearshore water quality under future climate scenarios	Actual and percentage of total of these management actions by each source	Estimated reduction in urban stormwater runoff and associated reduction in the incidence of CSOs and SSOs	Concentration of cyanobacteria (algal toxins) (Existing SOGL ecosystem indicator)	Estimated economic impact of beach closings
	Percentage of beaches potentially impacted by combined sewer overflows (CSOs) and sanitary sewer overflows SSOs)	Actual and percentage of total expenditures by each management action	Percentage of sewage treatment facilities upgraded (industrial, municipal, agricultural)	Incidence of fill kills	Incidence of human illness associated with use of nearshore waters
		Public expenditures to restore or maintain quality of nearshore waters as percentage of total public expenditures	Estimated reduction in nutrient runoff from concentrated animal feeding operations (CAFOs) and agricultural lands		
			Percentage of nuisance waterfowl populations addressed		
			Routine assessment of contamination risks to beaches by source (proposed HHAB metric)		
			Percentage of beach health education and outreach objectives achieved		
			Number of people receiving education and outreach materials on beach health		

We limited the scope of our project to retrospective assessments with long-term consequences, rather than real-time, short-term events in order to reduce the complexity of the project. Assessing the flow of information to support real-time decisions related to things such as detection of an invasive species, an *E. coli* outbreak, or a fish kill are critically important. However, real-time decisions such as these have very different and much less consistent information needs across issues and would therefore have greatly expanded the scope of the project. Specific assessments of information needs and barriers to information flow should be conducted for these types of decisions in the future, as is regularly done for the comparable 911 system in the United States (USDOT, 2011; USDOT, 2015).

Numerous conservation issues face the Great Lakes (GLWQA, 2012; Allan et al., 2015) and assessing barriers to information flow for all of these issues was beyond the scope of our project. Instead, we attempted to generally assess the management and delivery of information to decision makers in the Great Lakes and conducted more thorough assessments for general objectives ii (recreational waters) and vii (invasive species) of the GLWQA.

Spatial scale is another important dimension to decision making and information management and delivery, which adds complexity to our project. The questions in Table 2 and metrics in Table 3 are all relevant at local to basinwide scales in the Great Lakes. Where possible we attempted to assess barriers to information flow at local, state/provincial, lake basin, and basinwide scales. However, our assessments emphasized the larger scales that require integration of datasets collected and managed by multiple stakeholders.

2.3 Data vs. Information

The term information is often used interchangeably with the term data. Although these terms are closely related, there are key differences among these terms that must be understood to develop useful information management and delivery strategies. By extension these same differences are certainly relevant to any effort, such as ours, seeking to assess barriers to information flow.

Dr. Charles Oppenheim, a renowned information scientist, once said, “Information is like a piece of wet soap - it slips out of your hands if you try to grab it.” (Oppenheim 1994). While we certainly agree with this statement, we also agree with Stem et al. (2005) that a lot of confusion arises from a lack of clarity and shared definitions of commonly used terms. To help address this confusion we tried to clearly define many commonly used terms relevant to the issue of information management and delivery (Appendix A). Some may argue with these definitions, but their purpose was to facilitate effective communication among those participating in this project, to ensure consistency in the analyses and assessments conducted in this project, and clarity in conveying the findings and recommendations. Some readers may find familiarizing themselves with the definitions of terms in Appendix A helpful for reading other sections of this report.

While there are many definitions in Appendix A, the most important for this project is the very high standard for what information is and what defines a well-informed decision (Figure 3).

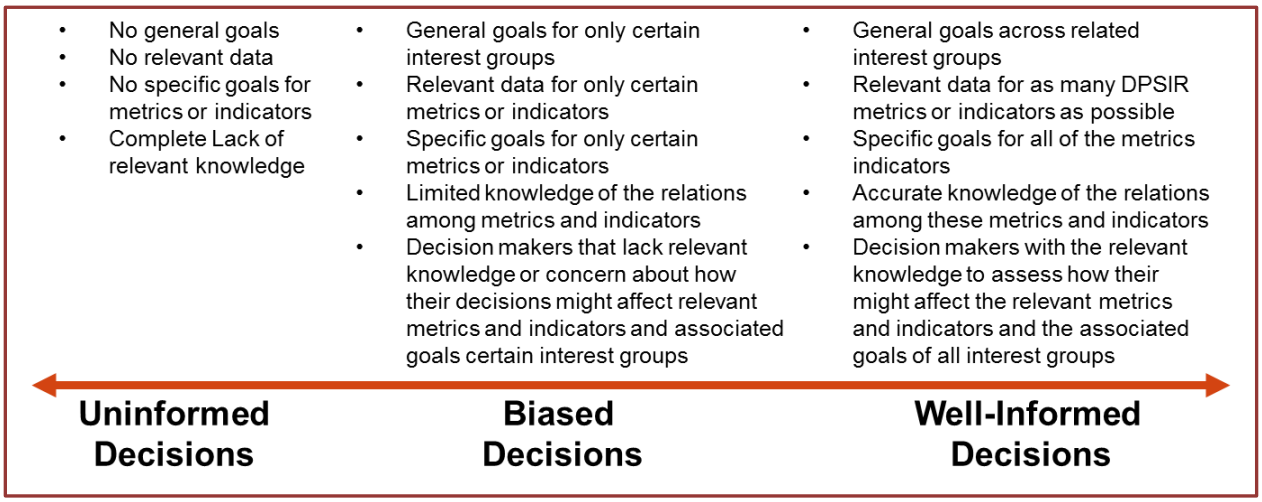

Figure 3. Examples of the circumstances that define a spectrum of uniformed to well-informed decisions based on the definitions provided in Appendix A.

As defined within this report, information only exists under a certain set of conditions, which is not the case for data. However, there is a definite relationship between these two terms and herein lies the source of confusion. Data has the potential to become information under the right set of conditions. Those conditions include a specific goal for a metric or indicator (i.e., specific objective or target), data for that metric or indicator (i.e., relevant data), and a decision maker that can properly interpret these relevant data (i.e., has relevant knowledge). What is often most confusing is that what is considered just data (useless information) to one person can be highly relevant information to another. For instance, a health report is very useful information to the person the report is based upon and her/his doctor, but only data to someone that doesn't know that person.

2.4 Major Components of Information Flow

Defining "information" was certainly an important first step to identifying barriers to the flow of information to decision makers. However, equally important was identifying and understanding the major components and activities that are essential to the flow of this information. For this project, we identified six major components of information flow that we believe are critical to generating the sets of conditions that lead to development and delivery of relevant information and well-informed decision making. These six major components and subcomponents are presented in Figure 4.

- Goal Setting and Strategies (Planning)
  - Plan cycles and standards
  - Prioritize issues
  - Establish general goals
  - Develop management strategies
  - Select metrics and indicators
  - Establish goals for metric and indicators
- Data Collection (Inventory and Monitoring)
  - Monitor design
  - Monitor plans and cycles
  - Collection and gear standards
  - Handle (Quality Assurance/Quality Control) standards
- Data Management and Sharing
  - Database standards
  - Data life cycle standards
  - Data processing/query protocols
  - Delivery format standards
  - Metadata standards
- Data Analysis and Delivery (Assessment and Reporting)
  - Calculate metrics and indicators
  - Analyze process standards
  - Quality Assurance/Quality Control protocols
  - Verification protocols
  - Report content, formats and cycles
- Knowledge Management and Delivery (Research, Education and Outreach)
  - Knowledge and value assessment
  - Science knowledge gaps
  - Research priorities and strategy
  - Decision maker knowledge gaps
  - Education and outreach strategy
  - Knowledge management strategy
- Information Management and Delivery
  - Information needs assessment
  - Information flow assessment
  - Information delivery strategy
  - Information delivery standards

Figure 4. Six major components and subcomponents of information flow to decision makers. Headings for the six major components are worded to more clearly illustrate where and how the three distinct components of information (i.e., goals, relevant data and relevant knowledge) are addressed and created in an adaptive management strategy. When necessary, more commonly used terms for these components are included in parentheses.

We also identified potential barriers to information flow associated with each of these six components, which are presented in Table 4. Lack of stable and consistent funding is another barrier that applies to all six components of information flow just as it applies to all components of the larger adaptive management process.

Table 4. Some examples of potential barriers to information flow associated with each of the six major components presented in Figure 4. Lack of funding is a potential barrier to all facets of adaptive management, including all facets of information management and delivery

General Barriers to Information Flow	Specific Barriers to Information Flow
Lack of goals or strategies	Lack of regular planning processes for establishing and updating shared general goals, objectives and strategies
	Lack of shared general goals
	Lack of shared strategies
	Lack of agreed upon performance metrics across Driver, Pressure, State, Impact and Response (DPSIR) categories
	Lack of specific goals for performance metrics across DPSIR categories
Lack of relevant data	Lack of monitoring programs to collect data for performance metrics
	Lack of incentives (funding or mandates) for monitoring programs to collect relevant data
	Lack of monitoring designs and collection standards that hinder integration of datasets for a specific metric
Lack of data sharing and integration	Lack of data management standards that hinder or prevent integration of datasets for a specific metric
	Lack of policies that require sharing data collected with public funding
	Lack of data sharing policies and agreements among relevant monitoring programs
	Policies that prevent sharing of sensitive data
	Lack of policies that facilitate sharing of sensitive data
	Lack of programs that manage and integrate data for a specific metric
	Lack of programs that manage and integrate data across DPSIR metrics

Table 4 (*Continued*). Some examples of potential barriers to information flow associated with each of the six major components presented in Figure 4. Lack of funding is a potential barrier to all facets of adaptive management, including all facets of information management and delivery.

General Barriers to Information Flow	Specific Barriers to Information Flow
Lack of data analysis and reporting	Lack of programs and regular reporting cycles to assess and report on **status and trends** for ecosystem metrics
	Lack of programs and reporting cycles to assess and report on **status and trends** for other Driver, Pressure, State, Impact and Response (DPSIR) metrics
	Lack of programs and regular reporting cycles for **forecasting possible future scenarios** and assessing potential changes in ecosystem metrics
	Lack of programs and regular reporting cycles for **forecasting possible future scenarios** and collectively assessing potential changes across multiple DPSIR metrics
	Lack of QA/QC protocols to ensure accuracy and consistency of status and trends
Lack of relevant knowledge	Lack of understanding of the patterns within and relations among DPSIR variables (gaps in scientific knowledge)
	Lack of research programs and projects to fill gaps in scientific knowledge
	Lack of relevant knowledge by decision makers
	Lack of programs to assess relevant knowledge of decision makers
	Lack of education and outreach programs to increase relevant knowledge of decision makers
Lack of effective information delivery	Lack of understanding of decision makers information needs and/or programs that regularly assess decision makers' needs
	Lack of understanding of decision makers' desired formats for information delivery
	Lack of programs and reporting cycles to assess and report on **progress toward goals** for ecosystem metrics
	Lack of programs and regular reporting cycles to collectively assess and report on **progress towards goals** across multiple DPSIR metrics
	Lack of programs and regular reporting cycles for **forecasting possible future scenarios** and assessing potential impacts on **progress toward goals** for ecosystem metrics
	Lack of programs and regular reporting cycles for **forecasting possible future scenarios** and collectively assessing potential impacts on **progress towards goals** across multiple DPSIR metrics

Appendix B provides links to online resources that demonstrate programs, projects, processes and products that help to address elements of the six major components of information flow. This inventory of resources focuses on information resources that are related to achieving general objective vii of the GLWQA:

"be free from the introduction and spread of aquatic invasive species and free from the introduction and spread of terrestrial invasive species that adversely impact the quality of the Waters of the Great Lakes."

The inventory is extensive, but by no means is it comprehensive. Our intent was to provide a resource that was educational and useful. Prior to reading subsequent sections of this report, we encourage readers to visit a variety of the links in Appendix B that fall within each of the six major components of information flow. Doing this will hopefully provide a clearer sense of the specific types of programs, activities and products that help to generate the goals, relevant data and relevant knowledge needed to support informed decision making for a specific issue.

3.0 Objective 1 – Identify and assess programs and projects that manage and deliver information to Great Lakes decision makers

3.1 Inventory of Information Resources

3.1.1 Purpose

There are many agencies and organizations responsible for the collection, management and delivery of data and information across the Great Lakes. Over the past decade many efforts have focused on improving the management and delivery of data and information, including the creation of the Great Lakes Observing System (GLOS; https://www.glos.us/), the efforts of the Annex 10 Data Management and Sharing Team (DMST; https://binational.net/annexes/a10/) and the GLAB's Science and Information subcommittee (https://www.glri.us/advisory/sis.html), and the recent launching of Blue Accounting (http://www.blueaccounting.org/) and Canada's new Policy on Results (http://ncc.evaluationcanada.ca/wp-content/uploads/2016/10/14_10_2016-CES-Breakfast.pdf). While these efforts have focused on improving distinct components of information flow, none have attempted to look across all the major components from goal setting to information delivery (See Figure 4), which was the focus of our project and this objective.

For this Project objective, we sought to identify and assess major past and ongoing efforts that deliver information to Great Lakes decision makers and/or seek to improve the flow of this information. This general assessment of information flow was accomplished through an inventory of Great Lakes information resources and an associated workshop. The inventory

consisted of Great Lakes a) programs (e.g., Chippewa Ottawa Resource Authority and Lake Michigan Monitoring Coordination Council), b) monitoring, assessment and planning processes (e.g., Lake Area Management Planning and TAPs), and c) online applications (e.g., GLOS and Ontario online water quality database) that play a role in the development and delivery of relevant information to decision makers. This inventory served three purposes. First, it provided data for a general assessment of information flow to support resource allocation decisions relevant to the GLWQA. Second, it helped to identify individuals associated with or responsible for these programs, processes and online applications that should be invited to the workshop. Lastly, it serves as a valuable resource for many stakeholders to help them identify useful information resources and opportunities to collaborate. Collectively, the purpose of this inventory, assessment and expert workshop was to:

- Identify major barriers to the flow of information
- Identify possible solutions, and
- Identify and foster collaboration among groups currently seeking to improve the flow of information to decision makers across the Great Lakes.

3.1.2 Methods

The ICF work group compiled an initial inventory of major Great Lakes programs, processes and resources that are relevant to the various components of information flow in Figure 4. This initial inventory relied on the knowledge of the work group members and built upon an earlier inventory compiled for the IJC's Research Coordination Committee (Sommer, 2013). This initial inventory was then iteratively reviewed and updated by the contractors and the work group. The inventory used 16 attributes to categorize each information resource:

1. Name (text)
2. URL (hyperlink to website)
3. Description of the program (text)
4. Partnership or collaborative? (yes/no)
5. Lead or host of the collaborative (text)
6. Watershed scales covered (three categories)
7. Lakes covered (five categories)
8. Government jurisdictions covered (four categories)
9. Nations covered (two categories)
10. Provinces covered (two categories)
11. States covered (eight categories)
12. Tribal/First Nation jurisdictions covered (text)
13. Affiliation of program or members of the collaborative (five categories)
14. Major indicator categories covered (four categories)
15. IJC ecological indicators covered (16 categories)
16. Major roles in adaptive management and information delivery (14 categories)

As we built the inventory we tried to ensure a balance in representation for seven key attributes (Table 5) to provide a more objective analysis of the percentage of information resources associated with each of the major roles in adaptive management and information delivery, which was the primary focus of our assessment.

Table 5. Percentage of the 106 records in the inventory of information resources that are associated with and/or cover different lake and sociopolitical geographic units and affiliations. Percentages within the five geographic unit categories do not add up to 100 percent because most of the resources in the inventory cover many of the units in each category. Percentages for the affiliation category do not add up to 100 percent because many of the resource in the inventory represent collaborative efforts with representation across these various affiliations.

Lake	
Erie	90%
Huron	86%
Michigan	76%
Ontario	86%
Superior	90%
Sociopolitical Scale	
Binational	37%
National	74%
Regional	87%
Provincial/State	90%
Local	82%
Nation	
Canada	60%
USA	80%
Province	
Ontario	60%
Quebec	25%
State	
Illinois	63%
Indiana	64%
Michigan	70%
Minnesota	65%
New York	61%
Ohio	63%
Pennsylvania	59%
Wisconsin	67%

Affiliation	
Academic	30%
Business	5%
Government	69%
Nongovernment Organizations (NGOs)	25%
First Nations/Tribes	10%
IJC Ecosystem Indicators	
Atmospheric deposition of Chemicals of Mutual Concern	30%
Chemicals of Mutual Concern	50%
Nutrients	53%
Persistent bioaccumulative toxic chemicals (PBTs)	22%
Contaminants in groundwater	28%
Tributary physical integrity	46%
Land cover conversion/fragmentation	32%
Coastal shoreline condition	36%
Water levels	40%
Water temperatures	40%
Fish species of interest	49%
Harmful algal blooms	34%
Food web health	34%
Aquatic Invasive Species	42%
Coastal wetland condition	38%
Fish eating/colonial nesting birds	16%

The contractors initially compiled an inventory of 120 information resources, which was used to perform a set of simple frequency analyses presented in Appendix C. The focus of these analyses was to assess how much emphasis is being placed on the six major components of information flow (see Figure 4). The work group reviewed the inventory used by contractors and added some key missing information resources and removed some redundant records and resources that were no longer available. This final inventory created by the work group consists of 106 information resources, which were used to repeat the analyses conducted by the contractors and are presented below. Even though the edits made to the contractor's inventory resulted in only minor changes to the results of the frequency analyses, the statistics presented in this report should take precedence in any citing of these statistics.

The work group also decided that the inventory was a valuable resource that should be put into a more useful format and made more widely accessible. Consequently, the work group converted the Microsoft Excel database into an online, accessible relational database using Zoho Creator, which allows users to develop custom online databases and applications (https://app.zohocreator.com/scottsowa/inventory-of-great-lakes-data-providers#Inventory_of_Great_Lakes_IMD_stakeholders). This database allows registered users to access the database from anywhere in the world to query, analyze and download these data. With additional permissions, users can also edit and update this online inventory of Great Lakes information resources. Zoho Creator has free and paid options for developing online applications. Due to lack of funding we used the free version of the software, which allowed us to develop a robust database with all of the desired attributes. However, the free version of this software only allows three registered users to access the database and has a more restricted set of analytical and reporting capabilities.

Finally, the work group, with in-kind assistance from The Nature Conservancy, also used this inventory to create an online interactive presentation that takes users through a visual tour of Great Lakes governance, general roles across the major components of information management and delivery, and finally issue-specific roles (http://prezi.com/vtnozk6pgbmj/?utm_campaign=share&utm_medium=copy) for just two issues: water level management and aquatic invasive species. This online resource provides a complementary visual representation of the inventory of information resources to more clearly show how the Great Lakes are governed and managed and also how the information to support this management is managed.

3.1.3 Results and Findings

The inventory is by no means comprehensive; however, we did achieve our desired objective of having balanced representation of information resources across geographies, affiliations and issues (Table 5). The lone geographic bias was the low percentage of resources covering the

Province of Quebec, but the percentage is commensurate with the geographic footprint of this province in the Great Lakes basin. There were a notable low percentage of resources affiliated with businesses (5 percent) and First Nations and Tribes (10 percent). This was not due to a lack of effort in trying to locate such resources but rather a true lack of online information resources associated with these groups. There was surprisingly good balance of representation across Great Lakes issues as reflected in the relatively similar percentages for each of the IJC ecosystem indicators. There were slightly fewer resources associated with persistent bioaccumulative toxic (PBTs) chemicals (22 percent), contaminants in groundwater (28 percent), fish eating and colonial nesting birds (16 percent). Despite this handful of biases, we are confident the inventory provides useful input into our two core analyses to assess the emphasis and availability of information resources dedicated to the six major components of information flow and the major types of information needed to make informed decisions.

Most of the resources in the inventory are concentrated in the middle of the information flow process (Figure 5). We are not certain how to interpret the lower percentage of information resources associated with planning, since it is not consistent with the more specific inventory of resources associated with the AIS inventory (Appendix B) where a high percentage of information resources were found to be associated with planning at binational, national, regional, state and local levels. It is also not consistent with the findings from the workshop. So, this result should be interpreted with caution. We are more confident with the low percentage of resources associated with information management and delivery, as these results were consistent with findings of the workshop and the more detailed inventory done for AIS.

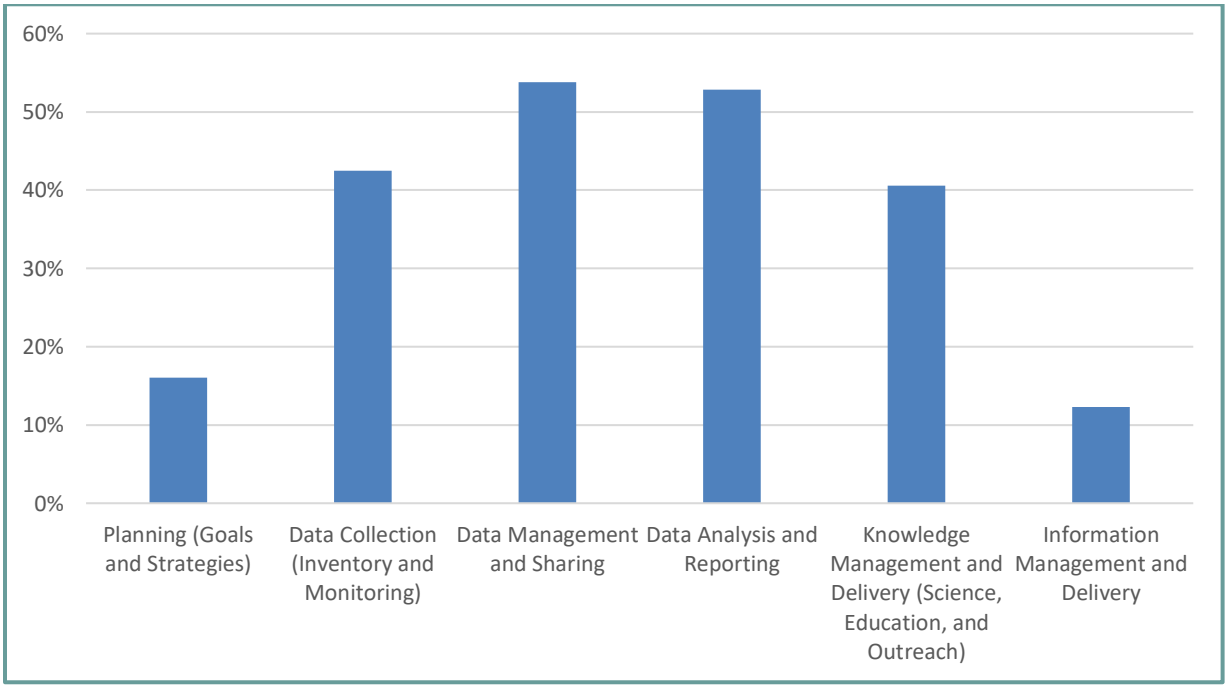

Figure 5. Percentage of information resources in the inventory that cover the six major components of information flow

The inventory also contained many fewer resources associated with the establishment, tracking or reporting on program (e.g., investments and action) metrics and indicators (Figure 6). This result is consistent with the findings from the workshop. However, for the more detailed inventory we developed for AIS, we did find quite a few programs and reports that report status and trends in the overall AIS expenditures and in some instances by individual management activity. Some good examples of these reports on program indicators include annual invasive species reports for the State of Michigan (http://www.michigan.gov/documents/invasives/DNR_Inv_Spec_Ann_Rep_16_558215_7.pdf) and Minnesota (http://files.dnr.state.mn.us/natural_resources/invasives/ais-annual-report.pdf) and also the Ontario Invasive Species Centre (http://www.invasivespeciescentre.ca/WHAT-WE-DO/Investing#projects2014_15).

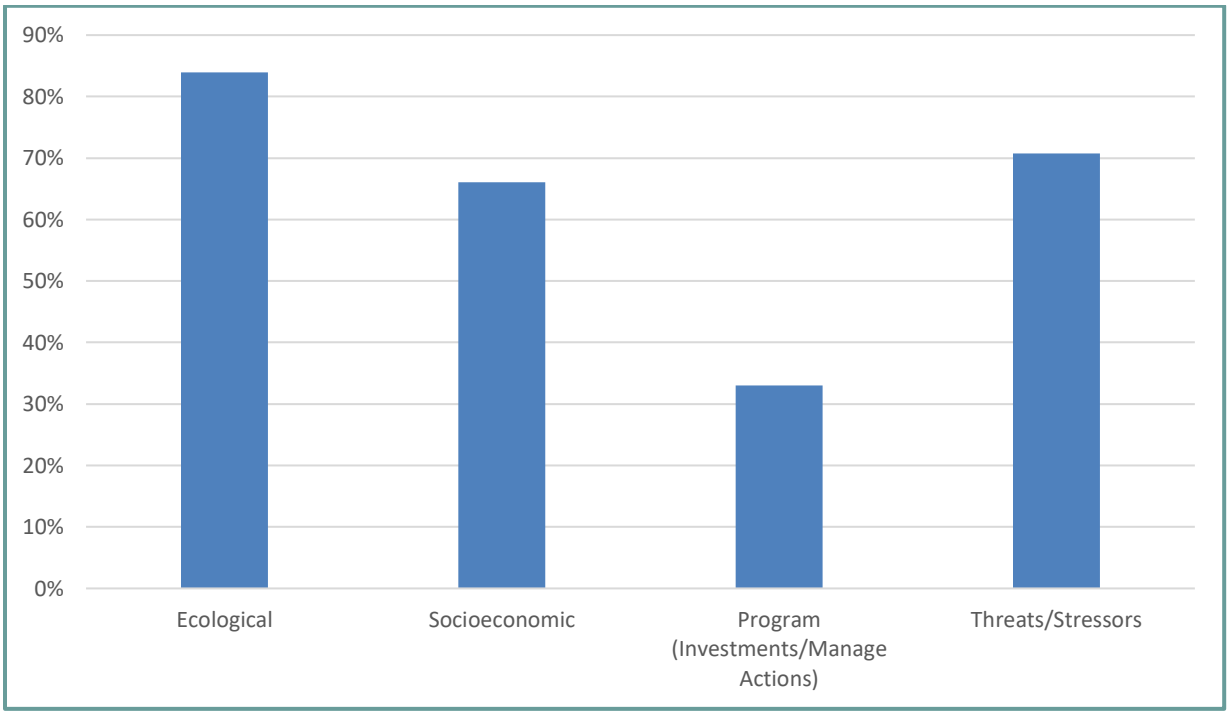

Figure 6. Percentage of information resources in the inventory that cover four major categories of metrics and indicators needed to make well-informed decisions

Again, the definition of information used in this project sets a very high bar, as it requires the delivery of metrics and indicators (relevant data) that have specific goals or benchmarks across the major categories of indicators (e.g., program investments and actions, ecological and socioeconomic) and provide context to advance the relevant knowledge of decision makers and their ability to properly interpret the data. We are not surprised that there are limited examples of information resources in the inventory that meet this definition. It should be noted, though, that several of the resources do meet multiple elements of this definition such as Environment and Climate Change Canada's regular reporting on the Canadian Environmental Sustainability

Indicators (http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=47F48106-1). This online resource reports on status and trends in metrics and indicators within the context of general goals and provides context (relevant knowledge) to help understand the relevance and interpret each indicator. The fact that there are some resources in the inventory that are close to meeting the very stringent definition of information delivery used in this project is encouraging. However, the last few steps of establishing and reporting on progress towards specific goals and doing this across most or all the major categories of indicators are still daunting challenges.

3.2 Workshop

3.2.1 Purpose

The workshop sought to bring together Great Lakes data collectors, information providers and decision makers to:

- Identify and assess programs and platforms that collect, deliver, and use data and information in the Great Lakes to support management and policy decisions
- Increase understanding of the major components of information flow, identify potential barriers and develop solutions impacting this flow
- Increase communication and harmonize past and existing efforts that focus on assessing/improving data and information flow in the Great Lakes.

3.2.2 Methods

An initial inventory of data and information resources (as discussed in section 3.1) was provided to the contractors by the Information Coordination and Flow work group. This inventory was supplemented by the contractors and used to compile a list of invitees to the workshop. A mix of data collectors, information providers and decision makers were sought for the workshop participants. Forty participants from the private, tribal, federal, state, provincial, municipal and academia sectors attended the workshop, which was held in Windsor, Ontario March 2-3, 2016 (please see Appendix 2 of the contractor report provided in Appendix C). Participants represented expertise from across the natural sciences and socioeconomic disciplines.

The workshop was facilitated with the intention to engage participants to provide information about new or existing data, identify barriers to information flow and dissemination, and discuss possible policies to overcome barriers. The majority of the sessions were focused on group dialogue and eliciting discussion from the participants. The workshop sessions included:

- Common Terminology and Concepts: Each participant at the workshop was given a handout with definitions of key terms (Appendix A). A complementary presentation was also given to provide additional clarity of these definitions; discuss the elements of a well-informed decision (see Figure 3); and identify the six components of information flow to discuss the barriers to information flow within each of these components (see

Figure 4 and Table 4). The handout and presentation provided a foundation for more productive discussion at the workshop by providing a common understanding and a common lexicon for key concepts and terms associated with information management and delivery.

- Information Flow Mapping: Participants were asked to consider which Great Lakes programs fit within each of the six components of information flow to help identify gaps in the flow and coordination of information and to understand duplication and synergy between efforts.
- SWOT Analysis: Participants were asked to identify strengths, weaknesses, opportunities and threats (SWOT) within the status quo information management and delivery chain for the Great Lakes region and resources.
- Needs of Frontline Decision Makers: A panel discussion with three invited decision makers was held to understand their decision-making processes, use of data and information, and barriers to data and information implementation and dissemination. The panelists included George Heartwell (former mayor of Grand Rapids), David Ullrich (Great Lakes and St. Lawrence Cities Initiative), and Barry Kreiner (Public Works, City of Marysville, Michigan).
- Strategic Planning and Brainstorming: Participants were asked to discuss the key challenges and priorities for providing salient, legitimate and credible information to Great Lakes decision makers.

3.2.3 Results and Findings

This section highlights the findings that emerged as a result of the discussions during the sessions at the workshop.

Information Flow Mapping

The discussion results of the information flow mapping exercise are highlighted in Table 6. The key observation that emerged from this activity was that the initial components of the information flow supply chain (goal setting, data collection, data management and delivery) have more programs and resources than the latter components (data analysis, knowledge management and delivery, and information management and delivery).

Table 6: Mapping of Great Lakes Programs to Components of the Information Supply Chain
Summary of Workshop Participant Discussions

Component of Information Supply Chain	Summary of Responses
Goal Setting	▪ A lot of goal setting is done via national statutes with other parties as the implementers (e.g. state/province, tribes and municipalities) ▪ Development of strategies and prioritization of issues is done at a high level (federal) ▪ Planning goals, cycles and implementation is done at a more local level ▪ Nongovernment organizations (NGOs) set their goals internally and can therefore be narrow
Data Collection	▪ There are a lot of different groups collecting data at various levels and in automated systems data is being generated faster than it can be analyzed ▪ Gap in collecting near shore data is challenging because the ships that collect data in the pelagic zone can't get close enough to shore, and boat access to near shore from boat launches and river mouths can pose a challenge ▪ Gap in linking various data collection programs in the region to each other is challenging ▪ State/local permit holders are another source of data not identified in the inventory
Data Management and Delivery	▪ Federal agencies dominate data management and delivery in all five indicator categories ▪ A few Great Lakes regional nonprofit organizations contribute in this area, especially in terms of socioeconomic data
Data Analysis	▪ Similar agencies produce data for the stressors, habitat and biological categories ▪ Organizations within the socioeconomic category were found to be mainly location-specific or advocacy groups ▪ The Great Lakes Commission and Great Lakes Fishery Commission were specifically mentioned as organizations that assist in data analysis and program evaluation ▪ A number of data analysis tools were mentioned, including SPARROW and EGRET

Table 6 (continued): Mapping of Great Lakes Programs to Components of the Information Supply Chain - Summary of Workshop Participant Discussions

Knowledge Management and Delivery	▪ How knowledge is created in the context of information creation is important, as well as how to work with that knowledge and how to share that knowledge ▪ Knowledge of the effectiveness of alternate management actions (for the purposes of adaptive management) is lacking ▪ There is more data in the Aquatic Invasive Species (AIS) and climate change spaces than there is knowledge ▪ There is a need to be able to quantify the benefits of management actions ▪ Ecosystem services quantification and resource valuation is underdeveloped ▪ There is a potential to learn from the emphasis of First Nations and Tribes on knowledge management and delivery across generations
Information Management and Delivery	▪ Most of the organizations identified (i.e., University of Michigan Water Center, National Park Service, Blue Accounting) address stakeholder assessment and education/outreach/communications, but do not address information flow assessment, information standards or decision needs ▪ Involvement of policy makers in design of data collection could help to ensure the data programs are effective and appropriate for existing goals

SWOT Analysis

The aggregated results of workshop participant discussions on the strengths, weaknesses, opportunities and threats (SWOT) within the information management and delivery chain for the Great Lakes region is detailed in Tables 3 (strengths and weaknesses) and Table 4 (opportunities and threats) in Appendix C. Some of the strengths highlighted during discussions were that the Great Lakes region is information rich with an engaged populace, and that the GLWQA is a strong regional framework with many invested partners. The Great Lakes Fishery Commission was held as a model for converting data into useful information for decision making. Information delivery via a "report card" format was viewed favorably, but these require primary data to be converted to relevant metrics and information relevant to managers, decision makers and the public. Weaknesses included lack of integration of social/cultural data with natural science data, and many issues associated with conversion of data into appropriate information for decision making (i.e., disparities in goals between data collectors and data users; disconnect in scale and resolution between available data and data required by decision makers; lack of appropriate analysis and synthesis; lack of access to critical data due to ownership or privacy issues). Many of the identified opportunities addressed these perceived weaknesses.

Needs of Frontline Decision Makers

Through the discussions with the panel of decision makers, the following key messages relevant to the needs and flow of information emerged:

- Decision makers are rarely asked about their data and information needs by those who gather, process and deliver data.
- Decision makers often make quick decisions within tight timelines; therefore, decisions are often made ahead of the data to support them.
- In order to initiate decisions and actions, arbitrary goals may be better than no goals at all (e.g., USEPA goal to complete cleanup on 100 superfund sites by the year 2000).
- Even when data and information are available, gaining access to data quickly and in a format that is usable and understandable can be challenging.
- Qualitative data may be more effective when presented to the public, whereas quantitative data are more effective for political decisions. A mix of qualitative and quantitative information is useful in order to reach and appeal to the broadest group of people who have different interests and goals.

Strategic Planning and Brainstorming

Based on the discussions, views and perspectives heard during the workshop, participants were asked to identify some key challenges to the flow of information and priorities for removing barriers and improving the flow and coordination of information. The items identified during this session formed the foundation for Project objective 2 and the recommendations in this report.

Key challenges to information flow (* indicates broad consensus):

- * Data discoverability is a greater issue than data availability; data are scattered; data often collected for project-specific purposes and difficult to locate
- * Data are difficult to compare and interpret because of the lack of data harmonization between the United States and Canada and varying methods of collection and reporting methods
- * A disconnect exists between the data collected and the need/purpose of its collection (i.e., context is limited to individual projects and programs); need a clear understanding of the data and information required for particular decisions
- Sustainability and maintenance of data and information are pervasive and difficult issues to address
- Lack of integration among different disciplines and components of the information chain.
- Forecasting what data and information will be needed in the future
- Lack of access to existing data (e.g. academic data is often kept closed until publication; some data sources are licensed and difficult or expensive to access).

Priorities for improving information flow (* indicates broad consensus):

- * Require that data collected as part of a funding program be made available with the appropriate metadata regarding how information products should be used
- * Improve data discoverability through the use of open data and a common data warehouse
- * Ensure data are provided in a format that is usable and understandable by decision makers and relevant to their needs
- Develop a strategy for a needs assessment scaled to the needs of information users
- Create a process to identify gaps in information flow in the following aspects: discoverability, compatibility and relevance
- Specific to the IJC, facilitate a tighter connection between the end users and GLWQA objectives
- Establish governance and framework to sustainably address information flow, including funding. Provide information in easier-to-consume formats (e.g. report cards) in addition to primary and synthetic data.

4.0 Objective 2 – Develop and Apply an Assessment Process to Identify Barriers to Information Flow for Two General Objectives of the GLWQA

4.1 Purpose

As stated earlier, the Communications Indicator Workgroup (CIW) developed an objective, repeatable process for assessing "communicability" of any type of indicator and metric, and used this process to identify eight of the 16 ecosystem indicators that should be the focus of communicating progress toward GLWQA objectives to the public (SAB-SPC, 2016). However, the CIW also stated that it is impossible to tell meaningful and compelling stories with only ecosystem indicators and thus recommended steps be taken to apply their "communicability" assessment process to the other major types of indicators and focusing more attention on the flow of information to decision makers and the public. The purpose of this objective was to use and expand the communicability assessment process developed by the CIW to assess and identify barriers to the flow of information to decision makers and the public. More specifically, this assessment of information flow focused on identifying barriers that hinder answering the following three focal questions:

1. How are our investments and management programs doing to address key stressors and help to maintain or restore the ecological and socioeconomic conditions associated with GLWQA objectives?"
2. Do we need to change course?

3. If so, what are the best alternative courses of action?

The assessment process developed by the CIW is a very rigorous and time-consuming process that focuses on the first four components of information flow (see Figure 4). Given time and funding constraints we could not fully apply this more rigorous process and needed to expand our assessment to cover all six components of information flow. To our knowledge this is the first time such a comprehensive assessment of information flow has been applied within the area of natural resource management.

4.2 Scope

We determined it was only feasible to assess barriers to information flow for two of the nine general objectives of the GLWQA. General objectives ii and vii of the GLWQA were ultimately selected based on interest and activity of IJC and annex work groups and because they require very different metrics and indicators to answer the three focal questions of this Project objective. These two general objectives state the Great Lakes should:

- Objective ii: "allow for swimming and other recreational use, unrestricted by environmental quality concerns" and
- Objective vii: "be free from the introduction and spread of aquatic invasive species and free from the introduction and spread of terrestrial invasive species that adversely impact the quality of the Waters of the Great Lakes."

All of the GLWQA general objectives are very broad and have a large number of potentially relevant stressor, program and socioeconomic indicators that could be assessed as part of this objective. Given time and resource constraints we had to clarify which aspects of these general objectives we would focus on for our assessments. For objective ii we primarily focused on resource allocation decisions that depend on longer term datasets seeking to reduce or eliminate beach advisories and closings or water use restrictions related to *E. coli* and harmful algal blooms (HABs). However, we also assessed the flow of information needed for the rapid response decision of issuing such advisories. We did not assess the flow of information to support decisions related to dangerous currents, high winds or waves, and other physical or meteorological conditions that affect recreational use of nearshore waters. For objective vii we focused almost exclusively on the early detection and control dimensions of managing AIS in the Great Lakes, particularly those resource allocation decisions addressing the best places and practices to use for early detection and control, and how many resources should be allocated to the selected activities and locations.

4.3 Methods

A detailed description of the work performed under this objective can be found in the contractor's report to the ICF (Appendix C). A general overview of the approach and methods is

provided in Table 7. The assessment of information flow consisted of three complementary tasks which included a survey, interviews and a tabular assessment information flow for specific metrics (Table 7). The surveys and interviews both focused Great Lakes resource professionals and attempted to identify the information needs of these individuals relative to their particular issues and associated management decisions. The surveys and interviews also attempted to identify challenges, solutions and success stories for meeting these information needs (Table 8).

Table 7. General indicators or specific metrics used in the tabular assessment of information flow

Major Indicator Category	General Objective: Issue	
	Objective ii: Recreational Water Use	Objective vii: Aquatic Invasive Species
Threats and stressors	Sanitary surveys	Rate of invasion - cumulative number of species over time
Program (management actions)	Amount of point and nonpoint source management practices	Number of returning adult lampreys
Ecosystem outcomes: habitat	Algal mass densities	*Phragmites* abundance
Ecosystem outcomes: biological	*E. coli* concentrations	*Dreissenid* abundance
Socioeconomic outcomes	Beach visits; Losses endured by tourism and recreation industry due to *E. coli*	Losses endured by tourism and recreation industry due to AIS

Table 8. Generalization of the types of qualitative data assembled from questions used in the interviews and online surveys of resource professionals for Project objective 2

Information Needs
• Decisions they make and the information they need for those decisions • Scale of information needs • Desired format of the relevant data/information • How they initiate a search for relevant data/information • How they go about compiling and delivering information to their superiors
Perspectives on Challenges and Solutions to Finding and Delivering Information

- Ability to find relevant data/information
- Amount of time and effort they put into finding relevant information
- Amount of data/information they receive or can find relative to their needs
- Problems with relevant data/information that hinder their usefulness for decision making
- General state of information management and delivery for their issue
- Credibility of existing online data/information resources
- How to improve information flow and existing information systems
- Amount of time they are willing to put into improving information flow in the Great Lakes

It is important to note that the interviews and surveys were not comprehensive and only descriptive in nature. They represent a snapshot of perspectives of a relatively small sample of Great Lakes resource professionals. However, we made every attempt to represent individuals from various geographies, scales and level of management, and institution types. To address the GLWQA objective ii, the surveys and interviews included resource managers and researchers from municipal, state, tribal and federal agencies, as well as academia. For GLWQA objective vii, they included resource managers and researchers from the shipping industry; state, provincial, federal and binational governmental agencies, and nongovernment organizations. To ensure openness and candid responses, we assured confidentiality to those participating in the surveys and interviews. The interview guide and online survey questions are provided in Appendix 4 and 5 of the contractor's report (Appendix C).

The online survey was distributed to nearly 150 individuals via the web using Survey Monkey. We received a total of 86 responses, with an even spilt of responses coming from resource professionals working in the area of AIS and recreational water use. Survey respondents that indicated they would be willing to be contacted for additional discussion of their responses were then included in the interviews.

The contractors collectively reviewed the qualitative (interview) and quantitative (survey) results to generally assess how well relevant data for each of the issues is managed per five dimensions of sound data management principles:

1. Discoverability - Can relevant data be found?
2. Accessibility - Have the relevant data been collected and/or are they available for use?
3. Usability - Are the data in formats that promote easy aggregation and analysis?
4. Preservation - Will management and access to the data be maintained in perpetuity?
5. Curation - Are provenance, quality and other metadata provided? (GEOSS Data Management Principles Task Force 2015)

4.4 Results and Findings

The contractor's report (Appendix C) provides a great level of detail of their findings from the surveys, interviews and tabular assessment. Readers are encouraged to read the more detailed findings in that report, which highlights specific strengths and weaknesses in the flow of information to decision makers for each of the two GLWQA objectives. Here we focus on a much higher-level synopsis of these findings. We first discuss general findings and then those related to each of the six components of information flow (see Figure 4). At the end of this section we also discuss the methods used for this objective and provide a recommended approach that builds on this and other related work that we believe should be used in future information flow assessments.

4.4.1 General Findings

Collectively, the results from the survey, interviews and tabular assessment clearly show that we currently struggle with answering the three focal questions of Project objective 3 for both issues. In fact, we could not identify any instance where the decision makers were receiving integrated reports across the relevant threat/stressor, program, ecological and socioeconomic indicators to help them make well-informed resource allocation decisions. Ironically, we found that the Great Lakes is rich in data across most of these major indicators, but the agencies and programs that collect the data for these different indicators are relatively siloed. The lack of sufficient or sustainable funding was also consistently cited as a problem that affects all components of information flow. However, it was most often cited as a problem for data collection and management efforts.

We did find that local decision makers generally have a more complete set of relevant data on which to base decisions. However, we also found that these local data are rarely aggregated to the larger spatial scales needed to inform regional and basinwide resource allocation decisions. We identified several barriers related to data sharing that hinder the aggregation of local data, such as lack of data sharing and licensing agreements, sensitivity of data, and unusable data formats. The best examples of aggregating local data to support larger scale resource allocation decisions were consistently associated with strong collaborations built upon principles of adaptive management with well-established, centralized governance structures that facilitate most aspects of this process, such as the Great Lakes Fishery Commission Sea Lamprey Control Program or the Great Lakes *Phragmites* Collaborative.

Decision makers for both issues consistently cited the importance of relying on their professional knowledge and experience to make their decisions, and only 34 percent of the respondents in the surveys stated they had sufficient information upon which to base their decisions. This suggests that many current decisions are not well informed by data. Finally, we did find strengths and

weaknesses in each of the major components of information flow and these are highlighted in the following sections.

4.4.2 Establishing Goals and Strategies

General goals, like those expressed in the general objectives of the GLWQA, were found to be consistently developed for both objective ii and vii. General goals were most consistently developed for ecological conditions; however, there were also many instances where general goals were expressed for socioeconomic conditions and program operations. General goal statements for these last two indicator categories were usually expressed in terms of minimizing impacts to human health and maximizing management efficiency. We also found that these general goal statements and associated management strategies were consistently established at all scales through existing planning efforts and strategic plans, like those listed under planning in Appendix B. This consistency of establishing general goals at multiple scales and across so many of the indicators is an important foundation for good information flow within this component. However, our findings were much different when it came to identifying metrics and indicators and establishing specific goals or benchmarks for these to more clearly define success.

There are very specific goals for many water quality metrics, such as *E. coli* concentrations, set as legal standards at state and national levels by agencies like USEPA and Health Canada. These standards are critical to beach managers charged with interpreting the data collected by local public health agencies to conduct sampling programs to assess water quality. Specific goals for program indicators related to the estimated amount of resources and actions needed to restore or maintain nearshore water quality and beach health are sometimes established by local municipalities and watershed groups. However, we were unable to find specific program indicators and goals being established and used at regional and basinwide scales for this particular objective.

There are good specific goals for efforts focused on control of specific invasive species such as sea lamprey and *Phragmites*. However, there is much less alignment on *specific* early detection and rapid response (EDRR) goals among Great Lakes states and Canada and the United States. Alignment on goals for the desired detection probability of new invaders (i.e., surveillance goals) are important for the establishment of consistent sampling protocols (e.g., sampling methods, locations and frequency) and associated program goals that will most efficiently achieve those detection probabilities (Lodge et al., 2006). Fortunately, there are many calls for more unified surveillance goals and sampling protocols among Great Lakes states (NISC, 2001, 2008; Great Lakes Panel, 2009; USFWS 2014; GLRI, 2010, 2014). And, a recently completed project, funded by GLRI, developed a surveillance framework for the US side of the basin that is being reviewed by the Interstate EDRR Core Team, which has representatives from all eight states in the basin. The most recent GLWQA also calls for consistent binational goals and strategies for AIS EDRR in the Great Lakes (GLWQA, 2012).

4.4.3 Data Collection

Relatively good data are available for generating relevant metrics and indicators for threats/stressors, ecological condition and socioeconomic conditions at all three spatial scales. Data related to program metrics and indicators are much scarcer and sporadically collected. Program indicators are more consistently collected and reported on for AIS than for recreational use of nearshore waters. However, in both cases the biggest challenge with program indicators is the lack of geographic specificity regarding where the investments and actions were made, which makes it difficult or impossible to relate trends in these metrics and indicators to those in the other categories.

Fragmented data collection efforts and a lack of collection/development standards among those efforts were consistently cited as two of the biggest barriers in this component of information flow. The immense number of data collectors increases the complexity and costs of obtaining and aggregating data. For instance, data collection to support AIS research and decision making is conducted by a diverse, loosely coordinated network of public agencies, universities and nongovernment organizations. Trying to obtain and aggregate these data was described by one person as "data wrangling." Lack of data collection or development standards is another problem often cited in this component of information flow. For instance, AIS risk assessments are performed separately by each of the states and provinces and there is a lack of standards for developing these assessments, which create obstacles to integrating these data to larger scales. The same problem exists for data related to beach visits and the resulting economic benefits, which are collected locally and sporadically using different methods that hinders aggregation. A good example of the importance of collection standards can be seen with *E. coli* in the United States where data collected by local public health agencies are relatively easily aggregated by state (BeachGuard) and federal (BEACON) data management systems, thanks to consistent data collection and reporting standards.

Lack of communication and coordination among programs that collect data on the various major indicators categories was another barrier identified for this component of information flow. For instance, there are many state and federal programs that collect ecological and socioeconomic data throughout the Great Lakes such as the USEPA, US Census Bureau, US Centers for Disease Control and Prevention, ECCC, Statistics Canada and the Public Health Agency of Canada. However, we found limited collaboration among the monitoring programs of these agencies.

4.4.4 Data Management and Delivery

We found excellent examples of online databases that provide easy access to relevant data for both issues such as GLANSIS, Open Data Canada, BeachGuard, and BEACON. These online resources primarily focus on delivering collection records for AIS and water quality. Links to these and many other online data management and delivery systems are provided in Appendix B. We were unable to find any regional or basinwide programs that manage and deliver datasets

that cover multiple Driver Pressure State Impact Response (DPSIR) categories for either of these objectives, which illustrates the fragmented management and delivery of relevant data for decision making.

Despite having these online resources, we still identified many barriers within this component of information flow. First, from the interviews we found that data are often not easily accessible due to intellectual property and licensing issues and the related lack of data sharing requirements by those funding data collection. We also found that even when data are available, it is generally in formats more suited for researchers than decision makers seeking data on specific metrics or indicators to answer questions. Fifty three percent of the survey respondents stated that the data they needed for making decisions was managed in formats that were not usable for them.

This statistic reflects a disconnect between data providers and users, which requires further investigation to determine the relative role each is playing in this barrier to information flow. Finally, we also found that political boundaries such as county, state or international borders are one of the biggest obstacles to data sharing. For instance, respondents in the surveys and interviews cited political and management jurisdictions as a major problem to compiling the relevant data needed to identify likely sources of recreational use impairments and developing remediation strategies.

4.4.5 Analysis and Reporting

Despite the challenges of data collection, management and sharing, this component of information flow is an area of strength for both general objectives. The are many excellent examples of analysis and reporting at all spatial scales for both issues that occur on regular cycles. These include the triennial SOGL and TAP reports of the Parties and the IJC, state and provincial annual AIS and water quality reports, and many municipal and tribal reports. Again, links to online versions of these reports are provided in Appendix B for AIS.

We did find quite a bit of variation in the content and quality of the reports. Some reports were largely narrative and qualitative, others were highly quantitative but lacked context, while others provided a mix of these two aspects. Most of the reports focus almost entirely on ecosystem indicators; however, there are some that reports across several of the DPSIR indicator categories and even in the context of progress towards general goals. Most of these reports are still delivered as PDFs on the US side, whereas interactive online reports are more prevalent in Canada.

4.4.6 Knowledge Management and Delivery

This is another area of strength for both objectives. We found abundant resources and an excellent network of education and outreach programs for both issues, particularly when it comes to educating key members of the public and training resource professionals in best management practices. Several examples of these resources available for AIS, like the USDA Invasive Species Information Center, can be found in Appendix B. There are even examples of education and outreach provided to policy makers, like what the Great Lakes Fishery Commission does in their communication program to provide sea lamprey control education, the programs needed to address that problem, and relevant metrics used to assess progress and inform resource allocation decisions.

There are good peer networks for sharing scientific knowledge, best practices and lessons learned such as the annexes, the Great Lakes Beach Association, and the Great Lakes Aquatic Nuisance Panel. These were consistently cited as critical to decision makers to advance their knowledge and find relevant data to help them make more informed decisions. There are also good collaborative processes in place for prioritizing science needs to fill key knowledge gaps within each issue and more broadly across all issues relevant to the GLWQA, like the Science Priority Committee.

Although not a focus of this project we did identify several key knowledge gaps that affect decision making around these two objectives. The most consistently cited knowledge gap was our lack of understanding of the relations between socioeconomic conditions and the other major categories of indicators.

4.4.7 Information Management and Delivery

Again, the surveys found that across both issues 34 percent of survey respondents stated they had enough information to make their decisions. Most of these responses are associated with local and/or rapid response types of decisions rather than larger scale resource allocation decisions. This is supported by the fact that through the interviews and tabular assessment, we were unable to find any example of programs providing information that would allow decision makers to fully answer all facets of the focal questions of this project. The closest example we could find for these two issues was the regular reporting done by the Great Lakes Fishery Commission (GLFC), which provides reports that integrate spatially explicit program metrics for investments (e.g., annual and longer-term costs) and actions (e.g., trapping, lampricide treatments) with lamprey population statistics and associated goals for each. The GLFC also takes steps to educate their commissioners and other decision makers to ensure they have the relevant knowledge to properly interpret these reports. There are new emerging programs and initiatives, like Canada's Results and Delivery Program that grew out of the recently established Policy on Results and the Blue Accounting initiative that grew out of a recommendation by the Council of

Great Lakes Governors and Premiers, that are aspiring to help decision makers answer the three focal questions and make more informed resource allocation decisions. However, it is too early to make an informed assessment of the success of these efforts.

4.4.8 Information Flow Assessment Process

The creation and delivery of information is a very complex process with many potential barriers to the flow of this information spread throughout this process (see Table 4). To our knowledge, this project is the first attempt at conducting an information flow assessment process that covers all six components of information flow. We believe the information flow assessment process developed and used for this objective was successful at helping to identify barriers to information, strengths and weaknesses in each of the major components, and identify clear steps forward for improving the flow of information to decision makers and more effectively achieving the GLWQA objectives. However, we also learned that we need to continually improve this process. To that end we developed a recommended process for future information flow assessments, which is laid out in Table 9. This process was built from the lessons we learned in this project and the related project of the CIW.

Table 9. Recommended assessment process for identifying barriers to information flow for each of the general objectives of the GLWQA

Step	Description
1	Identify specific metrics and indicators that enable answering the three focal questions of this project for each of the general objectives of GLWQA. Adhere to the principle of the "fewest that tell us the most." Incorporate traditional knowledge (TK) into the selection of these metrics and indicators.
2	Whenever possible, establish specific goals/benchmarks for each of these metrics and indicators. Incorporate TK into the establishment of these goals.
3	Develop and implement new approaches for engaging decision makers, including indigenous peoples. These assessments should be focused by assessing the relevance of the selected metrics and indicators to their resource allocation decisions, their information needs for rapid response decisions, and the desired formats and reporting cycles for this information.
4	Use the process established by CIW to identify and prioritize barriers to the delivery of the **individual** metrics and indicators to decision makers. However, expand the CIW process to include forecasting of metrics and indicators.
5	Identify and prioritize knowledge gaps for the inherent natural variation in each of the selected metrics and the relations among these metrics. When possible work through existing science prioritization processes such as those conducted by the IJC's SAB.
6	Use the process being developed by the Annex 10 Data Management and Science Team to identify and prioritize barriers to the **integrated** delivery of all the metrics and indicators identified for each of the GLWQA general objectives.
7	Develop specific recommendations and strategies to address the highest priority barriers to information flow.

An overarching lesson we learned is that information flow assessments need to be focused and as specific as possible. We believe that conducting information flow assessments separately for each issue or general objective of the GLWQA is the right approach. However, even within these issues it will be necessary to further break down the issue into relatively distinct decision domains, such as early detection, rapid response and control for AIS. We also believe that assessing barriers to the flow of information for specific metrics and indicators is essential. However, the metrics and indicators used for the tabular assessments in this project were a mix of general and specific metrics and indicators that would not necessarily be the ones that are collectively needed for well-informed resource allocation decisions. Therefore, we believe that future information flow assessments must focus on specific decisions and the specific set of metrics and indicators needed to answer them. We also believe these assessments should use the indicator and metric level assessment process developed by the CIW.

Unfortunately, for this project we did not have the time or resources to use this more rigorous and objective process, which affected our ability to more objectively identify and rank barriers to the collection, sharing, analysis and delivery of our selected metrics and indicators. Finally, we believe directly engaging decision makers is critical to all information flow assessments and is one of the most informative aspects of this project. We also believe that greater specificity in engaging decision makers will improve the assessment process.

The surveys and interviews used in this project produced a large amount of results that are useful, but also very hard to decipher. This is because we often did not know important context about the specific decisions and indicators that are being referred to when they made statements like, "I have enough information" or "It is hard for me to find the data I need." Therefore, we believe that future engagements with decision makers should be more specific by clearly defining the decision maker, their decisions, and assessing the specific metrics and indicators that are relevant to those decisions by following the process laid out in Table 9.

5.0 Objective 3 - Approaches for Including Traditional Ecological Knowledge Information Flows

Traditional Ecological Knowledge (TEK) is knowledge held by indigenous people that relates to the environment and the natural systems that govern ecosystems. It is holistic knowledge passed from generation to generation based on experience and teaching and is considered a way of life that underpins an authority system that governs the use of resources. From the perspective of non-indigenous scientists, TEK is often conceived of as a "body of knowledge" that can be tapped to supplement the empirical scientific method. This supplemental value, however, is not sufficient to fully include TEK in the information supply chain.

From an indigenous perspective TEK is viewed as a verb. That is, TEK is a process of participating in relationships between knowledge, people and the natural world. TEK is inherently linked to the people undergoing these relational actions and thus cannot be attained without participating in the experiences of being in these relationships (McGregor, 2008). According to the Alaska Native Science Commission (http://www.nativescience.org/issues/tk.htm), indigenous knowledge is considered to be truth and consists of both sacred and secular components. It is transmitted through story telling via oral or visual means. It is part of a whole system, and can be intuitive or subjective. In contrast to non-traditional knowledge, its acquisition time is lengthy and reflects long-term as well as recently gained wisdom, and has powerful predictive power in local systems, but not distant areas. The models are based on cycles, and explanations are based on examples, anecdotes and parables.

TEK's embrace by non-indigenous information systems works best when it is a relational process of building relevant knowledge to draw conclusions from data and information. Strategies for inclusion of TEK into Great Lakes information flows must start at this point. For Great Lakes information flows to benefit from TEK, indigenous groups, non-indigenous agencies and scientists must establish ongoing mutual relationships that exhibit reciprocity and respect with the indigenous people of the Great Lakes. Both the United States and Canadian governments have recognized the importance of TEK in governance issues affecting indigenous groups and have developed guidelines and protocols for its use. Two important underlying principles should guide decision about whether individual tribes and knowledge holders choose to share TEK: "Cause No Harm" and "Free, Prior, and Informed Consent" (CTKW, 2014). These principles recognize that each tribal community and individual has its own laws that guide use and dissemination of TEK.

There are two primary values that can be gained from engagement with TEK: supplemental value and governance value. Supplemental value is relevant knowledge or data that can be collected by scientists to establish informational truths in tandem with data collected through the non-indigenous scientific method. Indeed, most of the data collection from supplemental value is collected via classic non-indigenous research methodologies. Governance value derived from TEK is related to planning and prioritizing. For indigenous peoples, TEK provides the basis to ascertain goals, priorities and plans for survival in the face of multi-generational forces such as climate change and settler-colonialism. The most ethical and effective methods of including TEK in information flows include the supplemental value and governance value of TEK (Whyte, 2017).

There are a number of proven methods for incorporating TEK into scientific information flows, as summarized in Table 7 of Appendix C. Each of the five methods described can be used to include TEK into the information flow chain related to Great Lakes issues. Each method has strengths and weaknesses relative to its use for providing supplemental value versus governance value.

5.1 Results and Findings

- Underlying concepts of knowledge differ between indigenous and non-indigenous groups; among indigenous people's knowledge is a relational process that is built through experience and relationships, making it difficult to incorporate into non-indigenous information systems and decision frameworks.

- Currently, TEK mainly supplements and validates data collected via traditional scientific methods; in this context, current information flows allow for limited use of TEK for

governance (i.e., activities associated with planning and prioritizing) and more use for supplemental knowledge.

- Barriers to transmission of TEK to non-indigenous agencies and scientists include:
    - Concerns regarding commodification of knowledge focused on topics having spiritual value (e.g., use of environmental assessment metrics associated with sturgeon, wild rice)
    - Concerns associated with divulging information that might be used to exploit a critical resource (e.g., genetic material, distribution maps of wild rice).

6.0 Summary of Key Findings

Results from the analyses conducted on the program inventory and at the workshop showed that we dedicate most time and resources to the collection, management and analysis of data and much less attention to delivery of information to decision makers. In fact, we were unable to find a single example of a regional or basinwide decision maker who had access to the necessary information for assessing programs and progress toward GLWQA objectives and making well-informed resource allocation decisions. However, there are some programs that come close to meeting this high standard of information delivery and can serve as models, such as the Great Lakes Fishery Commission sea lamprey control reports (http://www.glfc.org/pubs/slcp/annual_reports/ANNUAL_REPORT_2015.pdf), and Environment and Climate Change Canada's environmental sustainability reports (http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=47F48106-1). We also found that the Great Lakes is a relatively data rich region, with monitoring programs that routinely collect ecological, socioeconomic and threat/stressor data that could be integrated to tell more complete, meaningful and compelling stories for many of the general GLWQA objectives. The lack of collaboration among these monitoring programs is the primary barrier to the integration of these data that must be addressed. We also found that decision makers are rarely asked about their information needs and even when the relevant data are available, they are often difficult to find or in unusable formats.

For Project objective 2, we found the lack of sustainable funding was a consistent problem affecting programs and efforts associated with all six components of information flow. We also found that local decision makers consistently had a more complete set of relevant data upon which to make decisions, compared to regional and basinwide decision makers who must rely on the aggregation of local datasets to generate information at their scale of interest. We found some major strengths and weaknesses when looking at each component of information flow. A strength of the planning and goal setting component was that general goal statements were consistently developed for both issues in the basin for all three scales we assessed (i.e., local,

regional and basinwide). These general goals provide the foundation for good information flow and decisions. General goal statements were most consistently developed for ecological conditions; however, there were also instances where they were expressed for socioeconomic conditions and program operations. A weakness in this component was the lack of specific metrics and indicators to measure progress toward these general goals and also a lack specific goals or benchmarks for these indicators when they did exist.

A strength of the data collection component was the availability of good data for generating relevant metrics and indicators for threats/stressors, ecological condition and socioeconomic conditions at all three spatial scales. Data for program metrics and indicators are much scarcer. Fragmentation of data collection efforts and a lack of collaboration and collection standards among those efforts were consistently cited as two of the biggest barriers to the aggregation and delivery of data within this component of information flow. All these findings are consistent with findings from Project objective 1.

For the data management and delivery component, we found several good online databases that provide easy access to relevant data for both issues, such as GLANSIS, Open Data Canada, BeachGuard and BEACON. But we also found many weaknesses in this component, like the lack of data sharing and licensing agreements, inability to share sensitive data, and incompatible data formats that were barriers to aggregate local datasets for nearly all the indicators we assessed.

Despite the barriers mentioned above, the analysis and reporting component of information flow is an area of strength for both GLWQA general objectives. We found many excellent examples of analysis and reporting for both issues that covered all three spatial scales and occurred on regular annual or longer-term cycles. These include the State of the Great Lakes (SOGL) and Triennial Assessment of Progress (TAP) reports of the Parties and the IJC, state and provincial annual AIS and water quality reports, and many municipal and tribal reports. However, we also found a lot of variation in the content and quality of the reports. Some reports were largely narrative and qualitative, others were highly quantitative but lacked context, while others provided a mix of these two aspects. Most of these reports focus almost exclusively on ecosystem indicators, but a few also cover the other major indicator categories. Another interesting finding was that most reports are still delivered as PDFs on the US side of the basin, whereas interactive online reports are more prevalent in Canada.

Knowledge management and delivery is another area of strength for both general objectives. We found abundant online resources and an excellent networking among education and outreach programs for both issues, particularly related to educating key members of the public and training resource professionals in best management practices.

Similar to Project objective 1, we were unable to find an example of a decision maker who is receiving appropriate information on integrated assessments across the relevant threat/stressor, program, ecological, and socioeconomic indicators to help them assess progress and make well-informed resource allocation decisions for either issue. There are new emerging programs and initiatives, like Canada's Results and Delivery Program that grew out of the recently established Policy on Results, and the Blue Accounting initiative that was the result of a recommendation by the Council of Great Lakes Governors and Premiers, which is aspiring to deliver this more complete set of information to decision makers. However, it is too early to make an informed assessment of the success of these efforts.

For Project objective 3, we understand that the underlying concepts of knowledge differ between indigenous and non-indigenous groups. Traditional ecological knowledge (TEK) is a relational process for indigenous peoples that is built through experience and relationships that are difficult to incorporate into non-indigenous information systems and decision frameworks. We found that current information flows to Great Lakes decision makers allow for limited use of TEK for governance and planning; thus, TEK is mainly used to supplement and validate data collected through traditional scientific methods. Some key barriers to transmission of TEK to non-indigenous agencies and scientists include concerns regarding commodification of knowledge focused on topics having spiritual value (e.g., sturgeon or wild rice) or divulging information that might be used to exploit a critical resource (e.g., genetic material, distribution maps of wild rice). The Canadian and United States governments have made commitments to include the perspectives of indigenous peoples in decision making; it is now incumbent upon program leaders to develop the appropriate protocols for including indigenous people in decision making bodies. This will require consideration of cultural sensitivities and patience on the part of all involved including development of ongoing mutual relationships that exhibit reciprocity and respect.

There were many important findings not necessarily associated with any specific objective of the project. First, we found our project to be very timely. There has been a recent surge of interest in the areas of accountability, information delivery, and monitoring a broader set of indicators to provide decision makers and the public with more complete and meaningful stories. Individuals continually expressed the need and an interest to foster collaboration among these efforts to support shared learning and minimize unnecessary duplication of effort. Despite this increased level of interest, we found the topic of information management and delivery and the terms in Appendix A are still unfamiliar to many resource professionals in the Great Lakes. We also found that there is a lack of real-world examples or case studies to demonstrate the value of integrating data across complementary metrics and aggregating these data across scales that support well-informed regional and basinwide decisions. There are data gaps that must be addressed before we can create robust case studies; however, this project did find that there is

some hope to creating these real-world examples in a relatively short time period, particularly with regard to integrating ecological and socioeconomic metrics.

Finally, the most important lesson we learned was that paying attention to all six components of information flow is an essential but extremely complex process that will require a long-term commitment and must be broken down into manageable pieces and steps. This is essentially what the IJC and the Parties did from the 1970s to early 2000s, by largely focusing on ecosystem indicators rather than the broader set of indicators. The amount of time, money and effort that has gone into putting in place the governance and funding structures to do the science, planning, monitoring and reporting for ecosystem indicators has been staggering and the progress has been phenomenal. But our project and the CIW project collectively found that by focusing on ecosystem indicators we have, by analogy, essentially built all components of a car except the dashboard and steering wheel. The recommendations in the next section center on how we begin to build these last two key components of the "car" and continually design new and improved models over time.

7.0 Recommendations

1. ***The IJC and the Parties should take steps to more equitably invest time and resources in all major components of information flow.*** We believe addressing the subsequent recommendations go a long way toward fully addressing this first recommendation.

2. ***The IJC and the Parties should make a long-term commitment to improving information flow to decision makers and the public.*** Effective information management and delivery is a persistent challenge that requires constant attention and a goal of continual improvement. The most important lesson we have learned from this and other projects is that performing "information flow audits" and developing sound information management and delivery strategies is unfamiliar territory to most Great Lakes natural resource professionals. To address this challenge, we believe the IJC should:

    a. Support development of a binational forum that fosters a regular dialogue among relevant programs and efforts (e.g., Annex 10 Data Management and Sharing Task Team, Blue Accounting, Canada's Policy and Results program, Global Earth Observation System of Systems (GEOSS), Great Lakes Advisory Board (GLAB) Science and Information subcommittee, Great Lakes Observing System (GLOS) and others) focused on generally improving information flow in the Great Lakes.
    b. Convene a regional discussion to define the entity or entities that are best positioned to facilitate information management and delivery related to the specific goals of the GLWQA.

3. ***The IJC and the Parties should support and build upon existing efforts to track and report on relevant threat/stressor, program and socioeconomic metrics and indicators.*** The IJC's efforts to identify human health and program indicators were important steps in improving information flow across the Great Lakes. However, these efforts need to be more focused by identifying relevant metrics and indicators related to each of the general objectives of the GLWQA, especially those socioeconomic and program indicators that are viewed as a priority by decision makers. The IJC should support and foster collaboration among complementary efforts that are addressing these types of metrics and indicators, such as Canada's Results and Delivery Program and Blue Accounting. The IJC should also encourage those responsible for SOGL reporting to collaborate with these complementary efforts in order to focus these reports on status and trends in ecosystem indicators and enable them to be integrated into the broader sets of indicators. This will provide more comprehensive assessments and reports to decision makers and tell more complete, meaningful and compelling stories in future TAPs.

4. ***The IJC and the Parties should immediately take steps to address barriers to information flow.*** There are some obvious and/or relatively easy steps the IJC could take or promote to improve the flow of information to decision makers. These include:
    a. Implementing already identified data collection and sharing policies needed to aggregate datasets for individual ecosystem metrics up to regional and basinwide scales. We believe the Annex 10 Data Management and Sharing Task Team should take the lead on prioritizing these relevant policies as they relate to specific sets of drivers-pressures-state-impact-responses (DPSIR) metrics tied to each general objective of the GLWQA.
    b. Encouraging collaboration of the Parties and IJC staff and boards with representatives of state, provincial and federal agencies that collect, track and report on socioeconomic metrics such as the US Census Bureau, US Centers for Disease Control and Prevention, Statistics Canada and the Public Health Agency of Canada. Starting these collaborations is an important step toward making the integration of ecological and socioeconomic data routine.
    c. Encouraging the Annex 4 and 6 work groups and task teams to address the specific barriers to information flow identified in Project objective 2 in this project. Specifically, we believe these work groups should review the detailed findings and recommendations laid out in the contractor's report provided in Appendix C of this report.

5. ***The IJC should ask the Parties to facilitate information flow assessments for each of the general objectives in the GLWQA using the recommended approach provided in this***

report. Identifying barriers to information flow is a complex process. Breaking down the assessment of information flow into manageable steps will lead to a more efficient and effective means of identifying and addressing barriers to information flow. This approach is likely to lead to tangible case studies that demonstrate how specific barriers to information flow (e.g., Table 4, section 2.4 of this report) can be addressed to more efficiently and effectively deliver relevant information to decision makers. This work could be conducted through existing groups such as the Annex Committees, Lake Committees, or other issue-specific partnerships such as Great Lakes Aquatic Nuisance Species Panel, Great Lakes Beach Association, Great Lakes Source Water Initiative or the Great Lakes Coastal Wetlands Working Group. We believe these groups are best suited to identify the specific sets of metrics and indictors for assessing barriers to the delivery of information to decision makers. Effort should be made to constantly improve the recommended assessment process to make it more objective, repeatable, and scientific. The information flow audit should:

d. Document the data and information needs of Great Lakes decision makers specially as they relate to setting priorities and making investments to achieve the objectives of the GLWQA.
e. Identify data gaps and identify barriers to information flow that inform decision making for each of the general objectives of the GLWQA using the framework laid out in section 4.4.8 and Table 9 of this report.
f. Identify specific policy solutions (see Table 4 and Appendix C) and processes to assess progress towards addressing gaps and barriers to information flow. These can be included in future Triennial Assessment of Progress reports or other special reports.

6. ***Traditional ecological knowledge (TEK) should be incorporated into all facets of information flow assessments and efforts to improve the flow of information to decision makers.*** To benefit from TEK, indigenous groups, non-indigenous agencies and scientists must establish ongoing mutual relationships that exhibit reciprocity and respect, and all parties must be included in all six components of information flow. Consideration should be given to cultural sensitivities in the way that different types of information are used in knowledge and governance systems and should embrace the concepts of free, prior, and informed consent when entering into agreements. Both Parties have recognized the importance of TEK and the governance systems of native people that support this; the Parties must now implement principles and protocols for delivering information and knowledge in an appropriate manner.

8.0 Literature Cited

Allan, J.D., Smith, S.D.P., McIntyre, P.B., Joseph, C.A., Dickinson, C.E., Marino, A.L., Biel, R.G., Olson, J.C., Doran, P.J., Rutherford, E.S., Adkins, J.E., Adeyemo, A.O., 2015. Using cultural ecosystem services to inform restoration priorities in the Laurentian Great Lakes. Frontiers in Ecology and the Environment, 13(8): 418–424

Barr, J., Hall, T. J., Harris, H.J., Krantzberg, G., and Sowa, S., 2010. Review report of the SOLEC independent expert panel. Presented to Environment Canada and the US Environmental Protection Agency

Borja, A., Galparsoro, I., Solaun, O., Muxika, I., Tello, E.M., Uriarte, A., Valencia, V., 2006. The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. Estuarine, Coastal and Shelf Science 66: 84-96

Climate and Traditional Knowledges Workgroup (CTKW), 2014. Guidelines for Considering Traditional Knowledges in Climate Change Initiatives. Retrieved from http://climatetkw.wordpress.com/

Congressional Research Service (CRS), 2013. The Great Lakes Restoration Initiative: background and issues. Retrieved from http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R43249.pdf

Council of Great Lakes Governors and Premieres (CGLGP), 1985. The Great Lakes Charter: principles for the management of Great Lakes water resources. Retrieved from http://www.web2.mnr.gov.on.ca/mnr/ebr/gl_charter/Charter1985.pdf

Environment Canada and U.S. Environmental Protection Agency (EC And US EPA), 2004. The Great Lakes indicator suite: changes and progress 2004. Retrieved from https://archive.epa.gov/solec/web/pdf/changes_and_progress_paper.pdf

Environment and Climate Change Canada and the U.S. Environmental Protection Agency (ECCC and USEPA), 2017. State of the Great Lakes 2017 highlights report: an overview of the status and trends of the Great Lakes ecosystem. Retrieved from https://binational.net/wp-content/uploads/2017/06/SOGL_17-EN.pdf

Environment Canada and the U.S. Environmental Protection Agency (EC and USEPA), 2014. State of the Great Lakes 2011. Cat No. En161-3/1-2011E-PDF. EPA 950-R-13-002. Retrieved from https://archive.epa.gov/solec/web/pdf/sogl-2011-technical-report-en.pdf

Fales, M.K., R. Dell, M.E. Herbert, S.P. Sowa, J. Asher, G. O'Neil, P.J. Doran, B. Wickerham., 2016. Making the leap from science to implementation: Strategic agricultural conservation in Michigan's Saginaw Bay watershed. J. Great Lakes Res. 42(6): 1372-1375. Retrieved from http://www.sciencedirect.com/science/article/pii/S0380133016301836

GEOSS Data Management Principles Task Force, 2015. GEOSS Data Management Principles. Retrieved from www.earthobservations.org/documents/dswg/201504_data_management_principles_long_final.pdf

Great Lakes Panel, 2009. Aquatic invasive species research priorities for the Great Lakes. Retrieved from http://www.glc.org/wp-content/uploads/2016/10/GLP-RC-AIS-ResearchPriorities2009.pdf

Great Lakes Restoration Initiative (GLRI), 2014. GLRI action plan II. Retrieved from https://www.glri.us/actionplan/pdfs/glri-action-plan-2.pdf

Great Lakes Restoration Initiative (GLRI), 2010. GLRI action plan FY2010-2014. Retrieved from http://www.dec.ny.gov/docs/regions_pdf/glriplan.pdf

Great Lakes Water Quality Agreement (GLWQA), 2012. Protocol Amending the Agreement Between Canada and the United States of America on Great Lakes Water Quality, 1978. Retrieved from https://binational.net/wp-content/uploads/2014/05/1094_Canada-USA-GLWQA-_e.pdf

Heinz Center, 2008. Environmental information: a road map to the future. The H. John Heinz III Center for Science, Economics and the Environment. Retrieved from https://library.dbca.wa.gov.au/static/FullTextFiles/071134.pdf

Health Professionals Advisory Board (HPAB), 2014. Recommended human health indicators for assessment of progress on the Great Lakes Water Quality Agreement. A report from the Health Professionals Advisory Board to the International Joint Commission. Retrieved from http://ijc.org/files/tinymce/uploaded/HPAB/Recommended-Human-Health_Indicators-June2014.pdf

International Joint Commission (IJC), 2014. Great Lakes Ecosystem Indicator Project Report: A Report of the IJC Priority. Retrieved from http://www.ijc.org/files/publications/Ecosystem%20Indicators%20-Final.pdf

International Joint Commission (IJC), 2013. Great Lakes ecosystem indicators summary report: the few that tell us the most. Retrieved from http://ijc.org/files/publications/Summary%20Report_Eco%20Indicators_2013.pdf

International Joint Commission (IJC), 2000. Indicators implementation task force final report. Retrieved from http://www.ijc.org/rel/boards/iitf/IITF-pdf/iitf_final.pdf

Lodge D.M., Williams S., MacIsaac H.J., et al., 2006. Biological invasions: recommendations for US policy and management. Ecol.Appl., 16, 2035–2054

McGregor, D., 2008. Linking traditional ecological knowledge and Western science: aboriginal perspectives from the 2000 State of the Lakes Ecosystem Conference. The Canadian Journal of Native Studies, 28(1): 139.

National Invasive Species Council (NISC), 2008. National invasive species management plan. Retrieved from https://www.invasivespeciesinfo.gov/council/mp2008.pdf

National Invasive Species Council (NISC), 2001. Meeting the invasive species challenge management plan. Retrieved from https://www.doi.gov/sites/doi.gov/files/migrated/invasivespecies/upload/2001-Invasive-Species-National-Management-Plan.pdf

National Research Council (NRC), 2004. Adaptive management for water resources planning. National Academies Press, Washington, DC

Oesterwind, D., Rau, A., Zaiko, A., 2016. Drivers and pressures –untangling the terms commonly used in marine science and policy. Journal of Environmental Management, 181: 8–15

Oppenheim, C., 1994. Are national information plans useful? Alexandria, 6(2): 133–143

Salafsky, N., Margoluis, R., Redford K.H., and Robinson, J.G., 2002. Improving the practice of conservation: A conceptual framework and research agenda for conservation science. Conservation Biology 16(6): 1469–1479

Science Adviosry Board Science Priority Committee (SAB-SPC), 2016. An assessment of the communicability of the International Joint Commission ecosystem indicators and metrics. Submitted to the International Joint Commission. Retrieved from http://www.ijc.org/files/publications/ScienceAdvisoryBoard_CommunicationIndicatorsReport_en.pdf

Seelbach, P.W, J.G. Read, K.A. Buckner, T. Eder and C. Manninen. 2014. Great Lakes Blue Accounting: empowering decisions to realize regional water values. A report to the Council of Great Lakes Governors, in response to the governor's 2013 resolution on water monitoring, March 28, 2014. Retrieved from http://www.blueaccounting.org/wp-content/uploads/2016/12/Great-Lakes-Blue-Accounting-Report-March-28-2014.pdf

Sowa, S.P., Herbert, M.E., Mysorekar, S.S., Annis, G., Hall, K., Nejadhashemi, A.P., Woznicki, S.A., Wang, L., and Doran, P., 2016. How much conservation is enough? Defining implementation goals for healthy fish communities. J. Great Lakes Res. 42(6): 1302-1321. Retrieved from http://www.sciencedirect.com/science/article/pii/S0380133016301848

Stankey G.H., Clark R.N., Bormann B.T., 2005. Adaptive management of natural resources: theory, concepts, and management institutions. General technical report PNW-GTR-654. U.S. Department of Agriculture, Forest Service, Portland, OR

Steinman, A., Cardinale, B., Munns, W., Ogdahl, M., Allan, D., et al., 2017. Ecosystem services in the Great Lakes. Journal of Great Lakes Research, 43: 161-168

Stem, C., Richard, M., Salafsky, N. and Brown, M., 2005. Monitoring and evaluation in conservation: a review of trends and approaches. Conservation Biology, 19(2): 295-309. Retrieved from http://www.proyectoibera.org/centroibera/download/cursos/doc/review_on_monitoring_and_evaluation.pdf

Tear, T.H., Karieva P., Angermeier P.L. et al., 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation. BioScience 55:835–849. Retrieved

from https://academic.oup.com/bioscience/article/55/10/835/274365/How-Much-Is-Enough-The-Recurrent-Problem-of

U.S. Department of Transportation (USDOT), National Highway Traffic Safety Administration, 2011. National 9-1-1 progress report. Retrieved from https://www.911.gov/pdf/national911progressreport2011.pdf

U.S. Department of Transportation (USDOT), National Highway Traffic Safety Administration, 2015. National 9-1-1 progress report. Retrieved from https://www.911.gov/pdf/National-911-Program-2014-ProfileDatabaseProgressReport-031315.pdf

United States Fish and Wildlife Service (USFWS), 2014. Early detection and monitoring work plan for non-native fishes and select benthic macroinvertebrates in the Great Lakes. Retrieved from https://www.fws.gov/northeast/lowergreatlakes/Programs/AIS/Projects/Lake%20Erie%202016%20EDM%20Report%20Final_3-17-2017.pdf

United States Government Accountability Office (USGAO), 2013. Great Lakes Restoration Initiative: further actions would result in more useful assessments and help address factors that limit progress. GAO-13-797. Retrieved from http://www.gao.gov/assets/660/658265.pdf

Walters, C. J., 1986. Adaptive Management of Renewable Resources. Macmillan Publishing Company, New York

Whyte, K., 2017. What do indigenous knowledges do for indigenous peoples? Forthcoming in Keepers of the Green World: Traditional Ecological Knowledge and Sustainability, edited by Melissa K. Nelson and Dan Shilling. Retrieved from https://static1.squarespace.com/static/55c251dfe4b0ad74ccf25537/t/5897ef53e6f2e12da00831c7/1486352211674/What_do_Indigenous_Knowledges_do_for_Ind.pdf

Williams, B.K. and Brown, E.D., 2014. Adaptive Management: From More Talk to Real Action. Environmental Management 53(2): 465-479

Alaska Native Science Commission, no date. What is Traditional Knowledge? Accessed at www.nativescience.org/issues/tk.htm August 12, 2017

Appendix A – Definitions of Key Terms Relevant to Information Management and Delivery

Value

- The importance, worth, or usefulness of something to an individual or group

General Goal (*referred to as General Objectives in GLWQA*)

- Something that you are trying to achieve; a desired ultimate outcome
- The end, the whole, longer term and large in size
- Not always measurable or tangible
- Examples:
    - The Great Lakes should
        - Be a source of safe, high-quality drinking water
        - Allow for swimming and other recreational use, unrestricted by environmental quality concerns
        - Allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants

Specific Goal (*often referred to as a Target or Specific Objective in GLWQA*)

- A sub-goal; intermediate outcome
- A means to an end, part of the whole, shorter term, and smaller in size
- A desired condition or set of conditions for a specific metric or indicator
- Should be specific, measurable, achievable, realistic and timebound (SMART)
- Examples:
    - Remove 34 additional Beneficial Use Impairments in the remaining 29 Areas of Concern by the end of fiscal year 2019 (GLRI Action Plan II, page 7; https://www.glri.us//actionplan/pdfs/glri-action-plan-2.pdf)
    - 40 percent overall load reduction in the amount of total and dissolved reactive phosphorus entering the WLEB by the year 2025 (https://www.epa.gov/glwqa/recommended-binational-phosphorus-targets)

Shared Goal

- Something that more than one person or group is trying to collectively achieve

Data

- Facts that lack context
- Facts that can be analyzed and used to gain knowledge

Relevant Data

- Data that could be used to make a decision

Metric

- A standard method of measuring a particular attribute of the universe

- Examples:
    a. Dissolved reactive phosphorus concentrations
    b. Annual corn production
    c. Total annual beach visits

Indicator

- An integrative measure that combines more than one metric to assess conditions
- Examples:
    a. Land Cover Conversion and Fragmentation Index (IJC 2015)
    b. Index of Biotic Integrity (Karr 1981)
    c. Gross Domestic Product (https://www.boundless.com/economics/textbooks/boundless-economics-textbook/measuring-output-and-income-19/measuring-output-using-gdp-92/gdp-equation-in-depth-c-i-g-x-349-12446/)

Knowledge

- Acquaintance with facts, truths or principles
- Understanding of patterns within and relationships among attributes of the universe (e.g., DPSIR metrics and indicators)
- Having the ability to understand and interpret data

Relevant Knowledge

- Having the ability to understand and properly interpret relevant data to make an informed decision

Decision

- A choice made between alternative courses of action to help achieve one or more goals

Decision Context

- The related set of goals and circumstances (past, present and possible future) that form the relevant setting and determine the relevant pieces of information needed for a given decision so that the alternative courses of action can be fully understood and assessed
- Piece of information (singular)
- An individual piece of relevant data, among many that are collectively needed, to inform a decision and you have the relevant knowledge to properly interpret that piece of data

Information (*plural*)

- The collection of relevant data that is used to inform a decision to reach a goal when you have the relevant knowledge to properly interpret those data

Uninformed Decision

- A decision made without any goals, relevant data and/or relevant knowledge to properly interpret the relevant data and assess alternative courses of action

Biased Decision

- A decision made based on an incomplete set of relevant data or knowledge that favors one goal over another

Well-Informed Decision

- A decision made using the full collection of relevant data and with the relevant knowledge to properly interpret these data to assess the alternative courses of action

Wise Decision

- A decision made using the full collection of relevant data and with the relevant knowledge to properly assess alternative courses of action and selecting the best course of action

Barriers to Information Flow

- Lack of specific goals, relevant data and/or relevant knowledge
- Anything that hinders the:
  - establishment of general and specific goals/targets
  - collection, management and analysis of relevant data
  - integration and effective delivery of relevant data to decision makers
  - understanding of the patterns within and relations among relevant metrics and indicators
  - education of decision makers and prevents them from having the relevant knowledge to properly interpret the relevant data

Appendix B – Inventory of AIS Resources

Please see Excel file attachment "Appendix B – AIS Resources" located at Appendix B - AIS Resources.xlsx.

Appendix C - Report to the Information Coordination and Flow Workgroup on Great Lakes Information Flows (Prepared by Great Lakes Commission and LimnoTech)

Please contact Matthew Child (childm@windsor.ijc.org) at the IJC GLRO Office to obtain a copy of the report.