Science Strategy

for

Improving Great Lakes Restoration

A Document from Directors of U.S. and Canadian Great Lakes Academic Centers and Initiatives in response to the U.S. EPA Science Advisory Board Report, *Great Lakes Restoration Initiative Action Plan Review* (Jan.2012)

October 2012

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Science Strategy for Improving Great Lakes Restoration

Executive Summary

This document was developed by U.S. and Canadian directors of academic Great Lakes centers and initiatives as a strategy for implementing the "solid, science-based framework that provides input and justification for actions [that] will be necessary to support restoration decisions, track the restoration plan's progress, and document the GLRI's success" identified in the US EPA's Science Advisory Board (SAB) evaluation of the Great Lakes Restoration Initiative Action Plan (SAB, 2). The challenges of restoring the Great Lakes to ensure they better benefit society and our economy within the constraining timelines of the GLRI program are daunting. To succeed, additional support for systematic and coordinated efforts that link the best science with progressive management focused on meaningful and tangible outcomes is required. Recognizing our responsibility as a scientific community to pursue relevant, use-inspired research, the SAB's review motivated us to develop a strategy to integrate science from all sectors into the restoration effort.

This document takes a pragmatic, applied approach to integrating science into Great Lakes Restoration Initiative (GLRI) efforts and is designed to better enable us to:

- Understand and assess the cumulative impacts of the hundreds of restoration projects funded during the opening years of GLRI at the sub-basin, individual lake, and basin-wide levels;
- Increase the efficiency and cost-effectiveness of restoration activities (e.g., reduce per unit cost of restoration activities);
- Understand the organizational/institutional actions necessary to facilitate implementation of effective adaptive management approaches in the coming years;
- Maximize the success of restoration projects by implementing science-guided corrective actions under an adaptive management approach;
- Advance restoration science by improving restoration techniques and methods;
- Identify key science gaps associated with each of the GLRI focus areas; and
- Provide a single, spatially organized database that integrates GLRI project results and enables resource managers to better analyze and prioritize subsequent restoration actions for maximum efficiency and benefit.

This science strategy is not designed to:

- Differentiate among decisions to mitigate, restore, or protect;
- Outline basic research needs or opportunities;
- Further assess or monitor the status of the Great Lakes; or
- Reassess the current stressor-oriented structure of the GLRI action plan, except to more explicitly include climate.

While currently funded GLRI projects were asked to provide pre/post restoration assessments of measurable outcomes, these were not primarily assessments of restored ecosystem function which requires science-guided monitoring to conduct. This kind of assessment was explicitly excluded in the 2012 Request for Proposals. Future GLRI efforts should refocus on assessment of restored ecosystem

function and fund this requirement, evaluate results, and reprioritize actions when necessary within an adaptive management framework. Such assessments not only help determine the extent to which projects have achieved their goals, but will also enable determination of how well tax-payer dollars have been invested. These evaluations will further inform the development of cost-effective restorations and remediation strategies.

We recognize that implementing adaptive management is challenging when constrained by short-term projects of one or two years. One of the primary goals of this review and report is to elevate adaptive management from the project-specific level to accommodate the longer timelines necessary to implement it effectively. GLRI's successes will be measured by how well restoration activities result in the social and economic benefits, including restored and enhanced ecosystem services, which the public understands and values. Only if we are successful in delivering these desired outcomes will there be resources to continue this important restoration work into the future.

There are a number of project examples, from the Great Lakes (including GLRI-supported) and other locations (e.g., the Everglades, Chesapeake Bay, Puget Sound), where science has been efficiently and effectively integrated into ecosystem restoration. We describe and build upon those examples to outline a framework for a short- to long-term, cost-effective, and efficient process for ensuring the goals of the GLRI are met to the benefit of society and the regional economy.

Introduction

Human activities in the region have always shaped the Great Lakes, but the past 200 years have taken a significant toll, permanently altering hydrologic, aquatic, and terrestrial ecosystems and the chemical and biological constituency of the lakes and their tributaries. We recognize therefore, that a GLRI program of five or even ten years will not fully correct these insults. However, an appropriately envisioned, strong science plan with an effective implementation strategy will set us up to restore, enhance, and protect Great Lakes ecosystems into the future.

We appreciate that a lot of the groundwork necessary to start the GLRI process had already been laid through various initiatives that many of us participated in, such as the regional priority setting of the Great Lakes Regional Collaboration, and the various Lakewide Management Plan and Area of Concern planning processes. However, we agree with the EPA Science Advisory Board's assessment that these initial projects, as well as the data and information gathered during their implementation, need to feed into science-based framework that will enable a new evaluation/ prioritization process to determine future GLRI projects, track restoration progress, and document GLRI success (SAB Report, 1-2).

> *The SAB recommends that EPA work with natural and social scientists and engineers from government, academia, non-government organizations (NGOs) and industry to create this science plan that, when coupled with the Action Plan, creates a framework for adaptive management. This science plan also should explicitly consider potential impacts of climate change on restoration.* (SAB,3)

In July 2012 the directors of Great Lakes academic centers and initiatives from across the U.S. and Canadian Great Lakes region came together in response to the US EPA's Science Advisory Board (SAB) review of the Great Lakes Restoration Initiative Action Plan (GLRI). Cognizant of our responsibility as a scientific community to pursue relevant, use-inspired research, the SAB's review heightened the need to integrate science support into the restoration effort. Understanding that the Interagency Task Force has directed the Regional Working Group to develop a science plan for the Great Lakes Restoration Initiative, we engaged in our effort to provide input to the federal plan by providing a strategy and guidance for better integrating science in support of more ecologically and financially effective decision making.

Use of scientific information is important throughout the decision-making and evaluation process in three ways.

1) While there are many factors to consider when selecting restoration projects (e.g., partner match requirements, economic and social justice issues, regulatory or statutory constraints or mandates), it is important that science is used to identify the appropriate restoration methods, which will lead to wiser expenditure of dollars by ensuring restoration dollars are not spent on poorly designed and executed projects.

2) Regardless of the criteria for final project selection, it is critical that the methods employed for implementation and evaluation of success are science based and credible.

3) Both of the above are related to individual project selection, implementation, and evaluation; however, a strong science program would also provide better tools for verification that the hundreds of individual projects add up to Great Lakes restoration, and a sophisticated recognition of the complexity of restoration at this scale.

Fully integrating use-oriented science will enable us to maximize the success of restoration projects by implementing science-guided corrective actions. Restoration science will also be advanced by improving techniques and methods and, importantly, ensuring those methods are widely shared so that subsequent restoration efforts can benefit. Fully integrating science into the restoration process will enable us to understand the cumulative impacts of the hundreds of GLRI projects, focused on individual lakes and sub-basins, on the health of the Great Lakes. **Most significantly, fully integrating use-oriented science will ultimately increase the efficiency and cost-effectiveness of restoration activities over time.**

This science strategy addresses two efforts: 1) integrating science support for adaptive management through assessment and evaluation; and 2) providing scientific support to guide and improve restoration efforts. We believe it is important that both of these efforts include a consideration of potential climate impacts as a necessary component.

There are many ways to organize a science-based effort designed to both evaluate and prioritize restoration efforts within an adaptive management framework. This could be by geography (by lake), by lake zone (pelagic, benthic, etc), or by stressor (linked to societal goals). However, when considering implementation it may be necessary to take a geographic approach as the organizational structure (SAB, 15).

This science strategy is designed to:

- Understand and assess the cumulative impacts of the hundreds of restoration projects funded during the opening years of GLRI at the sub-basin, individual lake, and basin-wide levels;
- Increase the efficiency and cost-effectiveness of restoration activities (e.g., reduce per unit costs of restoration activities);
- Understand the organizational and institutional actions necessary to facilitate implementation of effective adaptive management approaches in the coming years;
- Maximize the success of restoration projects by implementing science-guided corrective actions under an adaptive management approach;
- Advance restoration science by improving restoration techniques and methods;
- Identify key science gaps associated with each of the GLRI focus areas; and
- Provide a single, spatially organized database that integrates GLRI project results and enables resource managers to better analyze and prioritize subsequent restoration actions for maximum efficiency and benefit.

This science strategy is not designed to:

- Differentiate among decisions to mitigate, restore or protect;
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- Reassess the current stressor-oriented structure of the GLRI action plan except to more explicitly include climate.

Integrating Science into Restoration: Examples

There are several examples of integrating science support into restoration activities that can serve as a model for future GLRI efforts. Some are external to the Great Lakes Basin, such as efforts associated with regional restoration in the Chesapeake, the Florida Everglades, and Puget Sound. However, many can be found in the Great Lakes region as well. For example, a multi-sectoral effort to restore native fish spawning habitat in the Lake Huron to Lake Erie Corridor connecting channels has taken a science-based approach to site selection and an iterative approach to site design that has enabled significant project efficiencies over time.[1] Another example is the wetland restoration assessment program that uses protocols developed by a bi-national, multi-sectoral group of wetland experts and is designed to enable comparisons across geographies, as well as to determine cumulative impacts of multiple stressors on wetland restoration projects in common geographies.[2]

We support and endorse efforts such as these and consider them models for what we propose because:

- Science and action are iterative and incorporated directly into restoration;
- Successive projects build on knowledge developed from previous projects and relevant complementary activities in the system;
- Projects consider multiple stressors (e.g., invasive species, climate change);
- Projects are based on a restoration plan that is system-wide and considers impacts beyond the individual project site;
- Successive projects are both more cost-efficient and effective (e.g., in terms of fish response witnessing immediate spawning responses); and
- The project team is comprised of federal, state, academic, and private sector partners, each contributing their expertise and resulting in a stronger effort in the long run.

Explanation of the Strategy

We organized this Science Strategy around five major focus areas, four of which are the GLRI focus areas: "Toxic Substances and Areas of Concern," "Invasive Species," "Nearshore Health and Nonpoint Sources," and "Habitat and Wildlife Protection and Restoration." The fifth focus area – one recommended by the SAB – is climate change, included both as its own separate focus area, for those elements that stand alone, and incorporated into the other focus areas as necessary. For each of these focus areas we have identified key science gaps and connected those to outputs and outcomes intended to help achieve the associated societal goals. This approach is detailed in the Implementation Guidance and a separate Appendix.

We also recommend that the current GLRI focus area "Accountability, Education, Monitoring, Evaluation, Communication, and Partnerships" be integrated throughout the other focus areas as an overarching approach/process. This includes the kind of system-wide evaluation, adaptive management approach, and partnering that is required to implement the strategy outlined here. The SAB report concluded that:

> *"EPA should develop a strategic assessment and management plan that implements monitoring, synthesis, and integration across the focus areas to bolster the accountability goals of the GLRI. Without a science-based accountability framework, the GLRI will do little to advance coordination and collaboration among Great Lakes partners [and Great Lakes communities] to address key scientific issues." (SAB, 3)*

These kinds of accountability goals, fully integrated into each focus area, will enable the agencies to deploy resources more efficiently, identify and disseminate the restoration practices that work well, reduce redundancies otherwise missed by working across such significant distances (as a result of

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[1] This ten plus year multi-sectoral and multi-disciplinary effort has demonstrated both ecological effectiveness (e.g., fish were spawning at the team's latest project site in the Middle Channel of the St. Clair River delta before construction was complete) *and* financial efficiency in reducing per unit restoration costs from an initial $1.69M/acre in the early 2000s to approximately $500K/acre by 2012. (Bruce Manny, pers. Communication.)

[2] Great Lakes Coastal Wetland Consortium methods and protocols are available here: http://www.glc.org/wetlands/documents/finalreport/Great-Lakes-Coastal-Wetlands-Monitoring-Plan_FINAL.pdf

geographic and organizational isolation), and achieve many other benefits. In addition as described below, the data and information required to address these accountability goals will support the decision-making process by providing baseline information against which project outcomes can be assessed, help to integrate individual projects into analyses at basin-wide, sub-basin and individual lake level and identify remaining gaps.

Integration

The goals of the GLRI and the recommendations of the SAB can be achieved through an improved implementation plan that includes iterative learning to make successive management decisions more effective and restoration projects more efficient and cost-effective. It is imperative that meeting societal goals, such as restoring beneficial uses and other ecosystem services be the primary outcome. These outcomes can best be assessed within a framework that integrates a myriad of independent restoration actions, both across stressors and from the local to basin-wide scales.

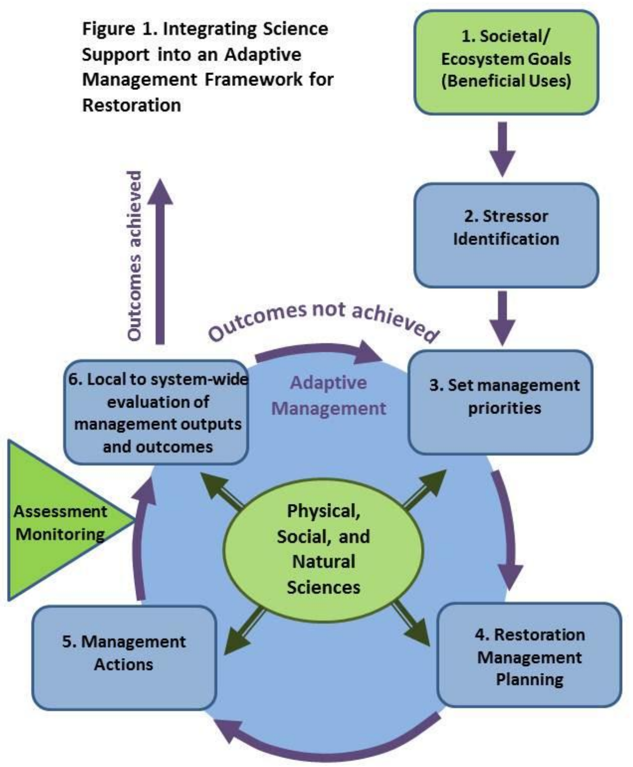

Figure 1. Integrating Science Support into an Adaptive Management Framework for Restoration

This framework must also support a science-based adaptive management process for restoration that monitors progress, makes adjustments as needed, and demonstrates *and replicates* the efficient and effective successful restoration efforts. It is critical that subsequent restoration projects build on lessons learned from previous efforts, such as which restoration techniques and methods are most efficient and effective. By establishing a single, spatially organized database that integrates GLRI project results, resource managers will be better able to analyze and prioritize subsequent restoration actions for maximum efficiency and benefit. This comprehensive restoration database will be of immense value in identifying knowledge gaps, guiding future Great Lakes restoration activities, and ensuring the goals of the GLRI are met. Assessment, analysis, integration, and synthesis all support more efficient and effective restoration practices and can result in earlier identification of the most effective methods and faster dissemination than under current practices.

Implementation Guidance

The implementation process (Figure 1) includes the development of conceptual models to evaluate appropriate management priorities, identify management actions, and evaluate progress toward achieving societal and ecosystem goals on lake-wide or basin-wide scales. In addition, existing evaluation efforts should be identified and information shared across government, academic, and NGO partners. Multi-sectoral – public, private, academia and non-governmental – science support is infused into each stage of the adaptive management framework to ensure restoration draws upon the full intellectual and experiential wealth of the region. This input is particularly critical in the evaluative step 6.

Step One of the implementation process for each GLRI project is to establish the desired **societal goals and ecosystem outcomes**. The GLRI has taken a stressor-based approach (e.g., AOCs, Invasives, Habitat); however, these stressors must not be considered in isolation. Effective restoration takes an integrated approach that considers potential interactions and synergies across stressors to make effective progress across broad geographies. In **Step Two**, a conceptual model is created that considers the **primary stressors** relevant to a specific geography and identifies the key assessment parameters required to establish baselines against which progress can be measured. It has been noted that the assessment process is initially resource intensive, especially where knowledge gaps are largest; however, over time, costs come down as fewer data are required for assessment activities. In **Step Three, Management Priorities are set**. This should be done in a transparent manner, using multi-sector expertise and considering all other relevant projects. **Step Four** consists of **Restoration Management Planning** and again builds on the expertise of science partners from multiple sectors to ensure optimal efficiency and leveraging of available resources. **Step Five** consists of taking the identified **Management Actions** outputs that are evaluated at multiple levels from local to basin-wide if applicable. **Assessment, Step 6,** reveals if the originally identified societal or ecosystem goals have been achieved; if so, the process is complete. However, when goals have been only partially met, this framework enables an adaptive management process to begin, integrating assessment results and new information to set management priorities.

Implementation principles

Regardless of the form of implementation taken, the following principles should apply.

- Longer-term planning and assessment horizons will ultimately yield better restoration results and reflect favorably upon GLRI-funded projects. The GLRI is in a position to put in place key infrastructure required for improving all restoration efforts, thus creating a legacy that would extend well beyond the expenditure of the initial resources;
- Adaptive management is a long-term proposition and therefore assessment activities should extend beyond the initial restoration activity (e.g., "moving mud") to: Assess progress; Determine the extent to which anticipated management outputs were achieved; Evaluate new management options, if necessary; Implement revised management actions; and Optimize future project designs, including pre- and post-assessments;
- Projects that use established restoration methods with known outcomes may need only assessment to ensure anticipated outcomes are reached;
- Projects or collections of projects that use innovative restoration methods with uncertain outcomes will require long-term scientific assessment programs that can guide adjustments before ultimate management outcomes are achieved (i.e., sufficient evidence to assure the restoration of ecosystem function and structure);
- Regionally appropriate reference sites should be identified to establish restoration goals and assess success;

- Baseline data/analyses are critical and need to be determined for all restoration projects in all geographies, and should be compiled from existing data, modeled data, data collected at project site locations, *and* reference sites;
- Projects should be configured to enable integration across stressors and with other projects/results.
- Project data outputs should be comparable/compatible with baseline data/information following clearly defined and specific protocols (note, this is much more than developing a QAPP);
- Project data must be made available as collected and quality-controlled, as near real-time as possible in internationally recognized formats and over the long-term. This will facilitate meta-analyses, such as cumulative assessment across stressors and geographies, as well as adaptive management;
- Every funded project must clearly articulate how it integrates into the broader restoration context (e.g., addresses a management need identified in the Science Strategy Appendix).

Implementation Strategy Options

The following are suggestions for ways to meet these implementation principles.

- **Target a subset of funding for integrating across stressors and scales.** For example, RFPs could require identification of the specific restoration goal, description of science required to meet the goal(s), and articulation of how the project fits into a multi-stressor and broader geographic context. A plan for pre- and post-project assessment should also be required including how the project will use existing data, and contribute to new data, as part of a larger data sharing and dissemination plan.
- **Require formation of teams addressing broader issues, geographies, and restoration needs.** Instead of supporting teams focused on very specific and localized projects, RFPs could require formation of broader, multi-disciplinary, multi-sector consortia with the expertise to understand multi-stressor interactions, and the interaction of multiple systems (biological, geophysical, social, economic, etc.). These teams would require communication and data management plans that embrace the principles articulated above. Facilitators would ensure that these teams interact in "teams of teams" so that common issues can be addressed, and solutions and challenges can be shared in ways that are more deliberate than our current regional meeting structure allows. This approach would provide a built-in mechanism for more effective communication, data-sharing, and collaboration across regions and stressors.
- **Information collection, management, and dissemination.** Develop more effective ways for collecting, managing, and disseminating data and information to scientists, managers, and stakeholders. This could be achieved through funding a distributed data system that provides access to data held and updated by the institution or entity that developed it.
- **Support multi-sector, multi-disciplinary** teams to conduct assessments and syntheses for all restoration activities. This team would be empowered to determine data and information collection protocols, collect and assess those data, work with managers to assess project outcomes and develop/determine additional management actions if restoration goals are not met for a project, region or lake.
- **Link Federal extramural research programs.** This has been done successfully in the past and has been a highly successful way of leveraging funds, enhancing efficiency and effectiveness (e.g., NSF-EPA's watershed initiative, NOAA-NSF-EPA's ECOHAB program, NSF-NOAA's GLOBEC program). Partners could include the National Science Foundation, National Institute of Environmental Health Sciences,

NOAA, and Strategic Environmental Research and Development Program (DOD, DOE and EPA) on the US side and, in Canada, the Natural Science and Engineering Research Council (e.g., strategic grants and shiptime programs), Environment Canada and Fisheries and Oceans Canada.

We suggest that regardless of the implementation strategies selected, the current proposal review process, conducted entirely by Federal employees, should be modified to incorporate third party academic and other experts as first round reviewers. The first round of reviews could then be followed by an administrative (i.e., "relevancy") review conducted by Federal employees (i.e., a model similar to SERDP or EPA-STAR programs).

Funding the Science

The kind of integrated science necessary for Great Lakes restoration cannot be funded through random projects, without regard for cumulative effects and the spatial distribution of stressors and responses. Instead, we recommend first developing a systematic, spatially explicit analysis of the types and distributions of stressors and responses to identify the areas of greatest need.[3] Further assessments of the costs and potential for successful restoration should then be followed by a dialogue among managers, scientists, and the engaged public to prioritize activities. Specific questions, such as those identified in the Appendix to this report, need to be fleshed out in a process that engages science support for resource managers. This kind of activity, such as described in the examples we identified above, requires bridging the science and resource management communities, clarifying questions and management needs for scientists, guiding inter-community dialogue, and developing consensus at various stages of the implementation process. The result needs to be larger in scale and scope and developed collaboratively among the multi-sectoral experts in the Great Lakes Basin. Finally, the selection process for these activities must also be multi-sectoral (e.g., government, academia, NGO/industry) and impartial; one where experts external to the region can also be engaged to evaluate and make recommendations on projects/project teams.

The historic disturbances we are addressing through the GLRI occurred over at least the last two hundred years. We have known from the beginning that restoration actions will not be complete with a five or even ten-year GLRI program. However a long-term, science-based adaptive management process for restoration requires resources to ensure continuity in implementation and evaluation of success. As such we need to identify a long-term mechanism for providing the necessary financial support for this effort. Directed scientific support for long-term management effectiveness might constitute upwards of ten percent of GLRI restoration funds, with additional resources accruing over time through relevant federal or state environmental settlement actions, regional user fees or other creative mechanisms.

Conclusion

We believe the strategy outlined above addresses the need for the "solid, science-based framework" outlined in the SAB review, resulting in more efficient and effective GL restoration efforts. The problems the GLRI seeks to address are both complex and massive (in scope and scale), requiring a systematic and coordinated effort that integrates the best science with progressive adaptive management. It is critical that we understand and assess the cumulative impacts of the hundreds of restoration projects funded during the opening years of GLRI at the sub-basin, individual lake, and basin-wide levels. This strategy

[3] There are several good, existing examples that could be employed to support this effort including the Great Lakes Environmental Indicators (GLEI) stressor gradient, Great Lakes Environmental Assessment and Mapping (GLEAM) Project data set, coastal wetland monitoring.

focuses on elevating adaptive management from the project-specific level to broader geographic and temporal scales. It would help to improve integration across stressors and spatial scales, while also accommodating the longer timelines necessary for effective restoration.

To achieve success, this strategy should be developed and implemented as a collaborative effort among the multi-sectoral experts in the Great Lakes Basin, bridging multiple communities but in particular, the science and management communities. Although the proposed science strategy requires investment, in the long run this approach will result in an overall increase in efficiency and cost-effectiveness of restoration activities (e.g., reduced per unit costs of restoration activities).

The implementation of the proposed long-term, science-based adaptive management framework would help ensure continuity across the GLRI and future Great Lakes restoration efforts resulting in more efficient expenditure of resources, improved restoration success, and ultimately, achievement of societal and ecosystem goals.

References:

U.S. EPA Science Advisory Board (SAB), *Great Lakes Restoration Initiative Action Plan Review.* (January 2012) accessed: http://yosemite.epa.gov/sab/sabproduct.nsf/96FEEE23D89A39E48525798F00768CCD/$File/EPA-SAB-12-002-unsigned.pdf

APPENDIX FOCUS AREAS/STRESSORS

We used the following template to organize our science strategy under each of the five themes:

Stressor: For example, Toxic Substances and Areas of Concern, Invasive Species, Nearshore Health and Nonpoint Sources, Habitat and Wildlife Protection and Restoration, and Climate.

Impacted Societal Goals: An analysis/listing of societal goals impacted by the stressor. Societal goals include: swimmable, fishable, drinkable, accessible, aesthetics, and biodiversity. We have mapped Beneficial Use Impairments (BUIs) to each of these goals (Table 1).

Management Need: Specific management needs to effectively reach, or move toward, the societal goals. This also includes a well-defined, measureable restoration goal, and goals should be prioritized according to projects that would provide the greatest benefits.

Science to Meet Management Needs: This is the science needed to guide and evaluate the management strategy and to help prioritize restoration actions – critical elements of an adaptive management framework. The science provides key information and metrics for evaluating progress toward overarching goals. Included is the need for quantitative risk assessment analyses that rank stressors in terms of importance and impact on BUIs (i.e. an assessment of which stressors or group of stressors should be targeted first for effective, long term restoration). See, for example, WICCI Green Bay working group report *Potential Climate Change Impact on the Bay of Green Bay – An Assessment Report, 2010*.

Outputs: Includes science products such as validated models informing management and environmental outcomes, science-based targets (e.g. for nutrients, toxins, etc.), science-based management plans, targeted geographic areas/regions for management actions and other restoration or management action-oriented products.

Outcomes: Outcomes include measurable impacts or results of the restoration work/process. Following EPA's definition and process, where possible we divide outcomes into short, medium, and long-term. Outcomes can include both process outcomes such as adoption of best management practices and environmental outcomes such as reduced nutrient loads.

- **Short-term outcomes** may include things such as increased knowledge, active stewardship programs, reduced nutrient flux in a sub-watershed, etc.
- **Medium-term outcomes** might include widespread adoption of best management practices, documented reduction of toxin or nutrient loads to lakes, etc.
- **Long-term outcomes** might include a documented reduction of nutrients in a lake, documented reduction in number of beach closure days, documented reduction in harmful algal blooms and hypoxia, documented reduction in botulism-associated bird mortality, etc.

The Five Stressors/Focal Areas

Toxic Substances and Areas of Concern

The GLRI Action Plan builds on EPA's experience addressing and controlling toxics in the Great Lakes. The major strategy outlined in the GLRI is to address Areas of Concern (AOCs) identified under the U.S.-Canada Great Lakes Water Quality Agreement. The EPA SAB agreed that cleaning up AOCs very likely reduces toxic chemicals and persistent pollutants. However, there was concern that a sole focus on known contaminants and hotspots could result in a failure to address more important sources of contamination or substances of concern, such as emerging contaminants, that have historically not received as much attention. The SAB stressed that there should be a solid plan/methodology in place to both prioritize polluted sites for cleanup as well as specific contaminants on which to focus, including a rigorous analysis of potential and actual benefits of AOC cleanups.

The SAB noted that the current Action Plan lacks metrics to monitor AOC cleanup efforts. Such metrics are critical for demonstrating success and improving on current efforts. It is unclear how current metrics of success, such as delisting a particular AOC, relate to key measures of management success, for example reducing the number and frequency of fish consumption advisories. SAB recommended that the plan include biologically-based human health and environmental indicators as metrics, and these should be monitored to evaluate success.

Impacted Societal Goals:

- Fishable
- Drinkable
- Biodiversity

Management Need: Delist beneficial use impairments (BUIs) in AOCs working across relevant ecosystems.

Science to Meet Management Needs:

- Determine which stressors (physical, chemical, and/or biological) dominate in an AOC and how they relate to BUIs of ecological risk as measured by aquatic population and community indices
- Develop new approaches (e.g., metagenomic) to assess biodiversity in sediments and remediation success.
- Determine how patchy sediment contamination relates to fishery health.
- Determine how redistribution of contaminants during dredging operation affects the contaminant levels in adjoining areas.
- Determine if dredging remediation activities are improving benthic and fish community health.
- Develop accurate bioavailability indicators of sediment and stormwater contaminants
- Determine if stormwater loadings (including CSOs) are linked to sediment contamination and impaired biotic indices.
- Determine if Contaminants of Emerging Concern (CEC) exist at AOCs, identify their source and determine if they pose an ecologically significant threat to the ecosystem.

- Determine if appropriate reference sites are being considered in terms of habitat, benthic macroinvertebrate and fish indices.

Outputs:

- Improved ecological risk assessments that consider all dominant stressors (physical, chemical and biological), and link exposure dynamics to adverse effects, and factor in decadal scale climate change projections.
- Early warning indicators of importance to ecosystem services and the blue economy that integrate multiple trophic levels (viruses/bacteria/fungi to fish and birds) into a holistic ecosystem assessment.
- Improved restoration techniques, especially contaminant removal, that minimize/limit unintended negative consequences (e.g., contamination of adjacent sites).
- A suite of scientifically defensible reference sites addressing habitat, water quality, benthic macroinvertebrate and fish indices.
- Assessment techniques that incorporate new approaches, identify CECs, and enable decision makers to understand relative risk of stressors in a given location, in order to prioritize restoration actions.

Outcomes:

- A decision making framework that links the ecological risk assessment (ERA) process, remediation strategies, and control of relevant stressor sources
- Delisting of BUIs

Invasive Species

The GLRI Action Plan outlines an objective to develop a consistent methodology and protocols for a basin-wide invasive species surveillance program. The SAB supported the stated intention to consider both invasive species and vectors. Specifically, the SAB recommended prioritizing species that present the greatest threats by using existing information and conducting risk assessments to evaluate potential vectors, invaders and ecosystem characteristics that either increase susceptibility or resistance to infection. It recommended more detail related to surveillance methods and invasive species management technologies (e.g., prevention and control strategies). The SAB emphasized that "meaningful and measurable metrics of ecological improvement" are a critical missing component in the current Action Plan.

Impacted Societal Goals:

- Fishable
- Swimmable
- Drinkable
- Biodiversity

Management Need: Reduce the introduction, incidence and impact of invasive species on ecosystem health and ecosystem services.

Science to Meet Needs:

- Conduct risk assessments for anticipated invasive species that evaluate vectors and current and future projected ecosystem characteristics potentially influencing the success or failure of an invading species
- Link recreational usage and ecosystem services shifts and feedbacks vs. invasive species and the resulting impacts on ecosystem health and the blue economy
- Assess existing prevention and control technologies for the highest priority potential invasive species
- Understand importance of organisms with terrestrial-aquatic linkages that impact restoration, ecosystem services and public health
- Assess feasibility of lake basin-wide eDNA-based surveillance programs
- Develop targeted solutions to reduce numbers of most problematic invasive spp.
- Refine and optimize risk analysis and predictive models on spread of potential invasive species
- Investigate biological techniques for reducing or eliminating specific aquatic nuisance species and develop technologies to employ against them (e.g., biological controls that can reduce impacts of sea lamprey, zebra or quagga mussels, gobies, ruffe, and other recent introductions)
- Develop virus monitoring technologies to rapidly detect new viral threats to Great Lakes species
- Compare the species composition of organisms in ballast tanks and on hulls of “lakers” and ships entering the Great Lakes to ambient organisms to determine if potential invasives are present, using both microscopic and molecular identification methods.
- Assess environmental knowledge, attitudes and beliefs of recreational boaters and identify relationship to environmentally responsible and irresponsible behavior (e.g., transport of invasives between waterways, inappropriate use of non-native bait species, etc.).

Outputs:

- Prioritized list of species to focus surveillance program, including anticipated vector(s) of introduction.
- Prioritized list of prevention and control technologies matched to species.
- Identification of adaptive actions for habitat or other restoration activities that address invasive species impacts.
- Implementation of scientifically defensible surveillance program for early detection of invasive species.
- Rigorous economic valuation of invasive species impacts, taking climate change effects into account.

- Development of an education program targeted to address specific knowledge gaps and psychological attributes associated with environmentally irresponsible behavior.

Outcomes:

- An invasive species surveillance program fitted to highest priority species based on multi-variable risk assessment.
- Invasive species prevention and control techniques/technologies matched to species for effectiveness.
- Reduction in introduction of new invasive species, particularly the most destructive/problematic ones.

Nearshore Health and Nonpoint Sources

The GLRI Action Plan includes the identification, mapping, and targeting of Great Lakes sub-watersheds showing severe signs of stress. The SAB supported this strategy but noted that a strategy for prioritizing stressed watersheds needs to be developed. In addition, the SAB noted the importance of considering impacts beyond the sub-watershed level and developing a plan that includes whole watersheds/regions.

The GLRI Action Plan indicates that a significant amount of monitoring will be needed to address this goal, but the SAB recommended a more critical evaluation of how metrics and target quantities were determined, and how/whether these target reductions (e.g. phosphorus) address the core societal/ecological problems (e.g. reduction in HABs, beach closures, botulism-associated bird mortality, etc.). The SAB noted that a strategic science plan includes both monitoring and measures of progress, and that modeling should be used to establish linkages between actions, measures, and targets.

Impacted Societal Goals:

- Fishable
- Swimmable
- Drinkable
- Biodiversity
- Aesthetics

Management Need I: Restored and expanded nearshore coastal ecosystems and their ecosystem services

Science to Meet Management Needs:

- Determine the role of key stressors, for example, invasive plants, shoreline hardening, nutrients, excessive sedimentation, extreme events, altered hydrologic regimes, construction and deconstruction, mowing and dredging, on wetland services through monitoring (e.g., baseline, pre-post BMPs, and experimental designs), experimental manipulation and modeling.
- Understand the thresholds associated with dominant stressors, particularly from tributaries and their watersheds.

- Understand how stressor impacts, include thresholds and multi-stressor interactions, vary from contextual, basin-wide perspectives.
- Assess public knowledge/attitudes/behaviors relative to wetlands and valuing wetlands by communities living within the Great Lakes watershed (public opinion survey).

Outputs:

- Predictive models relating specific stressors to improved structural and functional attributes (e.g., effect of water levels on system metabolism).
- Identification of specific knowledge, attitudes or beliefs associated with devaluing wetlands, as an important component of ecosystems.

Outcomes:

- Increased biomass of desirable species.
- Enhanced biodiversity of nearshore and coastal wetland habitat.
- Greater public awareness of, and support for, wetland protection and restoration.

Management Need II: Quantitative relationships among eutrophication symptoms and their drivers (nutrient loads, and interactions with invasive species and climate) with ability to manage the problem.

Science to Meet Management Needs:

- Develop a full understanding and assessment of external and internal nutrient loading
    - Quantify discharge of nutrients through rivers, groundwater discharge and other point source estimates.
    - Increased load monitoring within the watersheds.
    - Understand differences between lakes and basins within lakes.
    - Investigate the amount of nutrient discharge through groundwater discharge into the Lakes and rivers.
    - Determine spatial and temporal distribution of nonpoint sources within watersheds – defining the importance of storm-loading and extreme events.
    - Understand/model implications of internal loads/recycling including exchanges between water and sediments.
- Understand and model the effectiveness of methods for reducing loads (non-point focus)
    - Assess current efforts to reduce nutrients, with special focus on DRP.
    - Develop new technologies/approaches/BMPs (both soft and hard).
    - Develop and test next generation watershed models for BMP evaluations.
- Understand and model the effects of invasive species on eutrophication processes and vice versa (HABS vs *Cladophora* vs *Lyngbya*)
    - Nearshore shunt
    - Selective grazing
    - Habitat modification

- Understand and model impacts of climate change, including extreme events/temperature (storms, flooding, droughts), on loads and lake response
    - Understand and model climate impacts on watershed inputs.
    - Understand and model climate impacts on in-lake processes, including hypoxia.
    - Understand and model how groundwater discharge with change with climate.
- Assess the most effective infrastructure and technologies to mitigate climate-related events.
- Develop nutrient loading criteria for managers
    - Understand undesirable effects on ecosystem/food web responses from too much or too little nutrients. Reassess past loading-production curve relationships.
- Develop response curves of eutrophication indicators to nutrient loading.
    - Characterize uncertainty in model scenarios
    - Under present and future climates

Outputs:

- Validated models relating management actions to environmental outcomes.
- Nutrient load reductions needed to meet environmental end point goals set by managers (e.g., eradication of HABs, reduction of hypoxia).
- Identification of priority sources for reduction action and improved methods for nutrient load reductions (especially non-point).

Outcomes:

- Near-term: Reduced nutrient flux from sub-watersheds.
- Proximate: Reduced nutrient loads to Lakes.
- Ultimate: Reduced HABs and Hypoxia.

Habitat and Wildlife Protection and Restoration

The GLRI action plan includes improved aquatic ecosystem resiliency as a goal in this category, specifically maintaining, enhancing or improving native populations, especially in AOCs as well as wetland and associated upland, coastal upland and island habitats. The SAB report agreed that this was an appropriate goal, however key terminology such as resiliency need to be better defined and that research designed to demonstrate ecosystem characteristics contributing to resiliency, for example resistance to disturbance, will enhance best management practices in this area. Further, a set of metrics should be developed for tracking changes in resiliency over time as restoration measures are implemented. And, the SAB noted that there should be greater consideration given to whether the restoration actions will achieve the identified goals. An integrated, adaptive management plan with linkages among the vision, long-term goals, objectives, and principal actions would greatly enhance the connection between restoration actions and goals. As part of this process, the SAB noted that the plan should include a "system-level model, which identifies and prioritizes all factors (natural and anthropogenic) that could potentially affect attainment of the stated goal(s)."

Impacted Societal Goals:

- Fishable
- Biodiversity
- Aesthetics
- Accessibility

Management Need I: Striking a balance between exotic Salmonids and native fish species

Science to Meet Management Needs:

- Determine how native species recovery impacts exotic Salmonids and vice versa, including if there is a threshold or tipping point, and anthropogenic and natural factors determining the balance between native and non-native populations.
- Understand the impact of fishery restoration on societal and economic responses.
- Determine the effects of GLRI actions to date on exotic and native fish species.
- Characterize the impacts of climate change (including extreme weather events, temperature changes, potential water-level change) on wildlife habitat and ranges, pathogens, populations, communities, food webs, and ecosystem services.
- Develop coordinated, science-based, lake-wide targets for salmonid stocking so as not to adversely affect native and naturalized populations and their resource base and to minimize contaminant burdens.

Outputs:

- Clear understanding of foodweb and population dynamics of native and non-native fish to inform appropriate management plans and practices.
- Clear understanding of potential climate change impact on native and non-native species.
- Clear understanding of climate change interaction with other stressors and habitats to inform restoration practices.
- Clear understanding (quantified) of ecosystem services associated with native and non-native fish species.

Outcomes:

- Important fish species benefit from habitat restoration and other management actions for their restoration and conservation.
- Management plans and actions that incorporate knowledge of climate change impacts on species, habitats and synergies with other stressors.
- Improved ecosystem services associated with fish consumption and recreation.

Management Need II: Ensure habitat restoration is optimized to benefit the ecosystem

Science to Meet Management Needs:

- Identify and prioritize geographies where habitats can be restored and where they can simply be optimized for keystone species and their food webs.
- Understand the linkage between habitat and both structural and functional responses from a site-specific, contextual perspective (spatially and temporally).
- Determine the relative risk of each stressor on the system in order to prioritize restoration actions.
- Understand the organizational/institutional/societal measures necessary to bridge scientific understanding of ecosystem services and societal recognition of their value.
- Monitor restoration actions for sufficient duration, and conduct cost-benefit analysis, to determine best management practice (BMP) effectiveness.
- Determine what inputs, including monetary, are needed to make restoration sustainable.
- Understand and model impacts of climate change, including extreme events/temperature (storms flooding, droughts), on loads and lake response.
- Assess feasibility of basin-wide eDNA-based monitoring programs for indigenous biodiversity assessment.

Outputs:

- Identification of the most useful restoration methods for wetlands, harbors, and near-shore environments.
- Restoration priorities and management plans informed by knowledge of stress-response relationships and optimized to restore ecosystem function and deliver ecosystem services.
- Clear understanding of societal barriers to ecosystem restoration.
- Refined predictive models that relate specific restoration practices to improved structural and functional attributes, for example, identifying the optimal placement and sizing of flow-through marshes in watershed.
- Implementation of scientifically defensible assessment (e.g., surveillance/monitoring) program for determining the state of native biodiversity.

Outcomes:

- Habitat actions meet restoration goals, including restored/improved ecological structure (population/communities) and function (such as, nutrient assimilation, primary and secondary productivity).
- Improved societal understanding of the value of ecosystem services.
- Restoration and management plans that optimize ecosystem function, including delivery of ecosystem services.

Climate

The GLRI science plan did not include climate as one of the five key focus areas of the Action Plan, and the SAB also noted that it was not explicitly addressed under each of the focus areas. Given the magnitude and scale of the GLRI restoration efforts, the SAB indicated that climate change could significantly alter restoration efforts and should be considered throughout all areas of the Action Plan. It is critical to identify and assess the ecosystem components/characteristics/processes/beneficial uses that are susceptible to climate change impacts, for example, physical (hydrology, thermal, erosion, habitat loss/fragmentation, sedimentation, storm water conveyance and infrastructure), chemical (nutrients and toxicants), and biological (invasives, pathogen loadings, life-cycles, pests, migration, HABs, fisheries) impacts. The impacts/interactions of climate change are integrated above, but emphasis should also be placed on monitoring and adapting to climate change itself, since this is key to our abilities to effectively carry out restoration efforts on a long-term scale.

Management Need: Improve restoration activities in the context of climate change and interactions with other stressors; plan for influence of climate change into restoration activities

Science to Meet Management Needs:

- Assess the most effective infrastructure, technologies and other restoration practices and how they need to be modified, in order to support fish, wildlife and habitat adaptation to climate-related impacts.
- Identify factors that influence (impede and motivate) human decision-making related to climate change adaptation.
- Assess current capacity within existing governmental/management structures to implement climate change adaptation.
- Determine the impact of climate change on future water levels.
- Develop effective assessment/monitoring infrastructure to characterize climate change.

Outputs:

- A suite of climate-ready restoration infrastructure, technologies and best management practices.
- Outreach and education strategies/programs to address the main impediments to adopting needed adaptation actions.
- Policy and other governance/management tools are developed to ensure climate adaptation actions can be readily adopted.
- Predictive models relating climate change to ecosystem impacts.
- Assessment tools that enable managers to understand the impact of climate change on restoration projects, assess the effectiveness of management actions, and determine if adaptations in management actions are appropriate and effective.

Outcomes:

- Effective restoration and management plans that are responsive to a range of possible climate change scenarios.
- Measurable increase in environmentally responsible behavior, including adoption of climate adaptation strategies and actions.

Table 1. Beneficial Use Impairments Mapped to Societal Goals

Beneficial Use Impairment	Swimmable	Fishable	Drinkable	Accessible	Aesthetics	Biodiversity
Restrictions on Fish and Wildlife Consumption		✓			✓	✓
Tainting of Fish and Wildlife Flavor		✓			✓	
Degraded Fish and Wildlife Populations		✓		✓		✓
Fish Tumors and Other Deformities		✓		✓	✓	✓
Bird or Animal Deformities or Reproductive Problems		✓		✓	✓	✓
Degradation of Benthos		✓				✓
Restrictions on Dredging Activities	✓	✓	✓			✓
Eutrophication or Undesirable Algae	✓		✓	✓	✓	✓
Restrictions on Drinking Water Consumption or Task and Odor Problems			✓	✓	✓	
Beach Closings	✓			✓	✓	
Degradation of Aesthetics				✓	✓	
Added Costs to Agriculture or Industry				✓		
Degradation of Phyto and Zooplankton Populations		✓				✓
Loss of Fish and Wildlife Habitat		✓				✓

References:

WICCI Green Bay Working Group. 2010 *Potential Climate Change Impact on the Bay of Green Bay – An Assessment Report, 2010*. Accessed: http://www.wicci.wisc.edu/report/Green-Bay.pdf