Lake Erie Phosphorus Targets: An Imperative for Active Adaptive Management

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Abstract

Management actions taken to meet the phosphorus load targets in the 1978 Great Lakes Water Quality Agreement proved highly successful, initially. Eutrophication symptoms abated, and attention was redirected toward other important water quality problems. However, in the early 2000s Lake Erie, in particular, began to re-experience severe algal blooms and other problems associated with excessive nutrient inputs. The 2012 GLWQA prompted the development of updated phosphorus targets, and endorsed the concept of adaptive management. We propose that an *active* adaptive management program that maximizes learning opportunities will be imperative to sustain any future improvements realized in response to the new targets. Every year offers natural, albeit uncontrolled experiments to exploit the adaptive management concept of "learning by doing". A carefully thought out plan of complementary monitoring and modeling, supported by stakeholder engagement, will promote an improved understanding the processes that influence lake behavior and guide essential refinements to management goals and appropriate actions to attain them. In 2019 the International Joint Commission released a set of recommendations regarding the use of modeling approaches to support adaptive management in Lake Erie. We have incorporated those recommendations herein to further inspire the Great Lakes community to invest in an active adaptive management strategy that will serve us into the future.

Key words: Phosphorus, nutrient loading, eutrophication, nutrient target, Great Lakes

The 1978 Great Lakes Water Quality Agreement (GLWQA) included annual phosphorus load targets to mitigate eutrophication symptoms in the Great Lakes, a revolutionary action at the time. Whether or not eutrophication was reversible was unclear (Hasler, 1969), and the question of whether nitrogen, phosphorus, or carbon was key to limiting excessive algal growth was an ongoing debate (Schindler, 1977). Further, Hubschman (1971) questioned whether eutrophication reversal in Lake Erie was feasible or even desirable, arguing that agricultural pollution would be difficult to control, thus high productivity should be utilized to advantage. One of his supporting arguments was that Lake Erie was an "unsaturated ecosystem" with "room in the trophic scheme to support a population of large filtering detritus feeders," a prescient foreshadowing of the dreissenid mussel invasion.

Subsequent water quality improvements in response to management actions to meet the phosphorus targets seemed to resolve these issues (DePinto et al., 1986); Lake Erie, in particular, was considered successfully remediated (Makarewicz and Bertram, 1991).
However, since the early 2000s, Lake Erie has experienced a resurgence of eutrophication symptoms, despite meeting the 1978 phosphorus load target in most years (Maccoux et al., 2016). The reasons for this "re-eutrophication" are unclear, though many hypotheses exist.

Recognizing this recurrent problem, Canada and the United States updated the GLWQA in 2012, which included a requirement to reevaluate the 1978 phosphorus targets, emphasizing particular urgency for Lake Erie. Under Annex 4 of the 2012 Agreement, Canada and the United States proposed lower phosphorus targets (Annex 4 Objectives and Targets Task Team, 2015), which were approved in 2016.

The updated 2012 GLWQA also included language endorsing "adaptive management," defined in the Agreement as "implementing a systematic process by which the Parties assess effectiveness of actions and adjust future actions to achieve the objectives of this Agreement, as outcomes and ecosystem processes become better understood." The adaptive management concept was only in its nascent stage at the time the 1978 targets were under development, but has since matured and is widely advocated as a framework for effective environmental management (Allen et al., 2011).

Adaptive management is premised on the recognition that environmental management decisions have considerable inherent uncertainty, which results from a limited understanding of ecosystem behavior. For example, our understanding of ecosystem functioning in the winter season is limited by observations, yet developing evidence suggests that winter productivity can impact warm water conditions (Reavie et al., 2016; Wilhelm et al., 2014) when most data used to support existing ecosystem models in the Great Lakes are collected. This uncertainty is inevitable, although we understand stressor-response relationships, such as eutrophication, well at coarse scales; precise quantification of such relationships for specific systems is difficult. Moreover, the tools available to reduce this uncertainty all have limitations. For example, extrapolation of small-scale experiments to the ecosystem-scale is tenuous (Carpenter, 1996). Mathematical models, however complex, are simplifications of reality; observational data lack control, and whole ecosystem experimentation, the best option to reduce uncertainty, is seldom feasible, particularly at the temporal and spatial scale of the Great Lakes. The next best option is to recognize that thoughtful measurement of both management actions and the response of an ecosystem to these actions provide a learning opportunity that will reduce the uncertainty of subsequent refinement of these actions. Lake Erie, for example, offers a unique opportunity to carefully evaluate the role of nitrogen in algal bloom development (Wurtsbaugh et al., 2019), at the ecosystem scale. Though perhaps uncomfortable to acknowledge – all environmental management actions are experiments, thus adaptive management is often accompanied with the warning to "expect surprises."

Some sources emphasize a distinction between passive and active adaptive management. Passive adaptive management is described as taking appropriate management actions, observing the response of the system, and adjusting management as needed if the desired responses are not attained. In contrast, active adaptive management involves taking management actions, guided by testable hypotheses, to "push the system", and carefully tracking the system response. The underpinning of active adaptive management is to maximize learning. Generally, however, it is not practical to take management actions to push the system with the goal of maximizing a response; many realities intervene. Thus, adaptive management is best to view as a continuum - the closer we are to the active end, the better the learning opportunity (Fig. 1). In fact, we are always doing adaptive management; when we try something if it does not work, we try something else. Whether we call it adaptive management or not, operating at the passive end of the continuum is the default. If we are more thoughtful and deliberate, learning will be enhanced and future management refinements should be increasingly effective.

The 1978 phosphorus targets and consequent management actions put us near the passive end. Things improved, we declared victory, switched our management emphasis to other issues such as toxic contaminants. However, subsequently the lake changed. The visible symptoms of eutrophication reappeared, and we could only speculate why. Our understanding of ecosystem behavior has advanced considerably since the 1980s; into the future, a more proactive approach is imperative. The various ideas posited to explain the re-eutrophication of Lake Erie provide a basis for developing testable hypotheses to guide us on a path of active adaptive management.

Going forward, our willingness and ability to monitor, evaluate, and update the targets will be more important than the original targets.

To this end, the International Joint Commission (IJC) sponsored a study to review the modeling completed to support development of the updated targets, and offer recommendations to guide an active adaptive management path moving forward. The study produced a project report (Arhonditsis et al., 2018), several published papers (Arhonditsis et al., 2019a; Arhonditsis et al., 2019b), and a statement endorsed by the IJC commissioners with a set of specific recommendations (Great Lakes Science Advisory Board Research Coordination Committee, 2019). We close by reproducing those recommendations here in hopes that they will guide future research, stimulate funding opportunities, and encourage Canada and the United States to establish the institutional arrangements to support adaptive management in Lake Erie. As we look ahead to future endeavors to improve the quality of our Great Lakes, let us maintain our efforts in building a common awareness and understanding of the linkages between modeling and adaptive management among researchers, resource managers, and policy makers as well as stakeholders.

Recommendations From the Great Lakes Science Advisory Board Research Coordination Committee Report

Technical recommendations

To advance environmental modeling in supporting nutrient management of Lake Erie, the next steps should focus on "augmenting" the existing models rather than "reinventing the wheel" by building new models. Key to this process is to design augmentations that will effectively complement and improve the existing models.

- Ensemble modeling:
  - Maintain and improve the ensemble character of modeling and continue research to better coordinate the diversity of watershed and lake models in Lake Erie.
  - Use the diversity of models in the ensemble approach to better understand and quantify key processes in the lake and watershed.

    - In taking an ensemble approach, efforts should be made to quantify and reduce uncertainty in ecological forecasting in response to nutrient loading/concentration and other drivers.
- Couple lake and watershed models:
    - Establish an integrated system of watershed and lake models with ecological response indicators.
    - Establish and maintain consistency between the temporal and spatial scales of the watershed models with that of the lake models to serve as boundary condition inputs to the lake models.
    - Incorporate sediment transport along with erosion and deposition in the watershed and lake models.
- Monitoring Program:
    - Design a monitoring program based upon appropriate metrics and scales to measure changes in nutrient loading and the ecological response.
- Improved evaluation of model performance:
    - Identify a suite of appropriate skill metrics and evaluate model performance at multiple scales of resolution.
- Ground-truthing of the watershed models should include the following:
    - Model calibration and evaluation at finer temporal and spatial scales to better assess the role of episodic events (e.g., extreme precipitation and surface water discharge) and land use practices;
    - A directed evaluation of the management actions (BMPs) that will be necessary to achieve the new loading targets, including an assessment of associated uncertainties;
    - Increased attention to the role of legacy phosphorus bounded to the soil in the watersheds and sediment in the lakes in driving algal blooms and toxicity levels of harmful algal blooms (HABs); and
    - Consideration of additional watershed models that may better capture urban areas.
- Predictive ability:
    - To improve predictive ability, future lake modeling efforts should include an improved understanding of key phytoplankton growth processes, internal nutrient sources, the role of nitrogen, quantify the importance of winter diatom production to summer hypoxia in the Central Basin, interactions between phytoplankton and *Cladophora* growth, role of dreissenid mussels in nutrient cycling and availability, and zooplankton interactions and connection to the upper food web.

Institutional recommendations

The core principles of the Great Lakes Nutrient Adaptive Management (GLNAM) Framework (Fig. 2) serve as the basis for the following institutional recommendations. The GLNAM Framework is driven by an iterative process of research and management activities revolving around the phases: plan-act-monitor-evaluate-learn-adjust. As envisioned under the 2012 GLWQA, the intent of the iterative approach of adaptive management is to reduce uncertainty in the process of limiting nutrient loading to levels necessary for mitigating eutrophication in Lake

Erie as well as the other Great Lakes. The following recommendations are proposed by the IJC SAB-RCC as the next steps to institutionalize a GLNAM Framework:

- Define Lake Erie's eutrophication problem(s) aligning with a GLNAM Framework to provide the rationale for institutionalizing a framework based on collaboration across government agencies and jurisdictional lines.
- Develop consensus-based goals in support of the GLNAM Framework as a long-term, sustainable institutional arrangement.
- Integrate watershed and lake modeling (discussed above under technical recommendations) as part of the GLNAM Framework:
  - Frame the "correct" questions and testable hypotheses (linked to the aforementioned problem) in the development and implementation of models to better understand the ecological processes underlying eutrophication and to support nutrient reduction management.
  - Establish a common awareness and understanding among researchers, resource managers, and a broad spectrum of stakeholders of the linkages between adaptive management and watershed/lake modeling as part of the GLNAM Framework.
- Use the GLNAM Framework to inform coordinated planning and implementation of Lake Erie's watershed/ecosystem modeling and nutrient reduction management; as part of this coordinated effort, address the following:
  - Identify key players currently participating in the GLNAM Framework in Lake Erie and use this information to identify gaps and unmet needs that must be addressed to further advance the GLNAM Framework.
  - Provide a status report on the progress achieved thus far in the development and implementation of a GLNAM Framework.
- Establish and integrate a monitoring program as part of the GLNAM Framework on a long-term continuous basis and evaluate results to learn and adjust research, modeling and management decisions.
- Update models on a regular basis (characteristic of adaptive management approach) to reduce uncertainty and better represent an improved understanding of the ecological dynamics.
  - Diagnose models with "post audit process" (research, test, sensitivity analysis, recalibrate) and reapply to determine how model performance and management decisions can be improved (e.g., reevaluate target loads).
- Raise awareness for the following principles underlying an adaptive management approach:
  - Integration of testable questions/hypotheses that serve as key drivers to a GLNAM Framework;
  - Collaboration among stakeholders as a key element of adaptive management to ensure long-term sustainability guided by the GLWQA;
  - Conduct communication, outreach and engagement with stakeholders in building and maintaining spheres of influence in support of a GLNAM Framework; stakeholder engagement should play a role in identifying research and management priorities under the GLNAM Framework;
  - Consideration of the GLNAM approach as a learning process from which we should expect surprises (e.g., dreissenids, Cyanobacteria, climate change);

    - Management actions under the GLNAM Framework should be recognized as experiments that provide the opportunity for learning, given the inherent uncertainty associated with modeling and decision making. Track such actions and make data available publicly to enhance iterative learning.
- Institutional and governance considerations for the GLNAM Framework:
    - Establish the GLWQA as the binational authority to institutionalize the GLNAM Framework through Nutrients Annex 4 to facilitate implementation.
    - Identify agency and institutional partners as well as programs responsible for the development and conduct of a GLNAM Framework:
        - Lead federal agencies: U.S. Environmental Protection Agency (EPA) and Environment Canada Climate Change (ECCC)
        - Supporting Canadian and US federal agencies: US Department of Agriculture Natural Resource Conservation Service (NRCS), US Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA); Canadian Department of Fisheries and Oceans
        - Supporting state and provincial agencies: Ohio EPA, Pennsylvania Department of Environmental Protection, New York Department of Environmental Conservation, Indiana Department of Natural Resources, Michigan Department of Natural Resources
        - Partner institutions: International Joint Commission (IJC), academia, private sector
        - Reporting programs: Domestic Action Plans (DAPs), and GLWQA triennial reporting
    - Identify experts, resources and stakeholders needed to effectively meet identified adaptive management goals and objectives on a long-term basis.
    - Establish a cycle of adaptive management (annual modeling and assessment; annually or every 5-10 years (to be determined) to advance model improvement and to reduce uncertainty in the decision-making process on nutrient management.
- Identify and establish funding streams to support the GLNAM Framework through existing and/or new authorizations and appropriations. Among the funding streams identified to date are the IJC-International Watershed Initiative, USGS monitoring programs, NOAA granting programs (ECOHAB, Sea Grant, etc.) and NOAA research and development laboratories' base funding, Harmful Algal Bloom Hypoxia and Control Act (HABHRCA), Great Lakes Restoration Initiative (GLRI), Lakewide Management Programs (LAMPs), and state natural resource and environmental protection programs of the Great Lakes region.
- Establish justification for the GLNAM Framework: Quantify benefits of healthy ecosystem services, providing justification for investment in institutionalizing the GLNAM Framework. This is considered key in maintaining GLNAM Framework on a long-term, sustainable basis needed to advance nutrient management on eutrophication related problems. Case in point: the cost of nutrient loading reduction in Lake Erie should not be disconnected from the economic value of the ecosystem services provided by the lake.

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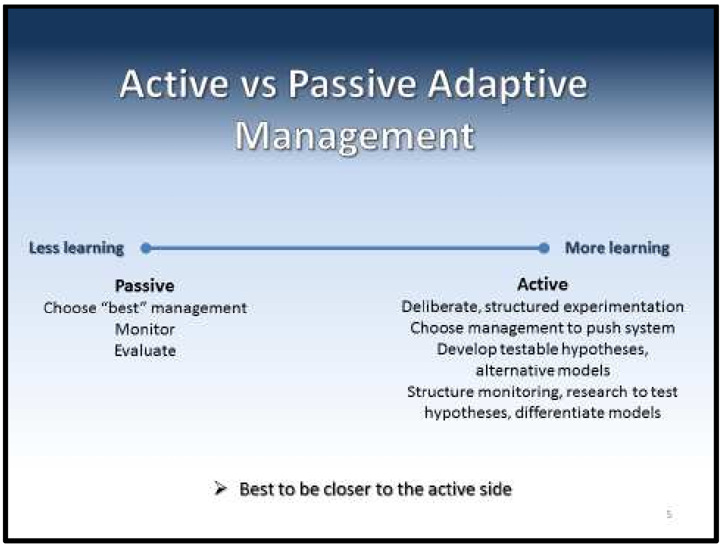
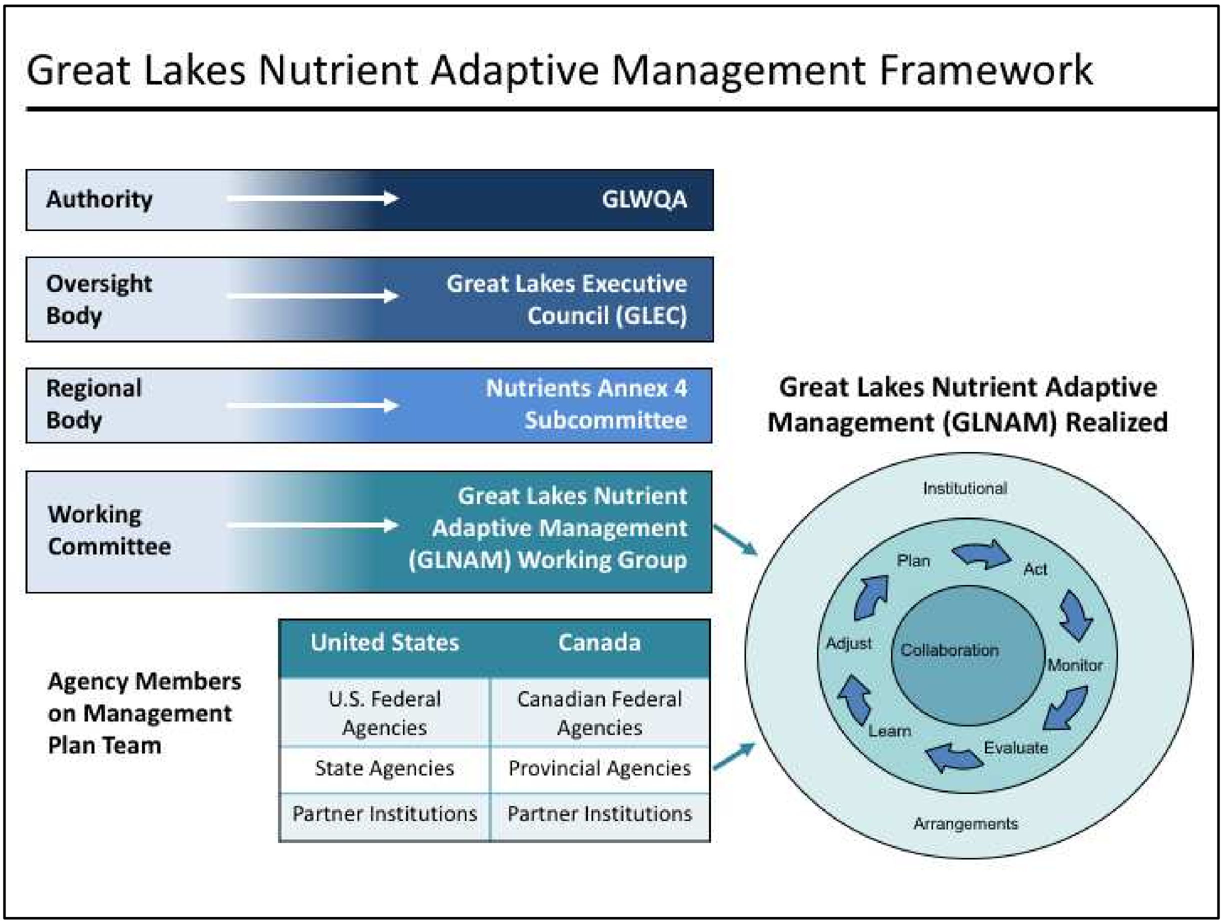
List of Figures.

Figure 1.



Active vs Passive Adaptive Management
Less learning
More learning
Passive
Choose "best" management
Monitor
Evaluate
Active
Deliberate, structured experimentation
Choose management to push system
Develop testable hypotheses, alternative models
Structure monitoring, research to test hypotheses, differentiate models
Best to be closer to the active side

Figure 2.


Great Lakes Nutrient Adaptive Management Framework
Authority
GLWQA
Oversight Body
Great Lakes Executive Council (GLEC)
Regional Body
Nutrients Annex 4 Subcommittee
Working Committee
Great Lakes Nutrient Adaptive Management (GLNAM) Working Group
Agency Members on Management Plan Team
United States
Canada
U.S. Federal Agencies
Canadian Federal Agencies
State Agencies
Provincial Agencies
Partner Institutions
Partner Institutions
Great Lakes Nutrient Adaptive Management (GLNAM) Realized
Institutional
Plan
Act
Monitor
Evaluate
Learn
Adjust
Collaboration
Arrangements