Great Lakes Water Quality

AGREEMENT

PRIORITIES 2007-09 SERIES

Work Group Report on Eutrophication

What is a "Priority?"

Because the Great Lakes Water Quality Agreement (GLWQA) focuses on a wide variety of water-quality issues facing the Great Lakes Basin Ecosystem, the Commission created a GLWQA "Priority" setting process to focus on what it considers the most pressing issues. The Commission and its advisory bodies review and revise these Priorities as needed every two years. After receiving input from the public on its Priorities work, the Commission prepares Biennial Reports to governments on the status of Great Lakes water quality.

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"Can I walk the shoreline without rotting algae?"

This Work Group report discusses a concept mapping process for taking a weight-of-evidence approach to determining the cause(s) of the resurgence of eutrophication in the near-shore waters of the Great Lakes. Weight-of-evidence is an approach to determine multiple lines of tacts or evidence to reduce uncertainty and support science-based decision-making. The effects of eutrophication include the return of blue-green algae (cyanobacteria) blooms and rotting masses of the green macro-algae, *Cladophora*, in shallow waters and on beaches in all of the Great Lakes except Lake Superior. Effects may also include the persistence and possible expansion of hypoxia (dissolved-oxygen depletion) in the bottom waters of Lake Erie's central basin (the so-called "dead zone"). Information for the workshops and mapping exercises has been compiled by conducting a literature review on eutrophication research since the early 1990s when this issue reemerged in the Great Lakes with adverse environmental and economic consequences.

In addition to preparing this report, the work group will host a session on Eutrophication on Wednesday, October 7, 2009 at the GLWQA Biennial Meeting in Windsor, Ontario. Using the work group report as background material, work group members will present findings and discuss the issue with the public to elicit various perspectives and to inform the Commission's 15th Biennial Report.

Work Group Report on Eutrophication

Great Lakes Water Quality Agreement Priorities 2007–09 Series

August 2009

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Table of Contents

Figures

Acknowledgments

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Summary

- The eutrophication problem in the Great Lakes is associated with a few key indicator variables (excess *Cladophora* growth, blue-green algae (Cyanobacteria) blooms and trends in soluble-reactive phosphorus (SRP).
- Analysis of these changes indicates that they have complex causation and that there are few direct management actions available to address them.
- Public perception of the eutrophication problem does not reflect the underlying scientific uncertainties and supports a range of management options that are unlikely to impact the key indicator variables directly.
- Public perception, however, does line up with a set of "no-regrets" management actions that can mitigate local eutrophication problems and create opportunities for better coordination of the regulation of point and non-point sources of nutrients.
- Managing the specific mix of nutrient sources in particular areas is the key to effective mitigation results in those areas; collectively this approach will address lake-wide issues.
- Promoting nutrient use efficiency is critical to effective source loading reductions.
- Several "no regrets actions" are already available to address various eutrophication issues; more effort and incentives are needed to promote, expand and communicate the benefits of these actions.
- Innovative approaches to the consumption of "surplus" nutrients in the aquatic environment for beneficial purposes need to be explored - these have the potential to "shunt" nutrients to desirable outcomes.
- More coordinated and frequent monitoring of algal fouling is needed.
- Watershed-specific monitoring and management action implementation is required to test both causal hypotheses and assess the impact of management actions.

Main Messages

From Science Community to IJC

- Long-term solution to the problems associated with eutrophication will require a systems approach that balances watershed phosphorus (P) inputs and outputs with other factors that regulate the appearance of local symptoms.
- There is no P-management strategy that can be universally applied to all watersheds or all lakes; each is unique and solutions must be tailored to susceptibility of landform to nutrient loss and the location of nutrient-sensitive waters.

To Public/Stakeholder Community from IJC

- The eutrophication problem of the 1970s had a dominant contributing factor in P loading, while today's problem is much more complicated and will thus require a different mix of solutions.
- Changes in lake hydrology and structure of the ecological community contribute to the periodic re-emergence of indicators of eutrophication.

Background

The eutrophication abatement success story of the late 1970s and early 1980s continues to be often cited as the principal achievement under the auspices of the Great Lakes Water Quality Agreement and as a model for cooperation on transboundary waters. The U.S. and Canada spent over $8 billion on phosphorus control programs, and eutrophication for a time was reversed in the Great Lakes. Now the most visible signs of eutrophication—nuisance Cyanobacteria (blue-green algae) blooms and rotting shoreline piles of the green macro-alga *Cladophora*—have returned to all of the Great Lakes except Lake Superior. The objectives in Annex 3 (control of phosphorus) of the Agreement on elimination of nuisance algal growths and dissolved oxygen depletion in the bottom waters of the central basin of Lake Erie are no longer being met.

Current observations on parts of all of the lakes except perhaps Lake Superior include:

- the return of *Microcystis* blooms (a HAB-harmful algal bloom species);
- *Cladophora* blooms (nearshore nuisance algal growths);
- dissolved oxygen depletion in the bottom waters of the central basin of Lake Erie;
- increases in the frequencies of beach postings or closings;
- botulism toxicity events re-emerging in the late 1990s and early 2000s for the first time in the Great Lakes since 1963-64;
- total phosphorus concentrations in offshore waters are well below what the old models said they should be given phosphorus loading estimations;
- "desertification" (loss of productivity) in offshore waters.

In a charge to the Eutrophication Work Group, the IJC noted that it can best add value in clarifying the eutrophication puzzle in the Great Lakes by developing advice and recommendations to the Parties on the weight of evidence on cause-effect relationships, research and monitoring to test hypotheses and predictive models, re-examination and recalibration of older eutrophication models and management strategies for addressing the eutrophication issue in the Great Lakes. Innovative methods such as a fuzzy cognitive map will be considered to make more explicit the hypothesized causal relationships. Based on this charge, the Work Group organized a series of workshops to carry out the charge and to provide advice on approaches to improving understanding and management of the eutrophication objective in the Great Lakes Water Quality Agreement.

Methods

To address its charge, the working group developed a staged series of workshops to implement the required weight-of-evidence approach to the problem. The first workshop in May 2008 gathered a group of experts to review the current understanding of the eutrophication issue in the Great Lakes. In the second workshop in February 2009, the Work Group implemented a Fuzzy Cognitive Mapping (FCM) approach to obtain expert evaluation of the important hypotheses for eutrophication in the Great Lakes as part of a weight-of-evidence (WOE) exercise. The work group's third workshop in March 2009 was also an FCM exercise with a group of stakeholders associated with the Lake Erie Lakewide Management Plan (LaMP). Finally, the work group planned to implement an FCM exercise using the scientific literature associated with the eutrophication literature. This last step was not completed in time for this report. The work group also will develop a detailed technical report with a more complete presentation of the WOE approach to the problem of re-emergence of eutrophication in the Great Lakes and of the analysis of the FCMs developed during the IJC 2007-2009 Priority cycle.

The basic assumption in the implementation of a WOE approach was that evidence-informed management recommendations for resolution of the eutrophication problem require a reasonably accurate understanding of both the causal factors and processes involved in eutrophication. Four obvious questions follow: (1) What is the hypothesized causal structure of the eutrophication problem? (2) To what extent is this set of causal hypotheses corroborated by existing evidence (i.e., what is the existing weight of evidence in support of the hypothesized relationship)? (3) Are there particular hypothesized causal relationships whose validity appears critical for effective management intervention but for which current evidence is largely lacking? (4) If so, what research ought to be prosecuted so as acquire the WOE sufficient to justify or eliminate particular management interventions?

The work group used fuzzy cognitive mapping (FCM) as a method to address these questions. Experts at the first workshop identified increased abundance of *Cladophora* in the nearshore waters of the Great Lakes and re-occurrence of blue-green algae (Cyanobacteria) blooms as major indicators of eutrophication in the Great Lakes. Construction of FCMs provided a means of structuring expert, public and scientific literature consultations designed to summarize current understandings of the causes and consequences of Great Lakes eutrophication. Hypotheses regarding causes of the increasing abundance of *Cladophora*, re-occurrence of blue-green algae blooms in some areas and the "desertification" or oligotrophication of offshore waters also were examined. Participants in FCM workshops also were asked to consider potential resource management and policy recommendations that the International Joint Commission (IJC) might communicate to governments to address the eutrophication problem, based on the causal structure of the problem elaborated during the workshops.

Fuzzy cognitive maps (FCM) are graphical representations of the relationships between elements of a system (or issue, e.g., eutrophication), as perceived by anyone with knowledge of the system under scrutiny. FCM comprise vertices or nodes representing concepts (C), joined by directional edges (connections or arcs) representing causal relationships between concepts. Each arc is parameterized by a set of values which quantify or qualify various attributes of the hypothesized causal connection between the concepts in question. For example, one such attribute is the sign of the postulated causal relationship, with a positive sign for the arc from concept Ci to vertex Cj indicating an excitatory relationship, i.e., as Ci increases Cj increases, while a negative sign indicates an inhibitory relationship, i.e., as Ci increases Cj decreases. The full set of arc attributes considered during the mapping exercises are provided in the technical report of the work group.

Findings

The work group completed two FCM workshops. The first FCM workshop provided a structured setting to elicit detailed understanding of the eutrophication problem with a group of technical experts, and the second FCM workshop provided a more general perspective on the eutrophication problem from the perspective of stakeholders.

Participants in the first FCM workshop generated a set of 14 independent FCMs (of which we used 10 for analysis), with the number of directed arcs ranging from 9 to 25 and the number of vertices ranging from 14 to 44. The consolidated consensual map from these 14 FCMs included 62 vertices and 193 directed arcs. Figure 1 presents a simplified version of the consensual map. Seven major outcomes of interest classes were identified (shown in red in Figure 1): phytoplankton biomass, *Cladophora* biomass, Cyanobacteria biomass, central basin reduced hypoliminion thickness, hypolimnetic hypoxia, botulism animal kills, *Lyngbia* biomass and *Spirogyra* biomass, with blue-green algae and *Cladophora* biomass having the largest number of causal inputs (Fig.1).

Dominant concepts (those concepts with a large number of causal inputs and/or outputs) include nearshore soluble reactive phosphorous, *Cladophora* biomass and dreissenid biomass (Figure 1). Major emitters (i.e., concepts which affect other concepts, but are not themselves affected by other concepts in the consensual map) include climate change, predatory fish biomass, urban activities, agricultural activities and natural vegetation cover (Figure 1).

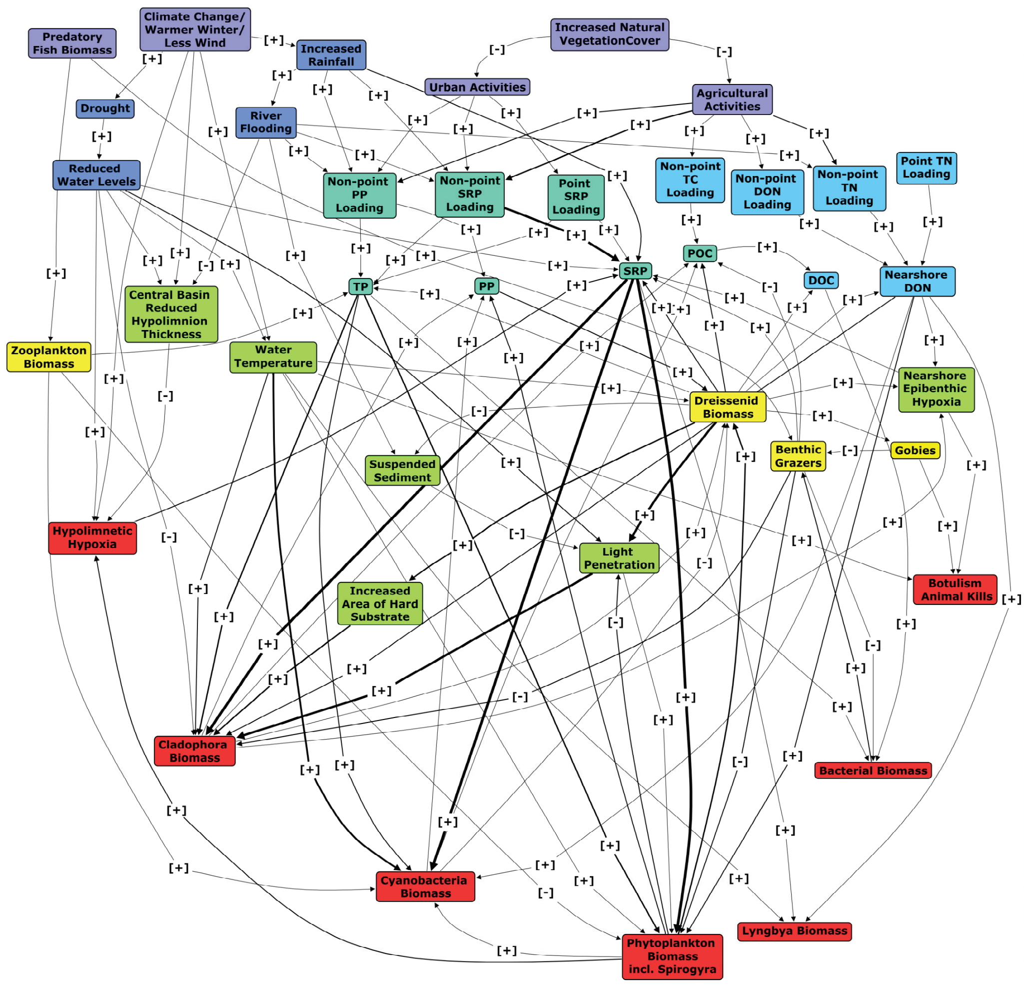

Figure. 1. The consensual eutrophication FCM from FCM Workshop 1.

Red concepts at the bottom of the FCM represent outcomes of interest, and dark blue concepts at the top of the FCM are primary causal inputs. Arcs have been simplified to indicate only positive (+) or negative (-) associations.

The second FCM workshop involved Canadian representatives and stakeholders on the Lake Erie LaMP Working Group. Participants in the workshop were led through an exercise to construct a fuzzy cognitive map of their understanding of eutrophication and potential management actions. As time was limited, the group was asked to focus on P sources and management. Several members of this group had participated in fuzzy cognitive modeling to form LaMP objectives in 1996. Thus their map was influenced by the beneficial use impairments and management levers identified through that process and recorded in LaMP documents. Recent investigations and documents for the LaMP Binational Nutrient Management Strategy being drafted also likely influenced this map. Participants were asked to indicate only the direction and sign (+/-) of the interaction between two concepts, and the strength of the relationship by using line thickness. Figure 2 is the consensual FCM generated by workshop participants.

In FCM Workshop 2, participants identified 36 concepts and 49 directed arcs. While many identified outcomes of interest were similar to Figure 1 (*Cladophora* biomass, blue-green algae biomass, bacterial biomass, hypolimnetic hypoxia, botulism and toxins, presumably associated with fish and wildlife mortalities), several qualitatively different outcomes principally associated with aesthetic impairments were also identified (Figure 2). Unlike Figure 1, Figure 2 is dominated by phosphorus concentrations and loading, doubtless as a result of the specific instructions to focus on this issue. Major identified emitters included climate change, urban activities, agricultural activities and natural vegetation cover (Figure 2). Other identified emitters, not represented in Figure 1 include wetlands, riparian buffers and shoreline alteration (Figure 2). Of the thirteen major causal relationships identified in Figure 1, nine were identified in Figure 2. Of the four missing relationships, two reflect the absence of hard substrate as an explicit concept and one because phytoplankton biomass was not identified as a concept. Surprisingly, the fourth missing causal relationship postulated in Figure 1, namely the positive effect of increasing dreissenid biomass on nearshore soluble reactive phosphorus, was not represented in Figure 2.

At a gross level, the two FCMs differ in a number of important aspects. Most obvious is the sharp contrast between endogenous (within-lake, Figure 1) versus exogenous (Figure 2) causal relationships, a difference almost certainly attributable to the expertise/knowledge of workshop participants and the explicit focus on phosphorus in FCM Workshop 2. Although not reflected in the FCM Workshop 1 consensual map (Figure 1), several individual maps provided very detailed sub-maps for exogenous concepts, especially those implicated in/associated with both point and non-point nutrient inputs. The endogenous versus exogenous difference is even more profound when one compares the complexity of postulated relationships affecting SRP, with

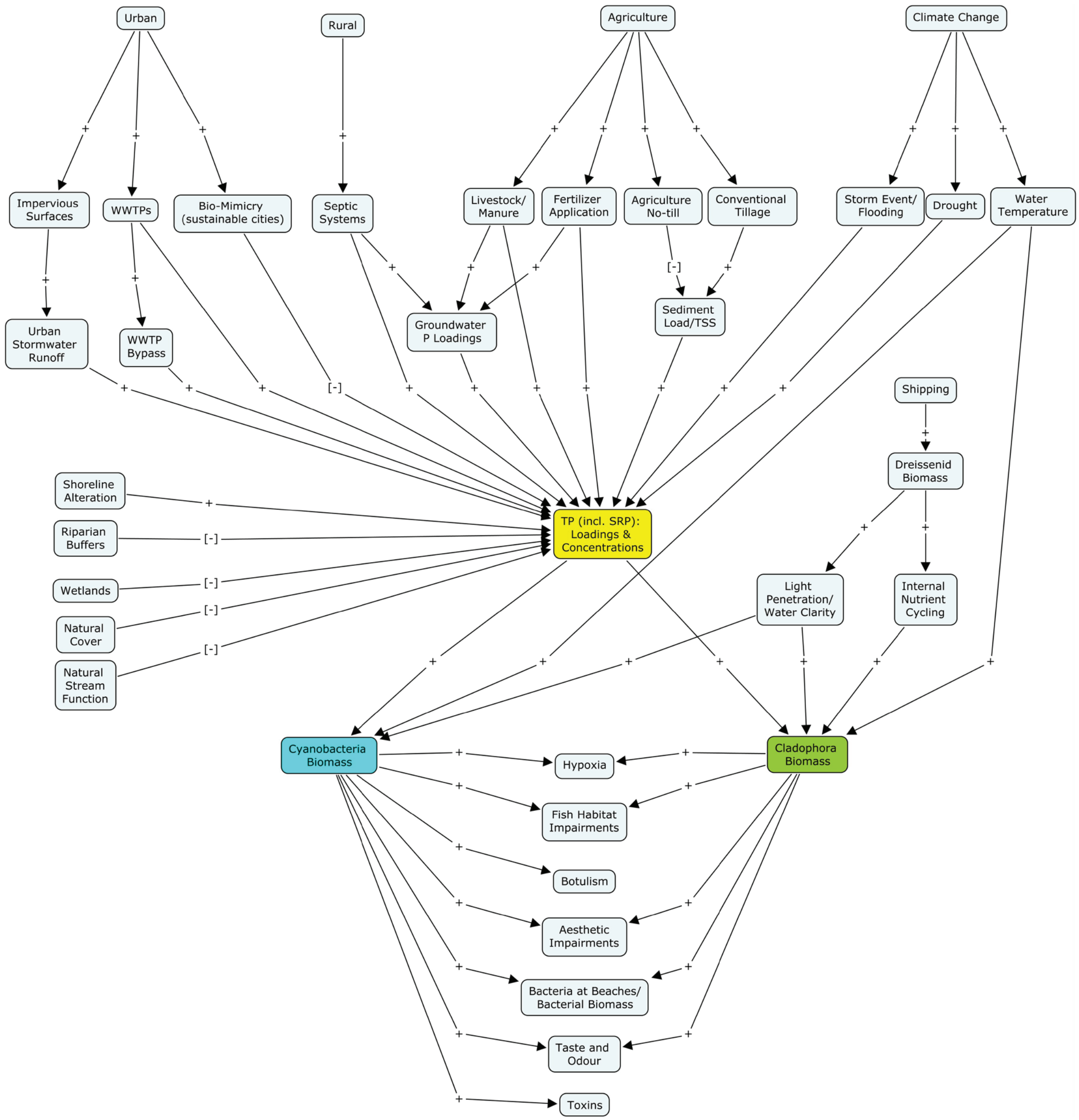

Figure 2. FCM consensual map from FCM Workshop II as proposed by stakeholders in the Lake Erie LaMP.

The FCM primarily reflects the understanding of influences of phosphorus loading on *Cladophora* and blue-green algae biomass.

Figure 1 indicating a major role for endogenous processes and Figure 2 dominated by exogenous processes. A second major difference, again related to the endogenous/exogenous focus, is the representation and postulated causal importance of land-use activities relating to alteration of natural habitats. Although both maps explicitly represented the postulated positive relationship between natural cover and reduced nutrient loading, Figure 2 explicitly recognizes the role of particular natural cover elements, including wetlands, riparian zones, and natural forest cover.

Implications

The weight of evidence evaluation is not yet complete. The work group must still complete a detailed analysis of the expert FCM from FCM Workshop 1 and write a final technical report of the work group. The FCM based on a review of the scientific literature could not be completed during the 2007-2009 Priorities cycle and will be left for future work in the 2009-2011 Priorities cycle. Nevertheless, the preliminary findings of the Eutrophication Work Group merit further analysis, and there are some important implications for management and for follow-up activities.

General Implications

- FCM proved to be a useful tool to capture expert (scientists) and local stakeholder knowledge of the eutrophication issue. Although the full WOE use of the FCM structure is not yet complete, this operational approach to the charge to the Work Group has considerable potential to provide more effective communication of scientific uncertainty and to justify options for management recommendations.
- Preliminary analysis of FCMs show eutrophication has complex causation largely from anthropogenically influenced changes on the cycling of different forms of P between terrestrial and aquatic ecosystems in the Great Lakes basin.
- Both FCMs show the eutrophication problem is driven by external drivers (changes in the land) and internal drivers (changes in lake ecosystem structure).
- Stakeholder perception of the eutrophication problem does not reflect scientific uncertainties with respect to the interaction of forms of phosphorus and internal versus external drivers of key indicators of eutrophication.

- A mixture of management interventions suggested by both FCM maps, with a set of "no-regrets" management actions, might mitigate some local eutrophication problems.

Implications for Management, Including Communication Messaging

The cognitive mapping process was unable to indicate management actions that will conclusively lead to less *Cladophora* or blue green algal biomass. The academic FCM and Nutrient Strategy being prepared by the Lake Erie LaMP indicate that management actions must be tailored to the spatial and temporal scale of interest. This work has applicability across the basin to deal with eutrophication.

On the basis of the expert FCM, there is clearly widespread belief that the dreissinid invasion has qualitatively changed internal P dynamics. **They** simultaneously clarify the water (increasing light penetration) and increase the solubility of particulate P through filtration. While total P loading targets for the lakes have apparently been achieved (Dolan; GLWQA review), there is nonetheless increasing eutrophication in the nearshore.

The various sources of soluble reactive P that could contribute to nearshore or open lake *Cladophora* and blue-green algae biomass growth are not well known. They can vary from location to location around any given lake (and from the nearshore to the offshore). Thus appropriate management actions are site or regionally specific and there is no "one size fits all" approach. Since there is uncertainty as to which sources of P (and also which algae biomass) are of the most concern, it has been proposed that both offshore and nearshore eutrophication issues need to be addressed simultaneously (T. Howell, pers. comm.)

Nearshore *Cladophora* and other algal growth apparently is largely controlled by tributary/shoreline loading concentrations of P and also by soluble reactive P contributed by the "near shore shunt" of dreissinids. The size of a watershed (length of delivery/retention time to the lake) affects the timing and concentration of P in the nearshore and the potential intensity and scale of management response as well. These nearshore problems seem to be most affected by "in season" rainfall-induced events from the watersheds contributing to sewage treatment plant (STP) combined sewer overflow (CSO) bypasses, stormwater or agricultural runoff.

Solutions to nearshore nutrient surpluses may include controlling the dreissinids themselves or farming/harvesting algal/*Cladophora* biomass for beneficial purposes such as green energy or bio-products. Besides reducing P inputs in the short term, we may need to evaluate systems that purposefully shunt P to more desirable outcomes.

Possible Management Actions for Eutrophication Abatement

It is well recognized by the scientific community that eutrophication is a complex process, and the FCM exercises reinforce this conclusion. This complexity reaffirms the need for greater cooperation between all orders of government. There are already programs in place in all jurisdictions to address urban, rural and agricultural, point and non-point sources of phosphorus. Over the years, many eutrophication management recommendations have been suggested for such programs with implementation having varying success in the Great Lakes. The descriptions below of possible eutrophication management actions therefore will have a familiar ring since they were taken from existing eutrophication literature and lake management plans for consideration by the IJC.

Point Sources/Sewage Treatment Plants: Under current programs, STPs should be able to demonstrate their annual loadings to a water body and that they are not exceeding current GLWQA targets (1.0 mg/L TP for Superior, Huron and Michigan; 0.5 mg/L for Erie and Ontario). These rates need to be reviewed in context of cumulative impact on a watershed/river and the lake when they are determined to be a significant source of eutrophication problems. There are opportunities to optimize sewage treatment plant operations to significantly reduce P discharges without significant capital inputs. Infrastructure investments from economic stimulus packages are another opportunity to improve STPs not meeting Great Lakes Water Quality Agreement (GLWQA) requirements and to meet stricter standards voluntarily. Fertigation or effluent reuse from STPs, regulating technology standards and phosphorus trading are longer-term options but need more study and acceptance.

Urban Run-off/Stormwater: Some jurisdictions have moved to banning P in lawn fertilizers and soaps or educating citizens about low P fertilizer use. Many jurisdictions have guidelines for combined sewer overflows which are being gradually separated with time. There are also guidelines existing for impervious surfaces and stormwater management design standards. Retrofitting or monitoring of facilities may be an option if this is a significant source of P. Reducing lawn size or regulating technology standards may be longer-term solutions.

Rural Non-Farm/Septic Systems: Many jurisdictions have septic inspection and pump-out programs to ensure that septic drainfields are functioning properly to remove P. Education and outreach on septic installation and maintenance is uneven in most jurisdictions. Disconnecting direct connections to waterways will improve P and public health outcomes.

Agricultural Non-point Sources: Agriculture extension programs strive for economic and environmental sustainability. Nutrients are needed by crops, and manures need to be applied in an economical manner. There will always be leakages from an "open system," but there are opportunities to efficiently and economically better utilize nutrients. Many Best Management Practices (BMPs) are promoted by programs but uptake is not 100% yet, nor are practices necessarily directed at the greatest source areas. There is a need to continue promotion of practices that i) will better match nutrient requirements with nutrients available on a farm (or in an area) (nutrient management planning, soil and manure testing) and ii) keep nutrients and soil in place where they can be utilized effectively (no winter application of fertilizers or manures, cover crops, crop residues (reducing bare soil days) is a no regrets action). Local and regional conditions and practices need to be considered.

In the longer term, once a determination of whether total phosphorus (TP), particulate P or soluble P from non-point agricultural sources are causing issues for nearshore (or offshore) eutrophication, then more tailored management practices can be designed for the long term. For example the no-tillage system was promoted broadly in the Great Lakes basin as a best practice to stop soil erosion and thus loss of particulate P. But it has now been implicated in Ohio for increasing the amount of SRP entering Lake Erie (although this effect on SRP was noted early on but thought to be small). A better understanding of the tradeoffs of promoting different tillage systems for environmental benefit (soil quality, spawning impairment) as well as eutrophication/P benefit would have to be done on a site specific/watershed basis.

Recommendations

"No-Regrets" Management Recommendations

'No-regrets' eutrophication management actions are best-bet actions that will lead to one or more improvements in the condition of eutrophic waters based on some scientific understanding of cause-effect relationships and not cause further anthropomorphic increases of nutrients to the lakes.

- Understanding the sources and managing the specific mix of nutrient sources in local eutrophic areas is the key to effective mitigation in those areas; collectively this approach should address lake-wide issues.
- Promoting nutrient-use efficiency in rural and urban communities–especially in P-sensitive watersheds–is critical to effective source loading reductions to Great Lakes.

- Agency programs designed to address urban, rural and agricultural point and non-point sources of P should be evaluated to ensure that these programs are functioning as intended.
- Reducing P discharges by optimizing STP operations at facilities located in P-sensitive watersheds.
- Retrofitting existing stormwater management infrastructure to green infrastructure alternatives in P-sensitive watersheds.
- Where green infrastructure not practical, promotion of highest design standards for urban run-off/ stormwater systems.
- Increasing the uptake of P-efficiency and loss reduction BMPs by farmers through extension programs and the increased efforts of such programs in watersheds where major tributaries flowing into the Great Lakes cause eutrophication concerns/issues.
- Promote nutrient use planning for croplands and livestock operations.
- Promote soil and water conservation BMPs to increase infiltration and reduce runoff and loss of soil and enhance efforts in watersheds which are priority for eutrophication concerns.
- Promote crop fertilizer applications that are sensitive to local hydrological conditions.
- Promote phosphorus soils testing to guide fertilizer and manure P application rates.
- Promote appropriate rates, methods and location of nutrient applications through the use of P-index.
- Promote riparian buffers to reduce runoff and phosphorus export.
- Ban or lower P in lawn fertilizers in P-sensitive basins. Education and outreach on appropriate use of low-P fertilizers in urban settings.
- Mandatory pumping of on-site septic systems on a periodic basis.
- Education and outreach to waterfront residents on septic system construction and maintenance; enhance outreach in P-sensitive basins.
- Mandatory disconnection of direct on-site septic system connections to waters of the Great Lakes.

Recommendations for Communications

- IJC should develop and provide information products on eutrophication for dissemination of consistent messaging through the media and for use by collaborating federal, state and provincial agencies.

- IJC should solicit help from the scientific community for one or more key spokespersons as key contacts for the media to ensure that areas of scientific uncertainty are carefully communicated.

- Communications that raise public expectation that a quick and easy solution to eutrophication is at hand should be carefully avoided; recovery may take up to several decades or longer.

- C conduct a tour of eutrophic shoreline areas for elected officials and the media to educate key communication stakeholders on the complexity of the eutrophication problem and options for abatement.

General Recommendations for Research and Monitoring

- Research on innovative approaches to resource-recovery of 'surplus' nutrients in the aquatic environment and harvesting of surplus nearshore algal biomass for beneficial purposes (green energy, bio-products).

- Research on feasibility of fertigation and waste water reuse in the basin for the purpose of P-loss reduction.

- Spatially identify open lake P loadings and specific watershed P contributions to assist in ranking mitigation priorities.

- Research and implementation of an early warning system approach for algal fouling across the Great Lakes basin to protect meso- and oligotrophic lakes.

- Research on development of 'P footprint calculator' of typical Great Lakes residents, businesses and communities and use it for education & outreach on necessary changes in behaviour for P reduction.

- Conduct enhanced monitoring (possibly by satellite imagery) of tributary and nearshore waters on a regular, sustained basis for a better understanding of eutrophication dynamics.

- Conduct enhanced monitoring of beaches to determine and benchmark frequency and occurrence of “nuisance” algal problems and help with adaptive management. Monitoring of tributaries, nearshore and beach algal fouling on a frequent basis and linking this with activities occurring in the watershed could help better understand the sources and causes of nuisance eutrophication.

- Design a sustainable monitoring program on the effectiveness of all eutrophication management actions.

Recommendations for Scientific Activities and Follow-Up Work

- Literature-based analysis to complete the WOE assessment. This work could not be completed during the current Priorities cycle. It remains an important component of an overall WOE approach and is left for future work.

- FCM workshops identified several important scientific issues that merit follow-up work and should be recommended to the Parties.

- Relative contribution of internal and external controls on regulation of *Cladophora* dynamics. New tests are required, along with a better understanding of spatial processes. Current dynamic models do not capture the scale of interactions of habitat, fish community structure and nutrient loading to make predictions about the effects of management actions on *Cladophora* and the reappearance of blue-green algae blooms. A new generation of models will be needed to address these issues, and it is important to make funding a priority.

- Need for better coupling of water quality and water quantity research. Variations in water levels and flows provide important and poorly understood context for the eutrophication problem. Without better linkage between water quantity and water quality models, there will be fundamental limitations to exploration of the linkage of land-based management changes to nearshore and offshore responses in the Great Lakes basin.

- Linkage of nearshore re-emergence of eutrophication and oligotrophication of offshore is not understood. Clearly need more complex models to assist this exploration.

- SRP dynamics issues need better characterization, including more detailed studies of the implications of recent increases in SRP concentrations.

Glossary

Best Management Practices (BMPs): Techniques that are recognized as being the most effective and practical means of achieving a desired end result such as eutrophication abatement.

Cladophora: *Cladophora* is a branching, filamentous, green macro-alga that is found in both fresh and marine waters. While *Cladophora* grows primarily on rocky substrates, it often becomes detached and accumulates along the shoreline, forming large, foul-smelling algal mats.

Dreissenids: Mussels in the family Dreissenidae. Zebra and quagga mussels are invasive species that are well-established in the Great Lakes and are collectively called "dreissenids."

Eutrophication: Eutrophication is a process whereby water bodies, such as lakes or slow-moving rivers or streams, receive excess nutrients that stimulate excessive plant growth. Nutrients can come from many sources, such as fertilizers applied to agricultural fields, golf courses and suburban lawns; erosion of soil containing nutrients; and sewage treatment plant discharges. This enhanced plant growth, often called an algal bloom, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die.

Fuzzy Cognitive Mapping (FCM): Fuzzy cognitive mapping is a structured activity focused on a topic of interest involving participants that produces a picture or drawing (concept map) of their ideas and concepts and how the concepts are interrelated. It is especially useful where there is need to develop weight-of-evidence on cause-effect relationships involving multiple factors and considerable uncertainty.

Green infrastructure: Green infrastructure is a concept that highlights the importance of the natural environment in decisions about land-use planning. A common example is the management of stormwater runoff at the local level through the use of natural systems, or engineered systems that mimic natural systems, to treat polluted runoff.

Hypoxia: Hypoxia means "low oxygen." In lakes and coastal waters, hypoxia means the waters do not have enough dissolved oxygen to support fish and other aquatic organisms. Hypoxia can be caused by the presence of excess nutrients in water. When the dissolved oxygen is all depleted, the condition is called, "apoxia."

Microcystis: The kind of blue-green algae (Cyanobacteria) most often forming algal blooms (high concentrations) in Great Lakes waters and an indicator of eutrophication. Also *Microcystis* is sometimes implicated as a human health concern because it secretes a toxin whose presence is known as "harmful algal blooms (HABs)."

Nearshore shunt: A theory whereby nutrients are redirected in nearshore waters consequent to dreissenid establishment that results in nutrient-rich nearshore waters (eutrophication) and nutrient-poor (oligotrophication) offshore waters.

Non-point pollution: Pollution entering rivers and lakes from diffuse sources (e.g., agricultural and urban run-off and combined sewer overflows (CSOs).

Oligotrophication: The process of nutrient depletion, or reduction in rates of nutrient cycling, in aquatic ecosystems. This condition is occurring in the offshore waters of most of the Great Lakes and appears to be associated with nutrients being sequestered or “shunted” in the nearshore waters.

Phosphorus: Phosphorus is a nutrient required by all organisms for the basic processes of life. It is a natural element found in rocks, soils and organic material and occurs in several forms. The most important use of phosphorus is in the production of fertilizers. It is also widely used in pesticides and detergents and is a component in all municipal and some industrial waste-waters. High water quality is generally low in phosphorus, and in the Great Lakes phosphorus is considered the “limiting nutrient” for plant growth. Reducing phosphorus concentrations in lake water has been the most effective management strategy for eutrophication control. Phosphorus exists in water in either a solid, bound phase (“particulate phosphorus”) or a dissolved phase (phosphates). There are several forms of phosphorus which can be measured in a water sample. Total phosphorus (TP) is a measure of all the forms of phosphorus, dissolved or particulate. Soluble Reactive Phosphorus (SRP) is the form of dissolved or soluble phosphorus that is most readily used by plants.

Point-source pollution: Pollution discharges to rivers and lakes from a single source (e.g., municipal or industrial pipes).\

Weight-of-evidence (WOE): An approach to determine multiple lines of facts or evidence to support science-based decision-making. Fuzzy Cognitive Mapping (FCM) is one kind of WOE and is especially useful when there are multiple factors involved and considerable uncertainty.

Appendices

Appendices are available in pdf format at:

http://www.ijc.org/en/priorities/2009/eutrophication/appendix