Great Lakes Water Quality Agreement
2009–2011 Priority Cycle Report
International Joint Commission

NUISANCE AND HARMFUL ALGAE

2009–2011 Priority Cycle Report on

NUISANCE AND HARMFUL ALGAE

Prepared by the
NUISANCE AND HARMFUL ALGAE WORK GROUP

For the
INTERNATIONAL JOINT COMMISSION
Canada and United States

COMMISSION MIXTE INTERNATIONALE
Canada et États-Unis

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The Ohio State University, Ohio Sea Grant College Program

SUMMARY

The International Joint Commission charged the Nuisance and Harmful Algae Work Group (NHAWG) with the implementation of a weight-of-evidence approach to prioritize management actions to address the nuisance algae problem in the Great Lakes. More specifically, the Commission directed the NHAWG to use the previous work of the Eutrophication Work Group in the 2007–2009 Priority Cycle as a starting point. Products of the previous work included expert consensus representation of the causal structure of the nuisance algae problem in the form of a Fuzzy Cognitive Map (FCM), a bibliography of research articles and technical reports, a set of recommended "no-regrets" management actions, and a set of general recommendations to the Commission about a communications approach for use by the media regarding the re-emergence of eutrophication in the lower Great Lakes. The findings in this report are relevant to the work products of the NHAWG and are not a summary of the current state of knowledge of the causes of the nuisance algae problems in the Great Lakes. The five main findings of the NHAWG are presented below.

1. There is a consistent belief among experts that a significant contributing factor to the excessive growth of *Cladophora* in various locations in the Great Lakes is the invasion and growth of dreissenid populations, mediated through three major mechanisms: (1) increasing light penetration; (2) increasing availability of hard substrate with the presence of dreissenid mussels; and (3) increased levels of soluble reactive phosphorus in the nearshore as a result of changes in phosphorus cycling by dreissenid mussels. Although evidence exists for the effect of increasing light penetration and, to a lesser extent, for the other mechanisms, the overall empirical evidence in support of the dreissenid hypothesis is not, as yet, particularly strong.
2. There is a strong belief that allochthonous nutrient loading, especially (but not limited to) phosphorus, from urbanization and agriculture is a major contributor to the nuisance algae problem. While the effect of nutrient availability on phytoplankton growth has been well established for decades, evidentiary support for the importance of nutrient loading on *Cladophora* is substantially weaker and the evidence for an effect on harmful algal blooms varies by location.
3. There is also a belief in some quarters that climate change is an important contributor to the nuisance algae problem. At least three different mechanisms have been suggested: (1) reduced water levels leading to increased light availability for substrate to support *Cladophora* growth; (2) increased frequency of high intensity rainfall events leading to increased flooding and runoff, resulting in increased nearshore nutrient loading; and (3) increased water temperatures leading directly to enhanced algal growth. Although evidentiary support for some of the causal linkages implied in these relationships is substantial, the relative importance of these mechanisms and, indeed, the overall importance of climate change in comparison to the effects of urbanization, agriculture, and dreissenids is unknown.

"There is a consistent belief among experts that a significant contributing factor to the excessive growth of Cladophora in various locations in the Great Lakes is the invasion and growth of dreissenid populations, mediated through...(1) increasing light penetration; (2) increasing availability of hard substrate with the presence of dreissenid mussels; and (3) increased levels of soluble reactive phosphorus in the nearshore as a result of changes in phosphorus cycling by dreissenid mussels."

4. There is a widespread belief that the lack of clear scientific understanding of the causal structure of the nuisance algal problem in the Great Lakes justifies advancing "no-regrets" management actions to reduce phosphorus loading. Review of the evidence for "no-regrets" management actions recommended in the 2009 Report of the Eutrophication Work Group found that these recommendations arise from a variety of sources (scientific

literature, conference proceedings, agency publications, and opinions of experts from professional associations) with the majority of publications being non-peer-reviewed. Although these recommendations emerge from a community consensus about best management practices to either minimize nutrient loss from runoff and erosion or to reduce nutrient loadings of surface waters from urban and rural point and non-point sources, there appears to be a deficit of studies about the effects of "no-regrets" management actions on algal blooms and their opportunity costs. Without strong scientific evidence for causal structure, the NHAWG cannot do a priority ranking of management actions. Effects may be site specific, and there is a need to determine whether "no regrets" management actions will have a substantial effect on the concentration of nutrients in problem areas.

"There is a strong belief that excessive nutrient loading, especially...phosphorus, from urbanization and agriculture is a major contributor to the nuisance algae problem."

5. Residents of shoreline communities are at the "front line" in terms of literally smelling and seeing the consequences of eutrophication on local beaches. However, they can also be the most challenging audience to effectively deliver a communications campaign to, because of the cultural diversity of these communities around the Great Lakes and the diversity in opinions and understanding of a complex environmental issue like eutrophication. Recent surveys of Ontario shoreline residents in southern Lake Huron and Lake Erie show minimal understanding of the role of phosphorus on algal blooms, and residents do not realize that they can have a direct role in contributing phosphorus to the Great Lakes and the resultant poor water quality. Nevertheless, residents are willing to make changes to common household activities (landscaping practices, septic tank inspection, and detergent use) in order to reduce phosphorus loading to lake water. Community-Based Social Marketing strategies targeting specific *behaviours* of shoreline residents have the potential to change their *behaviours* and reduce phosphorus loading, but there is a need to establish the contribution of shoreline residents' actions on phosphorus loading relative to other point and non-point sources.

"There is also a belief...that climate change is an important contributor to the nuisance algae problem. At least three different mechanisms have been suggested: (1) reduced water levels leading to increased light availability for substrate to support Cladophora growth; (2) increased frequency of high intensity rainfall events leading to increased flooding and runoff, resulting in increased nearshore nutrient loading; and (3) increased water temperatures leading directly to enhanced algal growth."


Environment Canada

BACKGROUND

Charge and Terms of Reference

During the 2009–2011 Priority Cycle, the Commission charged the NHAWG to better reflect the objective in the Great Lakes Water Quality Agreement to eliminate nuisance growths of algae. The Commission expected the NHAWG to inform the nearshore condition assessment. Work in the 2007–2009 cycle by the Eutrophication Work Group indicated that management interventions with respect to both urban and agricultural environments are likely important for resolving stinking masses of filamentous algae (*Cladophora*) washing up on shorelines and obnoxious scums of blue-green algae (also known as cyanobacteria). The latter are often called "harmful algal blooms" (HABs), some of which are toxic. The Work Group was asked to fill scientific gaps in assessment of conditions and diagnosis of problems, especially in regard to better understanding regarding urban sources of nutrients and about water quantity—water quality interactions. Prioritization of implementation actions was to focus on the "no-regrets" management actions identified in the 2007–2009 Eutrophication Work Group Report. The work was to be conducted through a series of workshops supplemented with contracted expert white papers. The Commission wanted the work conducted in association with the Nearshore Framework and the Beaches and Recreational Water Quality Work Groups and wanted communication of findings to the public and resource managers conducted with input and cooperation of the Public Information Office at the Commission's Great Lakes Regional Office.

Problem Statement and Work Plan

In adopting the nearshore condition assessment as the cornerstone to develop an adaptive management strategy through the nearshore framework, the NHAWG interpreted its charge as a mandate to assess the causes of nuisance algal growth and to prioritize implementation actions in an adaptive management context. Building on progress made by the Eutrophication Work Group in the 2007–2009 Priority Cycle, the NHAWG created a three-part work plan consisting of scientific, management, and communication components.

Scientific Component

1. Refine the Fuzzy Cognitive Mapping (FCM) analysis. Complete the transitive closure analysis of the 10 consensual maps previously developed by the Eutrophication Priority Work Group.
2. Obtain a literature-based FCM. Based on the priority arcs identified in step 1, conduct a survey of the scientific literature to document the evidentiary basis for the arcs and agree on specific methodology and protocol.
3. Compare weight of evidence (WOE) from the workshop FCM and the literature FCM. From the work in steps 1 and 2, develop a consensual WOE based on the workshops and a WOE based on published literature. This would allow evaluation of the correlation between the two and inform management actions.

Management Component

4. Evaluate intervention strategies ("no-regrets" recommendations). On the basis of step 3, management actions and strategies can be ranked.
5. Review candidate management actions and strategies from the adaptive management (AM) perspective. Evaluation in step 4 will lead to a ranked list of actions and strategies (as determined by step 1) in terms of the evidentiary support that changes in their level will improve the algal problem.
6. Hold a joint Water Quality Board—Science Advisory Board workshop to discuss findings and recommendations from step 5. Integrate the NHAWG findings with the Beaches and the Nearshore Work Groups.

Communication Component

7. Conduct a survey or hold focus group sessions with coastal residents or other target groups to better understand their knowledge of causal relationships between phosphorous and algal growth. This would provide an assessment of needs for the targeting, scoping and recommendations to promote and communicate current and future management actions and strategies.
8. Develop recommendations for management actions, strategies and communication approaches and materials.

Methods

In prior work, the Eutrophication Work Group implemented a Fuzzy Cognitive Mapping (FCM) exercise as part of a weight-of-evidence (WOE) approach to the problem of nuisance algae in the lower Great Lakes. This approach was adopted to address two questions: "What are the postulated causes of the nuisance algae problem?" and "To what extent are these hypotheses corroborated by existing evidence?"

FCMs are graphical representations of the causal relationships between elements of a system. FCMs include nodes (vertices) representing concepts, joined by directional edges (arcs) representing causal relationships between concepts. Each arc is parameterized by a set of values which denote specific attributes of the hypothesized causal relationship. One such attribute is the sign of the relationship. A positive sign for the arc from concept C_i to vertex C_j indicates an excitatory relationship, *i.e.* as C_i increases C_j increases, and a negative sign indicates an inhibitory relationship, *i.e.* as C_i increases C_j decreases. In the FCM exercise, a number of arc attributes (weights) were scored on a scale of 1 (very low) to 5 (very high), including importance; universality (*i.e.* the extent to which it is expected to hold at all times and locations); the characteristic spatial and temporal scales (ranging from small (local) and transient to large (global) and long-term); and change feasibility—the perceived difficulty in changing the level of the "head" vertex in the relationship.

Also in prior work, the Eutrophication Work Group commissioned a programmatic and a literature survey of existing work on nuisance algae problems in the Great Lakes. These surveys were derived from expert consultation and a variety of literature search engines.

Scientific Component

In February 2009, workshop participants generated a set of 14 independent FCMs. The consolidated consensus map from these FCMs included 62 vertices and 193 directed arcs (see 2007–2009 Biennial Report). Seven major outcomes of interest were identified (Fig. 1): phytoplankton biomass, *Cladophora* biomass, cyanobacteria biomass, central basin reduced hypoliminion thickness, hypolimnetic hypoxia, botulism animal kills, *Lyngbia* biomass and *Spirogyra* biomass, with cyanobacteria and *Cladophora* biomass having the largest number of inputs. Concepts with a large number of postulated causal inputs and/or outputs include nearshore soluble reactive phosphorus (SRP), *Cladophora* biomass and dreissenid biomass (Fig 1). Major emitters (concepts which affect other concepts, but not themselves affected by other concepts in the map) included climate change, predatory fish biomass, urban activities, agricultural activities, and natural vegetation cover (Fig 1).

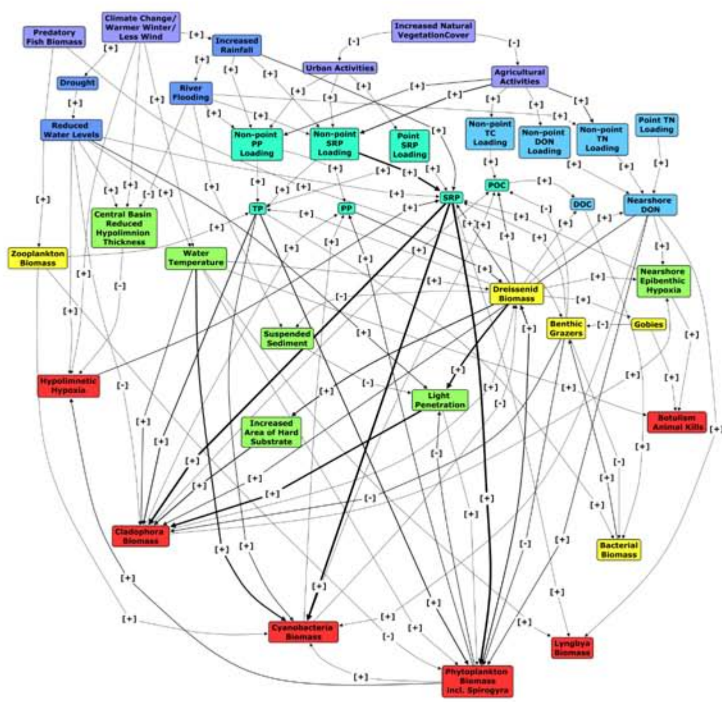

Figure 1. *Condensed consensual eutrophication Fuzzy Cognitive Map (FCM) derived from workshop 1. Arcs are labeled with sign only. The thickness of the arrow between any set of concepts represents one measure of weight of evidence for that particular arc i.e. the number of maps that the arc was present on. Colour scheme: Red=identified endpoint/indicator, yellow=biotic factor immediately upstream of endpoint, green=abiotic factor immediately upstream of endpoint, aqua=phosphorus-related factor, bright blue=carbon- or nitrogen-related factor, darker blue=important causal factor, purple=ultimate emitters/causal factor.*

One measure of evidentiary weight is the degree of consensus among independent expert opinions. Of course, expert scientific opinions are never truly independent. The lack of independence notwithstanding, it is reasonable to assign greater evidentiary weight to arcs that appear in many versus few maps. Of the 193 directed arcs in the consensus map, most were present only in a single map. This was probably caused, in large part, to the different approaches to represent the proximate and ultimate causes by different participants. Nonetheless, high to moderate consensuality (≥ 4/10 maps) was obtained for a positive effect of light penetration on *Cladophora* abundance (8/10 maps), a positive effect of allochthonous SRP on *Cladophora* abundance (6/10 maps), a positive effect of dreissenids on light penetration (6/10 maps), a positive effect of agriculture on allochthonous non-point SRP loading, a positive effect of allochthonous non-point total phosphorus on allochthonous SRP, a positive effect of nearshore autochthonous SRP on *Cladophora*, a positive effect of dreissenid abundance on nearshore autochthonous SRP, and a positive effect of hard substrate abundance on dreissenid abundance (all 4/10 maps).

A more refined measure of consensus reflects both the number of maps for which a particular arc was present and the similarity in assigned values (scores) of a particular arc attribute among these maps. For arcs appearing in multiple maps, the smaller the variance in arc weights assigned by multiple evaluators, the greater the confidence in the estimate. Across the set of arc attributes, consensus scores were, in general, highly correlated (range = 0.82 – 0.94), reflecting largely the fact that most arcs were represented in only a single map; and any arc represented in only a single map had the same assigned consensus (δ) for every arc attribute. In general, workshop participants attempted to assign values to all arc attributes.

The ten arcs having the highest consensus scores and highest importance involve comparatively few concepts and relationships: *Cladophora* and cyanobacteria biomass, dreissenid biomass, light penetration, amount of hard substrate, nearshore (allochthonous or autochthonous) SRP, and agricultural activities (Fig. 2). As most arcs were present in only a single map, by definition they have low consensus for any arc attribute.

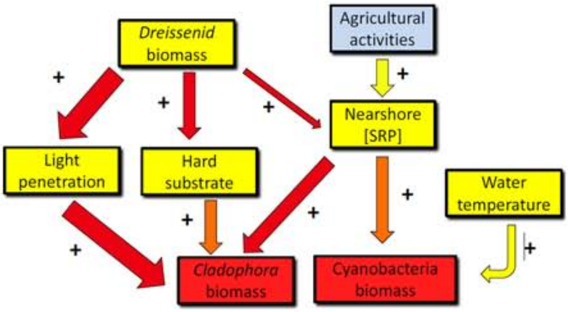

Figure 2. *Subgraph of Fig. 1 that includes the set of 10 arcs having the highest average importance. Average importance > 4.0, with the exception of the link between agricultural activities and SRP (average importance = 3.2), and water temperature and cyanobacteria biomass (average importance = 3.3). Importance consensus > 0.46. Consensus (ranging from 0.42 to 0.73) is indicated by the breadth of the arc, average importance by colour (red: > 4.5; orange: 3.5–4.4; yellow < 3.5). Allochthonous and autochthonous SRP have been combined into one vertex, so only 9 arcs are explicitly represented.*

For the 10 arcs having highest importance and consensus, average arc importance is moderate or high (range = 3.0–4.7), universality is at best moderate (range = 2.3–3.8), and all have moderate to high change feasibility (range = 3.7–5.0; Fig. 3). There is, therefore, reasonable consensus that, at different locations (and possibly times), the major drivers of the nuisance algae problem may differ, and modifying the level of any of the “head” vertices in Fig. 2 will be difficult to accomplish either because of technological limitations, sheer expense or tepid political enthusiasm (Fig. 3). Particularly noticeable are the very high change feasibility scores (all values > 4.5) for all arcs with dreissenid biomass as the head vertex. This presumably reflects widespread belief that reduction in dreissenid abundance to a level sufficient to reduce algal biomass will be very difficult to accomplish. On a more encouraging note, temporal scales were uniformly low (range = 1.6–2.5) reflecting the general belief that, if successfully implemented, management interventions would result in observable changes on time scales of a few years or less (Fig. 3).

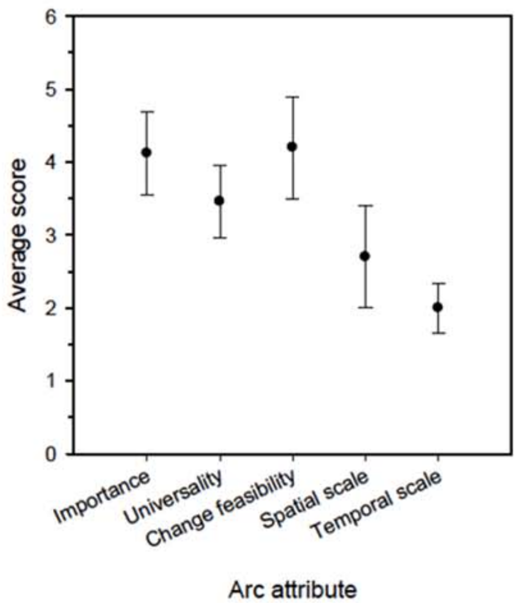

Figure 3. *Average scores (+/- 1 SD) for the 10 arcs of the subgraph shown in Fig. 2. With respect to importance, universality, change feasibility, spatial scale and temporal scale.*

The aforementioned analysis concerns arcs. Of more relevance are *directed walks*, that is, collections of directed arcs that define paths between any two vertices. For example, in Fig. 2 there are three directed walks between dreissenid and *Cladophora* biomass and one directed walk between dreissenid biomass and cyanobacteria biomass. Analysis of directed walks on graphs is important for two reasons. First, the arc connecting any two vertices may, at least in principle, be composed of an infinite number of subsidiary arcs and "interstitial" vertices. Hence, the presence or absence of a particular arc may simply reflect the level of detail deemed appropriate by its author(s). Second, any candidate management intervention designed to reduce or mitigate the nuisance algae problem will necessarily target one or more vertices. For example, reducing threshold concentrations for sewage treatment plant outflows is, one presumes, designed in part to reduce nearshore concentrations of SRP. Because the concern is with the impact of candidate interventions on nuisance algae, all possible directed paths connecting the vertex representing the target(s) of intervention and the outcome(s) of interest must be considered (Fig. 4).

"There is, therefore, reasonable consensus that, at different locations (and possibly times), the major drivers of the nuisance algae problem may differ, and modifying the level of any of the "head" vertices in Fig. 2 will be difficult to accomplish either because of technological limitations, sheer expense or tepid political enthusiasm. "

Analysis of all directed paths from a potential driver (or driver class) to algal endpoints shows several interesting patterns, most notably the differences between the two major endpoints, *Cladophora* and cyanobacteria. For both average importance based on minimum (Fig 4a) and on maximum (Fig 4b) arc weights, climate change was considered a considerably more important driver for cyanobacteria than *Cladophora*, whereas, for dreissenids, the situation was the opposite. While there was comparatively high consensus concerning the effects of agriculture on both endpoints, especially cyanobacteria, there was comparatively low consensus on the impacts of climate change, especially on *Cladophora* (Fig. 5).

By contrast, there was comparatively high consensus on the impacts of dreissenids on *Cladophora* and low consensus on their impacts on cyanobacteria. The apparent conclusion is that, for cynaobacteria, nutrient loading from agriculture and urbanization is an important driver with a comparatively high degree of consensus among experts; climate change—though considered very important by some—has much lower consensus; and dreissenids seem to be of lesser importance although, here again, there is low consensus. By contrast, for *Cladophora*, there is a widespread, high consensus that dreissenids are a major driver, with all other factors considered to be of lesser importance.

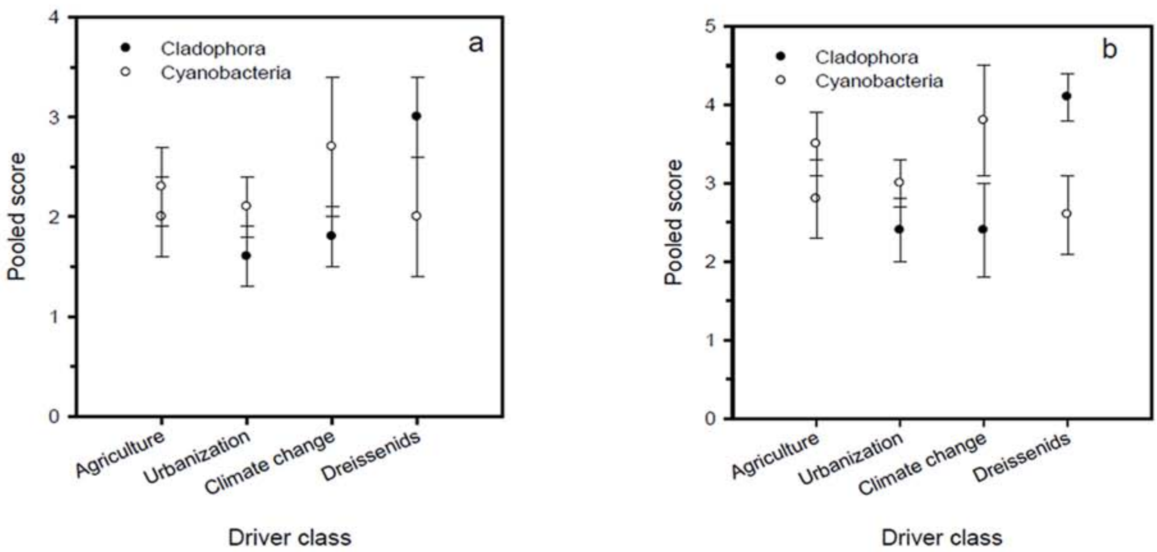

Figure 4. *Average (+/- 1 SD) importance of major classes of postulated drivers for Cladophora and cyanobacteria abundance based on minimum (a) and maximum (b) weights of the set of directed paths from each driver class to the endpoint in question.*

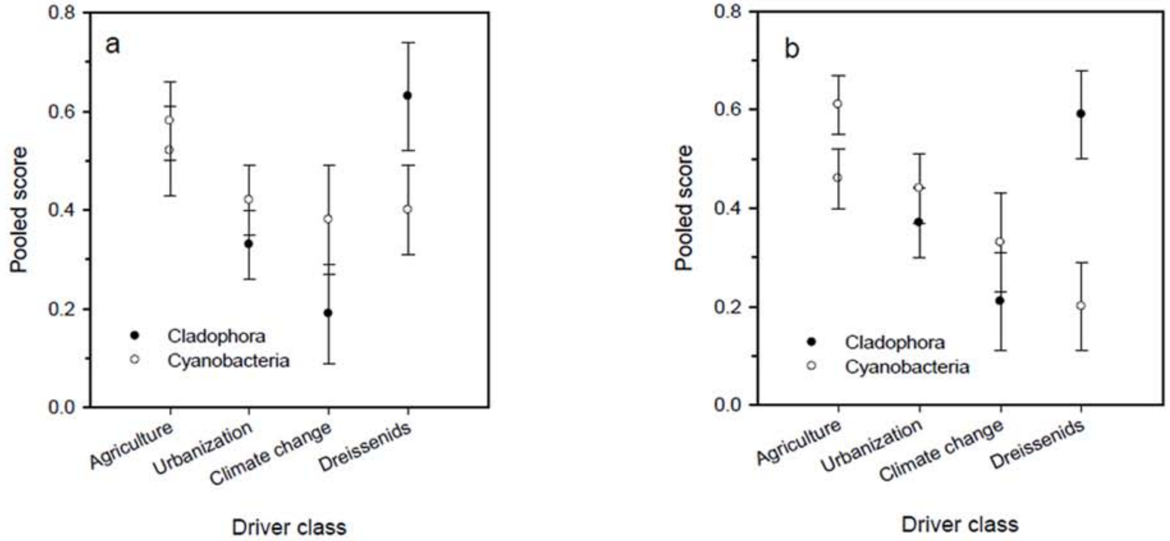

Figure 5. *Average (+/- 1 SD) consensus of major classes of postulated drivers for Cladophora and cyanobacteria abundance based on minimum (a) and maximum (b) weights of the set of directed paths from each driver class to the endpoint in question.*

A second approach to weight-of-evidence assessment involved searching the peer-reviewed literature for studies which, in principle, might be relevant to evaluating the evidence in support of or contradictory to, any of the 193 arcs in the original map. Given the potentially enormous scope of this inquiry, the search focused on a set of 22 published studies that experts had identified as particularly relevant to the problem. Most were observational studies (20 papers—2 meta-analyses, 3 model studies). Nutrient inputs (13 studies) and dreissenid biomass (5 studies) were the most studied independent variables (drivers). Nutrient inputs were usually non-point sources and included dissolved nitrogen and various forms of phosphorus, usually total phosphorus (9 studies) or soluble reactive phosphorus (6 studies).

Of the 62 concepts in the original consensus map, 30 were mapped (Fig. 6). The set of associated arcs for this subgraph closely resembled those in the original consensus map, with greatest consensus (as indicated by number of articles) occurring for the positive relationship between nutrient loading/levels and algal biomass, and dreissenid biomass and SRP concentrations. All arcs for this subgraph had the same sign as those assigned in the workshop consensus map, lending additional measure of empirical support.

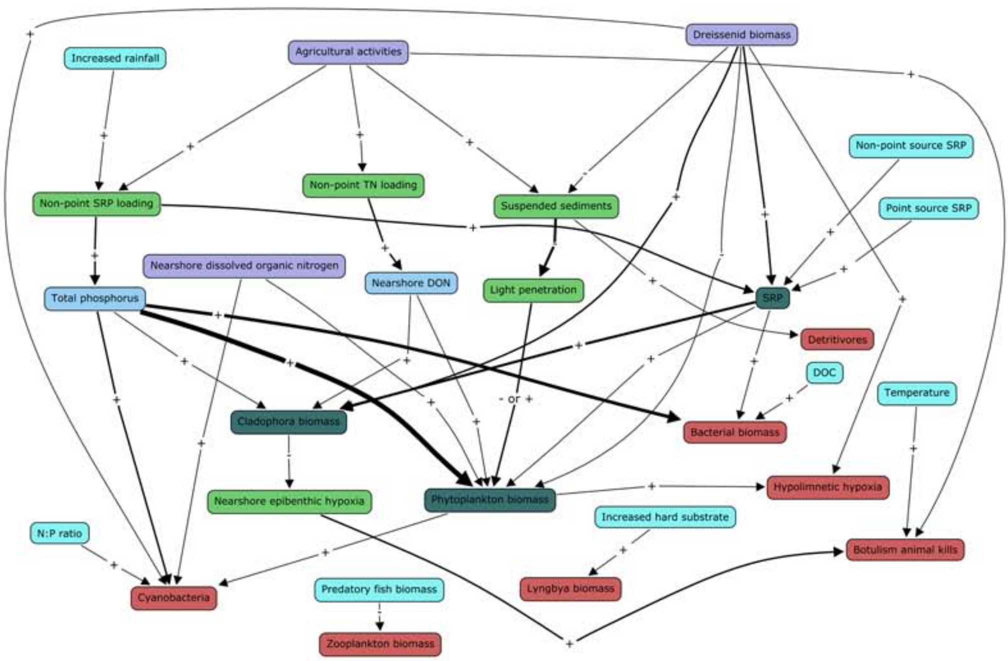

Figure 6. *Eutrophication FCM derived from the concepts and links identified with reference to review of 21 scientific papers listed in the appendix. Arcs are labeled with sign only. The thickness of the arrow between any set of concepts represents one measure of weight of evidence for that particular arc, i.e. the number of papers that identified that relationship. Concept colours used in Fig. 1 are retained here for consistency. However, the positions of some concepts on this map have been moved to facilitate interpretation in this simplified representation of the original suite of concepts.*

As noted above, the FCM exercise resulted in a comparatively strong consensus about the causal link between dreissenids, water clarity, nearshore SRP concentrations, and nuisance algae, and the general review of a subset of literature confirmed a similar causal structure. There is thus a strong and consistent belief that the dramatic increase in dreissenid abundance in the lower Great Lakes is an important contributing factor to the nuisance algae problem through at least three physical processes: increased availability of hard substrate for *Cladophora;* increased concentration of SRP for all algal types as well as cyanobacteria; and increased light penetration.

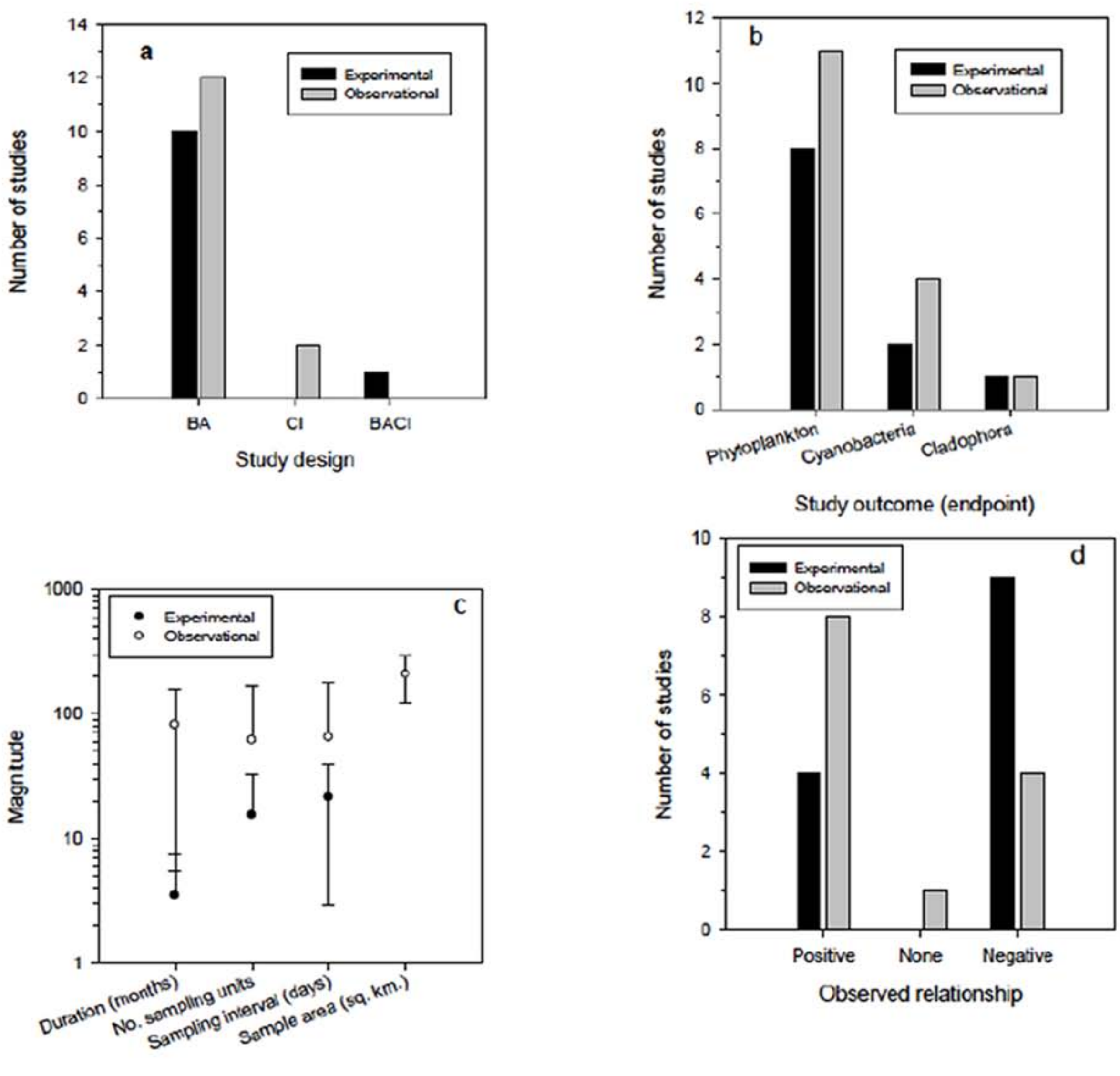

Figure 7. *Distribution of study designs (a), nuisance algae endpoints (b), relationships between nuisance algae endpoints and dreissenid abundance (d) for experimental and observational studies. Fig. 7c shows the mean (+/- 1 SD) of selected study attributes for experimental and observational studies.*

FINDINGS

But how strong is the empirical evidence? To assess this question, a systematic review was conducted of studies that examined the relationship between dreissenid abundance and algal endpoints (*e.g. Cladophora*, cyanobacteria, phytoplankton). Of 24 studies that satisfied the study selection criteria, 14 were observational studies that evaluated patterns of covariation (in space or time) between dreissenid abundance and one or more endpoints. The remaining 10 were experimental studies in which dreissenid abundance was experimentally manipulated and the effect on one or more endpoints evaluated. Virtually all studies had Before-After (BA) or Control-Impact (CI) designs, with only one having a Before/After-Control/Impact (BACI) design which allowed for much stronger inference (Fig. 7a). Sixteen studies focused on phytoplankton abundance. Another four considered specifically cyanobacterial abundance, with phytoplankton overwhelmingly (90%) the endpoint of interest in experimental studies (Fig. 7b). Only two studies, both observational, considered *Cladophora* abundance/biomass as the endpoint of interest. Observational studies conducted over larger spatial scales had longer study durations and longer intervals between sampling events and a larger average number of sampling units, than did experimental studies (Fig. 7c). In experimental studies, rarely were factors other than dreissenid biomass manipulated. By contrast, observational studies often included multiple covariates. Finally, most experimental studies documented a negative effect of dreissenids on algal endpoints, whereas study endpoints were much more heterogeneous for observational studies (Fig. 7d).

Taken together, the empirical evidence for the expert consensus of the important role played by dreissenids is not particularly strong. The study designs employed to date do not permit strong inference. Most experimental results were obtained from comparatively short-term studies where only one, and rarely two, factors were experimentally manipulated (thereby excluding testing of multiple hypotheses), and there was a sharp contrast between results from short and small-scale experimental studies and those from larger-scale, longer-duration observational studies. Especially worrisome is the variability in the inferred qualitative form (negative or positive) of the relationship between dreissenids and algae, not only between experimental and observational studies, but even within observational studies.

Management Component

The goal of this work was to review the management recommendations from the 2007–2009 Priority Cycle in an adaptive management context as part of the nearshore framework. Exploring management options in an adaptive management context for this portion of the work plan required coupling the causal structure identified through analysis of the weight of evidence from the FCM analysis in the scientific component of the work plan with the evidence for effectiveness of the management actions identified in prior work. The NHAWG created a Wiki (URL: http://Commission.org/rel/nhawg) for sharing knowledge about phosphorus management practices in the Great Lakes and for evaluating the effectiveness of these practices.

The NHAWG was not able to achieve this goal. Although the NHAWG considers the Wiki to be a dynamic document that requires participation of the wider scientific and management community of the Great Lakes, there are three major obstacles to achieving the Work Group goals:

1. The rationales for the "no-regrets" management strategies identified by the Eutrophication Work Group in the 2007–2009 Priority Cycle are distributed through a variety of sources (scientific literature, conference proceedings, agency publications, and opinions of experts from professional associations), some peer-reviewed but the majority non-peer-reviewed reports. With contractor support, the NHAWG documented sources of most, but not all of the previous set of "no-regrets" strategies and provided those in the Work Group Wiki. Since the majority of the agriculture-related "no-regrets" management strategies were written to be as general as possible without losing meaning at different scales of implementation, it would have been impossible to find a specific reference for such management strategies especially in the current scientific literature. Many of these multi-source broadly written "no-regrets" agricultural management recommendations were drawn from cumulative knowledge, based on both agro-economic scientific literature sources as well as agro environmental studies. For the most part, most if not all of these sources did not provide evidence of effectiveness of the strategies to reduce phosphorus loading for the purpose of controlling algal blooms from agricultural sources, since the goal of agricultural nutrient management recommendations are written to control farm field loss of crop nutrients and to reduce the risk of broad ecological off-site impacts on water quality from farm operations. Thus it is not surprising that the NHAWG found weak evidentiary support for the recommendations, especially those written in a way that would allow broad use by various types of agriculture in the Great Lakes basin.
2. Weak weight of evidence for the causal structure and weak evidence about the effectiveness and scales of implementation of management strategies do not permit ranking management actions relative to their effects on phosphorus load reductions or on nuisance algal growth in the Great Lakes.
3. Without well founded hypotheses about the consequences of management strategies, it is not possible to prioritize "no-regrets" management strategies either for their information value in improving understanding of the causal structure of the current set of nuisance algal problems or to justify their widespread implementation. However, some of these recommendations represent "best practice" in support of sustainable agriculture, and farmers in the basin would be well advised to follow those recommendations consistent with existing best practices.

Although the NHAWG could not prioritize management actions in an adaptive management context, the Wiki should continue as a repository of documentation for management actions. It is especially important for Great Lakes managers and researchers to add and update resources in the Wiki to address the effects of the implementation of man agement actions on nuisance algae problems and on the contribution to nutrient loading.

Communication Component

As stated earlier, previous work of the Eutrophication Work Group in the 2007–2009 Priority Cycle included explorations on how the Commission and collaborating agencies should best communicate the re-emergence of eutrophication in the lower Great Lakes to the public and other stakeholders, given the scientific uncertainty in the cause and potential solutions to eutrophication. Some of the communication challenges concern the contributing roles and responsibilities of industry, municipalities and residents to the eutrophication issue in the Great Lakes basin, as well as the identification of key messages and who is best suited to deliver such messages.


James B. Hyde

The residents of shoreline communities play an important role in the sustainability of the Great Lakes via their role as "citizen scientists" or sentinels of ecological change. Algal fouling of a shoreline is an unwelcome change for residents of waterfront communities, but they do not often know how to effect change towards restoring the water body to what they once enjoyed. They are also unaware of the role they may have played in contributing to the problem. As individual households and collectively as shoreline communities, normal residential household activities can have a negative impact on waters of the Great Lakes from landscaping activities and by choice of detergent products in the home (dishwasher and washing machine detergents and personal care products). The Commission recognizes that success in reducing phosphorus loading in the Great Lakes is dependent, in part, on changing environmentally harmful household resident activities to those that are not harmful to water quality (14th Biennial Report). For this reason, the NHAWG chose to explore the use of Community-Based Social Marketing (CBSM) as a tool to develop strategies to change environmentally harmful residential behaviours that contribute to eutrophication. Local communities along the Lake Huron shoreline were used as a pilot project.

Key messaging by scientists to raise awareness about the importance of the Great Lakes can influence people's behaviour over the short term, but it is not enough to effect long-term change to new environmentally sustainable behaviours. CBSM

"Key messaging by scientists to raise awareness about the importance of the Great Lakes can influence people's behavior over the short term, but it is not enough to effect long-term change to new environmentally sustainable behaviors."

identifies and designs strategies to overcome barriers to the adoption of desired environmental behaviours and to foster their long-term adoption. Since the solution to eutrophication has a local component (phosphorus loading varies by lake and by location), CBSM research includes interviewing residents from each locality to identify barriers to adoption of desired behaviours to ensure that behaviour change strategies are tailored to the unique human and natural environmental characteristics of a geographic area.

The Work Group engaged a contractor to conduct a combination of qualitative-quantitative research (surveys and focus groups) in the communities of Grand Bend and Port Franks, both located in Lambton County, along the south east shore of Lake Huron. The purpose of this research was to determine the range of activities in which shoreline residents are engaging that contribute phosphorus to the nearshore area and what their understanding or knowledge is of the role of fertilizers and phosphorus detergents in causing poor water quality. The analysis of this research was used to identify how changing specific residential phosphorus loading behaviours of area residents could be encouraged through a CBSM campaign. The eventual outcome of this work would be to determine how reductions in phosphorus loading from residential households and long-term sustainable contributions may result in improvement of Lake Huron water quality. The types of residential behaviours explored included using non-phosphorus or organic lawn fertilizers and keeping septic systems in good working order (maintenance and inspection).

Overall observations found that Lake Huron and its water quality are important to residents but there is a disconnect between what people do in their homes in terms of property maintenance and understanding how these activities can be directly linked to the water quality of the lake. Therefore, basic knowledge or awareness about the role of fertilizers and phosphorus on water quality is a significant barrier to changing residential behaviours and activities. Another knowledge barrier or misunderstanding was the belief that poor water quality is the result of poor performance of wastewater treatment facilities, the agricultural sector and government regulators, and not contributed to by the actions of individuals.

"Overall observations found that Lake Huron and its water quality are important to residents but there is a disconnect between what people do in their homes in terms of property maintenance and understanding how these activities can be directly linked to the water quality of the lake."

The research also identified a combination of CBSM tools (educational materials, personalized communication, commitments, prompts, incentives) that would be useful to address three specific residential behaviours affecting phosphorus loading: use of non-phosphorus fertilizer, inspection and maintenance of septic systems, and fix leaking septic systems. Pilot testing of the recommended CBSM tools to determine the effectiveness of each strategy and the most cost effective method of delivering the strategies was recommended.

Advancing CBSM strategies and integrating CBSM principles into programming to address undesirable behaviours affecting the Great Lakes will provide a proven technique to move a community toward more sustainable environmental behaviours. Qualitative and quantitative evidence of the likely effects of CBSM initiatives can be measured through pre- and post-monitoring forms of evaluation.

RECOMMENDATIONS

The Work Group developed the following recommendations:

1. The Parties undertake a coordinated, basin-wide observational study to quantify the relationship of *Cladophora* biomass and specific attributes of the physical, chemical and biological environment, including purported drivers such as light, water temperature, nutrient concentrations, nutrient status of *Cladophora*, and dreissenid biomass in order to confirm and quantify causal linkages and thereby improve and validate existing *Cladophora* growth models.
2. In combination with Recommendation 1, the Parties undertake a geographically replicated, in-situ mesocosm factorial Before-After Control-Impact (BACI) study in which the hypothesized physical and chemical drivers of algal growth are independently manipulated. Such a design would provide strong empirical evidence of the relative importance of these different factors.
3. The Commission design, establish and maintain an on-line database of published studies that would allow for continuous evaluation of the scientific weight of evidence associated with different hypotheses about the causes and consequences of the nuisance algae problem in the lower Great Lakes.
4. Continue using the Wiki to document effectiveness of "no-regrets" management actions and encourage use of the precautionary principle. For the agricultural sector, there are a number of agri-environmental management recommendations widely recognized as effective in reducing various types of pollutants such as sediment, nitrogen and phosphorus. The pollutant reduction efficiency for many of these recommendations is starting to appear in the literature and can help direct site-specific remediation on a farm or sub-watershed basis or help target management actions in the most critical "source areas" of phosphorus at a basin scale.

   For managing farm non-point sources of phosphorus, three general "no-regrets" actions are:

   - promote nutrient management planning, education and awareness of both economic and environmental aspects of nutrient use;
   - promote nutrient management focusing on the 4Rs of nutrient management: right product, right rate, right time, and right place; and,
   - promote soil and water conservation best management practices to keep phosphorus in the soil, on the field, and out of surface waters.

   For managing farm point sources of phosphorus, three general "no-regrets" actions are:

   - promote phosphorus reduction at source through changes to livestock feeding practices;
   - promote nutrient storage on farms to contain liquid and solid nutrients to prevent potential risk of runoff; and,
   - promote on-site treatment of wastewater where economically and environmentally feasible, that is wetlands and vegetated filter strips.

5. Implement pilot testing of Community-Based Social Marketing communication to determine the effectiveness of methods altering behaviours of shoreline residents with respect to phosphorus loading. Advancing the CBSM strategies and integrating CBSM principles into programming to address undesirable behaviours affecting the Great Lakes will provide a proven technique to move a community toward more sustainable environmental behaviours.

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

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 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.”

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

Non-point pollution: Enters rivers and lakes from diffuse sources, *e.g.* agricultural and urban run-off and combined sewer overflows.

Oligotrophication: The process of nutrient depletion, or reduction in rates of nutrient cycling, in aquatic ecosystems. This condition occurs 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: A nutrient required by all organisms for the basic processes of life. It is a natural element found in rocks, soil and organic material and occurs in several forms. The most important use of phosphorus is in the production of fertilizer. It is also widely used in pesticides and detergents and is a component in all municipal and some industrial wastewaters. High water quality is generally low in phosphorus. 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). Several forms of phosphorus can be measured in a water sample. Total phosphorus is a measure of all the forms of phosphorus, dissolved or particulate. Soluble reactive phosphorus is the form of dissolved or soluble phosphorus most readily used by plants.

Point-source 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.

Appendix

All supporting technical documents for this report are available at: http://ijc.org/rel/nhawg/index.php

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