Developing indicators of ecosystem health

P. Bertram[1], C. Forst[2], P. Horvatin[3]

[1]U.S. Environmental Protection Agency, Great Lakes National Program Office, 77 W. Jackson Blvd., Chicago, IL 60604. bertram.paul@epa.gov
[2]Oak Ridge Institute for Science and Education, on appointment to U.S. Environmental Protection Agency, Great Lakes National Program Office, 77 W. Jackson Blvd., Chicago, IL 60604
[3]U.S. Environmental Protection Agency, Great Lakes National Program Office, 77 W. Jackson Blvd., Chicago, IL

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Introduction

Over the past several decades, human and societal pressures have unequivocally induced global environmental degradation and disruption to a degree that now requires assessment, intervention, and remediation. In the Great Lakes basin alone, abuses such as cultural eutrophication, chemical contamination, overfishing, habitat destruction, and the introduction of non-native species represent just some of the problems that affect both ecosystem function and human health (Bertram et al., 2003a). Assessing the condition of the Great Lakes basin ecosystem is extremely important, yet it is a monumental challenge. The Great Lakes contain one-fifth of the world's liquid fresh water and they provide drinking water, food, recreational opportunities and other support services to about 33.5 million people across two nations, eight states, two provinces, and hundreds of local and municipal communities (Government of Canada and US EPA, 1995). Lake Michigan, the second largest Great Lake by volume, supports about 10 million people in its basin, including Milwaukee and Chicago, the third largest city in the United States.

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Periodic evaluation of the components of the Great Lakes ecosystem remains vital for making informed decisions about environmental management activities, measuring progress toward restoration goals, documenting successes or failures of specific management efforts, and guiding future environmental programs. How is such a task attempted? The process is navigated by the acceptance of a consistent and common framework of Great Lakes basin ecosystem indicators among all parties involved, including government and non-government organizations, industry, academia, and the public (Bertram et al., 2003a). An indicator is a piece of evidence or signal that reflects the state of conditions being measured. It is a gauge or clue that reveals insight about a large system by examining one smaller aspect of it. A group, or suite, of indicators can work together to reveal environmental and ecosystem trends in large systems over time. Indicators of Great Lakes ecosystem components have been derived through processes associated with the State of the Lakes Ecosystem Conferences (SOLEC). Additional indicators specifically for the Lake Michigan ecosystem have also been developed though activities supporting the Lakewide Management Plan.

Great Lakes Water Quality Agreement

The Great Lakes Water Quality Agreement (GLWQA) is a framework and guide for sound Great Lakes management (U.S. and Canada, 1987). First signed in 1972 by the governments of Canada and the United States, the GLWQA contains some of the most important and definitive goals for the Great Lakes ecosystem. The Agreement is not a formal treaty between the two countries, but it is specifically referenced in the U.S. Clean Water Act and is thereby part of the U.S. Code. The main purpose of the GLWQA is to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem. The Agreement's original intent was to reduce phosphorus loadings to the Great Lakes, and a revision to the Agreement in 1978 specified, among other changes, annual maximum target loadings of phosphorus for each of the five lakes. The agreement was amended again in 1987, this time to reflect an emphasis on a more holistic, ecosystem based approach to Great Lakes water quality problems, including addressing issues of toxic contamination, control, and elimination, and the creation of specific plans for the assessment, implementation and management of each of the Great Lakes.

Lakewide Management Plans, or "LaMPs", were established to address critical pollutants and other stresses to each lake and their connecting channels. Similarly, Remedial Action Plans, or RAPs, were developed for each designated Area of Concern (AoC), of which there are currently 41 around the Great Lakes. Two

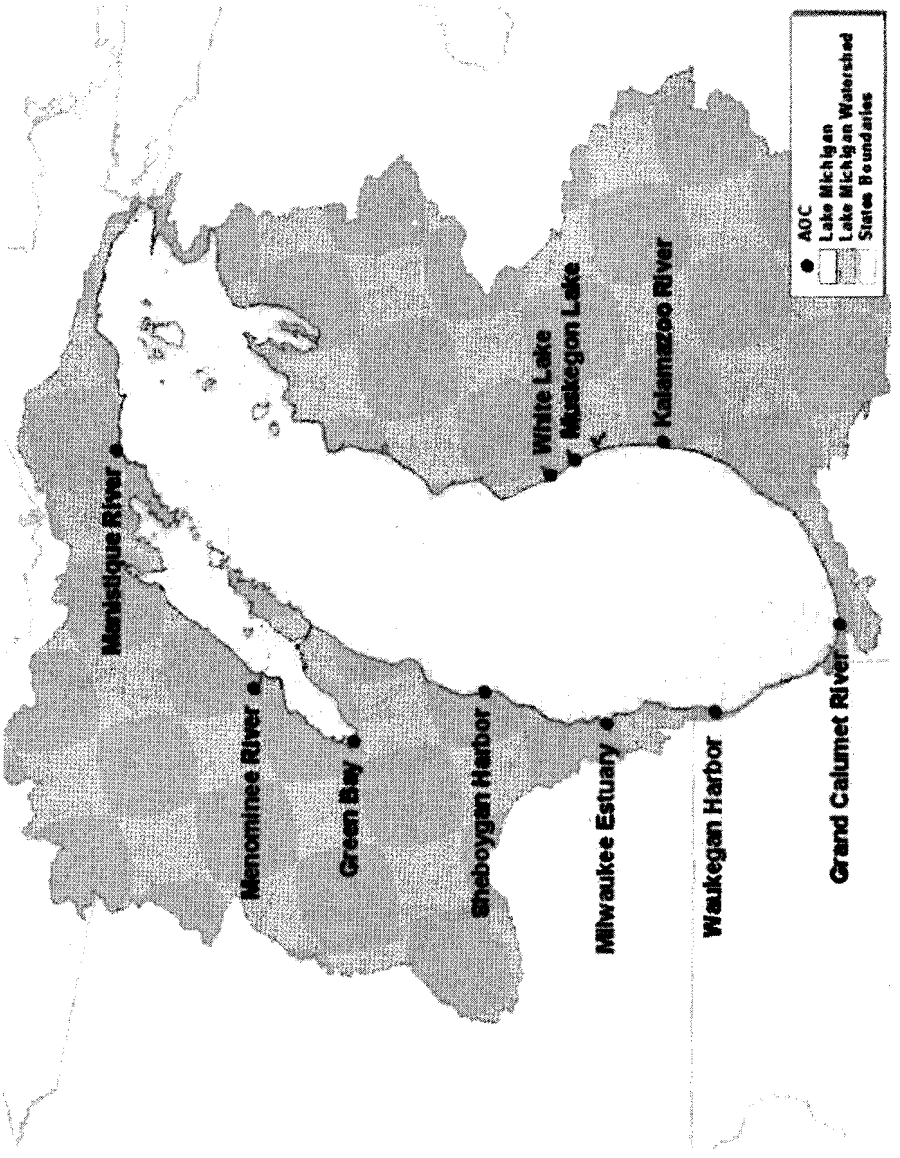

Fig. 1. Locations of Lake Michigan Areas of Concern.

additional sites have been remediated and "de-listed" and clean-up activities have been completed at another. Ten of the AoCs are within the Lake Michigan basin (Figure 1). The Areas of Concern focus priorities on a smaller scale for specific problems, and much of the remedial activities occur at the local level. When looked at collectively for an entire lake or for the entire basin, however, they reveal a more general assessment of ecosystem health. The GLWQA also presents the concept of Beneficial Use Impairments and lists fourteen specific ecosystem impairments for consideration by each of the LaMPs and RAPs. Examples include bird or animal deformities, restrictions on fish consumption due to accumulated contaminants, beach closings and loss of fish and wildlife habitat. The Agreement further stipulates the need for ecosystem objectives to be developed for each of the Great Lakes, and for associated indicators to be identified in order to measure progress toward the objectives. The GLWQA also stresses the importance of maintaining a monitoring system for the evaluation, observation and the collection of standardized measurements. This will ensure a scientific system for assessing effectiveness of remedial programs and management strategies, and for identifying emerging issues and progress toward meeting objectives (U.S. and Canada, 1987). Finally, the Agreement calls for the governments of Canada and the United States to report every two years on the progress achieved in accordance with established goals.

SOLEC

One of the primary venues used for fulfilling the mandated reporting requirements of the GLWQA is the "State of the Lakes Ecosystems Conference" (SOLEC). Held every two years to evaluate the conditions of Great Lakes ecosystem components in relation to corresponding goals and objectives, the conferences are a scientifically-based, collaborative product of the governments of Canada and the United States, other federal, state, provincial and local government agencies, environmental groups, industry, and the public (Bertram et al., 2003b). At the conclusion of each conference, the information and assessments that have been researched and reviewed are compiled into the comprehensive State of the Great Lakes report (Canada and the U.S., 2001, 2003), which provides a written, documented response to the GLWQA's biennial question: What is the current status of the Great Lakes Basin ecosystem?

The conference and the State of the Great Lakes report are important to and intended for environmental managers, decision makers, senior administrators and the public. They are part of an ongoing process that provides a framework to integrate many Great Lakes environmental programs. Four main objectives have been declared for SOLEC:

- *To assess the state of the Great Lakes ecosystem based on accepted indicators.* Reporting on a suite of Great Lakes indicators facilitates a rational, disciplined approach toward assessing the various components of the Great Lakes ecosystem and reporting the findings.
- *To strengthen decision making and environmental management concerning the Great Lakes.* Indicator assessments provide information and interpretations that are useful to those who make decisions or who influence environmental management practices, whether they are in government, industry, environmental groups or private practice.
- *To inform local decision-makers of Great Lakes environmental issues.* This objective emphasizes the importance of participation by local government and organizations.
- *To provide a forum for communication and networking among all the Great Lakes stakeholders.* Great Lakes stakeholders include representatives from federal governments, state and provincial governments, local governments, First Nations and Native American Tribes, non-government environmental organizations, industry, academia, and private citizens.

To achieve these objectives, SOLEC organizers recognize several key underlying principles regarding Great Lakes governance and environmental management. Of primary importance is the understanding that the information in the State of the Great Lakes reports represents the combined, official voices of the governments of Canada and the United States, and that the assessments on the state of the ecosystem must be useful to environmental managers and decision makers at all levels of government, as well as to the general public. The importance of partnerships and collaboration to achieve the objectives cannot be overstated. The assessment of Great Lakes indicators is dependent on stakeholder contributions for much of the information that is derived from existing monitoring programs within the Great Lakes basin.

Great Lakes indicators

Indicators may be selected to reflect environmental conditions on a variety of scales in both space and time. From a satellite, one can obtain an image of the entire Great Lakes basin. From an airplane, one can view an entire lake or lake basin. From a canoe, one can view a single turtle. Indicators identified for the Great Lakes are intended to be generally applicable on a basin-wide or lake basin scale. Lake-by-lake differences may exist in endpoints or reference values for

some indicators, but the indicators themselves should be relevant across lakes. In addition, the indicators should reflect changes in conditions in the short, medium, and long-term.

To better facilitate assessments of key ecosystem components of the Great Lakes, indicators were originally developed within the categories of open and nearshore waters, coastal wetlands, nearshore terrestrial (land adjacent to the lakes), socio-economics/land use, human health, and stewardship. The themes could just as easily have been constructed around other ecosystem components, such as air, water and land, or around Great Lakes issues, such as nutrient enrichment, toxic contaminants, non-native species, and habitat availability. In some cases, the Great Lakes indicators have, in fact, been mapped to other groupings for ease of comparison (Bertram and Stadler-Salt, 2000). Although these generalized themes provide valuable ways to categorize key ecosystem components, the organizing groupings are actually artificial constructs and should not be overly emphasized.

Due to time and resource constraints, some important ecosystem components were not fully explored during the initial identification of Great Lakes indicators. Examples include indicators for ground water, forests, inland surface waters and tributaries. These gaps and others will be addressed as personnel time and resources permit. The current suite of indicators, however, does include components of the natural resources of the Great Lakes basin ecosystem, the influence of the Great Lakes on human health, and societal values and activities related to the use and/or restoration of the Great Lakes.

Indicators for Lake Michigan

The Lake Michigan LaMP was developed to comply with the provisions in the GLWQA. Unlike the other four Great Lakes, Lake Michigan is completely contained within the border of the United States. The Clean Water Act holds the U.S. Environmental Protection Agency accountable for provisions of the GLWQA (U.S., 1987), and by inference the Lake Michigan LaMP (LMTCC, 2000). The development and implementation of the Plan, however, results from the collaboration of many contributors including federal, state, tribal, and local governments in the basin, as well as other important stakeholders. In essence, the document serves to guide the management practices and partnership activities of the lake in a way that will maximize achievement of ecosystem goals, as well as restoration of the 14 beneficial use impairments cited in the GLWQA. The lakewide management adaptive planning process includes identifying problems, scheduling reductions in the loadings of critical pollutants, establishing remedial and regulatory policies, and monitoring to determine the status of ecosystem impairments. These activities

work together to focus on critical pollutants and other stressors to the ecosystem, resulting in a comprehensive approach toward the environmental protection and natural resource management of Lake Michigan. After several years of intensive effort, which included published drafts and public comments, the Lake Michigan LaMP was released in 2000 (LMTCC, 2000), with updates scheduled every two years.

The goals of the Lake Michigan LaMP are based on principles of sustainability and integrity, remediation, and developing key partnerships, i.e., "to restore and protect the integrity of the Lake Michigan ecosystem through collaborative, place-based partnerships" (LMTCC, 2000). This goal supports the overarching vision to have "a sustainable Lake Michigan ecosystem that ensures environmental integrity and that supports and is supported by economically viable, healthy human communities." In addition, eleven supportive and clarifying "subgoals" exist, which identify endpoints and means to reach those endpoints (Table 1). The endpoint subgoals represent societal priorities for using the lake: drinking its water, eating its fish, and using it for recreational and economic activities. The subgoals associated with *how* to reach those endpoints focus on eliminating the factors that cause contamination while simultaneously increasing proactive efforts to reverse damage. The most reliable way to assess the progress toward reaching these goals is through the use of indicators.

The Lake Michigan LaMP has utilized and incorporated environmental indicators developed through the SOLEC process as well as adopting the Great Lakes indicator categorizations of nearshore and open waters, coastal wetlands, nearshore terrestrial, human health, land use, societal and unbounded. The indicators can also be interpreted and categorized according to another useful framework since some provide a valuable way to identify the pressures on the ecosystem, some reflect the state of the environment that results from that pressure, and others document the action taken by government agencies or the community in response to such changes (LMTCC, 2000). This "Pressure-State-Response" framework is a logical, organizational technique used by many respected workgroups, projects and organizations that rely on indicators, including the Lake Michigan LaMP. Table 2 lists indicators applicable to the assessment of Lake Michigan. Many of the indicators have been adopted through the SOLEC process, while some (identified in italics) were considered important for assessing Lake Michigan even though they were not included in the suite used for SOLEC reporting. Each indicator is associated with at least one LaMP subgoal, and it is designated as a pressure, state, or response indicator. Many of the indicators developed through the SOLEC process and/or proposed to assess Lake Michigan ecosystem components have not yet been fully implemented. In some cases the metrics or methodologies have

Table 1. Goals and Subgoals of the Lake Michigan Lakewide Management Plan.

To create a sustainable Lake Michigan ecosystem that ensures environmental integrity and that supports and is supported by economically viable, healthy human communities.	
End Point Subgoals:	
Subgoal 1	We can all eat any fish.
Subgoal 2	We can all drink the water.
Subgoal 3	We can all swim in the water.
Subgoal 4	All habitats are healthy, naturally diverse, and sufficient to sustain viable biological communities.
Subgoal 5	Public access to open space, shoreline, and natural areas is abundant and provides enhanced opportunities for human interaction with the Lake.
Subgoal 6	Land use, recreation, and economic activities are sustainable and support a healthy ecosystem.
Means to End Point Subgoals:	
Subgoal 7	Sediments, air, land, and water are not sources or pathways of contamination that affect the integrity of the ecosystem.
Subgoal 8	Exotic species are controlled and managed.
Subgoal 9	Ecosystem stewardship activities are common and undertaken by public and private organizations in communities around the basin.
Subgoal 10	Collaborative ecosystem management is the basis for decision-making in the Lake Michigan basin.
Subgoal 11	We have enough information/data/understanding/indicators to inform the decision-making process.

not been completely worked out, and in other cases appropriate monitoring programs do not exist.

Management implications

Because multiple jurisdictions are involved in monitoring and data collection in the Lake Michigan basin, data are maintained by a number of agencies. As the suite of indicators becomes more fully implemented, information management may become a challenge in order to assemble, analyze and summarize the information in relation to the stated LaMP goals and subgoals. To enhance coordination, communication, and data management among agencies and other organizations that conduct or benefit from monitoring efforts in the Lake Michigan basin, the

Table 2. Indicators for assessing the Lake Michigan basin ecosystem, with reference to Lake Michigan LaMP subgoals and to types of indicators. Indicators in *italics* are proposed for Lake Michigan, but are not part of the Great Lakes indicators identified through the SOLEC process. Associated Subgoals are listed in Table 1.

Indicator Name	Associated with LaMP Subgoal #	Indicator Type		
		State	Pressure	Response
Open and Nearshore Water Indicators				
Aquatic Habitat	4	x		
Lake Trout and Scud	4	x		
Salmon and Trout	4, 6	x		
Preyfish Populations	4, 8	x		
Phytoplankton populations	4, 8	x		
Zooplankton populations	4, 8	x		
Benthos diversity and abundance	4, 8	x		
Native Unionid Mussels	4, 8	x		
Sediment available for coastal nourishment	4	x		
Phosphorus concentrations and loadings	4, 7		x	
Toxic chemicals in offshore waters	1, 2, 4		x	
Concentrations of contaminants in sediment cores	1, 4, 7, 8		x	
Contaminant exchanges between media: air to water and water to sediment	2, 4, 7		x	
Contaminants in young-of-year spottail shiners	1, 4		x	
Contaminants in colonial nesting waterbirds	4		x	
Sea lamprey	4, 6, 8		x	
Sport fishing	6	x		
Sediment, land and water habitat	7	x		
Round goby	8		x	
Spiny water flea	8		x	
Zebra mussel	8		x	
Ship ballast water controls	8			x
Atmospheric deposition of toxic chemicals	1, 2, 4, 7		x	

Table 2. (contd..)

Indicator Name	Associated with LaMP Subgoal #	Indicator Type		
		State	Pressure	Response
Coastal Wetland Indicators				
Invertebrate Community Health	4	x		
Fish Community Health	4	x		
Amphibian diversity and abundance	4	x		
Wetland dependent bird diversity and abundance	4	x		
Wetland area by type	4, 6	x		
Gain in restored wetland area by type	4, 6	x		
Presence, abundance and expansion of invasive plants	4, 8	x		
Habitat adjacent to coastal wetlands	4	x		
Contaminants in snapping turtle eggs	4		x	
Sediment flowing into coastal wetlands	4, 7		x	
Water level fluctuations	4, 6		x	
Stream flow and sediment discharge	7			x
Deformities, **E**roded fins, **L**esions and **T**umors (DELT) in coastal wetland fish	1, 4	x		
DELT in nearshore fish	1, 4	x		
Nearshore Terrestrial Indicators				
Extent and quality of nearshore natural land cover	4, 6	x		
Area, quality and protection of lakeshore communities	4, 6	x		
Nearshore species diversity and stability	4	x		
Extent of hardened shoreline	4, 6		x	
Nearshore land use intensity	4, 6, 7		x	
Artificial coastal structures	4		x	
Nearshore plant and animal problem species	4		x	
Contaminants affecting productivity of bald eagles	4		x	
Contaminants affecting American otter	4, 7		x	

Table 2. (contd..)

Indicator Name	Associated with LaMP Subgoal #	Indicator Type		
		State	Pressure	Response
Community / Species Plans	4, 6, 8			x
Shoreline managed under integrated management plans	6, 7			x
Land Use Indicators				
Habitat fragmentation	4	x		
Land conversion	4, 5, 6, 7		x	
Mass transportation	4, 5, 6		x	
Green planning process	4, 5, 6, 10		x	x
Urban density	4, 5, 6, 7		x	x
Sustainable agricultural practices	2, 3, 4, 6, 7, 10			x
Brownfield redevelopment	4, 5, 6, 10		x	x
Ground level ozone	6, 7			x
Human Health Indicators				
Chemical contaminants in human tissue	1, 6		x	
Contaminants in edible fish tissue	1		x	
Contaminants in recreational fish	1		x	
Fish consumption advisories	1			x
Public perception: gauge awareness of fish safety	1			x
Incidents of boil-water advisories	2	x		
Incidents of water borne disease outbreak	2, 3	x		
Drinking water quality	2, 6		x	
Susceptibility (results from source water assessments)	2		x	
Wastewater pollution control	2, 3, 4		x	x
Source water protection plans	2			x
Escherichia coli and fecal coliform levels in nearshore recreational waters	2, 3, 6		x	

Table 2. (contd..)

Indicator Name	Associated with LaMP Subgoal #	Indicator Type		
		State	Pressure	Response
Beach closures	3			x
NPDES permits	3, 7			x
Air quality	6		x	
Public perception of safety of recreational resources	6			x
Contaminants in recreational fish	4		x	
Societal Indicators				
Aesthetics	4, 5, 6, 9	x		
Economic prosperity	4, 5, 6, 9	x		x
Capacities of sustainable landscape partnerships	4, 5, 6, 9			x
Organizational richness of sustainable landscape partnerships	4, 5, 6, 9			x
Citizen/Community place-based stewardship activities	4, 5, 9, 10			x
Financial resources allccated to Great Lakes programs	4, 5, 9, 10			x
Solid waste generation	4, 7		x	
Energy Consumption	4, 6		x	
Water consumption/withdrawl	4		x	
Integration of ecosystem management principles across landscapes	2, 3, 4, 5, 6, 9 10			x
Unbounded Indicators				
Atmospheric visibility	4	x		
Acid rain	4		x	
Climate change: number of extreme storms	4		x	
Climate change: first emergence of water lilies in coastal wetlands	4		x	
Climate change: ice duration on the great lakes	4		x	
Threatened species	4	x		
Breeding bird diversity and abundance	4, 6	x		

Lake Michigan Monitoring Coordinating Council was established. The Council members represent federal, state, tribal, and local governments, nonprofit watershed groups, and other environmental organizations, educational entities, and the regulated community. Working groups of the Council coordinate existing monitoring networks around several common considerations: monitoring objectives; spatial, temporal and parameter network design; methods comparability; quality assurance and control planning; database sharing; and data analysis approaches (LMTCC, 2002).

Given sufficient attention toward the quality of data collected, as well as the implementation of as many indicators as resources will allow, the use of environmental indicators should remain critical to environmental managers and decision-makers concerned with the Lake Michigan basin ecosystem. Indicators help to guide managers in the attainment of and progress toward the stated goals of the GLWQA, LaMPs, and AoCs. Moreover, indicators help to identify priority issues, prompt the allocation of resources to implement and maintain effective control programs, select and apply the most appropriate management tools for remediation, demonstrate the importance of diligence in monitoring, and emphasize the timely communication of existing problems and emerging issues (Canada and the U.S., 2001, 2003). Such early detection of impending problems allows appropriate management plans to be developed accordingly. Indicators also help managers to understand the ecological implications of their decisions or indecisions. Some of the managerial program areas that indicators support and elucidate include non-native species control, point and non-point source controls, atmospheric emissions, drinking water, technology development, infrastructure and maintenance (to reduce contaminant and nutrient loadings), restoration and protection programs, human population impacts, and climate change. As the use of indicators becomes increasingly expanded and refined, the resulting data and indicator reports will likewise play an increasingly important role among environmental managers, as well as wider audiences, to help make sound decisions leading toward the established goals for the Great Lakes.

Summary

The road to ecosystem health for Lake Michigan (and the Great Lakes as a whole) is a goal-oriented process that requires the cooperation of many stakeholders and governing agreements. The Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States guides much of the work in assessing ecosystem health, and establishes Lakewide Management Plans (LaMPs), Remedial Action Plans, Beneficial Use Impairments, ecosystem objectives, monitoring programs, reporting requirements, and indicator development and assessment. A reporting venue that fulfills one of the mandated requirements of

the GLWQA and almost exclusively employs the use of indicators is the bi-national State of the Lakes Ecosystem Conference (SOLEC), held every two years to evaluate the conditions of Great Lakes ecosystem components in relation to corresponding goals and objectives. The indicators are organized in categories that address (among other issues) natural resources, human health and societal values of the Great Lakes basin. The Lake Michigan LaMP has adopted goals and utilized the SOLEC indicator framework and organizational structure as well. It uses these indicators, in addition to its own established goals, to measure progress and guide management practices. The management of such an immense and variable ecosystem presents innumerable challenges, and the mandates of the GLWQA become extremely important in guiding management decisions, priorities and control programs.

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