Chapter 3:
Indicators and Monitoring of the Health of the Lake Michigan Ecosystem

This chapter outlines a set of environmental, social, and economic indicators that can be used to assess the achievement of the LaMP vision, goals and objectives. The chapter also describes a monitoring assessment project that analyzes the ability to measure indicators in the Lake Michigan basin. These indicators will allow Lake Michigan stakeholders to better gauge the status of the Lake Michigan ecosystem and guide the selection of management activities that will restore and protect the health of the system.

The list of Lake Michigan indicators included in this chapter is provided to help generate discussion and is based on previous work completed in support of the State of the Lakes Ecosystem Conferences (SOLEC), the International Joint Commission, Fish Community Objectives, the Great Lakes Fishery Commission, and others.

Environmental indicators are a measure of environmental condition such as ecological integrity, aquatic health, human health, or quality of life. Environmental indicators are a useful tool for identifying pressures on the ecosystem, the state of the environment due to these pressures, and the response or action taken by environmental agencies or other parties to address the environmental conditions and pressures.

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Chapter 3: Indicators and Monitoring of the Health of the Lake Michigan Ecosystem

3.1 About This Chapter

In the preceding chapters of this LaMP, the vision, objectives, and goals for the Lake Michigan ecosystem were defined. This chapter outlines a set of environmental, social, and economic measures that can be used to assess the achievement of those goals and objectives and discusses monitoring programs in the Lake Michigan basin. These measures, or indicators, will allow Lake Michigan stakeholders to better gauge the status of the Lake Michigan ecosystem and guide the selection of management activities that will restore and protect the health of the system.

The list of Lake Michigan indicators included in Table 3-1 of this chapter is provided to help generate discussion and ultimately achieve consensus about which environmental indicators should be monitored and reported in order to measure progress toward the vision and goals of the Lake Michigan LaMP, which includes the directive "*. . . to restore and maintain the chemical, physical, and biological integrity of the waters of the Lake Michigan Ecosystem*." This list of indicators is based on previous work completed in support of the State of the Lakes Ecosystem Conferences (SOLEC), the International Joint Commission, Fish Community Objectives, and others.

While some information and data are being collected to assess these indicators, most of these proposed indicators are yet to be fully characterized. Some of the indicator data and information collected to date are presented in Chapters 4 and 5. However, much work remains to apply these indicators in a way that will support Lake Michigan ecosystem management.

3.2 Environmental Indicators

The use of environmental indicators is not a new concept and has been recognized as a valuable tool needed to assist in the establishment of management recommendations. Environmental indicators are also a means to track both environmental improvement and environmental protection of the Lake Michigan ecosystem. State and federal agencies have tracked trends in certain environmental measures over time, such as fish populations. What has changed in the environmental indicator process is the growing need to link actual environmental condition responses directly to programs and other activities as defined and set forth by the Lake Michigan LaMP.

Environmental indicators are a measure of environmental condition such as ecological integrity, aquatic health, human health, or quality of life. Environmental indicators can measure trends over time in changes or nonchanges in environmental and ecological conditions. Environmental indicators can function as an early warning signal for identifying environmental concerns, and they are a valuable tool for measuring progress towards achieving of identified environmental goals. When properly developed and utilized, environmental indicators will affect improvements in environmental conditions, with clear linkages showing the effectiveness of programs or other activities to successfully control environmental stressors.

Environmental indicators are a useful tool for identifying pressures on the ecosystem, the state of the environment due to these pressures, and the response or action taken by environmental agencies or other parties to address the environmental conditions and pressures. This "Pressure-State-Response" approach

is also the organizing framework used by the National Goals Project, the State Environmental Goals and Indicators Project, the Interagency Sustainable Development Indicators Workgroup, and Region 5/State Watershed Indicators Development Workgroup. Regardless of how the Pressure-State-Response approach is organized, in order to be successful, it is absolutely necessary to select indicators that are measurable, can be monitored, and that link the pressures with the environmental conditions. Otherwise, it will be difficult or impossible to tell whether the changes in environmental trends are due to program activities or something else.

The key to picking and tracking sound and scientifically identifiable environmental indicators is to have clearly identifiable goals. As outlined in Chapter 2, The Lake Michigan LaMP has identified one main goal with 11 supporting subgoals. The first six subgoals have been identified as endpoints or the ultimate state to be achieved in the Lake Michigan ecosystem. Subgoals 7 through 11 are identified as means to achieving the first six subgoals. These subgoals must function together to define the full ecosystem state. By developing an appropriate mix of environmental indicators and performance measures, one can better evaluate environmental conditions, identify existing and emerging environmental problems, set environmental priorities, make program specific decisions and address the highest priorities. Tracking trends in environmental indicators can serve as a means of communicating environmental successes or failures to the public and stakeholders and can serve as a tool for identifying remaining or new challenges. The environmental indicator process is as dynamic as the lake itself, and a part of the implementation of the Lake Michigan LaMP may require that new indicators be developed over time.

A defined framework for the development and selection of environmental indicators will provide a common reference point for basin management and monitoring efforts. The Lake Michigan LaMP has followed the guidelines set forth in the EPA guidance document titled “Region 5 Guide for Developing Environmental Goals, Milestones, and Indicators” (See Appendix H). In conjunction with this guidance, the Lake Michigan LaMP has incorporated environmental indicators developed by SOLEC. In 1998, SOLEC developed a set of environmental indicators for the Great Lakes Basin. These environmental indicators are still undergoing refinement following public input. The Lake Michigan LaMP is adopting the eight defined areas as presented by SOLEC. These areas are Nearshore Waters, Open Waters, Coastal Wetlands, Nearshore Terrestrial, Human Health, Land Use, Societal Indicators, and Unbounded. Using the most recent SOLEC list of environmental indicators, Table 3-1 relates the SOLEC indicators to the 11 subgoals set forth by the Lake Michigan LaMP. Work will continue in the next 2 years to identify and select these or other environmental indicators that are specific to Lake Michigan’s 11 subgoals at the appropriate scale. Once selected, the indicators will be linked to specific human activities and LaMP management actions to establish the pressure-state-response linkage needed to track progress in implementing environmental management programs. Place holders for the LaMP measurement actions are included in Table 3-1. The indicator–subgoal matrix as set forth in the chart will be used for future additions.

Table 3-1. Environmental Indicators

SubGoal 1: We can all eat any fish

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Human Health	[Unspecified detrimental effects on human health from exposure to fish contaminants]	Contaminants in edible fish tissue	Fish consumption advisories	
	[Unspecified assessment of risk to human health inferred from environmental factors related to fish]	Contaminants in recreational fish	Public perception: gauge awareness of fish safety	
	Body burden: concentration of contaminants in human tissue	Contaminants in young-of-year spottail shiners		
		Toxic chemical concentrations in offshore waters		
		Concentrations of contaminants in sediments cores		
		Atmospheric deposition of toxic chemicals		
	Deformities, eroded fins, lesions and tumors (DELT) in nearshore fish			
	DELT in coastal wetlands fish			

Table 3-1. Environmental Indicators (Continued)

SubGoal 2: We can all drink the water

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Human Health	Incidents of boil-water advisories	Drinking water quality	Use of sustainable agricultural practices	
			Drinking water treatment needs	
	Incidents of water-borne disease outbreak	Toxic chemical concentrations in offshore waters	Use of sustainable agricultural practices	
			Wastewater pollution control	
			Integration of ecosystem management principles across landscapes	
		Atmospheric deposition of toxic chemicals		
		Contaminant exchange between media: air to water and water to sediment		
		E. coli and fecal coliform levels in nearshore recreational waters		
		Susceptibility (results from source water assessments)	Source water protection plans	

Table 3-1. Environmental Indicators (Continued)

SubGoal 3: We can all swim in the water

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Human Health	Incidents of water-borne disease outbreaks	*E. coli* and fecal coliform levels in nearshore recreational waters	Use of sustainable agricultural practices	
			Beach closures	
			Integration of ecosystem management principles across landscapes	
		Wastewater pollution	NPDES permits	
Nearshore Terrestrial Integrity	Extent and quality of nearshore natural land cover	Extent of hardened shoreline	Shoreline management under integrated management plans	
		Nearshore land use intensity	Community/species plans	
	Area, quality, and protection of special lakeshore communities		Shoreline management under integrated management plans	
			Protected nearshore areas	
		Artificial coastal structures	Shoreline management under integrated management plans	
		Urban density		
		Sediment available for coastal nourishment		

Table 3-1. Environmental Indicators (Continued)

SubGoal 4: All habitats are healthy, naturally diverse, and sufficient to sustain viable biological communities

Geographic Area	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Open and Nearshore Water	Aquatic Habitat	Phosphorus concentrations and loadings	Use of sustainable agricultural practices	
		Toxic chemicals in offshore waters	Use of sustainable agricultural practices	
		Concentrations of contaminants in sediment cores		
		Contaminant exchanges between media: air to water and water to sediment		
		Atmospheric deposition of toxic chemicals		
		Contaminants in young-of-year spottail shiners		
		Contaminants in colonial nesting waterbirds		
	Lake trout and scud	Sea lamprey		
	Salmon and trout	Sea lamprey		
	Preyfish populations			
	DELT in nearshore fish	Contaminants in recreational fish		
		Concentrations of contaminants in sediment cores		

Table 3-1. Environmental Indicators (Continued)

Geographic Area	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Open and Nearshore Water (continued)	Phytoplankton populations	Phosphorus concentrations and loadings	Use of sustainable agricultural practices	
	Zooplankton populations	Phosphorus concentrations and loadings	Use of sustainable agricultural practices	
	Benthos diversity and abundance	Concentrations of contaminants in sediment cores		
	Native Unionid mussels			
	Sediment available for coastal nourishment			
Coastal Wetlands	Invertebrate community health	Contaminants in snapping turtle eggs		
		Sediment flowing into coastal waters	Use of sustainable agricultural practices	
		Nitrates and total phosphorus into coastal waters	Use of sustainable agricultural practices	
		Water-level fluctuations		
	Fish community health	Contaminants in snapping turtle eggs		
		Sediment flowing into coastal waters	Use of sustainable agricultural practices	
		Nitrates and total phosphorus into coastal waters	Use of sustainable agricultural practices	
		Water-level fluctuations		
	DELT in coastal wetland fish	Contaminants in snapping turtle eggs		

Table 3-1. Environmental Indicators (Continued)

Geographic Area	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Coastal Wetlands (continued)	Amphibian diversity and abundance	Contaminants in snapping turtle eggs		
		Sediment flowing into coastal waters	Use of sustainable agricultural practices	
		Nitrates and total phosphorus into coastal waters	Use of sustainable agricultural practices	
		Water-level fluctuations		
	Wetland-dependent bird diversity and abundance	Sediment flowing into coastal waters	Use of sustainable agricultural practices	
		Nitrates and total phosphorus into coastal waters	Use of sustainable agricultural practices	
		Water-level fluctuations		
	Wetland area by type	Water-level fluctuations		
		Land conversion		
	Gain in restored wetland area by type	Water-level fluctuations		
		Land conversion	Use of sustainable agricultural practices	
	Presence, abundance and expansion of invasive plants	Water-level fluctuations		
	Habitat adjacent to coastal wetlands	Land conversion	Use of sustainable agricultural practices	

Table 3-1. Environmental Indicators (Continued)

Geographic Area	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Nearshore Terrestrial	Extent and quality of nearshore natural land cover	Extent of hardened shoreline	Shoreline management under integrated plans	
		Nearshore land use intensity	Community / species pans	
			Shoreline management under integrated plans	
			Protected nearshore areas	
		Artificial coastal structures	Shoreline management under integrated plans	
		Urban density		
		Land conversion		
	Area, quality, and protection of special lakeshore communities	Water-level fluctuations		
		Extent of hardened shoreline	Shoreline management under integrated plans	
		Nearshore land use intensity	Community / species pans	
			Shoreline management under integrated management plans	
			Protected nearshore areas	
			Shoreline management under integrated plans	

Table 3-1. Environmental Indicators (Continued)

Geographic Area	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Nearshore Terrestrial (Continued)	Area, quality, and protection of special lakeshore communities	Nearshore plant and wildlife problem species	Community / Species Plans	
	Nearshore species diversity and stability	Contaminants affecting productivity of bald eagles	Community / Species Plans	
		Contaminants affecting the american otter	Community / Species Plans	
	Sediment available for coastal nourishment			
Land Use	Breeding bird diversity and abundance	Land conversion		
	Habitat fragmentation	Land conversion		
	Threatened species	Land conversion		
	[Unspecified integrated measure of human impact on Great Lakes ecosystem structure and function]	Urban density		
		Mass transportation		
		Water consumption		
		Energy consumption		
		Wastewater pollution		
		Solid waste generation		
			Brownfield redevelopment	
			Green planning process	

Table 3-1. Environmental Indicators (Continued)

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Societal Indicators	Aesthetics			
	Economic prosperity			
	[Unspecified measure of societal capacity, willingness and commitment to stewardship]		Capacities of sustainable landscape partnerships	
			Organizational richness of sustainable landscape partnerships	
			Integration of ecosystem management principles across landscapes	
			Integration of sustainability principles across landscapes	
			Citizen/Community place-based stewardship activities	
			Financial resources allocated to Great Lakes programs	
Unbounded	Atmospheric visibility			
	[Unspecified ecosystem effects]	Acid rain		
		Global warming: number of extreme storms		
		Global warming: first emergence of water lilies in coastal wetlands		
Unbounded		Global warming: ice duration on the Great Lakes		

Table 3-1. Environmental Indicators (Continued)

SubGoal 5: Public access to open space, shoreline, and natural area is abundant and provides enhanced opportunities for human interaction with the Lake Michigan ecosystem

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Societal Indicators	Aesthetics			
	Economic prosperity			
	[Unspecified measure of societal capacity, willingness, and commitment to stewardship]		Capacities of sustainable landscape partnerships	
			Organizational richness of sustainable landscape partnerships	
			Integration of ecosystem management principles across landscapes	
			Citizen/Community place-based stewardship activities	
			Financial resources allocated to Great Lakes programs	
Land Use	[Unspecified integrated measure of human impact on Great Lakes ecosystem structure and function]	Urban density		
		Land conversion		
		Mass transportation		
			Brownfield redevelopment	
			Green planning process	

Table 3-1. Environmental Indicators (Continued)

SubGoal 6: Land use, recreation, and economic activities are sustainable and support a healthy environment

Geographic Area	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Open and Nearshore Water	Salmon and trout	Sea Lamprey		
	Sport fishing			
Coastal Wetlands	Gain in restored wetland area by type	Water level fluctuations		
		Land conversion	Use of sustainable agricultural practices	
	Wetland area by type	Water level fluctuations		
		Land conversion		
Nearshore Terrestrial	Area, quality, and protection of special lakeshore communities	Extent of hardened shoreline	Shoreline management under integrated plans	
		Nearshore land use intensity	Shoreline management under integrated plans	
			Community/Species plans	
	Extent and quality of nearshore natural land cover	Artificial coastal structures	Shoreline management under integrated plans	
Human Health	[Unspecified effects due to exposure]	Coliform levels of nearshore recreational waters	Public perception of safety of recreational resources	
		Chemical contaminants in fish tissue		
		Drinking water quality chemical and microbial		
		Air quality		
Land Use	Breeding bird diversity and abundance	Land conversion		
Issue	**State Indicator**	**Pressure Indicator**	**Human Activity Indicator**	**LaMP Management Action**
	[Unspecified integrated measure of human impact on Great Lakes ecosystem structure and function]	Urban density		

Table 3-1. Environmental Indicators (Continued)

		Land conversion	Use of sustainable agricultural practices	
		Mass transportation		
		Energy consumption		
			Brownfield redevelopment	
			Green planning process	
			Ground level ozone	
Societal Indicators	Aesthetics			
	Economic prosperity			
	[Unspecified measure of societal capacity, willingness and commitment to stewardship]		Capacities of sustainable landscape partnerships	
			Organizational richness of sustainable landscape partnerships	
			Integration of ecosystem management	
			Principles across landscapes	

Table 3-1. Environmental Indicators (Continued)

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Societal Indicators (Continued)			Integration of sustainability principles across landscapes	
			Citizen/community place-based stewardship activities	
			Financial resources allocated to Great Lakes programs	

Table 3-1. Environmental Indicators (Continued)

SubGoal 7: Sediment, air, land, and water are not sources or pathways of contamination that affect the integrity of the ecosystem				
Geographic Area	**State Indicator**	**Pressure Indicator**	**Human Activity Indicator**	**LaMP Management Action**
Open and Nearshore Water	Sediment, land, and water habitat	Phosphorous concentrations and loadings	NPDES permits	
		Atmospheric deposition of toxic chemicals		
		Concentration of contaminants in sediment		
		Contaminant exchanges between media: air to water and water to sediment		
Coastal Wetlands		Sediment flowing into coastal wetlands	NPDES permits	
		Nitrates and total phosphorous into coastal wetlands		
			Urban density	
			Land conversion	
			Stream flow and sediment discharge	
Nearshore Terrestrial		Nearshore land use intensity		
		Contaminants affecting the American Otter	Shoreline managed under integrated management plans	
			Use of sustainable agricultural practices	
			Ground level ozone	
			Wastewater pollution	
			Solid waste generation	

Table 3-1. Environmental Indicators (Continued)

SubGoal 8: Exotic species are controlled and managed

Geographic Area	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Open and Nearshore Water	Native unionid mussels	Sea lamprey	Ship ballast water controls	
	Preyfish populations	Round goby		
	Benthic communities	Concentrations of contaminants in sediment cores		
	Phytoplankton	Spiny water flea		
	Zooplankton	Zebra mussel		
Coastal Wetlands	Presence, abundance, and expansion of invasive plants			
Nearshore Terrestrial			Community/species plans	

Table 3-1. Environmental Indicators (Continued)

SubGoal 9: Ecosystem stewardship activities are common and undertaken by public and private organizations in communities around the basin

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Community health and well-being	Aesthetics			
	Economic prosperity			
Common stewardship activities	Integration of ecosystem management principles across landscapes		Capacities of sustainable landscape partners Organizational richness of sustainable landscape partners Integration of sustainability principles across landscapes Citizen/community place-based stewardship activities Financial resources allocated to Great Lakes programs	

Table 3-1. Environmental Indicators (Continued)

SubGoal 10: Collaborative ecosystem management is the basis for decision making in the Lake Michigan basin

Issue	State Indicator	Pressure Indicator	Human Activity Indicator	LaMP Management Action
Collaborative ecosystem management	Nearshore terrestrial development		Shoreline managed under integrated management plans	
	Basin-wide land use	Abandoned industrial sites	Brownfields redevelopment	
		Acreage in conservation tillage	Use of sustainable agricultural practices	
		Comprehensive land use planning	Green planning process	
	Commitment to collaborative ecosystem management		Integration of ecosystem management principles across landscapes Integration of sustainability principles across landscapes Citizen/community place-based stewardship activities Financial resources allocated to Great Lakes programs	

Table 3-1. Environmental Indicators (Continued)

SubGoal 11: We have enough information/data/understanding indicators to inform the decision-making process				
Issue	**State Indicator**	**Pressure Indicator**	**Human Activity Indicator**	**LaMP Management Action**

3.3 Monitoring in the Lake Michigan Basin

If the indicators outlined in the preceding section are to provide information to support future management decision-making, they must be adopted by Lake Michigan monitoring programs and guide the selection of parameters and media to be sampled and assessed. Numerous monitoring programs and activities are underway in the Lake Michigan basin. These programs monitor water quality, sediments, fish, air quality, and habitat. They involve collecting chemical, microbiological, fish and wildlife, physical characteristics, land use, and other environmental data. These programs exist at the federal, state, county, municipal, and watershed level.

The Lake Michigan Monitoring Coordination Council (LMMCC) was established jointly by federal, state, and tribal agencies to provide a forum for coordinating and supporting monitoring activities in the Lake Michigan basin and to develop a shared resource of information, based on accepted standards and protocols, that is useable across agency and jurisdictional boundaries. The LMMCC is currently analyzing data collected from an inventory of monitoring programs in the Lake Michigan basin.

This work is being supported through a cooperative agreement with the Great Lakes Commission, EPA Region 5, and other partners involved in the Lake Michigan LaMP process to assess existing monitoring efforts in the Lake Michigan basin and subwatersheds, including the 10 AOCs and four other tributary watersheds. The project will include a comprehensive review of monitoring programs at the federal, state, and local levels for the targeted watersheds; an analysis of gaps, inconsistencies, and unmet needs; an assessment of the adequacy of existing efforts to support critical ecosystem indicators; and a plan for addressing major monitoring needs, particularly those considered most important for lakewide management decision-making. The report will also be used to train members of the Lake Michigan Forum, Public Advisory Councils, and other stakeholders to determine current, local monitoring efforts and establish community-based monitoring programs.

The project and report are consistent with the ecosystem approach of the LaMPs and RAPs especially with regard to emphasis on community involvement and participation. Monitoring will be viewed in the broadest sense, including not only traditional water quality parameters, but also habitat, wildlife, land use, nonpoint source pollution and other measures of ecosystem health. The report and future project outcomes are expected to provide stakeholders with important tools for developing RAPs and will enable them to engage their community in a valuable dialogue regarding the status of knowledge on their local watershed. Working closely with the states and tribes, stakeholders will benefit from the exchange of information and the opportunity to enhance local participation in state-sponsored monitoring programs. Finally, the project is fully consistent with the EPA Region 5 emphasis on community-based environmental protection and will comply with the Government Performance and Review Act.

One of the main purposes of the LMMCC project is to determine whether the current monitoring coverage is sufficient to support indicators proposed in the Lake Michigan LaMP. The findings and understanding gained through this project will be applied to each of the indicators, and a simple assessment will be made of each. The findings will include a list of each relevant open water, near shore, human health, land use, and coastal wetlands indicator, with a rating of the ability of the current monitoring infrastructure to provide sufficient data to assess the indicator. The project results will be released in the summer of 2000.

Mass Balance Approach

The questions confronting managers responsible for the Great Lakes are complex and regulatory action (or inaction) may have major social and economic consequences. It has become evident that rational approaches must be found to: address the issues; more clearly identify and quantify problems; locate and quantify sources of important chemicals; quantify rates of principal physical, chemical, and biological processes that control behavior of chemicals in the environment; and predict future conditions under alternative remedial actions to arrive at optimal programs. To help manage environmental quality and solve existing problems, a scientifically-based management framework has been implemented and prototyped within the Great Lakes community of managers and scientists referred to as the "Mass Balance Approach." EPA, led by the Great Lakes National Program Office (GLNPO), conducted and intensive study of Green Bay (Lake Michigan), the Green Bay Mass Balance Study.

The Green Bay Mass Balance Study was conducted as a pilot study to test the feasibility of using a mass balance approach for the assessment of sources and fates of toxic pollutants in the Great Lakes ecosystem. It was intended to validate and refine monitoring and analytical assumptions made by the coordinating agencies, and to rigorously test the models. Specific objectives included:

1. Assessing the technical and economic feasibility of the mass balance approach for use in the management of pollutant loadings and impacts on Great Lakes ecosystems.

2. Calibrating the mass balance model for sources, transport routes, and fates of pollutants in the Great Lakes ecosystem.

3. Identifying the major sources of selected pollutants entering the Green Bay ecosystem and rank their relative significance.

4. Demonstrating methods and priorities for further studies of toxic pollutants in the Great Lakes.

The Office of Research and Development played an important role in this study and provided leadership and resources for several aspects, most importantly in leading the development of the scientific tools, including mathematical models, to assess the data and develop forecasts of expected water, sediment and food web concentrations under alternative courses of action.

Lake Michigan Mass Balance Study

The mass balance approach, demonstrated in the Green Bay Mass Balance Study, provided a consistent framework for integrating load estimates, ambient monitoring data, process research efforts, and modeling, leading to the development of scientifically credible, predictive cause-effect tools. Building on the experience of this project, the EPA GLNPO initiated a mass balance approach, the Lake Michigan Mass Balance Project (LMMB), to provide a coherent, ecosystem-based evaluation of toxics in all of Lake Michigan. The primary goal of the LMMB study was to develop a sound, scientific base of information to guide future toxics load reduction efforts for Lake Michigan at the state and federal levels. The LMMB study is discussed further in Chapter 5.

Monitoring Information

The mass balance project was based on the Enhanced Monitoring Program, a comprehensive, 1.6-year synoptic survey for selected toxic chemicals in the Lake Michigan ecosystem. In support of the mass balance study, the Environmental Research Laboratory Duluth Large Lakes Research Station in cooperation with the Atmospheric Research and Exposure Assessment Laboratory, the U.S. National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory, and other cooperations, developed a suite of integrated mass balance models to simulate the transport, fate and bioaccumulation of toxic chemicals in Lake Michigan.

Field sampling for the project covered the period from April, 1994 through October, 1995, and included the following:

Tributaries - eleven Lake Michigan tributaries were monitored intensively to determine the loads of the subject compounds to the lake. Sampling frequency varied from 12 to 45 samples per tributary in a year long period.

Atmosphere - nine sites were monitored to determine atmospheric loads to Lake Michigan. Additional field activities, part of the Great Waters Study, provided data to help determine the net atmospheric load. Additional atmospheric samples were taken during each Lake Guardian survey.

Sediment - one hundred and thirty-one sediment sampling sites ere targeted for sampling, with the majority in sediment depositional zones. Surface sediment segments from box core samples were analyzed for contaminants to determine the sediment contaminant inventory (available for resuspension and contaminant release to the water column). Additional studies will determine contaminants in sediment trap materials, and erodibility of sediment (resuspension).

In summary, over 38,000 samples were collected with more than 1 million result data points. The results of this effort are presented in Chapter 5: Lake Michigan Stressor Sources and Loads, but, it is only the beginning. The effective use of the mass balance tool will require coordinated and continued monitoring on a basin-wide scale, thus the importance of the LMMCC and the actions presented in Chapter 6 to support its mission.

Table 3-2 provides an illustration of more detailed indicators that may be developed as this process evolves. The Great Lakes Fishery Commission developed Table 3-2 to illustrate the type of specific information that could be collected to monitor and assess portions of the Lake Michigan ecosystem.

Table 3-2. Lake Michigan Indicators

Ecological Criteria and Beneficial Use Impairments	Objectives / Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish community structure and function	To restore and maintain the biological integrity of the fish community so that production of desirable fish is sustainable and ecologically efficient.				
	Salmonines: Maintain a diverse salmonine community consisting of both wild and planted fish, and capable of sustaining an annual harvest of 6 to 15 million pounds, of which 20 to 25% is lake trout.	Standing stock (biomass) of salmonines.	A predicted standing stock of salmonines ranging from about 21 to 58 million pounds (Lake Michigan Salmonine Stocking Task Group, 1998, CONNECT model).	Based upon historical yields of native lake trout, a range in catch of about 5.7 to 7.3 million pounds annually is considered to be a minimum measure of the lake's capacity to yield salmonines; the theoretical maximum yield has been estimated at about 15.4 million pounds (*Fish Community Objectives for Lake Michigan*, Eshenroder et al, 1995, GLFC).	Current standing stock biomass of salmonines is thought to be about 65 million pounds (Salmonine Stocking Task Group, 1998. CONNECT model).
	Establish self-sustaining lake trout populations.	Percentage of unmarked lake trout in assessment and sport catches.	The percentage of unmarked lake trout in assessment and sport catches is increasing towards 100% (all stocked lake trout are marked).	The percentage of unmarked lake trout in lakewide assessment catches has ranged from 0 to 8.8% since the mid-1980s without an apparent trend.	No recruitment from natural reproduction is occurring and the lake trout population is comprised entirely of stocked fish.

Table 3-2. Lake Michigan Indicators (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives / Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish community structure and function (continued)	Enhance natural reproduction of coho and chinook salmon, and rainbow and brown trout.	Proportion of unmarked salmon and trout in assessment and sport catches (a known portion of each species must be marked prior to release).	Stable or increasing numbers of naturally-produced fish from each species.	Naturally-produced chinook comprised an estimated 32% of the 1990-93 cohorts in Michigan waters; naturally-produced coho comprised an estimated 9.3% of the 1979 lakewide sport catch; naturally-produced rainbow trout (steelhead) comprised 6 to 18% of annual smolt production in Michigan streams in the 1980s.	Coho and chinook salmon, rainbow and brown trout are naturally-reproducing in some watersheds tributary to the lake. The Michigan DNR has estimated that from 2.2 to 2.7 million chinook smolts have been produced annually in the 1990s as compared to 0.6 to 0.8 million in the 1970s (Salmonine Stocking Task Group, 1998).
Fish community structure and function	Planktivores: Maintain a diversity of prey species at population levels matched to primary production and to predator demands; expectations are for a lakewide planktivore (alewife, smelt and bloater) biomass of 1.2 to 1.7 billion pounds.	Lakewide biomass estimates of alewife, smelt and bloater.	Alewife, smelt and bloater in varying proportions constitute the bulk of the prey fish biomass; biomass size-spectrum models suggest that a total biomass of planktivores amounting to 1.2 to 1.7 billion pounds is a reasonable range for Lake Michigan (*Fish Community Objectives for Lake Michigan*, Eshenroder et al, 1995, GLFC).	Lakewide planktivore biomass estimates (portion of population available to bottom trawls) since 1973 have increased from .14 to .88 billion pounds as the dominant planktivore shifted from alewife to bloater (USGS-BRD); catches in bottom trawls represent only a portion of preyfish biomass and will therefore always be lower than the actual biomass.	The 1996 lakewide planktivore biomass estimate was .65 billion pounds from bottom trawls (Note: studies are needed to understand how shifts in species composition affect biomass estimates, and the relationship between trawl catches and total biomass).

Table 3-2. Lake Michigan Indicators (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives / Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish community structure and function (continued)	Inshore fishes: Maintain self-sustaining stocks of yellow perch, walleye, smallmouth bass, esocids, catfish and panfish; expected annual yields are 2 to 4 million pounds for yellow perch and .2 to .4 million pounds for walleye.	Indices of relative abundance (CPUE).	CPUEs for yellow perch and walleye capable of sustaining the expected ranges of annual yield have not been calculated and must be derived from lakewide assessment data.	The Lake Michigan fishery management agencies are in the process of developing a lakewide assessment plan which will include yellow perch and walleye, as well as other inshore species.	Self-sustaining populations of all these species exist, however, the relative abundance of yellow perch declined an estimated 90% in the southern portion of the lake from 1990 to 1996.
	Benthivores: Maintain self-sustaining stocks of lake whitefish, round whitefish, sturgeon, suckers and carp; expected annual yield of lake whitefish is 4 to 6 million pounds.	Indices of relative abundance (CPUE).	CPUEs for lake whitefish capable of sustaining the expected range of annual yield have not been calculated and must be derived from lakewide assessment data.	The Lake Michigan fishery management agencies are in the process of developing a lakewide assessment plan which will include lake whitefish, as well as other benthivores.	Self-sustaining populations of all these species exist, however, the lake sturgeon and longnose sucker are still listed as protected within the basin.
	Maintain a self-sustaining burbot population compatible with the rehabilitation and self-sustainability of lake trout.	Relative abundance indices (CPUE).	A ratio of relative abundance of lake trout to burbot at about 3.5:1 in the southern portion of the lake and 1:1 in the northern portion.	Historical catches of native lake trout and burbot in small mesh gill nets fished lakewide for chubs by the vessel Fulmar (U.S. Bureau of Fisheries) in 1931-32 suggest mean ratios of 3.5 lake trout per burbot in southern waters and a 1 to 1 ratio in northern waters.	Current ratios have not been available from annual stock assessments but will be as the new lakewide assessment plan is implemented; studies comparing the catchability of these two species are needed to evaluate the reliability of using the proposed ratios.

Table 3-2. Lake Michigan Indicators (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives / Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish community structure and function (continued)	Other species: Protect and sustain a diverse community of native fishes including species such as cyprinids, gar, bowfin, brook trout, sculpins and others not previously mentioned.	Species richness.	A species is considered to be present in the lake if at least one individual (any life stage) is captured.	By 1970 five species of deepwater ciscoes had been extirpated from the lake as well as the paddlefish (*Fish Community Objectives for Lake Michigan*, Eshenroder et al, 1995, GLFC); lake herring and emerald shiner populations also have never recovered to their historical levels of abundance.	A total of 92 species are known to occur in the lake proper, of which 75 are native and 13 are naturalized (*Fish Community Objectives for Lake Michigan*, Eshenroder et al, 1995, GLFC).
	Sea lamprey: Suppress the sea lamprey to allow the achievement of other fish community objectives.	Wounding rates on lake trout.	A lakewide mean wounding rate not greater than 5 per 100 lake trout of all sizes.	The 1984-96 mean wounding rate was 4 per 100 trout, but has generally been increasing since 1987 (*Sea Lamprey Wounding of Lake Trout in Lake Michigan*, Ebener, 1997, GLFC).	The lakewide mean wounding rate was 5 per 100 lake trout in 1996.
Fish habitat	Protect and enhance fish habitat and rehabilitate degraded habitats, including historic riverine spawning and nursery areas for anadromous species.	Measure key features of the physical (substrate, water depth), chemical (dissolved oxygen, total phosphorus), and biological (vegetation) components of aquatic habitats.	A formal process such as the Classification and Inventory of Great Lakes Aquatic Habitats (CIGLAH) should be considered to classify and inventory habitats in the lake basin.	Inventories have been compiled on the general locations of many important fish spawning habitats in Lake Michigan (*Atlas of the Spawning and Nursery Areas of Great Lakes Fishes*, Vol.IV, Goodyear et al, 1982, USFWS), but specific locations, habitat characteristics (e.g. chemical and biological features), and current status has not been addressed but for a few spawning shoals for lake trout.	The classification, location, and status of important fish habitats in Lake Michigan has not been addressed in a comprehensive fashion.

Ecological Criteria and Beneficial Use Impairments	Objectives / Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Exotic species	Minimize the unintentional introduction of new exotic species and the spread of existing exotics that may negatively impact the structure and function of existing fish communities.	The appearance of new exotic species and the expansion in range (number of locations) of existing exotic species.	An exotic species is considered to be present in the lake or in a specific area if at least one individual of any life stage is captured.	Since the 1800s some 136 non-indigenous aquatic organisms have become established in the Great Lakes (*Exotic Species in the Great Lakes: A History of Biotic Crises and Anthropogenic Introductions*, Mills et al, 1991, GLFC); most of these have come from Europe (47%), the Atlantic Coast (18%), and Asia (14%), and the rate of introduction has increased as the rate of human activity has increased; more than one-third of the organisms have been introduced in the past 30 years, coincident with the opening of the St. Lawrence Seaway in 1959.	Although various ballast water and aquaculture control measures, and importation and possession bans (bait buckets, pet stores) have been implemented at the state, provincial and federal levels to address potential pathways for the unintentional introduction of exotic species, the appearance of new introductions and range expansion of existing exotics remains a constant threat, and a vigilant watch must be kept throughout Lake Michigan.

Table 3-3. Lake Michigan LaMP Summary Table (Chapter 3)

CHAPTER 2	CHAPTER 3				CHAPTER 6	
Lake Michigan LaMP: Vision, Goals and Ecosystem Objectives	**Indicators and Monitoring of the Health of the Lake Michigan Ecosystem**		**Chapter 4 Lake Michigan LaMP: Current Status of the Ecosystem, Beneficial Use Impairments and Human Health**	**Chapter 5 Lake Michigan Stressor Sources and Loads**	**Strategic Action Agenda: Next Steps**	
Endpoint Goal	**Monitoring**	**Human Activity**			**Means to an End Goal**	**Recommendations**
1. We can all eat any fish.	• Chemical contamination in fish • Site assessments • Eagle reproduction	• Fish advisories • Congressional reports on: - Great Water - Mercury - Dioxin				
2. We can all drink the water.	• Raw water quality data • Source water assessments	• Water utility notifications • Source water protection				
3. We can all swim in the water.	• E Coli levels in recreational water	• Beach closing advisories • State 305(b) WQ reports				
4. All habitats are healthy, naturally diverse and sufficient to sustain viable biological communities.	• Fish assessments • Bird Counts • Wetlands inventories and assessments • Stream flows • Eco-rich area assessments	• Endangered species list • Wetlands mitigation and protection • Zoning • Fish stocking • Fish refuges • USFWS refuges • Ballast water exchange • Dune protection • Eco-rich cluster map				
5. Public access to open space, shoreline and natural areas is abundant and provides enhanced opportunities for human interaction with the Lake Michigan ecosystem, aquatic habitat and biological population.	• Urban density • Coastal parks acreage • Conservation easements	• Open space funding and protection statutes • Coastal zone management				
6. Land use, recreation and economic activities are sustainable and support a healthy ecosystem.	• Contaminants in recreational fish • Sustainable forests • Land conversion	• Superfund cleanups, dredging • CRP percent of eligible farm lands • Brownfields to greenfields redevelopment				