Chapter 4:
Lake Michigan LaMP: Current Status of the Ecosystem, Beneficial Use Impairments, and Human Health

Chapter 4 describes the current status of the Lake Michigan ecosystem, including the Beneficial Use Impairments found at the ten Lake Michigan Areas of Concern and the status of wildlife and human populations in the basin. The Lake Michigan ecosystem includes the atmosphere, which serves as a significant pathway for contaminant load to the lake, and seven interrelated habitat types:

- Open water system;
- Coastal wetland system;
- Inland wetland system;
- Tributary system;
- Coastal shore system, and
- Lakeplain system
- Inland terrestrial system;

The chapter also describes the role Lake Michigan plays in the economic vitality of the basin.

Lake Michigan supports many beneficial uses: safe drinking water for 10 million; internationally significant habitat and natural features; food production and processing; fish for food, sport, and culture; and valuable commercial and recreational activities.

In the open waters of Lake Michigan, phosphorous and chlorophyll concentrations have decreased significantly since the late 1970s. However, chloride concentrations continue to increase and the rate of increase is accelerating. In the heavily-populated and industrial southern part of the basin, water quality is diminished. The leading stressors are urban in nature, including occasional backflows induced by combined sewer overflows, direct stormwater runoff, and industrial discharges. Throughout the basin, pollutant loads are derived from atmospheric deposition, legacy sources (contaminated groundwater and sediments), point source discharges, and nonpoint source runoff. The presence of toxic chemicals in the water and sediment continues to affect the health of fish and bird populations. Oil and gas drilling in the waters of the lake are banned due to a compact of the governors. However, slant or directional drilling from a land-based site to reach a specific target underwater up to 4,000 feet away is permitted.

The abundance and type of phytoplankton are highly variable within the lake. Changes to phytoplankton communities may occur as a result of exotic species predation and the unintentional introduction of non-indigenous algae. Increased salinity and other environmental changes may be enabling the introduced algae to adapt more readily to the environment at the lake.

Zooplankton populations may also be experiencing pressure as a result of the introduction of *Bythotrephes*, a Eurasian predator/cladoceran. Dramatic declines in *Daphnia* populations have coincided with increases in *Bythotrephes*. Benthic communities in the lake are also under pressure. Zebra mussels are having a significant impact on benthic community structures and plankton abundance. The rapid decline in amphipod (*Diporeia spp.*) populations in the southern end of the lake is linked to the introduction of zebra mussels and resulting competition for food. Because amphipods normally make up to 70 percent of the living biomass in a given area of a healthy lake bottom, their decline in Lake Michigan may affect a variety of fish species that depend heavily on them for food.

Fish communities represent the highest trophic levels within the Lake Michigan aquatic ecosystem. They are also the most visible indicators of the health of the ecosystem and represent, to most people, one of the most important resources of the lake. The alteration of fish communities has been the most obvious impairment to the aquatic ecosystem in Lake Michigan. The current status of the fish community is dependent upon human management by the various agencies responsible for the fisheries of Lake Michigan.

Overall, multiple stressors continue to degrade the open lake system. Toxic chemicals contaminate water and sediment quality. Fish advisories are still in effect. Beaches, particularly in the southern part of the lake, are closed episodically. Aquatic habitats do not sustain healthy and diverse fish communities. Exotic species continue to disrupt native plant and animal communities.

Millions of acres of inland wetlands have been lost in the Lake Michigan basin to agriculture, industry and urban development over the last century. Wetland losses in the four states at least partially within the Lake Michigan basin have been disproportionately greater than in many other U.S. regions. Since the 1780s, Lake Michigan basin states have lost an estimated 21.9 million (62.9 percent) acres of wetlands out of their 34.8 million original wetland acres. This compares with an average loss of 52.8 percent nationwide. There are an estimated 12.9 million acres of wetland remaining in the four states, representing more than 12.3 percent of the wetlands within the lower 48 states.

Multiple stressors continue to degrade the Lake Michigan coastal wetland system. Non-indigenous invasive species such as purple loosestrife are still largely uncontrolled despite chemical, physical and biological attempts to eradicate. The sediments from tributaries that nourish coastal wetlands do not contain woody debris needed by some habitats. Fast flowing tributaries deposit too much sediment and bury submergent and emergent aquatic plants.

The quality of many rivers in the Lake Michigan basin has been significantly impaired due to channelization, dredging, damming, sedimentation, loss of bankside vegetation, eutrophication, increased spring flooding, and toxic contamination. Large areas of inland forests and wetlands that once served to regulate the quantity and quality of water flowing into tributaries have been lost. As a result, tributaries pass on their pollutant and sediment loads to the lake and their suitability as spawning habitat has been seriously impaired. Pollution from agriculture, industry and urban development has polluted rivers and contaminated sediments. The result is the contamination of fish and wildlife that depend on river habitats. Many rivers, particularly at the rivermouths, have been declared Areas of Concern and have impaired beneficial uses.

Lake Michigan is home to the largest collection of freshwater dunes in the world, but uncontrolled land uses are threatening the dunes and other important coastal resources. Cities sprawling into adjacent open spaces as well as recreational home development is increasing on the Lake Michigan coast and islands. In addition, invasive non-native species are beginning to impact dune areas. Key protection needs include developing inventories of significant biodiversity areas and establishing monitoring programs for rare and threatened plants and animals. Mining of sand for use in industrial processes, continued shoreline bordering to prevent erosion of private properties, longshore sand transport disruption by jetties and other structures, invasive species introductions, and an increase in off-road dune use is altering the coastal shore system and reducing its ability to function.

The Lake Michigan basin is home for many species of mammals, birds, reptiles and amphibians. It is also a resting and feeding place for several species of migratory birds. Land use changes from industrial development, residential development, shoreline modifications, and navigation have dramatically and permanently altered Lake Michigan basin habitat available for wildlife.

Even though residents of the Lake Michigan basin are exposed to toxic substances from many sources originating within and outside the basin, the main route of human exposure to contaminants from the waters of Lake Michigan is ingestion of fish. Although there have been sporadic outbreaks of illness related to the use of drinking water, the drinking water in the Lake Michigan basin is of good quality.

At this time, the Lake Michigan ecosystem is an outstanding natural resource of global significance that is under stress and in need of special attention. Although efforts have been made to remediate damage, particularly in the area of chemical pollution at legacy sites, human impacts to the ecosystem are continuing to impair its function. Toxic air deposition and nonpoint source pollution are still problems. Fish advisories remain in effect. In some areas, drinking water supplies are susceptible to contamination. Some Lake Michigan beaches are closed periodically due to high bacteria counts. Unique habitats are fragmented by poor land use practices, including uncontrolled development. Contaminated sediments threaten nearshore waters and wildlife. Many exotic aquatic nuisance species have not been prevented from entering the ecosystem nor controlled once established.

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Chapter 4:
Lake Michigan LaMP: Current Status of the Ecosystem, Beneficial Use Impairments, and Human Health

4.1 About This Chapter

An ecosystem is defined as "An interconnected community of living things, including humans and the physical environment with which they interact. As such, ecosystems form cornerstones of sustainable economies." (Federal Interagency Ecosystem Management Task Force 1995)

This chapter presents information about the status of the Lake Michigan ecosystem. Section 4.2 describes the health of the ecosystem; the status of the major habitats in the basin, and the historical context for assessment in terms of geology, climate, plants, animals, and human settlement. Section 4.3 summarizes the impacts observed in the lake ecosystem and introduces management activities that are further discussed in Chapter 6. Section 4.4 concludes with a general description of the lake ecosystem status.

Appendix G contains facts and figures about land uses, Areas of Concern, and Areas of Stewardship in the Lake Michigan basin.

4.2 Current Status of the Lake Michigan Ecosystem

The boundaries of the Lake Michigan ecosystem are generally described as the Lake Michigan watershed, the land area that delivers runoff water, sediment, and dissolved substances by way of rivers and groundwater to the lake. The watershed boundary alone, however, is not sufficient to characterize the entire Lake Michigan ecosystem. The airshed, which extends beyond the watershed boundaries, is also part of the Lake Michigan ecosystem. In addition, land and water shipping brings goods from all over the world into the region. Ship ballast water or wooden pallets may bring unwanted exotic species that impact the natural Lake Michigan ecosystem.

Complex ecological processes link organisms and their environment in the Lake Michigan ecosystem. The products of these processes are often referred to as "ecological services" because they perform functions that work together to sustain life in the Lake Michigan basin. Nutrient cycling, carbon cycling, predation, and primary productivity are examples of ecological services. Ecological processes are embedded in ecological systems. The ecological systems of Lake Michigan (and of the Great Lakes basin) include open lake, coastal wetland, inland wetland, tributaries, coastal shore, lakeplain, and inland terrestrial. They overlap and intermingle in terms of boundaries and functions. Plants and animals may need one or several of these systems for habitat in the course of their life cycles (The Nature Conservancy 1994).

The ecosystem, through fully functioning ecological systems, provides the services and the resources necessary to sustain life. Humans are an integral part of the Lake Michigan ecosystem. Humans use the resources, sometimes reducing the capacity of the ecosystem to provide these resources in the future. Humans also act as stewards of the ecosystem, recognizing the necessity of protecting the services and resources to maintain a good quality of life. Thus, the Lake Michigan ecosystem is not a "closed" ecosystem. It is subject to natural and human influences both inside and outside of natural watershed boundaries.

The overall status of the Lake Michigan ecosystem is derived from an assessment of the health of the ecological systems in conjunction with the degree to which humans act sustainably to protect the services and resources provided by the ecosystem. This assessment addresses all areas of the basin: aquatic, atmospheric, terrestrial, and human health.

The following subsections summarize the status of the key components of the Lake Michigan ecosystem. Section 4.2.1 describes the Lake Michigan airshed and its importance to the Lake Michigan system. Section 4.2.2 describes and assesses specific aquatic and terrestrial habitat types in the Lake Michigan ecosystem in greater detail. Section 4.2.3 addresses the status of wildlife communities in the basin and the role that humans play in the ecosystem. Section 4.2.4 describes human systems in the basin and our interactions with the Lake Michigan ecosystem. Finally, Section 4.2.5 describes the role Lake Michigan plays in the economic vitality of the region.

Beneficial Use Impairments in the Areas of Concern

Areas of Concern (AOC) are severely degraded geographic areas where beneficial uses--activities that are dependent on the chemical, physical and biological integrity of the water--are threatened or impaired. Restrictions on fish and wildlife consumption, loss of fish and wildlife habitat and beach closings are examples of the 14 beneficial use impairments identified under the Great Lakes Water Quality Agreement. Throughout this chapter, the AOCs will be discussed as examples of the status of the Lake Michigan ecosystem. This introductory discussion provides a general overview of the AOC.

Of the 42 AOCs in the Great Lakes basin, ten are in the Lake Michigan basin: Manistique River, White Lake, Muskegon Lake and the Kalamazoo River in Michigan; the Grand Calumet River in Indiana; Waukegan River in Illinois; and Milwaukee Estuary, Sheboygan River, Fox River/Southern Green Bay, and Menominee River in Wisconsin and Michigan. Descriptions of each of the AOCs are included in Appendix F. All 14 beneficial uses are impaired at one or more of the AOCs. Remedial Action Plans (RAPs) are being developed in each AOC. The Waukegan Harbor AOC is working toward delisting. PCB contaminated sediments have been removed from the harbor.

Contaminants and Use Impairments in the Lake Michigan Areas of Concern

Area of Concern	Use Impairments	Media	Contaminants
Manistique River	- Restriction on fish and wildlife consumption - Degradation of benthos - Restrictions on dredging activities - Beach closings - Loss of fish and wildlife habitat	Water	Heavy metals detected but below levels of concern.
		Sediment	PCBs, chromium, copper, lead, heavy metals (zinc, lead and cadmium), undecomposed sawdust, oil and grease
Menominee River	- Restriction on fish and wildlife consumption - Degraded fish and wildlife populations - Degradation of benthos - Restrictions on dredging activities - Beach closings - Loss of fish and wildlife habitat	Water	PAHs. Lead, cyanide, chromium, copper, mercury, and phosphorous are at detectable levels but below levels of concern.

Contaminants and Use Impairments in the Lake Michigan Areas of Concern (Continued)

Area of Concern	Use Impairments	Media	Contaminants
Menominee River		Sediment	Arsenic problem near Ansul. Mercury, PCBs, oil and grease, copper, zinc, lead, cyanide, cadmium, PAHs and chromium.
Lower Green Bay and Fox River	- Restriction on fish and wildlife consumption - Degradation of fish and wildlife populations - Bird or animal deformities or reproductive problems - Degradation of benthos - Restrictions on dredging activities - Eutrophication or undesirable algae - Restrictions on drinking water consumption or taste and odor problems - Beach closings - Degradation of aesthetics - Degradation of phytoplankton and zooplankton populations	Water	Phosphorous and suspended solids, PCBs, ammonia, pesticides, PAHs and volatile organics.
		Sediment	PCBs, PAHs, chlorinated phenols, ammonia, cadmium, mercury, chromium, nickel, copper, zinc, lead, pesticides, oil and grease.
Sheboygan River	- Restriction on fish and wildlife consumption - Degradation of fish and wildlife populations - Fish tumors or other deformities - Bird or animal deformities or reproductive problems - Degradation of benthos - Restrictions on dredging activities - Eutrophication or undesirable algae - Degradation of phytoplankton and zooplankton populations	Water	Phosphorous, heavy metals, PAHs, nitrogen and suspended solids.
		Sediment	PCBs, PAHs, lead, copper, and chromium

Contaminants and Use Impairments in the Lake Michigan Areas of Concern (Continued)

Area of Concern	Use Impairments	Media	Contaminants
Milwaukee Estuary	- Restriction on fish and wildlife consumption - Degradation of fish and wildlife populations - Fish tumors or other deformities - Bird or animal deformities or reproductive problems - Degradation of benthos - Restrictions on dredging activities - Eutrophication or undesirable algae - Beach closings - Degradation of aesthetics - Degradation of phytoplankton and zooplankton populations - Loss of fish and wildlife habitat	Water	Oil and grease, heavy metals, and dissolved oxygen
		Sediments	Mercury, cadmium, chromium, copper, lead, arsenic, zinc, PCBs, pesticides, PAHs, oil and grease, ammonia, phosphorous, and nitrogen.
Grand Calumet River and Indiana Harbor Ship Canal	- Restriction on fish and wildlife consumption - Tainting of fish and wildlife flavor - Degradation of fish and wildlife populations - Fish tumors or other deformities - Bird or animal deformities or reproductive problems - Degradation of benthos - Restrictions on dredging activities - Eutrophication or undesirable algae - Restrictions on drinking water consumption or taste and odor problems - Beach closings - Degradation of aesthetics - Added cost to agriculture or industry - Degradation of phytoplankton and zooplankton populations - Loss of fish and wildlife habitat	Water	PAHs, oil and grease, arsenic, ammonia, chlorides, cyanide and phosphorous.
		Sediments	PCBs, PAHs, phosphorous, nitrogen, iron, magnesium, volatile solids, oil and grease, mercury, cadmium, chromium, lead, naphthalene, benzo(a)pyrene, zinc, and fluoranthene.

Contaminants and Use Impairments in the Lake Michigan Areas of Concern (Continued)

Area of Concern	Use Impairments	Media	Contaminants
Waukegan	- Degradation of benthos - Restrictions on dredging activities - Beach closings - Degradation of phytoplankton and zooplankton populations - Loss of fish and wildlife habitat	Water	Total phosphorous, total ammonia, chloride, sulfates, cyanide, phenols, dissolved oxygen, pH and total dissolved solids.
		Sediment	PCBs, arsenic, barium, cadmium, chromium, copper, cyanide, iron, lead, manganese, nickel, phosphorous, Kjeldahl (estimate of organic-N) nitrogen, chemical oxygen demand and volatile solids.
Kalamazoo River	- Restriction on fish and wildlife consumption - Degradation of fish and wildlife populations - Bird or animal deformities or reproductive problems - Degradation of benthos - Restrictions on dredging activities - Loss of fish and wildlife habitat - Beach closings - Degradation of aesthetics	Water	PCBs, nonpoint source pollution (urban)
		Sediment	PCBs
Muskegon Lake	- Restriction on fish and wildlife consumption - Degradation of fish and wildlife populations - Restrictions on dredging activities - Eutrophication or undesirable algae - Restrictions on drinking water consumption or taste and odor problems - Degradation of aesthetics - Loss of fish and wildlife habitat	Water	Phosphorous, un-ionized ammonia, dissolved oxygen, pH, and total dissolved solids at levels below concern. Heavy metals, oil and grease, phosphorous, and nitrogen of concern in localized areas.
		Sediment	PCBs, mercury, lead and arsenic, cadmium, chromium, copper, nickel and zinc.

Contaminants and Use Impairments in the Lake Michigan Areas of Concern (Continued)

Area of Concern	Use Impairments	Media	Contaminants
White Lake	- Restriction on fish and wildlife consumption - Degradation of fish and wildlife populations - Degradation of benthos - Restrictions on dredging activities - Eutrophication or undesirable algae - Restrictions on drinking water consumption or taste and odor problems - Degradation of aesthetics - Loss of fish and wildlife habitat	Water	Phosphorous, heavy metals, chloride and nitrogen.
		Sediment	Chromium, lead, arsenic, cadmium, manganese, mercury, nickel, zinc, PCBs, oil and grease.

(Source: Lake Michigan Forum. (1996). Lake Michigan Areas of Concern, [Online] http://www.lkmichiganforum.org/areasofconcern.html [1999, Jan.])

4.2.1 Atmospheric Component of the Lake Michigan Ecosystem

The atmosphere is an important and sometimes dominant pathway for Lake Michigan stressors. The very nature of Lake Michigan contributes to the intensification of air quality related problems caused by the industrial and urban heartland surrounding the lower Lake. The Lake Michigan basin houses some of the largest concentrations of steel mills (lower Lake Michigan) and paper mills (Fox River Valley) in the world. In addition, the cumulative impacts of other human activities within the Lake Michigan basin (e.g. transportation, manufacturing, agriculture) impose further stresses on the ecosystem.

Water quality conditions in the Great Lakes are greatly improved compared to a few decades ago, as the result of environmental regulatory programs and public and industrial cleanup efforts addressing primarily waterborne pollution. However, despite the improvements, the Lake Michigan ecosystem is still recovering, and it is necessary to address the more diffuse sources of pollution, including the air component, in order to attain water quality goals and to ensure protection of human health and the environment.

4.2.1.1 The Atmosphere's Influence on Lake Michigan

The role of the air pollution as an important contributor to water pollution has long been recognized and, in recent years, has been the subject of growing scientific study and concern. Over the past 3 decades, scientists have collected a large and convincing body of evidence showing that toxic chemicals released into the air can travel long distances and be deposited on land or water at locations far from their original sources. Some of the early scientific studies of air deposition are described below:

- Studies of fish from Siskiwit Lake - a small lake on an island in northern Lake Superior that is isolated from most human influences - have shown contamination with PCBs, toxaphene, and other pesticides, which have no known sources on the island. Toxaphene, a pesticide banned in the U.S. in 1982, had limited use in the Lake Superior region but was used heavily in the southeastern U.S. Cotton Belt from the late 1960s to the mid-1970s. The use pattern implies that toxaphene was probably transported by air from the Southeast to the Great Lakes region. Airborne levels of toxaphene are highest in the southeastern U.S. and decline with distance as one moves toward the Great Lakes and north Atlantic regions.

- Air and rainfall in the Great Lakes region have repeatedly been shown to be contaminated with a variety of toxic chemicals. The Integrated Atmospheric Deposition Network (IADN) has monitored elevated levels of PCBs, PAHs, lead and a number of chlorinated pesticides in rainfall and the atmosphere since 1991 on each of the Great Lakes.

- A series of studies of Wisconsin lakes indicate that the air is a major contributor of mercury to these lakes and that modest increases in air deposition of mercury could lead directly to higher levels of mercury in fish.

- It is likely that other pesticides present in the Great Lakes, including DDT, are transported long distances by the air, from their sources to the Great Lakes region. Based on the amount and chemical form of DDT present in core samples from peat bogs in the Great Lakes region, new releases of DDT are apparent and may be originating from sources outside the U.S., possibly from Mexico and Central America. Atmospheric deposition of DDT, toxaphene, HCB, and PCB in the Great Lakes region, as measured in peat cores, are consistent with the U.S. production and use history of these chemicals.

These examples, along with many similar discoveries - including the much-studied phenomenon of acid rain - provide convincing evidence that long-distance atmospheric transport is an important global pathway for the distribution of some of the pollutants of concern. Perhaps most notably, it appears that PCBs and some other persistent pollutants, including several pesticides that have not been used in significant amounts in the U.S. since the 1970s, have become widely distributed in the environment and are now, in essence, part of the global "background." These toxic chemicals remain in our environment and continue to cycle between air, water, soil, and biota even after their manufacture, use, or release has stopped.

Although these studies have documented the importance of long-range transport for some pollutants of concern (e.g. PCBs and chlorinated pesticides), more recent ongoing studies point to influence of local sources, particularly nearby urban areas, on loadings to the Great Lakes. In order to quantify the total atmospheric load, it is important to consider both long-range and local sources. The relative importance of each source to the overall loading to the Great Lakes is variable depending on the pollutant and the Lake. For Lake Michigan, it is thought that the Chicago-Gary urban area contributes to the loadings of PCBs, PAHs and mercury to the entire lake.

4.2.1.2 Atmospheric Interaction Within the Lake Michigan Ecosystem

Transport distances depend on the characteristics of the chemicals and source emissions as well as weather patterns. Scientists have long recognized the basic processes by which air pollutants can enter rivers, lakes, and other waterbodies. The steps in this process are described below and illustrated in Figure 4-1 below.

- First, pollutants are *released* to the air from a source, which may be natural or anthropogenic. Anthropogenic sources include point sources, such as industrial smokestacks or any other fixed location that releases pollutants, area sources, such as pesticide applications on agricultural fields, and mobile sources, such as exhaust from automobiles. Natural sources include forest fires, volcanic eruptions, and windblown dust. Pollutants can be released as either gases or as particles.

- Second, pollutants released to the air are *transported* away from their source to other locations. Depending on weather conditions and the chemical and physical properties of the pollutant, air pollutants may be transported either short or long distances from their sources and may under physical and chemical changes while in transit.

- Third, air pollutants are *deposited* to the earth, in most cases directly to a waterbody or to a land area that drains into a waterbody. Pollutants are deposited by "wet deposition" or "dry deposition". In wet deposition, pollutants are removed from the air by a precipitation event such as rain or snow. Dry deposition occurs when particles settle out of the air and into water. Air pollutants can also enter a waterbody indirectly, by first depositing onto surrounding land or tributaries and then moving into the waterbody by other routes, such as stormwater runoff or inflow from tributary streams.

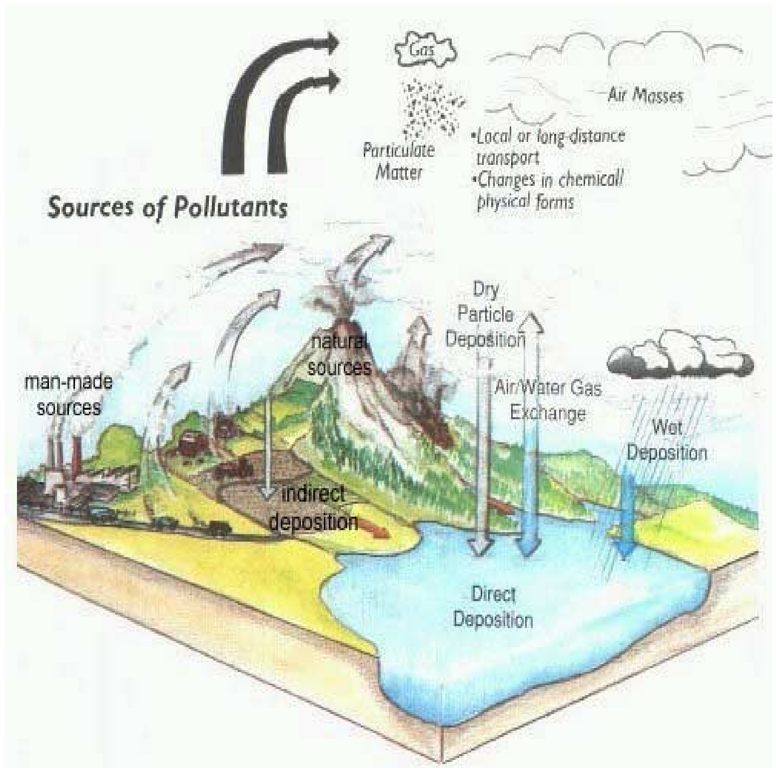


Figure 4-1. Atmospheric Sources of Pollutants

Source: EPA (www.epa.gov/owow/oceans/airdep/)

4.2.1.3 Current Status of Lake Michigan's Airshed

The Integrated Air Deposition Network (IADN) has collected data to support the following findings:

> "IADN shows that many of the measured persistent toxics are still being introduced to the Lakes from the atmosphere. Levels in air and precipitation appear stable for current-use pesticides such as endosulphan, but levels for most other pesticides, PCBs and lead are decreasing. Gas absorption appears to be the dominant deposition process for delivering semi-volatile compounds to Lake surfaces, while wet and dry deposition dominate for trace elements and heavier PAHs. For some IADN substances, like dieldrin and PCBs, the waters themselves are behaving like a source since the amount that is volatilizing from the water is greater than the amount being deposited to the water."

Although used in other parts of the world, many substances measured by IADN are no longer used in Canada or the United States. IADN data have shown that these substances are nonetheless transported through the air to the Great Lakes from areas where they are currently used, as well as from areas where they have not been used for many years but where residues still exist in soils. IADN data have also shown that the Great Lakes receive pollutants from local sources such as industry, agriculture, incineration, and automobiles and other combustion sources.

Chemical (year sampled)	Loading estimate to Lake Michigan (kg/yr)	Loading estimate to Lake Michigan (lb/yr)
PCBs (wet and dry)		
1988	400	880
1992	110	242
1994	69	152
1996	42	92
PCBs (net gas)		
1988	-5140	-11,308
1994	-2700	-5,940
DDT (wet and dry)		
1988	64	141
1992	25	55
1994	32	70
1996	12	26
DDT (net gas)		
1988	-480	-1.056
1994	67	147
B(a)P (wet and dry)		
1988	180	396
1992	84	185
1994	250	550
1996	117	257
Pb (wet and dry)		
1988	540,000	1,188,000
1992	26,000	57,200
1994	72,000	158,400
1996	na	na

Source: Integrated Air Deposition Network

Notes:

1) B(a)P may have been underestimated in 1992; thus over the 6 year period there is a general decline

2) "A recent study found that total wet and dry deposition for B(a)P was 50 times higher at an urban site (Chicago) than at the remote IADN site for Lake Michigan (SBD). The investigators concluded that these elevated PAH deposition rates are due to emissions from nearby urban areas. Although the total deposition of PAHs are lower in rural than urban sites, the relative amounts of individual PAHs (i.e., relative ratios of the individual PAHs) is very similar at urban and nonurban sites, suggesting that little chemical degradation occurs during transport of PAHs from urban source areas to rural and remote sites several hundred kilometers away.

3) Seasonal variations in deposition - wet and dry deposition of PCBs are similar over seasons, while net gas exchange is highly seasonal, exhibiting much greater effect with high temperatures; to date no seasonal variations have been published on PCB concentrations in water.

Furthermore, the Second Great Waters Report to Congress (pg. 104) found the following:
"...Recent research suggests that deposition of contaminated large particles carried by winds passing over urban areas can result in substantial inputs of toxic chemicals to the Great Lakes."

The influence of pollution from the Chicago-Northwest Indiana area on water quality in southern Lake Michigan was studied by Sweet and Basu (1994). The Sweet and Basu study compared data from one remote and two urban sites. The Sleeping Bear Dunes site (in the State of Michigan) is located one kilometer from the northeastern shore of Lake Michigan and 50 kilometers from the nearest urban area or major source and, thus, is considered a remote site. The first urban site is located 1.5 kilometers from the shore on the campus of the Illinois Institute of Technology, which is near major expressways and surrounded by commercial and residential areas. The second urban site is located at the Indiana Dunes National Lakeshore in the vicinity of large steel mills. Particulate concentrations were measured for target compounds (PCBs, pesticides and trace metals). Gas concentrations of PCBs and pesticides were determined, and rain was analyzed only for PCBs.

Results from Sweet and Basu indicate that for PCBs, DDT (and its metabolites), dieldrin, chlordane, and several trace metals (manganese, zinc, chromium, and lead), the measured particulate and gas concentrations values were 10 to 40 times higher in urban areas than at the remote site. For other pesticides (alpha-HCH, lindane, HCB) and trace metals (arsenic and selenium), concentrations were nearly the same at all three sites, indicating these pollutants were well mixed in the air throughout the region (and that there were probably few local sources).

Although 90 to 99 percent of the PCBs were found in the gas phase, the most toxic PCB congeners were enriched in the particulate phase. Thus, dry deposition may be an important transport mechanism for certain, especially toxic, PCBs to the lakes. Urban particulate matter also carried high concentrations of trace metals and pesticides, causing dry deposition of these materials in southern Lake Michigan. Dry deposition of large particles may be especially significant for Lake Michigan because 200 kilometers of the southwest shoreline are heavily developed. Prevailing southwest winds carry emissions over the lake where they travel for 100 to 150 kilometers before reaching land again, allowing a significant portion of deposition to enter the lake. Finally, the concentration of PCBs in precipitation is roughly the same in urban and rural sites.

Ozone levels associated with urban areas are also a continuing problem. Ozone causes oxidative damage to soft tissue in plants and animals. The impacts to animal species are largely via the respiratory tract. Impacts to plants are decreased growth due to damage to leaves and subsequent reduced photosynthetic activity. For the Lake Michigan ecosystem, the damages will be indirect. Decreased plant growth affecting terrestrial systems will affect the lake ecosystem only to the extent terrestrial systems interact with lake systems. These indirect effects are mostly the result of food chain issues.

The Lake Michigan air basin contains a number of generally contiguous ozone nonattainment areas including several major urban nonattainment areas (Chicago, Milwaukee, Northwest Indiana). The entire region is affected by ozone concentrations and ozone precursors that are generated and transported into the area. It is because of these meteorological characteristics that the ozone problem in the Lake Michigan area is considered to be a very broad geographic phenomenon.

Overall, the influence of urban areas on atmospheric deposition of certain pollutants to the Great Lakes is substantial, especially in heavily developed areas, such as the southwestern shores of Lake Michigan.

4.2.2 Status and Assessment of Lake Michigan Habitats

This section addresses the status of the basin ecosystem and is organized by habitat type. For the purposes of this section, "habitat" means that space that is or can be successfully occupied (inhabited) by a species or biotic community or some broader (taxonomic or phylogenetic) entity due to specific chemical, physical, and biological characteristics. Habitat is the place where an organism or group of closely related organisms lives. The goal of habitat preservation can only be described in terms of those biotic entities.

To facilitate this discussion, the complex web of habitat and subecosystem types found in the Lake Michigan ecosystem has been divided into the following seven categories:

- Open Water System
- Coastal Wetland System
- Inland Wetland System
- Tributary System
- Coastal Shore System
- Lakeplain System
- Inland Terrestrial System

In general, the natural distribution of habitat types within the Great Lakes depends on lake bed and shore topography, geology and climate.

The diverse forms of animals and plants associated with different habitats have received much attention, and is a reason, along with primary productivity, given for habitat preservation (Nature Conservancy 1994). For purposes of evaluating habitats in this section, two common measures of biological diversity have been separated for clarity's sake: richness or number of species and rarity.

Richness

One measure of biodiversity is the number of species or unique community types found within a habitat. A greater number of species, particularly endemic species, is generally an indicator of higher quality habitat. For example, as eutrophic and mesotrophic aquatic systems become degraded, species numbers often decrease.

However, the degradation of coldwater oligotrophic systems, such as the addition of nutrients to Lake Superior, generally results in an increase in the total number of species (Busiahn 1999). Consequently, species richness cannot be used as an absolute indicator of habitat quality, in the same manner that higher productivity is not always a sign of higher quality habitat. This phenomenon complicates the interpretation of trend data and comparisons among habitat types.

Nevertheless, the comparative species richness of habitats does give some indication of their value when combined with other information about the habitat. Recently, EPA began compiling data provided by partner organizations to begin identifying ecologically rich regions in the basin. Preliminary data are presented in Figure 4-2. These data are under review at the time of the LaMP release and will be updated. Further information is available at www.epa.gov/ecopage/err. Additional data will be needed on species richness in the various habitat types to begin to make meaningful comparisons.

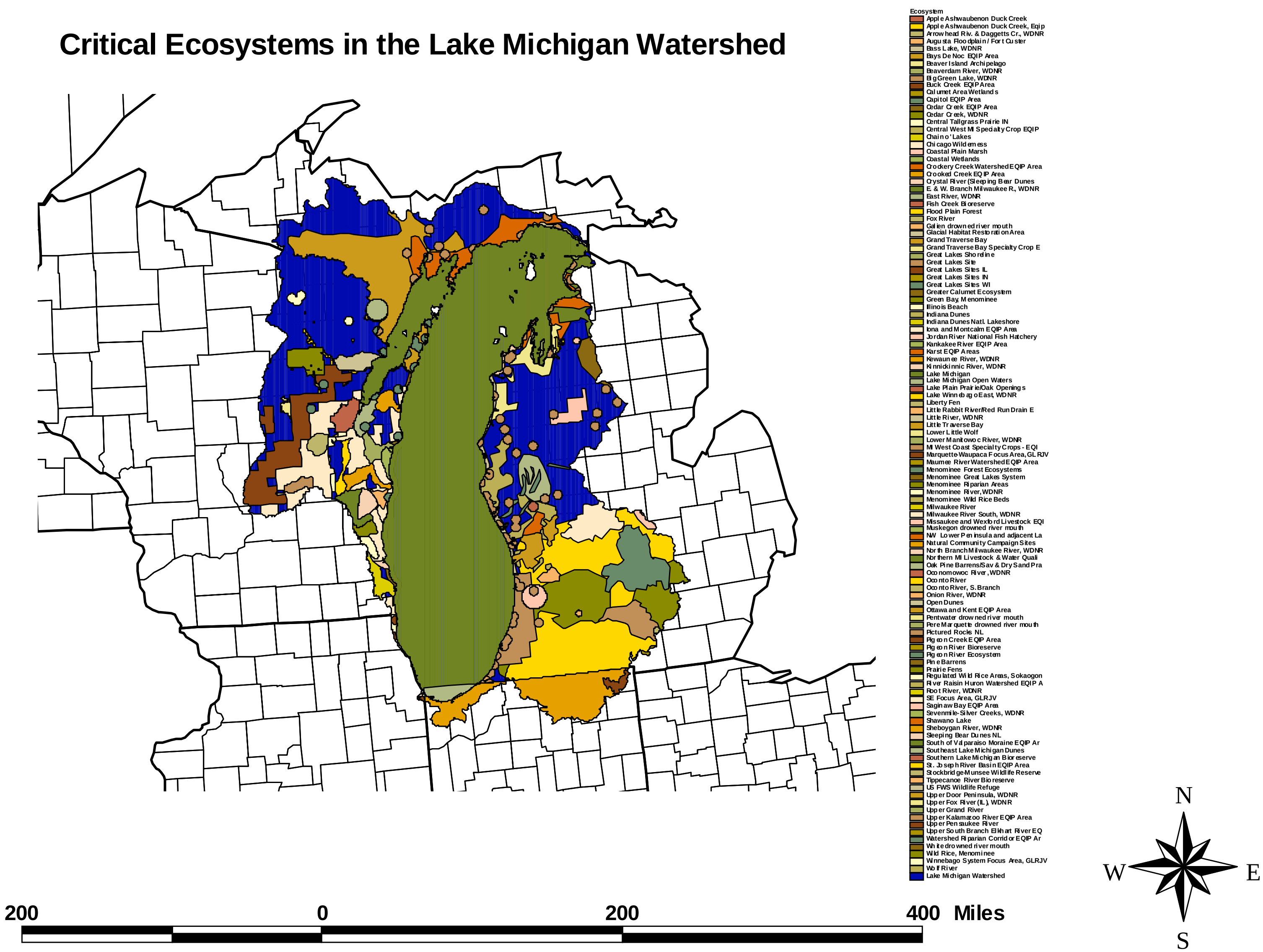


Figure 4-2. Critical Ecosystems in the Lake Michigan Watershed

Indicator Species and Rarity

Rare and endangered species often have very specific habitat needs. The number of rare species depending on a particular habitat type is a further indicator of habitat significance. Preserving species and community richness at the global level requires priority protection for habitats that host globally rare species. With regard to the Lake Michigan basin, it also means preserving the habitat of species that have become rare in the basin or in one or more of its subregions.

The U.S. Fish and Wildlife Service (1993) has compiled a list of 22 endangered and/or threatened species that are potentially affected by Great Lakes water quality. The county-level locations of several of these species are presented in Figure 4-3. Another 71 species in the Great Lakes watershed are candidates for designation as endangered or threatened species. A list of rare and imperiled elements compiled by the Nature Conservancy (1994) is especially useful because it shows what proportion of the rare and imperiled elements is found in each habitat type. The Nature Conservancy cites the network of state and provincial natural heritage programs which have identified 131 elements within the Great Lakes basin that are critically imperiled (22), imperiled (30), or rare (79) on a global basis. Of these globally significant elements, 31 are natural ecological community types; the rest are individual species, subspecies or varieties including 49 plants, 21 insects, 12 mollusks, nine fish, five birds, three reptiles and one mammal. In addition, 12 natural community types are recognized that, while not globally rare, form major components of the basin's landscape and support a wealth of biological diversity that is important to the basin's ecological integrity. The Nature Conservancy (1994) shows the distribution of species and communities that are found either exclusively or primarily in the basin, or have their best representation in the Great Lakes basin, among the ecological systems that support them. The Nature Conservancy data confirm that the coastal systems (marshes, shores and lakeplains) contain a disproportionate amount of the unique biodiversity of the Great Lakes. However, the Nature Conservancy's data tend to be weaker in wet environments compared to dry.

In isolation, rarity as an indicator of habitat value leads eventually to a view of preservation as masking the value of representative species in creating and maintaining a healthy ecosystem. Thus, rarity too, is better combined with other indicators to give a rounded view of the comparative value of any particular habitat. Rarity, reflected in state or provincial Natural Heritage inventories, used as one data source among several, and cast in the context of a broader analytical process, helps protect productive ecosystems rather than just rare species.

Healthy populations of diverse native species are one of the best indicators that habitats are of optimum quality. Accordingly, it may be simpler to monitor the health of selected indicator species rather than trading off difficult-to-compare criteria. By choosing a suite of species that require a broad range of high quality habitat types, it may be possible to read ecosystem health more accurately than measuring many attributes of different habitats in order to make comparisons that may be controversial. However, species populations are affected by other factors, such as disease, predation and harvest, that are not directly linked to habitat quality. Thus, using a small number of species as "canaries" for the habitat needs of most or all species will still require some level of complementary data gathering on habitat quality. Impacts limited to subtle changes in the lower trophic levels (e.g., relative composition of zooplankton species) while the top trophic level is relatively unaffected could be harbingers of more profound changes later on. Various governmental and nongovernmental programs are working together to develop such a coordinated monitoring effort (see Chapter 3, Section 3.3).

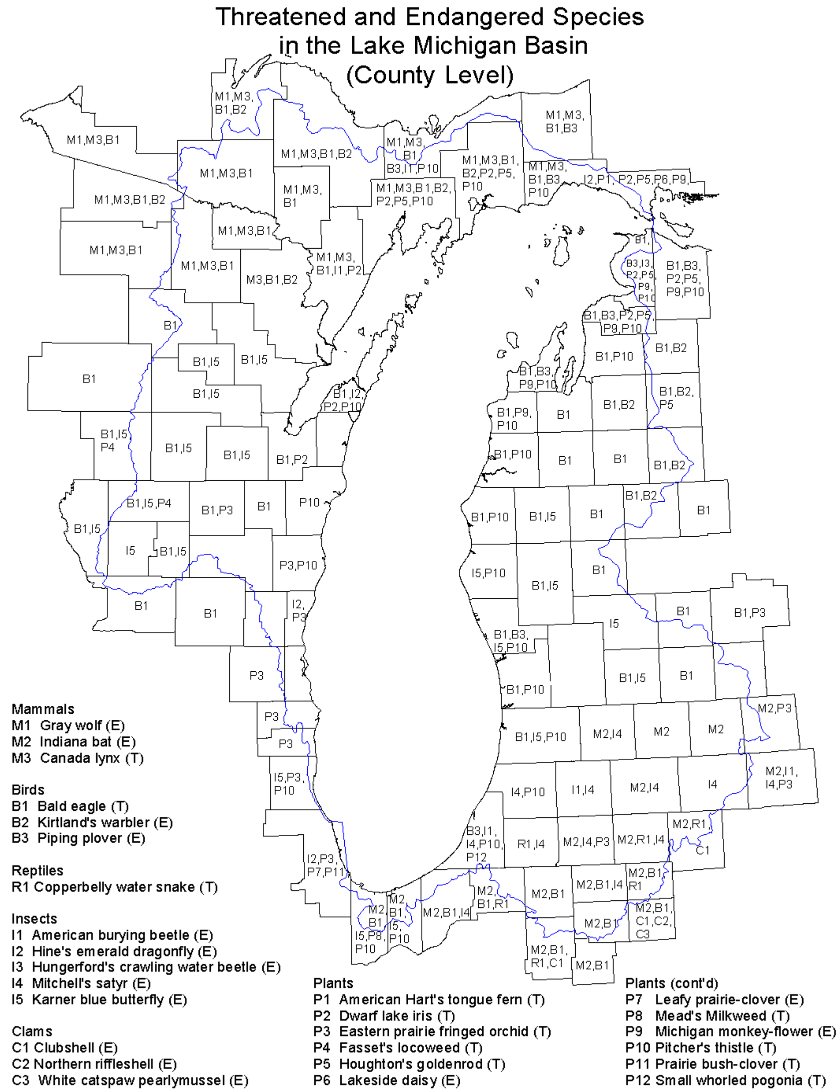


Figure 4-3. Threatened and Endangered Species in the Lake Michigan Basin

Of all the habitat types, the coastal shore and coastal wetlands rank most consistently high for all indicators of ecological and biological significance. The only exception would seem to be that they do not provide a home for a high percentage of the basin's globally rare species and communities (The Nature Conservancy 1994).

Although relatively small, the inshore zone concentrates much of the biological productivity and richness of the Great Lakes. The inshore zone plays a critical role in absorbing nutrients, organic matter and sediments, and through its high productivity removes some toxic chemicals. Coastal wetlands are uniquely adapted to and even require fluctuating water levels to maintain their vitality. Their productivity provides forage for many species from other habitats. Animals from the land, including insects, reptiles, amphibians, mammals and migrating birds, as well as, sub-adult fish that subsequently migrate to the open lake, use the inshore zone seasonally or for parts of their life cycle.

The productivity and diversity of the inshore zone stem from the interaction of the water with land. In comparison to both the land and the open lake, the inshore zone has extra dimensions in determining the fine gradations of habitat type. Both the nature and topography of the substrate, as well as the depth, flow, and temperature of the water, determine the type of communities that establish themselves.

Besides the incoming solar radiation available equally in all habitat types, the inshore zone benefits from the energy inputs of water currents, wave and wind. These forces bring dissolved nutrients, sediments and organic matter in quantities sufficient to ensure that nutrients do not limit productivity to the same degree they do terrestrial communities. At the same time, the combination of currents, waves and solar radiation ensure good circulation and resulting oxygenation. The greater warmth of inshore waters allows a higher metabolic rate and thus also contributes to overall productivity. Even when water and wind destroy the vegetation, this ultimately benefits the wetland by resetting succession and maintaining the highly productive, herb-dominated system (The Nature Conservancy 1994). To the degree that connecting channels and tributaries include a high proportion of shallow water inshore habitat, this discussion applies to them as well.

The following discussion describes and assesses the current status of the seven habitat types in the Lake Michigan ecosystem.

4.2.2.1 Open Waters

The open lake includes both the inshore and offshore waters of the lake. The inshore waters begin at the offshore edge of the coastal wetlands and extend lakeward to the point where vertical thermal stratification can be measured in summer. This point, where the thermocline intersects with the lake bed, is usually taken as the boundary between the inshore and offshore waters. This boundary is dynamic and moves progressively farther offshore and into deeper water as the summer progresses. Minor differences in water depth and distance from shore at the boundary location can occur between lakes and in response to local hydrologic conditions within each lake and at any point in time. At the end of summer the thermocline may be as deep as 30 meters (90 feet) in Lake Michigan.

Fish are the dominant fauna of the open lake. During the summer, coldwater fish including trout, salmon, and whitefish occupy the deeper, colder offshore waters, while cool and warmwater fish inhabit the shallower, warmer, inshore waters. Phytoplankton occupy the upper layers of the open lake, and benthic algae colonize the shallower portions of the lake bed where sunlight is sufficient to support photosynthesis. Light penetration may extend only a meter (3 feet) or less in some areas and to more than 60 meters (180 feet) in others. Zooplankton colonize the open lake from the surface of the water to the lake bed, and productive and diverse benthic invertebrate communities occupy the lake bed wherever it has not been degraded.

Most inputs of energy, nutrients, and pollutants to the open lake are made directly to the inshore waters. These additions may cycle in the inshore waters, but they eventually most find their way into the offshore waters, where they may be cycled less frequently or simply stored in bottom deposits in deep water. Smaller amounts of these energy and material resources, when incorporated into fish, find their way back into coastal wetland, tributary, connecting channel, and terrestrial habitats as fish migrate inshore to spawn or as avian predators and humans ingest fish from the open lake.

Open Water: System Description

The aquatic ecosystem of Lake Michigan has experienced profound changes in the past 140 years. During that time period, the science of ecology and the understanding of the mechanisms of the Lake Michigan ecosystem have greatly increased. The current status of the ecosystem is volatile and heavily dependent on human management in the form of the stocking of predator fish. Any assessment of the status and trends of ecosystem health must begin with an understanding of the catastrophic loss of habitat, biological diversity and subsequent establishment of non-indigenous populations.

The last glacier, which left in its wake the present form of Lake Michigan, retreated between 14,000 and 9,000 years ago, which is very recent in geologic terms. During and following the retreat, fauna and flora colonized the lake mostly from the surrounding watersheds that connected to the lake through channels, rivers and wetlands (Baily and Smith 1981). The fish species that colonized the lake began to evolve in response to opportunities or niches present in the form of varying depths, embayments and the corresponding food supplies and habitats afforded by geography. In particular, one fish family (the *Coregonids*) became very successful at filling these niches. This family includes the lake whitefish, lake herring, chubs and ciscoes. Expansion of this fish family into different habitats within the lake resulted in the development of separate stocks, species, and sub-species, including the deepwater ciscoe known as *C. johannae* which was endemic to Lake Michigan (Baily and Smith 1981).

Before the arrival of large numbers of settlers in the region, Lake Michigan was a more diverse ecosystem. A diverse ecosystem can “bounce back” after perturbations such as extremes in weather, water quality or even introduction of exotic species. However, the modern history of Lake Michigan illustrates that ecosystems can only endure so many perturbations before they can no longer “bounce back”. Instead, the Lake Michigan ecosystem has evolved into a less diverse form that diminishes its ability to provide services and resources.

Significant changes to the environment and ecosystem of the lake began in the mid-1800s when large numbers of people began to settle the region. By 1850, commercial fishing was a major industry and had resulted in a noticeable decline in fish populations by the 1870s (Wells and McLain, 1973; Eshenroder and others 1995). Industrial pollution had also begun to affect fish populations as the result of the damming of rivers, deforestation, and the dumping of sawmill and other industrial waste into the tributaries and lake itself. Commercial fishing and degradation of local waters continued due to greatly expanding industrial operations in the region until a significant change to the ecosystem occurred in the 1940s and 1950s. Sea lamprey, which entered the upper Great Lakes when bypasses to Niagara Falls were constructed, were first noted in Lake Michigan in 1936. By the late 1940s, the sea lamprey had decimated the top predator fish populations: lake trout and burbot. With the virtual elimination of the top predator fish, two exotic species, the alewife and rainbow smelt, flourished. By the 1960s, the lake was dominated by the alewife and, to a lesser extent, rainbow smelt. By then, the native fish community was severely disrupted, and important commercial and sport fisheries had collapsed. Coregonid populations were also affected and resulted in the extinction of several species of deepwater ciscoes including *C. johannae*. Lake trout were extirpated and to this day are not self-sustaining in Lake Michigan. (Koonce 1994)

In response to the collapse of the fisheries, the Great Lakes Fishery Commission (GLFC) was formed in 1956 to achieve two major goals: first, to develop coordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures that will permit the maximum sustained productivity of stocks of fish of common concern; and second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. Efforts to suppress the sea lamprey population began to pay off in the 1960s. Lake trout plantings began in 1965 and coho salmon and chinook salmon (introduced from the Pacific Northwest in 1966 and 1967, respectively) were introduced to Lake Michigan. These plantings of trout and salmon resulted in a marked decline in the alewife population in the 1970s and 1980s. Suppression of the alewife resulted in increases of native species such as bloater chub (the only remaining deepwater ciscoe species), yellow perch and deepwater sculpin - all species which are either in competition with alewife for plankton or whose fry are preyed upon by the alewife.

Open Water: Plankton

The plankton communities (phytoplankton and zooplankton) of Lake Michigan are the base of the food web and therefore are one of the most important components of the lake's ecosystem. Unlike fish populations that can be compared to historic data from fisheries records extending back to the 1800s, changes in the plankton community are more difficult to assess. However, limnological studies are available for much of the lake in recent decades.

Phytoplankton

Phytoplankton are composed of microscopic plants that convert sunlight into biomass and are therefore the true base of the Lake Michigan food web. The abundance and types of phytoplankton are highly variable within the lake depending on time of year, area of the lake and availability of phosphorous and other nutrients. The increase in phosphorus load to the lake has resulted in the greatest man-induced change to phytoplankton communities, especially in nearshore areas. In the mid-twentieth century, changes in the phytoplankton community were noted as algal blooms in nearshore areas, including: Green Bay; the extreme southern crescent of the lake from Chicago to Benton Harbor, Michigan; the northeastern coast from Ludington, Michigan to Frankfort, Michigan; and local areas near most major harbors (Wells and McLain 1973). Since that time phosphorous loadings have decreased as the result of improved technology and implementation of the Great Lakes Water Quality Agreement, the Clean Water Act, and other programs, although preliminary sampling indicates that phosphorus levels in the open waters of the lake may be increasing. In addition, changes to plankton communities may be occurring as a result of exotic species such as the spiny water flea (*Bythotrephes cederstroemi*) and the zebra mussel (*Dreissena polymorpha*). Additional monitoring is needed to confirm these trends. Many species of non-indigenous algae have also been introduced into Lake Michigan (Mills and others 1993) and studies indicate that increased salinity and other environmental changes are enabling introduced algae to adapt more readily to the environment of the Great Lakes (Sheath 1987).

Zooplankton

Zooplankton includes many different invertebrates and fish fry and comprises the bulk of the diet of planktivorous fish. Because most zooplankton feed on phytoplankton, their abundance and geographic occurrence are similarly dependent upon water temperature, seasonal changes and availability of food. In addition, certain zooplankton exhibit vertical diurnal migrations, sinking to deeper waters to avoid being eaten during the day and rising to shallower waters at night to feed. Population dynamics over the past 100 years include observations that would indicate that zooplankton community structure and abundance have changed markedly in Lake Michigan, especially during the mid-twentieth century when phosphorous loadings were higher and water quality more degraded.

Research conducted in the past 15 years also indicates that zooplankton populations may be experiencing changes induced by *Bythotrephes* (Lehman 1991). *Bythotrephes* is a Eurasian predatory cladoceran that was first documented in Lake Michigan in the 1980s. Dramatic declines in local *Daphnia* have coincided with increases in *Bythotrephes* populations. Preliminary studies indicate that between 10 and 40 percent of zooplankton production can be consumed by *Bythotrephes*. *Bythotrephes* is not a preferred prey for many fish. Thus, this new addition to the fauna is at best an extra trophic level between algae and fish, which results in greater inefficiency in energy transfer. At worst, *Bythotrephes* is an energy sink from the standpoint of fish production (SOLEC 1996).

Open Water: Benthos

There is a lack of historical information on benthic communities. Surveys of benthos in local areas of concern have been used as indicators, especially in relation to oligochaetes that are tolerant of anaerobic conditions resulting from overloading of organic matter and other pollution (SOLEC 1996).

Areas with historically degraded benthos include all 10 of the Lake Michigan AOCs, including the lower Menominee River, Green Bay, Sheboygan Harbor, Milwaukee River, the southern crescent of Lake Michigan from Waukegan Harbor to the St. Joseph River, the Kalamazoo River and Manistique harbor. While many of these areas have been assessed in the past 20 years, new assessments are needed. Improving conditions are indicated by increased abundance of certain burrowing insects, such as the mayfly. However, past studies indicated increased abundance of oligochaetes in the southern end of Lake Michigan were leading to organic enrichment (Nalepa 1987).

Further studies suggest that zebra mussels are having a significant impact on benthic community structures and plankton abundance. Zebra mussels, which can attach themselves to any hard surface in the lake, have reached densities higher than 16,000/m^2 in southern Lake Michigan (Tuchman 1999). The mussels divert energy away from the pelagic food web by filtering out a significant portion of the plankton. Negative impacts include increased competition for plankton at the expense of fry from nearshore species (such as yellow perch), increased biomagnification of contaminants in piscivores feeding on benthivores and possible zebra mussel induced mycrocystis blooms (Sea Grant 1994).

Recent research suggests that benthic species may be directly impacted by zebra mussels (NOAA 1997). Tiny shrimp-like organisms called amphipods (Diporeia spp.) that are normally found in bottom mud of healthy lakes were absent in samples taken at a monitoring site 5 miles off St. Joseph, Michigan on southern Lake Michigan, according to NOAA's Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan. Routine monitoring of the abundance of these environmentally sensitive organisms at 40 sites in Lake Michigan's southern basin provides researchers with a reliable measure of the lake's health. While the NOAA scientists have not yet determined the exact cause of the disappearance of amphipods at the St. Joseph site, they suspect it is linked to the introduction of zebra mussels in southern Lake Michigan in 1989, severely limiting food available to the amphipods. Because amphipods normally make up to 70 percent of the living biomass in a given area of a healthy lake bottom, their decline in Lake Michigan may affect a variety of fish species that depend heavily on them for food.

Open Water: Fish Communities

Fish communities represent the highest trophic levels within the Lake Michigan aquatic ecosystem. They are also the most visible indicators of the health of the ecosystem and represent, to most people, one of the most important resources of the lake. The alteration of fish communities has been the most obvious impairment to the aquatic ecosystem in Lake Michigan. The current status of the fish community is dependent upon human management by the various agencies responsible for the fisheries of Lake Michigan. Without the continued planting of predator fish by management agencies, the lake would revert to a fish community dominated by alewife.

The federal, state and tribal managers of the fisheries resource of Lake Michigan, through their participation in the GLFC, have recently reached consensus on a revised version of the Strategic Great Lakes Fisheries Management Plan (SGLFMP), which defines their common goals for the management of the Great Lakes fisheries.

Fish Community Objectives for Lake Michigan (GLFC Special Publication 95-3) recognized the following positive developments in the fisheries of the lake:

- Recovery from the highly degraded, nearly single-species (alewife) fish community of the early 1960s is evident.
- Sea lampreys are being suppressed.
- Deepwater ciscoes and whitefish have recovered - in some cases to near-historic levels.
- State and federal governments have invested in modern fish-production facilities to help maintain ongoing fisheries and rehabilitation efforts.
- Loadings of phosphorous and toxic chemicals have declined.

The document goes on to present the following remaining problems:

- Not enough natural reproduction of top predators, especially lake trout.
- Low abundance or complete loss of many native fish stocks.
- Continued problems with unintentional introduction of undesirable exotic species.
- Continued difficulties in suppression of sea lampreys.
- Continued unacceptable levels of pollution and toxic chemicals.

Fish Communities: Prey Fish

Since the early 1970s, the pelagic prey fish community in Lake Michigan changed from an assemblage dominated by (in descending order of abundance) alewives, rainbow smelt and bloaters, to one dominated by bloaters, rainbow smelt, and alewives. The reasons for these changes are unclear. It has been suggested that alewife populations may not be able to sustain desired predator populations. If true, other prey fishes such as rainbow smelt and bloaters may eventually contribute a greater proportion to the salmonid (predator) diet. Others contended that climatic effects were primarily responsible for the decline in alewife abundance. Whatever the reasons, alewife stocks and, to a lesser extent, rainbow smelt stocks have both declined greatly since the mid-1970s while bloater and other native fish stocks increased in abundance (Argyle and others 1995).

Fish Communities: Whitefish

Lake whitefish (*Coregonus clupeaformis*) is one of the most important commercial fish in Lake Michigan. Whitefish are predominantly benthivores and occur in Lake Michigan in at least 10 reproductively isolated stocks. Current assessments indicate that whitefish populations are stable and self-reproducing. Records indicate that the 1995 harvest of 20 million pounds was greater than at any other time in the twentieth century (Ebener 1997). Populations of whitefish were devastated in Lake Michigan in the first half of the twentieth century approximating the decline of lake trout. One of the main reasons for the decline appears to be the exponential population increases of alewife and rainbow smelt, both of which prey on whitefish fry. Consequently, with the suppression of sea lamprey and intense stocking of salmonids, populations of whitefish rebounded and continue to experience healthy recruitment.

Despite healthy recruitment in recent years, whitefish populations in northern Lake Michigan are showing signs of stress, including lower body mass possibly due to an explosion of the zebra mussel population in this area. There is evidence that the natural whitefish diet of *Diporeia* and other native benthic invertebrates is disappearing possibly due to ecosystem perturbations caused by zebra mussels. Routine assessments of larger whitefish from this area indicate an almost exclusive diet of zebra mussels which coincides with lower body mass in the fish themselves. More research on this phenomena is needed.

Rise and Fall of the Lake Trout

Lake trout (*Salvilinus namaycush*) is a North American salmonid which thrives in cold, fresh water. Following the retreat of the last glacier, the lake trout colonized Lake Michigan and over the subsequent 10,000 years or so became the top predator in a complex ecosystem which co-evolved with the species. Over that period of time different strains of lake trout evolved. Some strains thrived in the deepest waters of the lake feeding on the abundant chubs and deepwater ciscos, other strains thrived in shallower areas of the lake.

Starting in the mid 1800s the population of the region began to increase and cities started growing around the lake. With abundant resources and the convenient access to waterways, Lake Michigan quickly became a major industrial hub of the United States. Commercial fishing for lake trout also became an industry and by the beginning of the twentieth century the population of lake trout was in decline. The decline continued until the mid-1950s when predation by sea lamprey, overfishing and the effects of industrial pollution led to the destruction of the lake trout fisheries and the disappearance forever of many of the strains of lake trout that had evolved in the lake.

Currently, federal, state and tribal management agencies around the lake are attempting to reestablish naturally reproducing populations of lake trout by planting fry and eggs in historical spawning areas. Assessments indicate that self-sustaining populations of lake trout have yet to be established. Research into the reasons for this failure are ongoing but may include

- loss of suitable spawning habitat
- environmental contaminants
- predation on larval lake trout by alewife
- thiamine deficiency from diet of alewife
- loss of genetically distinct strains.

Fish Communities: Predator Fish

Following the introduction and annual stocking of Pacific salmon, lake trout and other trout in the 1960s, an impressive sport fishery was created on Lake Michigan. The development of the Lake Michigan sport fishery has been called one of the most successful fish management stories in North America. Predator fish were able to thrive on an abundant prey base of predominantly alewife throughout the 1970s, until the mid-1980s when the alewife population crashed. The subsequent stress of a decreased forage base resulted in the spread of bacterial kidney disease (BKD) and the collapse of the chinook salmon fishery.

Currently, BKD appears to be less prevalent (Belonger and others 1997), and salmonid populations on Lake Michigan have rebounded and are currently at levels comparable to those of the 1980s. Some recent assessments have shown, however, that populations of prey fish have decreased and may be leading to stress in chinook salmon similar to the scenario of the 1980s. Therefore, the fisheries management agencies from around the lake are developing management options to avert another crash in predator fish populations.

Fish Communities: Nearshore Fish

Nearshore fish prefer the shallow, warm and nutrient rich environments of embayments, river outflows and other shallow areas of the lake. Species of nearshore fish in Lake Michigan include yellow perch, walleye, pike, and panfish. The populations of these fish have also declined in the 20th century due to environmental degradation and habitat loss; however, they have improved in recent years due to improving environmental conditions with some exceptions. Yellow perch populations have been drastically declining throughout the lake in recent years with continued poor recruitment. It appears that adequate numbers of larval yellow perch have been produced but fail to reach maturity. Causes are unknown but may include predation, or the effects of zebra mussels, contaminants or nutrient declines. In order to address the problem, several steps are being taken including the formation of a Yellow Perch Task Group comprised of a multi-state team of fisheries managers and scientists, as well as restrictions on commercial and sport fishing of yellow perch. In addition, a number of research projects have been funded and are currently in progress.

Other localized populations of nearshore fish that have been degraded include the walleye, muskellunge and pike fisheries in Green Bay and the lake sturgeon fisheries throughout the lake. Habitat loss has been a major factor in the decline of these fisheries, including the obstruction of sturgeon spawning habitat by dams on tributaries to Lake Michigan.

Open Water: System Assessment

While the Lake Michigan open lake system has remained virtually unchanged in size, its quality has been impaired. Nutrient concentrations have been reduced from their highs of the 1960s and 1970s. As a result, growth rates of nuisance algae have also been reduced. However, agreement on ideal long-term nutrient levels has not been reached (Nielson and others 1993). Locally, such as in many AOCs, nutrient levels are still too high, leading to oxygen depletion and impaired fauna.

In the open waters of Lake Michigan, phosphorous and chlorophyll concentrations have decreased significantly since the late 1970s, primarily due to improved municipal sewage treatment and laws requiring reduction or elimination of their use in certain products such as soaps and detergents, although preliminary sampling results indicate that phosphorus levels in the open waters of the lake may be increasing. Chloride concentrations continue to increase and the rate of increase is accelerating. The primary source of chloride seems to be municipal waste water discharges (a point source) and salt from road deicing (a nonpoint source) (Michigan Office of the Great Lakes 1996). In the heavily-populated and industrial southern part of the basin, water quality is severely diminished. The leading stressors are almost entirely urban in nature, including occasional backflows induced by combined sewer overflows, direct stormwater runoff, and industrial discharges (Thorp 1996).

The presence of toxic chemicals in the water continues to affect the health of fish and bird populations. As discussed in Chapter 5, toxic chemical loads are derived from atmospheric deposition, legacy sources (contaminated ground water and sediments), point source discharges, and nonpoint source runoff.

Oil and gas drilling in the waters of the lake are banned due to a compact of the governors. However, slant or directional drilling from a land-based site to reach a specific target underwater up to 4,000 feet away is permitted. Beginning in 1979, 100 oil and gas wells with bottom-hole locations have been permitted and directionally drilled under Lake Michigan. More applications for drilling are being requested, with as many as 30 potential sites under review.

Biological sources of degradation include the introduction of non-indigenous invasive species, such as the zebra mussel. The current status of the fish community depends on human management by the various agencies responsible for the fisheries for Lake Michigan.

Zebra mussels out-compete native filter feeders and alter the substrate and water clarity. Other non-indigenous invasive species are affecting the food web. It may be argued that stresses associated with biological factors have, in fact caused more severe degradation than physical and chemical stresses. Several endemic fish species–formerly dominant species–have been eliminated, and others, such as the lake herring and the globally rare lake sturgeon, now have severely restricted distributions.

Although portions of the lake appear to support high quality benthic communities, the overall documentation of the character and quality of invertebrate biota is still scanty. The lake’s biotic communities also have not been systematically described or ranked from a biodiversity standpoint. However, many communities would presumably rank as globally rare or imperiled due to restricted distribution, level of threat, ecological fragility, widespread damage and because they are part of the single largest source of fresh surface water in the world (The Nature Conservancy 1994).

Multiple stressors continue to degrade the open lake system. Toxic chemicals contaminate water and sediment quality. Fish advisories are still in effect. Beaches, particularly in the southern part of the lake, are closed occasionally. Aquatic habitats do not sustain healthy and diverse fish communities. Exotic species continue to disrupt native plant and animal communities. Unsustainable human activities, like habitat destruction, continue to threaten the ecosystem. Ecosystem stewardship activities are currently not sufficient to overcome human-induced stressors. Data gaps continue to impede remediation or restoration progress. Lake Michigan Lakewide Management subgoals 1, 2, 3, 4, 6, 7, 8, 9, and 11, have not yet been met. Great strides have been made, however, in regard to subgoal 10, as the fish community objectives set forth by the Great Lakes Fishery Commission are carried out in a collaborative fashion by fishery managers basinwide.

4.2.2.2 Coastal Wetland System

The coastal wetland system supports the greatest diversity and biological productivity of the basin. Wetlands are important because they collect nutrients and organic materials that are washed off the land into the tributaries. Tributaries carry the materials to the lake, where they are deposited on the shore by longshore currents. These materials support both the aquatic food web and the habitat for bird, mammal, reptile, amphibian, and invertebrate resident and migratory species. Most Lake Michigan fish spend a portion of their life cycle in coastal wetlands. Migratory birds use coastal wetlands as staging and feeding areas. Both lake level fluctuations and longshore sediment transport are important in maintaining this highly productive system because of their roles in bringing the materials needed to nourish and protect it (The Nature Conservancy 1994).

Coastal Wetland System: Description

It can be said that Lake Michigan is the most diverse of any of the Great Lakes. Its wetlands are equally diverse. The most common are the embayment, barrier beach, and riverine. Deltaic formation only occurs weakly at some Green Bay sites, because in all other situations the shore currents quickly carry away any alluvium or detrital accumulations.

The diverse coastal wetland is habitat for numerous species of wildlife dependent on wetlands. Many insects have an aquatic larval stage. Amphibians also depend on wet conditions, at least during the larval stage. Many reptiles spend their entire lives in or near these coastal wetlands. Coastal wetlands provide important habitat for small fish, due to the abundant food supply and relative safety from predators. A great variety of bird life uses coastal wetlands for foraging, resting, and breeding. Mammals too are an important part of the coastal wetland community.

The location of these coastal wetlands, with access both to the open lake and inland terrestrial systems, constantly augments the food chain and enhances the value of these wetlands as a refuge for a greater diversity of plant and animal life.

Great Lakes coastal wetlands differ from inland wetlands in that they are shaped by large lake processes, including waves, wind tides and especially long and short-term water level fluctuations. The fluctuating water levels result in a constant shifting of the communities in the wetland. Many species have adapted to this constant fluctuation, and indeed require it to eliminate stronger competitors that thrive under more stable conditions.

Accordingly, Great Lakes marshes can be classified based on how they are influenced by Great Lakes processes. The Lake Erie Water Level Study (International Lake Erie Regulation Study Board, 1981), identified the following six wetland types that also occur on Lake Michigan.

- **Open shoreline wetlands** usually exist as a fringe of aquatic plants adjacent to the shore. That fringe has expanded inland or lakeward in response to lake effects such as wave action and changes in lake levels. The dominant vegetation is usually emergent, but submergent plants can also be present and do not necessarily border on a shoreline. Examples of this wetland type are found along the north shore of Lake Michigan east of Manistique.

- **Unrestricted bays** are characterized by a marshy fringe along a bay shoreline. These sites are afforded some protection from such lake effects as wave action. Depending on its size and depth, the whole bay could be vegetated. Submergent plants can be a part of those vegetative communities. This wetland type also includes typical open shoreline areas that are sheltered by an island or peninsula. Examples of this wetland type are found in Little Bay de Noc.

- **Shallow sloping beach wetlands** are areas with very gentle to flat slopes on sand substrates. Very small variations in lake levels have had widespread effects on vegetation zones. Sand bars, if present, provide some wave protection. The large sand split formations of Lake Michigan (such as Cecil Bay Marsh) constitute most of this wetland type.

- **Restricted riverine wetlands** are characterized by marsh vegetation bordering a river course. The extent of the vegetated wetland is often restricted by a steep backslope on the landward side and the deeper water of the river channel on the other. The Betsie River wetlands are examples of restricted riverine wetlands.

- **<u>Lake-connected inland wetlands</u>** are typified by the presence of a barrier beach or ridge that restricts the outlet to the lake and also provides protection from wave action and other disturbances. Such wetlands can have a definite steep backslope or a gradual slope permitting some shifting of vegetation zones with changes in water regime. This type of wetland will have a connection to the lake, but a stream or groundwater discharge from its drainage basin could also contribute to its water supply. The Arcadia Lake wetlands are examples of this wetland type.

- **<u>Protected (or Barrier beach) wetlands</u>** are separated from the lake by an unbroken natural barrier beach or ridge. The natural wetlands and some of the diked wetlands obtain their water from inland groundwater discharge, streams, and, at times, from the lake, when the wetland floods during storms. There is some seepage of water through dikes, which can be magnified by extremes in lake levels. Examples of this type may be found at Seagull Bar, Marinette, Wisconsin.

In total, 411 wetlands covering almost 49,000 hectares (ha) were identified along the shores of Lake Michigan in the early 1980s (Herdendorf and others 1981). There are 61 wetlands larger than 100 ha, with 13 of these covering more than 1000 ha. The eight largest, which exceed 2,000 ha, are Big Bay de Noc (3,867 ha), Oconto Marsh (3,792 ha), Manistee River (3,705 ha), Sturgeon River (2,710 ha), and Pere Marquette River (2,532 ha), Muskegon River (2,449 ha), Seul Choix Point Complex (2,361 ha), and Peshtigo River (2,040 ha) (Wilcox 1996).

The Hine's emerald dragonfly *(Somatochlora hineana)* is one of the most endangered dragonflies in the United States. It is known to occur in three areas in the Lake Michigan basin: northeastern Illinois, Door County Peninsula, and northern Lake Michigan on the Upper Peninsula. The dragonfly's habitat is wetland found on dolomite bedrock. It is endangered because its much of its habitat has been fragmented or destroyed by development. The priority is to protect remaining populations and habitat and to reestablish populations at restored sites within the dragonfly's historic range (Zercher 1999).

A brief description of areas around the lake where coastal wetlands are found is presented in Appendix G.

The distribution of coastal wetlands in the Great Lakes system is summarized in Table 4-1.

Table 4-1. Distribution of the Approximately 300,000 Acres of Coastal Great Lakes Wetlands in the U.S.

COASTAL WETLAND	Percent
Lake Ontario-St. Lawrence	6.9
Whitefish Bay	3.6
St. Mary's River	4.4
Lake Erie-Niagara	6.7
St. Clair-Detroit	3.2
Lake Superior	14.5
Lake Michigan	40.4
Lake Huron	20.4

(Sources: Herdendorf and others 1981).

Coastal Wetland System: Assessment

Coastal wetland loss estimates from different sources have been compiled for various sections of the Great Lakes by Bedford (1992). Bedford reports that 50 percent to 72 percent of the coastal wetlands have been lost in sections of Lake Michigan.

South of Chicago and around the southern end of Lake Michigan many smaller remnant wetlands and larger interdunal wetlands remain post-industrialization. Some in the area of Lake Calumet and the Grand Calumet and Little Calumet Rivers are being restored and reconnected to the Lake Michigan water table (Maynard and Wilcox 1996).

South of Sturgeon Bay, all the way to Chicago, development in coastal wetland areas has been limited because most of the shore consists of high bluffs with narrow beaches, and few unmodified river mouths. The rivers have small watersheds limiting sediment loads. At all of the river mouths, urbanization has eliminated coastal wetlands (Maynard and Wilcox 1996).

On the Door County Peninsula, development is continuing to increase. This will result in water quality degradation and altered hydrology (Scheberle 1999).

The Green Bay area has suffered from losses and degradation of its wetlands due to industrial development, dredging, upstream damming, and toxic contamination. On the western shore of Green Bay, however, large coastal wetlands are protected and managed as state wildlife areas by the Wisconsin Department of Natural Resources (Maynard 1996).

In the less densely populated northern shore, many of the coastal wetlands remain intact. Scenic shoreline roads, however, bisect both marsh and dune communities northwest of the Mackinac Bridge (The Nature Conservancy 1994).

The drowned river mouth marshes along Lake Michigan's eastern shoreline have had their hydrology altered by road crossings, thus increasing sediment deposition, and have been affected by ditching, agricultural practices, and colonization by invasive plant species (Maynard 1996). Significant parts of the Grand River Estuaries are in public ownership; however, the highest quality marshes are in private ownership. Increased nutrient loadings from non-point sources are the greatest threats to the water quality of these marshes (The Nature Conservancy 1994).

Multiple stressors continue to degrade the Lake Michigan coastal wetland system. Non-indigenous invasive species such as purple loosestrife are still largely uncontrolled despite chemical, physical and biological attempts to eradicate. The sediments from tributaries that nourish coastal wetlands do not contain woody debris needed by some habitats. Fast flowing tributaries deposit too much sediment and bury submergent and emergent aquatic plants. The pace of shoreline modification is increasing. No comprehensive, cross-jurisdictional effort exists to monitor the status of the system or to fill research gaps. Coastal marsh system stewardship activities are not coordinated, nor are there efforts being undertaken to protect or restore all remaining fragments. Lakewide Management Plan subgoals 4, 8, 9, 10, and 11, therefore, have not yet been attained in regard to the Lake Michigan coastal marsh system.

4.2.2.3 Inland Wetland System

The inland wetland system–wetlands away from the Lake Michigan shoreline–is the reservoir for water in the Lake Michigan drainage basin. There are many types of inland wetlands, including fens, bogs, wet meadows, and wet forests. The health of inland wetlands is dependent on the quantity and quality of groundwater and surface water. Inland wetlands help to regulate the basin's volume of water as well as sediments and chemicals. They also store nutrients and serve as the nutrient exchange vehicle for the diversity of species that use inland wetlands as habitat and feeding areas. Both wetland and upland species breed and feed in Lake Michigan's inland wetlands (The Nature Conservancy 1994).

Inland Wetland System: Description

Wetlands are defined in numerous state statutes. For example, Wisconsin statute [Section 23.32 (1)] defines wetlands as areas "where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions." Federal wetland definitions are provided by the U.S. Army Corps of Engineers and the National Wetland Inventory.

The inland wetland system is composed of a variety of wetland types. Each wetland type has a different suite of animal and plant species and habitat conditions. For example, the Pine and Popple River area in northeastern Wisconsin is a wet northern forest. It occurs on acid peat and is dominated by black spruce, tamarack, white cedar, and balsam fir, as well as an understory of mosses, sedges, and shrubs. The Turner Creek Wetlands in the southwestern part of Michigan's lower peninsula, on the other hand, has a wet prairie complex, a grassland of bluejoint grass, sloughgrass, and big bluestem on wet soils (The Nature Conservancy 1994).

The inland wetland system is an important part of the water cycle for all ecosystems in the Lake Michigan basin. They are generally a buffer between lakes and ponds and upland areas. They trap sediments, remove nutrients and soak up floodwaters, thereby functioning to keep water clean. They are discharge and recharge areas for groundwater. They provide diverse habitats for many plants and animals (Wisconsin Department of Natural Resources 1995).

The role of inland habitats in maintaining water quality is perhaps overshadowed by their importance in regulating water flows and levels. From a basin-wide perspective, the inland habitats are the principal collectors of precipitation for the basin. The ability of forests and wetlands to store and release water is critical to moderating tributary and groundwater flows to the lakes (The Nature Conservancy, 1994). Inland habitats moderate tributary flows, reduce erosion and sedimentation associated with flooding, and thus moderate the seasonal and long-term fluctuations of lake levels.

Many animal species move between different habitats, with periods ranging from daily through seasonally to once or twice in their life cycle. In this way, habitats other than the one they are normally associated with, can play a critical role in the survival of the species, especially when normally dispersed populations concentrate in very small areas. In such a case, this habitat becomes far more important than what is suggested by the community of species that are more permanent residents. Examples of several different kinds of periodic use are summarized below.

Migration Stopovers

Historically, the marshes of Wisconsin's Winnebago Pool Lakes, as well as other areas in the Great Lakes such as the Detroit River, Lake St. Clair, Long Point and Western Lake Erie, have been important resting and feeding stops for the eastern population of canvasback duck, which winters on the Atlantic Coast. This population declined from 400,000 birds in the early 1950s to less than 147,000 by 1960 and has just finally recovered to its former levels.

The canvasback duck has rigid habitat requirements and behavioral traits that limit its adjustment to environmental change. It does not tolerate disturbance by boat traffic and depends strongly on wild celery. Densities of wild celery tubers decreased by 72 percent from eutrophication, sedimentation, carp, and pollution at two of five locations where ducks once fed between 1950 and 1985 (Schloesser and Manny 1990; Kahl 1991).

Several authors have suggested that the decline in canvasback numbers is at least partially linked to the reduction in forage on their migration routes (Bellrose and Crompton 1970; Mills and others 1966; Trauger and Serie 1974).

Spawning and Nursery

Many of the fishes of the open lake and tributaries move to the shallow waters or wetlands to spawn. In this respect, their needs are very specific: a certain kind of substrate, a certain amount of current, depth and temperature and within a narrow time-window. Often they return to the same places where they hatched. In a manner similar to waterfowl, during spawning a widely-dispersed population becomes concentrated in a habitat of relatively small size. For these populations, these spawning habitats become far more important than their relative size would suggest. An atlas of spawning grounds in Lake Michigan is available at http://www.glsc.nbs.gov/information/atlas/index.htm. Although artificial reefs have been created in marine waters and in small freshwater lakes and reservoirs for decades, their effectiveness in the Great Lakes as a fishery management technique is still being evaluated. Three of eleven intentional artificial submerged reefs in the Great Lakes Basin have been set up in Lake Michigan. An "International position statement and evaluation guidelines for artificial reefs in the Great Lakes"(Gannon 1990) has been developed to ensure that fishery management, not waste disposal, must be the driving force behind artificial reef construction in the Great Lakes. As of this writing, there is no basinwide policy on artificial reef construction.

Nesting

While bald eagles have attracted attention, mostly because of the effects of toxic chemicals on their reproduction and development, it has also become apparent that reestablishing viable populations of eagles in the Great Lakes requires more than clean water. For example, nesting adult eagles prefer coniferous perches that are isolated from human disturbance (Bowerman and Geisy 1991).

A survey of Lake Michigan found that 49 percent of the coast is unsuitable as eagle nesting habitat (Bowerman 1993). Sensitivity to disturbance and the large forage area require the protection of extensive coastal and inland habitat if bald eagles are to play more than an isolated and infrequent role in the ecosystem.

Of special importance are habitats where a large part of the population gathers periodically in a limited area, more so when there do not appear to be alternative habitats to which these migrations may shift if the favored habitat becomes degraded.

Overall, inland wetlands are exceptionally rich in plant and animal species. Many of these species are threatened or endangered. Plants include, among many, calypso orchid, tussock bullrush, umbrella sedge, and algal-leaved pondweed. Animals include reptiles and amphibians such as the Blanding's turtle, wood turtle, and Massausauga rattlesnake, and Blanchard's cricket frog; birds such as the trumpeter swan, yellow-throated warbler, and red-shouldered hawk; and Lepidopterans such as the silphium borer moth. It is estimated that 32 percent of the State of Wisconsin's threatened and endangered plants and animals are wetland-dependent (Wisconsin Department of Natural Resources 1995).

Numerous wetlands remain throughout the Lake Michigan basin in spite of tremendous losses. Several of the most significant remaining parcels, in terms of biodiversity and representative type of wetland, are described in Appendix G to illustrate the diversity of the inland wetland system.

Inland Wetland System: Assessment

Millions of acres of inland wetlands have been lost in the Lake Michigan basin to agriculture, industry and urban development over the last century. Over the last two centuries, wetland losses in the four states at least partially within the Lake Michigan basin have been disproportionately greater than in many other U.S. regions. Since the 1780s, Lake Michigan basin states have lost an estimated 21.9 million (62.9 percent) acres of wetlands out of their 34.8 million original wetland acres. Wisconsin has lost about 47 percent of its original ten million acres of wetlands (Wisconsin Department of Natural Resources 1995). Illinois has lost approximately 85 percent of its wetland acreage, Michigan has lost greater than 50 percent of its wetland acreage, and Indiana has lost greater than 70 percent of its acreage (U.S. Fish and Wildlife Service No Date). These figures compare with an average loss of 52.8 percent nationwide. There are an estimated 12.9 million acres of wetland remaining in the four states, representing more than 12.3 percent of the wetlands within the lower 48 states (Dahl 1990). Recent historic losses of wetlands in the Great Lakes basin have been estimated to be 20,000 acres/year (Great Lakes Basin Commission 1981).

State and federal regulatory programs have begun to stem the tide of losses; however, exemptions for agriculture, forestry, and other uses do not protect all wetlands from being destroyed. Fortunately, acquisition of major inland wetlands for waterfowl and fishery management was initiated by groups such as Ducks Unlimited and resulted in wetland protection. Management for waterfowl and fish have helped other wetland-dependent species such as wading birds and sandhill cranes. Restoration of many wetlands is also taking place, although restorations have not proved to be as rich or diverse as the original wetlands.

Subgoal 4 has not yet been met, although current efforts to protect and restore the inland wetland system have made significant progress over the last two decades. Subgoal 8 is problematic due to the invasion of exotics such as purple loosestrife. It will be some time before these invasives are controlled. Progress is being made toward the attainment of subgoals 9, 10, and 11, primarily through the cooperative efforts of agencies and organizations striving to better understand inland wetlands and share problem-solving resources.

4.2.2.4 Tributary System

Water from the basin drains to Lake Michigan by way of the tributary system. In addition to water, tributaries contribute chemicals, nutrients, organic materials, and sediments to Lake Michigan. These materials enter the lake and then are carried by longshore transport around the lake's nearshore and nourish coastal shore and marshes Tributaries are spawning habitat for many fish species as well as for invertebrates such as the Hungerford's crawling beetle, endemic to the Maple River in northwest lower Michigan. Tributaries are also major migratory corridors for many species (The Nature Conservancy 1994).

Tributary System: Description

Tributaries are connected to Lake Michigan in several ways. Energy is transferred from lake to tributary and tributary to lake by way of fish movement up and downstream and material movement downstream. Diverse plant and animal habitats are found throughout the tributary system. The range of tributary habitats depends upon the size, slope, substrate, geology and land-use in the drainage basin, groundwater characteristics, climate, and the nature of the terrestrial vegetation. Many of these habitats accommodate Lake Michigan fish. Sediments and vegetative materials are sent downstream to the lake and are transported around the coastal shores and marshes of the lake to create habitats. The connectivity to the lake maximizes fish biodiversity and production (Whelan 2000).

Of the 36,000 miles of rivers in the state of Michigan, 35 percent flow to Lake Michigan. In the north, the rivers are rough and rocky. In the south, the rivers flow through other states' gently rolling agricultural lands. Michigan's most outstanding rivers have been designated as natural rivers and protected as authorized by the Michigan Natural Rivers Act, Part 305, P.A. 451 of 1994.

Several examples of rivers that are both outstanding and impaired are listed in Appendix G to illustrate the wide range of both type and quality of rivers in the basin.

Tributary System: Assessment

The quality of many rivers in the Lake Michigan basin has been significantly impaired due to channelization, dredging, damming, sedimentation, loss of bankside vegetation, eutrophication, increased spring flooding, and toxic contamination. Large areas of inland forests and wetlands that once served to regulate the quantity and quality of water flowing into tributaries have been lost. As a result, tributaries pass on their pollutant and sediment loads to the lakes and their suitability as spawning habitat has been seriously impaired. In urban areas, degradation has been most severe. Pollution from agriculture, industry and urban development has polluted rivers and contaminated sediments. The result is the contamination of fish and wildlife that depend on river habitats. Many rivers, particularly at the rivermouths, have been declared Areas of Concern and have many impaired beneficial uses.

Information on the status of rivers and streams is available from several sources. The states regularly report on the status of their water bodies under Section 305(b) of the Clean Water Act. EPA then compiles these state reports into a *National Water Quality Inventory Report to Congress.* Information on individual water bodies and watersheds is also available on the worldwide web at EPA's "Surf Your Watershed" site (www.epa.gov/surf). Finally, the Federal *Clean Water Action Plan* requires that the states prepare "Unified Watershed Assessments" to identify priorities for watershed management. Those reports are available through the state agencies.

Subgoals 1, 2, 3, 4, 6, 7, and 8 have not been met in regard to tributaries. Although the public utilizes Lake Michigan rivers, the actions are not necessarily sustainable. Tributaries are pathways for contaminants. Exotic species are impacting waterways. Subgoals 9, 10, and 11, however, are progressing favorably. Watershed groups are working to clean up rivers. Stakeholders and governments are collaborating to remediate Areas of Concern and take down dams that impede tributary system flows. Issues relating to dam removals are further discussed in Chapter 5. Information is being gathered at all levels that will lead to more effective remediation and future management of the tributary system.

4.2.2.5 Coastal Shore System

The coastal shore system – sand beaches, sand dunes, sand spits, bluffs, bedrock and cobble beaches, etc. – buffers coastal wetland and inland systems from the waves, wind, and ice of Lake Michigan. It is ever changing, formed by deposits of sediment from rivers and other shoreline areas and carried by longshore currents around the shoreline (Reid and Holland 1997). Lake level fluctuations are an important part of this system, assisting in sediment transport and beach and dune maintenance. The coastal shore system is rich in species diversity. Sand dunes, in particular, harbor more endemic species than any other part of the Great Lakes basin (The Nature Conservancy 1994). Many natural factors act to change the shape and structure of the Lake Michigan shoreline. The most significant among them are climate, erosion, and lake-level fluctuations.

Coastal Shore System: Climate

Advancing and retreating glaciers carved out the lake basin as water levels changed in response to melting ice. The results of the glacial retreat can be seen along the varied and rugged shoreline, and in abandoned former shorelines inland from today's lake. As the ice retreated, the climate warmed at a rate of one or two degrees every 1,000 years. New plant and animal species colonized and interacted, contributing to the rich natural heritage that remains today.

Today, warm, moist air from the Pacific Ocean and the Gulf of Mexico collides with cold, dry arctic air over the Great Lakes basin. Due to their sheer size and volume, the lakes moderate the effects of both systems by acting as a heat "sink" or cold "sink." As a result shoreline temperatures around Lake Michigan are cooler than inland in the summer. In the winter, the warm lake waters moderate the air temperature and the shoreline is warmer than inland. In addition to modifying temperatures, the lake influences weather patterns, precipitation, and wind velocity and direction (Reid and Holland 1997).

Global warming resulting from human activities poses the threat of increased temperatures and changing precipitation rates. Shorelines could change quickly, submerging or exposing ecosystems accustomed to harshness and variability but unable to cope with rapid change. An abrupt change in climate could prevent ecosystems that now survive in small, isolated areas from adapting (Reid and Holland 1997).

Coastal Shore System: Lake-Level Fluctuations and Global Climate Change

Lake-level fluctuations contribute to erosion, sediment transport, and sand dune maintenance. On average, Great Lakes water levels fluctuate 12 to 18 inches per year. Three types of water level fluctuations occur. First, water may be temporarily displaced as a result of high winds or atmospheric pressure. This short-term fluctuation is called a seiche. Second, the volume of the lake changes seasonally as a result of storm actions, runoff, evapotranspiration, or groundwater flow. Third, long-term water level fluctuations are due to precipitation, temperature, and evapotranspiration changes.

Based on projections using several state-of-the-art models (Mortsch and Quinn 1996, Croley 1991), experts from the U.S. National Oceanic and Atmospheric Administration (NOAA) and Environment Canada believe that global warming could result in a lowering of lake levels by a meter or more by the middle of the 21st century. This development would cause social, economic and environmental impacts throughout the Great Lakes region (IJC, 2000). The impact of global climate change as a stressor to the lake is further discussed in Chapter 5.

Of particular concern are the predictions of poorer water quality and shifts in species composition. Increases in fish yields (warm water species) will be concurrent with eutrophic-like conditions and increased contaminant loading and bioavailability. While a warmer climate will provide longer seasons for agriculture and commercial shipping, changes in seasonal runoff patterns, decreases in total basin moisture and lake level decline will have negative consequences. Lake level decline will also result in significant loss, migration and changes in wetlands. Most impact assessment efforts have been concentrated on physical responses. The biological consequences of the physical responses to climate change have yet to be seriously explored.

Sand dunes, sand beaches, bedrock shores, and alvars are the primary coastal shore system communities on Lake Michigan. Islands are included here as well. Each is described briefly below.

Coastal Shore System: Sand Dunes

From northern Indiana and continuing northeasterly into Michigan, the most colossal shore feature in all the Great Lakes is apparent: the massive coastal dunes that flank the shore. These dunes run without interruption, except in river valleys, some cities, and roads, along the entire shore to heights of 300 feet and breadths of more than 1 mile. The dunes were formed following the last glaciation in the region and are 2,500 to 10,000 years old.

The dunes are subjected to residential development with summer homes and permanent residences, often very close to the shore. Ancient high lake levels formed the beach ridges, and as the lake receded, the prevailing on-shore winds continued to blow beach sand up the slopes. The most significant dune features lie on the shores of Lake Michigan and Lake Superior, with Lake Michigan encompassing the largest collection of freshwater dunes in the world.

Sand dunes form where sand grains from 1/16 to 2 millimeters in size are abundant, wind blows frequently, and there is a place for sand to be deposited. As saltation occurs–sand grains bouncing and colliding with other grains–over time, dunes actively move. Abundant and easily erodible quartz from the rocks of the Canadian Shield is the primary mineral component of sand (Reid and Holland 1997).

Foredunes, sand dunes closest to the beach, begin to grow as vegetation such as marram grass *(Ammophila breviligulata)* forces the winds to drop sand, which then piles up. As a foredune grows, other grasses such as sand reed *(Calamovilfa longifolia)* and little bluestem *(Andropogon scoparius)* and shrubs and trees such as cottonwood *(Populus deltoides)*, trembling aspen *(Populus tremuloides)*, sand cherry *(Prunus pumila)*, dogwood *(Cornus stolonifera)*, and willows *(Salix sp.)* gain a foothold. Numerous animals find shelter and food among the trees and shrubs (Reid and Holland 1997).

Blowouts occur most frequently in the foredune area. Wind or human activity that treads heavily and wears away vegetation creates gaps in the dune. As a break in the side of a dune is excavated by the wind, sand and vegetation quickly erode, leaving a saucer-shaped depression. Serious blowouts begin as a result of human activities (Reid and Holland 1997).

Interdunal areas lie protected from wind and waves behind the foredunes. These areas include unique sand dunes and globally imperiled communities called pannes or interdunal wetlands–calcareous, wet, interdunal depressions–which form near the water table. Vegetation in these areas may include asters *(Aster ptarmicoides)*, sedges *(Carex garberi, Carec viridula)*, and lobelias *(Lobelia kalmii)*, with jack pines *(Pinus banksiana)* and cottonwoods *(Populus deltoides)* at the edges (Reid and Holland 1997).

Parabolic, longitudinal, and transverse dunes form as a result of vegetational patterns and wind direction and are characterized by their unique shapes. Backdunes occupy inland areas. Their size and shape are more stable than those of foredunes due to the well-established vegetation that prevents wind erosion except in extreme weather. Successive ridges of backdunes contain different plant communities. At the Indiana Dunes National Lakeshore, for example, the first ridge of backdunes is dominated by jack pine *(Pinus banksiana)*, white pine *(Pinus strobus)*, juniper *(Juniperus communis)*, and an understorey of plants that includes poison ivy *(Rhus radicans)*. The second line of backdunes supports an oak community characterized by black oak *(Quercus velutina)*, white oak *(Quercus alba)*, and basswood *(Tilia americana)*. Furthest inland is the beech-maple dune community with a forest of beech trees *(Fagus grandifolia)* and maple trees *(Acer rubrum)*, well-developed soil, a complex plant understorey, and diverse populations of mammals, reptiles, and amphibians (Reid and Holland 1997).

Several unusual dune types are found at Sleeping Bear Dunes National Lakeshore. Perched dunes rest on a plateau of glacial sediment. Falling dunes form as sand migrates off perched dunes and builds on an adjacent lowland. De-perched dunes form on lowland areas beyond plateaus (Reid and Holland 1997).

Dune and swale or ridge and swale community complexes are found in several places throughout the Lake Michigan basin. They were formed as the ancestral Great Lakes receded. In the south, the dunes or ridges stretch parallel to the Lake Michigan shore and are rich in oak savanna species. The wet swales between these ridges support rich prairies and sometimes rare coastal plain marsh communities. In the north, ridges are typically dominated by red and white pine and other conifers, and the swales by white cedar swamps or sedge meadows (Reid and Holland 1997).

On the eastern shore of Lake Michigan an invasive non-indigenous species is threatening dune ecosystems. Baby’s breath is moving into sensitive areas and out-competing native species. Control measures such as hand pulling and herbiciding are being used at Point Betsie and at the outskirts of Sleeping Bear Dunes National Lakeshore.

The Lake Michigan dunes are numerous, diverse, and irreplaceable. A list of representative protected dune types are provided in Appendix G.

Coastal Shore System: Sand Beaches

Sand beaches form when waves and wind deposit sand eroded from other places on exposed shoreline. The sand settles until storms or ice transport it elsewhere or until the wind lifts and deposits it inland to form dunes. Beaches are rich areas for migrating shorebirds that feed on algal mats and for a variety of microfauna.

Sand beaches may be erosional, transitory or depositional. Erosional beaches lose more sand than is deposited by waves or wind. Transitional beaches collect and lose sand so that there is no net gain or loss. Depositional beaches receive more sand than is lost over time. Shoals, sandbars, and spits protect lagoons and coastal marshes from wave and wind action (Reid and Holland 1997).

On the psalmolittoral part of the beach, land and water constantly interact. Its inhabitants include microscopic protozoans, algae, mircrocrustaceans, and insect larvae. Next to the psalmolittoral beach lies the lower beach. Waves scour the sand, which is devoid of vegetation, most heavily during summer storms. Scavenger beetles, flies, and spiders visit here. The middle beach collects driftwood and debris deposited by winter and summer storms and ice. Tiger beetles, ground beetles, flies, spiders, and other insects, as well as shorebirds, feed here. Vegetation is sparse and hardy. The drought-tolerant sea rocket *(Cakile edentula)*, an annual herb, colonizes early. The upper beach is vegetated with biennials and perennials such as wormwood *(Artimesia campestris)*, beach pea *(Lathyrus maritimus)*, and evening primrose *(Oenothera rhombipetala)*. Butterflies, beetles, spiders, and ants frequent this drier sand habitat (Reid and Holland 1997).

Artificial shoreline structures and hardening of the shoreline have interrupted the important process of longshore sediment transport that naturally erodes and replenishes sand beaches. Tons of sand are brought in to artificially replenish beaches each year for recreational purposes.

Beaches are found all around the Lake Michigan basin. In urban areas such as Chicago where the shoreline is artificial, sand must be brought in every year to nourish the beaches, which are held in place by a series of revetments. These urban beaches are recreational and offer little in the way of wildlife habitat or nourishment as described above. Some of these beaches also experience episodic, short-term closures due to high bacteria counts. The elevated bacteria levels may be derived from urban runoff following storm events, combined sewer overflows, animals, or other sources.

Away from urban centers, more beaches with values for wildlife are protected. A series of national and state parks around the lake provide set-aside beaches for animals, particularly shorebirds and plant communities. Illinois Beach State Park and Indiana Dunes National Lakeshore, for example, have a high number of visitors each year because of their accessibility to Chicago. However, a part of their beaches are off limits to park visitors to protect rare plant and animal communities. The Indiana Dunes National Lakeshore ranks third in species diversity of all national parks.

In the north, where Lake Michigan is colder, beaches are less crowded; therefore, wildlife areas are more numerous. Several plant species are endemic to the Great Lakes and found on the northern shore of the lake. The dwarf lake iris *(Iris lacustris)*, ram's head lady's slipper *(Cypripedium arietinum)*, and the federally threatened pitcher's thistle *(Cirsium pitcheri)*, which is also found at the southern end of the lake, are all endemics.

The piping plover *(Charadrius melodus)* is a Great Lakes endangered shorebird found along the north shore of the lake. Once common in the Great Lakes, its breeding range is now limited to protected areas such as Sleeping Bear Dunes National Lakeshore and Wilderness State Park.

The sites mentioned in the previous section on sand dunes also have sand beaches of ecological importance. Two sites illustrating the differences in sand beaches from north to south in the Lake Michigan basin are discussed in Appendix G.

Coastal Shore System: Alvars

The northern Lake Michigan Garden Peninsula is home to a rare ecological habitat called an alvar. Alvars are open areas of thin soil over limestone or marble bedrock, which host a distinctive vegetation community, including a considerable number of rare plants. In North America, alvars occur only in the Great Lakes basin, where they are scattered in an arc from Michigan's Upper Peninsula through southern Ontario to northwestern New York state.

Alvars undergo periodic flooding followed by drought, and their very shallow soils are subject to high surface temperatures in mid-summer. Alvars have been described as "habitats for the hardy," since plants that thrive there must be able to withstand harsh conditions. Trees are scattered and often stunted or deformed.

Alvar habitats support several types of bedrock pavement, grassland, and savanna communities, most of which are considered globally rare. Plant species include an unusual blend of boreal and prairie species, relics from the period following the last glaciers. Alvars are home to unusual wildlife species including the loggerhead shrike *(Lanius ludovicianus)* and a large number of distinctive invertebrates, such as leafhoppers and land snails (Reschke and others 1999).

Second home development and recreation are increasing in the Garden Peninsula and may have an impact on alvars. There is no known organized effort to protect alvars in the areas at this time.

Coastal Shore System: Lake Michigan Islands

Off the coast of Little Traverse Bay are 11 islands known as the Beaver Island Archipelago. They provide significant habitat for shoreline species such as colonial nesting birds, including the Piping Plover. They are important stopover sites for migratory birds. The natural landscapes found on the mainland are found on the islands. These include dunes, sand and cobble beaches, boreal and hardwood forests, and cedar swamps. The Great Lakes endemic pitcher's thistle *(Cirsium picherii),* dwarf lake iris *(Iris lacutris),* and Houghton's goldenrod *(Solidago houghtonii),* are found along the shorelines.

Several other island groupings are found in Lake Michigan. The North and South Fox Islands lie just to the south of the Archipelago. Just over 16,000 acres in size together, the islands are beach and second growth forest communities.

South of the Fox Islands and off the shore from Sleeping Bear National Lakeshore are North and South Manitou Islands. The interior of the islands are hardwood forest with small lakes. There are fragile perched dunes on the west side of South Manitou, and a grove of virgin white cedar trees is more than 500 years old. Island mammals include fox, beaver, coyote, and snowshoe hare. Much of the island is managed as wilderness.

The topography of North Manitou Island varies considerably. Part of the island is low dunes with a lake in the center and rugged bluffs to the west. Deer introduced to the island in 1927 multiplied considerably due to lack of predation. As a result, deer overbrowsing began to damage the island's vegetation. The deer population is now managed (Michigan Department of Natural Resources 2000).

Coastal Shore System: Wildlife

Of the 94 species of Wisconsin breeding birds associated with aquatic habitats, 31 rely on nearshore, shoreline, and islands of Lake Michigan for nesting, cover, roosting, or feeding (Robbins 1991). Seven of the 10 Wisconsin threatened or endangered bird species use shoreline and islands during the breeding season. Important waterfowl nesting sites for 33 percent of the breeding pairs of dabbling ducks in the Great Lakes are located on Lake Michigan at sites concentrated in Green Bay, Big Bay de Noc, and along the eastern shore.

Osprey and bald eagles are two aquatic raptors that historically nested along the shoreline of the Great Lakes and on offshore islands. While bald eagles have attracted attention, mostly because of the effects of toxic chemicals on their reproduction and development, it has also become apparent that reestablishing viable populations of eagles in the Great Lakes requires more than clean water. Nesting adult eagles use coniferous perches that are isolated from human disturbance (Bowerman 1991). A survey of Lake Michigan found that 49 percent of the coast is unsuitable as eagle nesting habitat (Bowerman 1993). The eagle's sensitivity to disturbance and need for a large forage area require the protection of extensive coastal habitat if bald eagles are to play more than an isolated and infrequent role in the ecosystem. Continuing work by Bowerman confirms these findings (Beck, personal communication).

For several species of reptiles and amphibians, the temperature moderating effects along Lake Michigan's shoreline is, in part, responsible for an extension of their range north into Wisconsin.

Species such as the western ribbon snake are adapted to sandy margins of the lake (Wisconsin Department of Natural Resources 1993).

Coastal Shore System: Assessment

Recreational home development is increasing on the Lake Michigan Islands. In addition, invasive non-native species are beginning to impact dune areas. Key protection needs include developing inventories of significant biodiversity areas, establishing monitoring programs for rare and threatened plants and animals, and developing and implementing protection programs.

Conflicting coastal shore values and uses will continue to degrade the coastal shore system. Use of sand in industrial processes, continued shoreline bordering to prevent erosion of private properties, longshore sand transport disruption by jetties and other structures, invasive species introductions, and an increase in off-road dune use will alter the coastal shore system and reduce its ability to function as a system. Beaches are a primary environmental and economic concern in the coastal shore system. Periodic, short-term beach closures due to elevated bacteria levels and the need to regularly replenish sand on the beaches impose management costs and may result in the loss of recreational revenue.

These threats have resulted in the established of protection programs for certain Lake Michigan islands. Several islands are Designated Environmental Areas under Part 323 of Michigan Act 451 of 1994, as amended. In addition, part of the Beaver Island group and some islands near the Straits of Mackinac are Designated Environmental Areas. These areas are set apart for the protection and maintenance of fish and wildlife. Permits are required for dredging, filling, soil or natural drainage alteration, vegetation cutting, and building.

Subgoals 4 and 8 have not been met. Subgoal 5 is well on its way to being met as public access to the shoreline increases in parks and protected areas. Subgoal 6, however, will not be met until conflicting land uses are sorted out and prioritized. Subgoals 9, 10, and 11 are underway in pockets throughout the basin.

4.2.2.6 Lakeplain System

The lakeplain system occupies the area of the ancestral lakebed of Lake Michigan, formed as the lake receded after the last ice age. Southern Lake Michigan has a low topography and a high water table supporting extensive beach ridges and swales, prairies, savannas, wet meadows, sand barrens, and coastal plain ponds. Lakeplain prairies and savannas, two of the most imperiled ecological communities in North America, are found here. Rare alvar communities are found on the shores of northern Lake Michigan. The lakeplain system harbors a rich diversity of plant and animal species, more than any other system. Several species, including the prairie white-fringed orchid *(Plantanthera leucophaea)* and the Karner blue butterfly *(Lycaeides samuelis)*, are federally endangered (The Nature Conservancy 1994).

Lakeplain System: Description

Lakeplains occur where the ancestral Great Lakes occupied a different basin than those present today. Those former lakebeds are characterized by low topography with sandy, silty, or clay soils and a high water table. The major topographic features are linear sandy beach ridges that were formed as the lakes receded in incremental stages (The Nature Conservancy 1994).

Hydrologic fluctuations, both of groundwater and of Lake Michigan, are important to the functioning of the lakeplain system. Lakeplain systems have two important functions. First, during times of severe weather, this system is a refuge for species that normally reside on or near Lake Michigan. Second, prior to heavy impacts to the lakeplain system due to development, this system was probably important in floodwater retention.

Although the lakeplains may extend some distance back from the shore, natural hydrological cycles associated with groundwater flow and lake level fluctuations play a key role in maintaining habitats for rare communities (The Nature Conservancy 1994). They also are a significant source of fine materials that erode to the lakes in tributary floods and contribute to the sand and clay components of littoral drift.

Four important lakeplain ecological communities–lakeplain prairies, oak savannas, sand barrens, and Atlantic coastal plain disjunct communities–are described briefly.

Lakeplain System: Lakeplain Prairies

Lakeplain prairies consist of rich and deep soils on which a variety of tall grasses and flowers grow. The grasses may reach 12 feet in height. The roots of some of the prairie plants reach as far below the ground as the plant above ground. The lakeplains on which the tallgrass prairies grow were formed from sediments deposited as the Wisconsin glacier receded more than 10,000 years ago.

Prior to European settlement, the tallgrass prairie peninsula extended from the southern Lake Michigan area in northeastern Illinois and Northwest Indiana through southern Michigan to Ontario. Since the mid-1800s, lakeplain prairies have been converted to agriculture. Only tiny parcels remain–less than 0.01 percent of the original. The best remaining fragments in the Lake Michigan basin are found at Chiwaukee Prairie in Southeastern Wisconsin, Markham Prairie in Northeast Illinois, Hoosier Prairie in Northwest Indiana, and Allegan State Game Area in Southwest Michigan (Albert 1996).

Lakeplain prairies depend on the water-level fluctuation of the lake. Their deep root systems enable these prairies to hold water, acting much as marshes do. Periodic fires and fluctuating water levels help prairies maintain their open, treeless condition. Organic material such as leaf litter is eliminated, allowing new growth.

Wet lakeplain prairies are found at the shoreline or growing contiguously with coastal marshes. Vegetation includes grasses such as blue joint grass *(Calamagrostis canadensis)* and prairie cordgrass *(Spartina pectinata)*, sedges such as *Carex stricta* and *Carec aquatilus*, red osier dogwood *(Cornus stolonifera)*, and shrubby cinquefoil *(Potentilla fruticosa)* (Reid and Holland 1997).

Dry or mesic lakeplain prairies lie at the edges of the wet prairies. Plant species include big bluestem grass *(Anropogon gerardii)*, little bluestem grass *(Andropogon scoparius)*, Indian grass *(Sorgastrum nutans)*, switch grass *(Panicum virgatum)*, tall coreopsis *(Coreopsos tripteris)*, blazing star *(Liatris spicata)*, and Ohio goldenrod *(Solidago ohioensis)* (Reid and Holland 1997). The Prairie white fringed orchid *(Platanathera leucophaea)* is a federally threatened lakeplain prairie plant (Reid and Holland 1997).

Formerly, the foremost lakeplain prairie animals were bison and elk. Both species are gone, along with other large mammals, from present lakeplain prairies. Today, muskrats are found in wet prairie areas. Prairie ant mounds and crayfish chimneys lie inconspicuously among tallgrasses. The king rail is sometimes spotted at wetter sites. Insects, including grasshoppers, true bugs, leafhoppers, spittlebugs, planthoppers, and treehoppers. *Papaipema sciata*, a moth borer dependent on Culver's root (*Veronicastrum viginicum*), is also a notable lakeplain prairie forb (Reid and Holland 1997).

Lakeplain prairie fragments retain insect populations and many plant species. However, few of these prairies remain. The tiny sites that have been preserved are disconnected from the large lakeplain system and are still at risk from being impacted by stressors from outside the preserves, such as water level changes due to nearby development. In addition, lack of prescribed fire and exotic species are major challenges for preserve managers. Since many sites are located in urban areas, conducting prescribed burns must be done with extreme caution. Exotic species are numerous and require laborious efforts to control. Examples of significant lake plain prairies are presented in Appendix G.

Lakeplain System: Oak Savannas

Oak savannas are areas that lie between the prairies of the west and the deciduous forests of the east. In pre-European settlement times, they were a transition zone, maintained by frequent fires and probably by bison, elk, and deer. A variety of oaks dominate the canopy. The understory and ground layer vegetation is characterized by few shrubs and a rich variety of grasses and forbs. Plant species vary in relation to shade and sun tolerance. Savanna plant species found in preserves today include Indiana plantain, yellow pimpernel, downy wild rye, elm-leaved goldenrod, and New Jersey tea (Wisconsin Department of Natural Resources 1995).

Savannas formerly were habitat for the timber wolf, bison and elk, now extirpated from this landscape. Long-tailed weasels, red fox, woodchuck, rabbits, and white-tailed deer, however, are doing well today. Except for the ill-fated passenger pigeon, many savanna birds species such as the American robin, indigo bunting, blue jay, and American goldfinch are still doing well. This is due to the many woodlots still found on many home sites. A number of species have begun to decline in recent years, including the red-headed woodpecker and the warbling vireo. One butterfly, the Karner blue butterfly *(Lycaeides melissa samuelis),* is currently designated as a federally endangered species, but remains in healthy populations in the savannas of Northwest Indiana and central Wisconsin as well as in oak barrens (Wisconsin Department of Natural Resources 1995).

Of the many amphibians and reptiles associated with oak savannas, many seem to be surviving well. These include gray treefrog, five-lined skink, and smooth green snake; however, the western slender glass lizard and the eastern Massasauga rattlesnake are now threatened. The Blanding’s turtle is also considered rare and threatened (Wisconsin Department of Natural Resources 1995).

Although they were probably relatively dynamic, not much is known about the original savannas. Since they were attractive to early settlers, they were first settled and cleared for agriculture or used for cattle grazing. Fires were controlled, and invasive exotic species such as honeysuckle and buckthorn moved in to replace the diverse ground cover. It is estimated that of the original 5.5 million acres of oak savanna in Wisconsin at the time of European settlement, less that 0.01 percent remains, most in degraded condition. Threats to the oak savanna ecosystem continue due to increasing development, invasion by exotics, a resistance or lack of understanding about the role of prescribed burning in maintaining the ecosystem, and the acceleration of forest succession and lack of recruitment (Wisconsin Department of Natural Resources 1995).

Several outstanding examples of remaining oak savannas in the Lake Michigan basin are described in Appendix G.

Lakeplain System: Sand Barrens

Sand barrens are areas of deep sands with scattered, sometimes scrubby, oak and pine trees and a ground layer of sedges and forbs. "Sand savanna" is sometimes used interchangeably with "barrens." Barrens, however, are differentiated by their poor, sandy soils and frequent, intense fires. They are dynamic -- sometimes characterized by open-canopies with prairie-like vegetation, and sometimes characterized by denser vegetation more like woodlands (Wisconsin Department of Natural Resources 1995).

In the Lake Michigan basin, sand barrens are found on the southern lakeplain and on the eastern shore of Lake Michigan in the northern part of the lower peninsula of Michigan. Sand barrens are associated with white pines *(Pinus strobus)* and jack pines *(Pinus banksiana),* species that dominate the first back dunes. At the time of European settlement, white pines were heavily logged, and, as a result, jack pines flourished. Few white pines remain today (Wisconsin Department of Natural Resources 1995).

In addition to jack pines, pine barren communities consist of junipers *(Juniperus communis)*, shrubs such as sand cherry *(Prunus pumila)*, and forbs such as sand cress *(Arabis lyrata)*. The endangered Kirtland's warbler *(Dendroica kirtlandii)* is a jack pine barren species (Reid and Holland 1997).

Dune ridges and back dunes inland from pine barren communities are dominated by black and white oak barrens communities *(Quercus velutina and Q. alba)*. The oak communities have a lush understory of grasses, including tallgrass prairie species like big and little bluestem *(Andropogon gerardi and A. scoparius)*, sedges such as Pennsylvania sedge *(Carex pennsylvanica)*, and forbs such as lupine *(Lupinus perennis)*, hoary puccoon *(Lithospermum canescens)*, and yellow lady's slipper orchid *(Cypripedium calceolus)*. The endangered Karner blue butterfly *(Lycaeides melissa samuelis)* is an oak barrens resident. Oak barrens are also rich in bird species, including the red headed woodpecker *(Melanerpes erythrocephalus)* (Reid and Holland 1997).

Oak barrens communities are fire dependent. The suppression of fire since European settlement has had a damaging effect on oak communities. A buildup of woody debris prevents oak regeneration and may be a hazard to nearby properties as well. In addition, increased development is threatening barrens communities (Wisconsin Department of Natural Resources 1995).

Two examples of high quality oak barrens communities are Shakey Lakes and Dunbar Barrens are discussed in Appendix G.

Lakeplain System: Atlantic Coastal Plain Disjunct Communities

Atlantic coastal plain disjunct communities are whole communities of plants whose normal distribution lies in a band along the Atlantic coast of the eastern United States. In the Lake Michigan basin, these communities are concentrated around the southern end of Lake Michigan and extend northward into Michigan. These communities occur only on sandy or peaty shores with fluctuating water levels. They appear to be relic fragments of previously more extensive sandy shores associated with past higher lake levels. Coastal plain community species are thought to have migrated into the Great Lakes basin some 11,000 years ago, when a drainage channel down the Hudson River connected with the Atlantic coastal plain. These communities are vulnerable to shoreline development and stabilized water levels. Atlantic coastal plain disjunct communities are protected in the Indiana Dunes parks and in preserves in southwestern Michigan (Reid and Holland 1997).

Lakeplain System: Assessment

Because of their location primarily at the southern end of Lake Michigan and also because of their desirability as both building sites and agriculturally rich soils, the lakeplain system of the Lake Michigan basin has been largely transformed since European settlement. Many of the original plants and animals of these ecosystems survive in small protected areas, although threats are still degrading these protected areas. The ecosystems of the lakeplain system are considered rare because few remain. Of the original thousands of acres of lakeplain prairies and oak savannas, less than 1 percent exists today. The consequences are that the original services provided by the lakeplain system have been severely disrupted or are non-existent. For example, the wetland-like capacity of lakeplain system to hold water is greatly diminished due to a decrease in the size of lakeplain area, and, therefore are of little help during flooding.

Subgoals 4 and 8 have not been met. The communities are not viable or sufficient to sustain a diversity of communities. Exotic species are a major concern throughout the lakeplain. However, the actions of groups such as Chicago Wilderness and other partnership groups may help to establish a sustainable system. Therefore, subgoals 9, 10, and 11 are well on there way to being accomplished.

4.2.2.7 Inland Terrestrial System

The inland terrestrial system or upland areas of the Lake Michigan basin include numerous forest types, barrens, and prairies. The oak and pine barrens of northern Wisconsin and Michigan are globally significant ecological communities due to their rarity. The Kirtland's warbler (*Denroica kirtlandii*) is an endemic species found only in the barrens of Michigan. The inland terrestrial system is the result of a glaciated landscape and of the climatic effects, such as temperature and humidity, of the Great Lakes themselves. It is the collector of precipitation that feeds the other systems. Large forested areas, for example, influence the rate and quality of that precipitation. The system filters the water going to groundwater and to the lakes and rivers. A healthy inland system provides for erosion control as well as habitat and migration corridors for many species (The Nature Conservancy 1994).

Inland Terrestrial System: Description

Although forests, barrens and prairies are all a part of the inland terrestrial system of Lake Michigan, only forests and the Niagara Cuesta will be discussed in this section because a description of barrens and prairies appears elsewhere in this document as part of other systems. The Niagara Cuesta is included because it is a rare landform in the Great Lakes basin.

Inland Terrestrial System: Forests

In general, the inland terrestrial system of the Lake Michigan basin is forest interspersed with numerous lakes and streams. The southern forests are generally dominated by oak species and the northern forests are dominated by conifers.

Southern Forests

In the southern part of the basin, the forests are characterized by red, white, black, bur, northern pin and swamp white oaks trees, and by shagbark hickory, hackberry, boxelder, and black walnut. Conifers are generally absent except for remnant jack and white pines in sandy areas of preserves close to the lake. Although dominated by oak communities, these southern forests also have an eastern hardwood component. Sugar maple, basswood, American beech, ironwood, American elm, and white ash are found, particularly in southwest Michigan (Wisconsin Department of Natural Resources 1995).

In addition to the general absence of conifers in the southern forests, the groundlayer of southern forests is known from surveyors' notes to have differed from northern forests in that it was in general more open due to lack of small trees and shrubs. This was a result of frequent fires that were a part of the landscape for thousands of years prior to human settlement (Wisconsin Department of Natural Resources 1995).

All of the large mammals, including buffalo, bison, elk, cougar, bobcat, and black bear, have been extirpated from Lake Michigan southern forests. Generalist species and those that adapt well to human inhabitants remain, sometimes in large numbers. Racoons, skunks, red fox, and coyote have been particularly adaptive to changed landscapes. White-tailed deer are present in populations considered unsustainable by many wildlife biologists. Deer have increased greatly and are browsing on native vegetation causing great damage. Browsing is hampering the reproduction of trees and certain rare plants such as orchids (Wisconsin Department of Natural Resources 1995).

Fragmentation or elimination of southern forests has resulted in a change in the composition of bird species. The understory or groundlayer has changed from a rich assemblage of forbs and grasses to an over-grazed or mowed simplified structure and therefore does not support a variety of bird species. Songbird species, therefore, have decreased and are undergoing further declines. Even cavity nesting and insect-foraging birds have declined due to logging and wood gathering (Wisconsin Department of Natural Resources 1995).

Forests in the southern part of the basin are extremely fragmented. In some southeastern Wisconsin counties, for example, there are probably no true remaining forests. In Michigan, the percentage of forests remaining compared to pre-European settlement is not known. Current predictions are that these forests, now woodlot size for the most part, will continue to be lost due to harvest and fragmentation; forest composition will continue to shift from commercially valuable oak species to less desirable species; and the long-term economic value of the southern forests will diminish (Wisconsin Department of Natural Resources 1995).

Northern Forests

North of the transition zone that separates the predominantly deciduous southern forests from the northern forest, about 30 tree species are found interspersed among several community types. In richer soils are the hardwoods, sugar maple, basswood, hemlock, yellow birch, white ash and American beech. Before settlement, white pine was an important component. In poor, sandy soils, jack, red, and white pine, as well as aspen, white birch, red maple, and red oak dominate. Wetland forests are common and are of two types. Conifer swamps are dominated by black spruce, tamaracks, and white cedars. Hardwood swamps are dominated by black ash, red maple, and elm (Wisconsin Department of Natural Resources 1995).

With the exception of the sustainable yield forests of the Menominee Indian Reservation, the mixed-deciduous forests of the northern part of the basin have lost their coniferous component. White pine is largely absent and not regenerating in these forest types. In addition, the composition of hardwoods has changed. Sugar maple dominates, yellow birch is less common, and basswood and white ash are now more dominant. The aspen-birch forest type is the largest forest cover type in the state of Wisconsin at the present time (Wisconsin Department of Natural Resources 1995).

It is thought that few mammal species have been lost due to change in forest composition, although the relative abundance of a variety of species has decreased. At one time, the elk, woodland caribou, Canada lynx, fisher, pine marten, eastern timber wolf, and eastern cougar have been extirpated. The fisher, pine marten, and eastern timber wolf have been reintroduced. Eastern cougars and moose have been found in low numbers. A list of 389 vertebrate species of northern forests was compiled by Benyus and others (1992). Of those species, 152 were restricted by habitat type, 53 percent were uncommon, and 71 percent were birds. Lack of large blocks of uninhabited lands limits large animal populations (Wisconsin Department of Natural Resources 1995).

Interior bird species have been impacted by forest fragmentation and the changes in forest composition. Included are a variety of warblers, the eastern wood-pewee, and Swainson's thrush. Species that adapt easily to edge and young forests, such as the ruffed grouse and the rufous-sided towhee, however, have increased (Wisconsin Department of Natural Resources 1995).

The size of the northern forests will probably remain approximately the same for the near future. If forest succession progresses, the aspen-birch forest type will decrease and will be replaced by white pine, red maple, and red oak. Clearcuts and plantations will continue to fragment mature hardwood forests (Wisconsin Department of Natural Resources 1995).

Several examples of forests and their composition around the Lake Michigan basin are presented in Appendix G. They illustrate the rich variety of forest types and species present. Many more forests exist than are discussed in Appendix G, particularly in private holdings either by large corporations or by individuals.

Inland Terrestrial System: Niagara Cuesta

The Door County Peninsula and the Garden Peninsula form the western end of the Niagara Cuesta, a rocky outcrop of dolomite and limestone that arcs to Niagara Falls on the western edge of New York. The escarpment is forested with maple, beech, red oak, white pine and hemlock. The trees cool the thin-layered soils of the escarpment. Moisture seeps from the rock and harbors populations of rare land snails including *Succinea bakeri, Catinella gelida* and *Vertigo hurichti*. Until recently, the escarpment was protected from development found elsewhere in Door County because of its relative inaccessibility and the difficulty of installing wells and sewage treatment. However, an increase in tourism is putting pressure on these areas. In both Door County and the Garden Peninsula, development is increasing on the escarpment even as new species, such as the rare snails, are being discovered (Grimm No Date).

Inland Terrestrial System: Peninsula Park Beech Forest State Natural Area, Wisconsin

Peninsula Park White Cedar Forest includes cliffs of Niagara dolomite, open marshes, calcareous meadows, cedar-spruce swamps, and an upland forest of white cedar, white birch, and sugar maple. A variety of flora is seen in all the communities and includes blue joint grass and rushes, birds-eye primrose, gaywings, fringed gentian, low juniper, yellow lady's-slippers and Indian paint brush. Birds include the winter wren, red-breasted nuthatch, black-throated green warbler, blackburnian warbler, ovenbird, and veery. Peninsula Park's beech forest features sugar maple, American beech, hemlock, yellow birch, white birch, and ironwood. Relic red oak and white pine are found in the area. The bluff is terraced and forested with white cedar and hardwoods. At the base of the bluff are ferns including cliffbrake, walking, and marginal wood ferns (Wisconsin Department of Natural Resources 2000).

Inland Terrestrial System: Assessment

Currently, there is no unified forest classification system for Lake Michigan basin forests. Nor is there a regional landscape overview or forest plan in place to protect forest diversity and therefore, the economic potential of the region. Little consideration is given to forest processes and their functions in relation to the inland terrestrial system, and as a consequence, the relationships to overall basin health. Exotic species have had an impact in the southern forests and are beginning to have an impact in the north. Nevertheless, there is a potential, particularly in the northern forests, to develop ecologically sound management techniques to encourage natural processes and therefore, a richer forest ecosystem and biodiversity.

Subgoals 4 and 8 have not been met. However, strides are being made in subgoal 9 with the model of forest management offered by the Menominee Tribe. No collaborative management system is in place for forest management basinwide, and there are many data gaps yet to be filled. Thus, subgoals 10 and 11 remain unmet.

4.2.3 Wildlife

The preceding sections described and assessed the status of individual habitats in the basin. The following section provides an overview of wildlife status and health throughout the ecosystem.

The Lake Michigan basin is home for many species of mammals, birds, reptiles and amphibians. It is also a resting and feeding place for several species of migratory birds. This section chronicles a few key trends in the populations of this assemblage of wildlife. Land use changes from industrial development, residential development, shoreline modifications, and navigation have dramatically and permanently altered Lake Michigan basin habitat available for wildlife.

There is a growing body of literature supporting the use of wildlife populations as indicators of ecosystem health; it suggests that many species are sentinels for toxic chemical effects, although conclusive linkages between all such effects and chemicals remain elusive.

Lake Michigan provides migratory and nesting habitat for waterfowl. Approximately 26 percent of prime waterfowl habitat on the shores of the Great Lakes is on Lake Michigan. This habitat is so good that it supports more than its share of waterfowl nesting, accounting for approximately 33 percent of breeding pairs of dabbling ducks in the Great Lakes. These sites are concentrated in Green Bay, Big Bay De Noc, and the coastal marshes in Michigan along the eastern shore of the lake.

The only advisories for human consumption of avian wildlife in the Lake Michigan basin are for mallards in selected reaches of Lower Fox, Sheboygan, and Milwaukee Rivers in Wisconsin and for lesser scaup, black ducks, mallards and ruddy ducks in the Milwaukee River Harbor.

Top predators, such as the bald eagle and osprey are gradually making a comeback in the Lake Michigan watershed after years of decline due to reproductive failure caused by toxic chemicals. As levels of contaminants dropped in the food web, contaminant concentrations in top predators, along with the associated health effects, also decreased. However, as noted below, there are still continuing problems with wildlife in the Lake Michigan basin.

Mammals in the basin live primarily on land. A number of species, such as mink, beaver, and otter, rely on water for food, supplies or shelter. Effects of toxic chemicals on mink and otter are well documented, but current levels of contaminants in Lake Michigan wildlife are not well-known.

Not all wildlife in the Lake Michigan basin are beneficial, either because a species is non-native or because a species is locally too abundant. Gulls and geese are sources of biological pathogens that can cause problems in local areas if the birds are overly abundant. In addition, cormorants may be a nuisance to Lake Michigan fisheries. Aquatic nuisance species are documented elsewhere in this LaMP. Non-native terrestrial wildlife have not developed into serious nuisances in the Lake Michigan basin to date.

Key stressors for wildlife include habitat disruption, exotic species, and toxic contamination. Habitat disruption and exotic species are examined in Chapter 5 and are discussed briefly below. This section concludes with a discussion of the impact of toxic contamination on Lake Michigan wildlife.

Habitat Disruption

Habitat disruption is typified by physical alteration such as building, dredging and filling, roads, and deforestation. These effects are documented in the preceding habitat discussions of this LaMP, especially related to wetlands. Habitat changes have a major effect on wildlife in the Lake Michigan basin and have great potential future effect on healthy populations of wildlife due the permanent nature of the changes. The single most important factor currently impairing or threatening populations and productivity of most bird species within the Great Lakes basin is the lack of suitable habitat. This condition results from the loss of wetlands and forests, effects of dam and water course modifications, human disturbance of breeding locations, and reduction of natural nesting sites due to human encroachment (Limno-Tech 1993).

Aquatic Nuisance Species

Effects of aquatic nuisance species are documented in Chapter 5. These nuisance species have had the greatest impact on aquatic plants and fish. Tremendous changes have occurred in the Lake Michigan basin due to accidental and intentional introductions of non-native species. Some habitat and food supplies have been altered by aquatic plants in wetlands and shoreline areas. An example is the proliferation of purple loosestrife and the poor quality food supply it provides for native species of wildlife.

Toxic Contamination

This stressor's effect on wildlife populations is well documented for top predators in the Lake Michigan basin. Sources of toxic contaminant stressors are documented in Chapter 5. Top predators in the open lake waters include osprey, bald eagle, terns, cormorants, and humans.

Mammals

Mink are considered to be one of the most biologically sensitive mammals to PCB, PBB, HCB and TCDD contamination (Aulerich and others 1977), and as early as 1965 it was suggested that a diet containing fish from Lake Michigan could be causing reproductive problems in mink populations. Mink harvest numbers began to decline in the mid-1950s, reaching a low point in the 1970s and slightly recovering in the 1980s. This trend is similar to population changes witnessed for some fish-eating and predatory birds (Environment Canada 1991).

More recent reports from trappers surveyed in 1991 and 1994 found that wild mink populations throughout marshes adjacent to Green Bay were depressed (Meyer and Hurley 1991). The mink trappers' success ratio along an area within one mile of the Fox River and Green Bay shoreline was lower than any other area surveyed throughout Wisconsin. (A success ratio is developed by considering the number of trappers, number of mink trapped, and a success index equaling the amount of effort, number of traps, number of sets, etc.) While no studies have been conducted on the possible impact of PCBs on mink and otter in the Green Bay area, circumstantial evidence suggests that these mammals may be affected by contaminants in the Fox River/Green Bay ecosystem.

Mink populations have declined along the Great Lakes shoreline, industrialized rivers, and undammed rivers to which Great Lakes fish have access (Wren 1991). Likewise, the habitat in the Sheboygan AOC is suitable for mink, but population levels are thought to be below normal for this type of habitat (WDNR 1993). Fish from Green Bay and the Fox River shoreline have elevated PCB concentrations second only to those below Wisconsin's Sheboygan River Superfund site (Meyer and Hurley 1991). Rodents and shrews collected from the industrialized portion of Wisconsin's Sheboygan River had levels of PCBs and metals that exceeded background indicating that contaminants in this ecosystem are also bio-available to terrestrial species. Some rodents had whole body PCB concentrations exceeding dietary exposure known to cause reproductive impairment in mink (Heaton and others 1991). Given the known contamination of potential prey, it is highly probable that litter sizes and kit survival are lower along both the Green Bay/Fox River and Sheboygan River shorelines.

Over-harvesting of the river otter in the early 19th century resulted in the near destruction of most otter populations (WDNR 1993). Their slow recovery was probably due to a combination of factors including low reproductive potential (Burt 1972), habitat loss due to development and reproductive suppression from environmental contaminants (Environment Canada 1991). A wildlife contaminant monitoring study done by MDNR analyzed otter carcasses for PCB's, lead, cadmium, arsenic, and mercury. Twelve out of thirteen animals found in the Lake Michigan basin had detectable levels of mercury in their system (Schmitt and others 1993). The highest mercury concentration of these samples was 6.26 parts per million (ppm), found in an otter carcass in Schoolcraft County, Michigan. None of the carcass samples analyzed had detectable levels of either arsenic or lead at a 1.00 ppm level of detection (Schmitt and others 1993).

The potential impact of environmental contaminants on otter populations around the Great Lakes is speculative and based on harvest data; no laboratory studies comparable to those in mink have been performed with otter. Harvest records show that trappers in Michigan take fewer otter near the Great Lakes shoreline than they do from uncontaminated inland waters. PCBs were detected in otter collected in Michigan in 1982,1986, and 1987 with a mean lipid concentration of 3.18 ppm and range from 0.4 to 38.5 ppm. Levels were generally higher in females and juveniles (Stuht 1991). Although field toxicity data have not been collected, these observations indicate that reduced otter populations and highly contaminated prey are correlated.

Birds

Numerous studies have been conducted into chemical related reproductive problems and deformities in avian species of the Great Lakes. Published reports of contaminant-induced adverse reproductive outcomes exist for six species of colonial fish-eating birds; namely, common terns; Caspian terns; black-crowned night-herons; herring gulls; Forster's terns; and double-crested cormorant. Observed problems include congenital malformations in chicks including bill malformations, clubbed feet, abnormal eyes, and reproductive problems (Fox and others 1991). Other abnormalities have been documented in the Great Lakes areas as well. Porphyrias are a group of disorders in which the liver metabolic processes are disrupted, causing an accumulation of nitrogen containing organic compounds, or porphyrins. These excessive levels of porphyrins can cause adverse effects, including sensitivity to sunlight and skin lesions. Porphyrins can also be used to indicate liver toxicity in wildlife. Causative agents include some heavy metals, hexachlorobenzene, and some dioxins. Various polyhalogenated aromatic hydrocarbons

(PAHs) have experimentally been shown to induce the accumulation of highly carboxylic porphyrins (HCP). High levels of HCP have been found in birds from lower Green Bay, suggesting heavy contamination by PAHs (Fox and others 1988).

Cormorants

Since their introduction to the area in the early 1900s the double crested cormorant experienced population increases up to their peak numbers in the late 1940s and early 1950s (Fox and others 1991). Since that time there has been a population collapse of the double-crested cormorant. Sometime in the early 1960s this species ceased to breed in Lake Michigan and was declining elsewhere in the Great Lakes basin (Gilberston and others 1991; Fox and others 1991). There was almost total reproductive failure of double-crested cormorant in Lake Michigan caused by the breakage and disappearance of eggs (Weseloh and others 1983). Fox and others (1991) found the prevalence of malformed chicks in Green Bay was significantly greater than in all other regions in the Great Lakes, except Lake Ontario. It is believed that the problems with Lake Michigan colonies were due to environmental contamination, since numerous studies have shown the food chain in Green Bay to be tainted with contaminants (Environment Canada 1991). Studies of double-crested cormorants in the upper portion of Green Bay and Lake Michigan have established that there is statistically significant reduced hatchability and increased incidence of structural deformities in this area when compared to a relatively uncontaminated reference area in Canada (Ankley and others, 1993). The rate of deformities had remained relatively constant to the present.

Cormorants in Green Bay and elsewhere in the Great Lakes are now becoming increasingly abundant and more widely distributed and are successfully raising many of their young to fledgling. Double-crested cormorants' eggshell thickness has increased concomitantly with declining DDE levels in the egg contents, since the late 1970s (Fox and others 1991).

Bald Eagles

The bald eagle, once flourishing in Canada, the U.S., and Mexico, experienced population declines beginning in the late 1940s and early 1950s (Environment Canada 1991). The declines were associated with reproductive failure, characterized by severe eggshell thinning and poor hatchability and chick survival that was unrelated to physical habitat alteration or a microbiological pathogen (Gilberston and others 1991). Eagle reproductivity is significantly lower in those regions where nesting eagles feed on Great Lakes species. Reproductive impairments along the Lake Michigan shoreline are correlated to DDE and PCBs. DDE has been shown to cause egg shell thinning, while PCBs have been inversely correlated to reproductive productivity and success rates (Bowerman 1993). Eagle reproductive performance of the Great Lakes is lowest on Lake Michigan, with nesting pairs approaching complete failure within five years of nest establishment (Environment Canada 1991). Since the North American ban on DDT, eagle populations and their egg shell thickness have increased. However, the recovery has not been uniform and in several regions, including the Great Lakes shores, eagle populations are not reproducing at a level considered to be healthy (Bowerman 1993). Recent research confirms this trend (Beck, personal communication with Bowerman, 2000).

The first "post-DDT era" Green Bay/Lake Michigan nest was initiated on the Oconto River near the Green Bay shoreline in 1987. Six nest attempts were made at this site from 1986 to 1991 and only one young hatched. No nest attempts have been made following the 1991 nest failure. However, adult eagles are occasionally observed on this territory. Three additional territories were established along the Green Bay shoreline in Oconto, Marinette, and Brown counties from 1988 to 1994. In 1994, the first nest was established on the West side of Door County on Toft's Point. Despite 20 nest attempts for the eagles nesting on the Green Bay/Lake Michigan shoreline, only 7 young have been produced from 1987 to 1994, for a productivity rate of 0.35 young/occupied territory. A production rate of 1.0 young/occupied territory is considered indicative of a healthy, expanding bald eagle population while <0.70 young/occupied territory is associated with a declining population (Wiemeyer and others 1993).

Availability of physical habitat does not seem to be limiting expansion of the bald eagle population along the upper Great Lakes shorelines. While bald eagles are restricted from some areas due to human disturbance or physical structure of the habitat, there are still areas, deemed to be suitable nesting habitat, which are currently unoccupied by bald eagles. It is important to maintain a healthy, uncontaminated eagle population in the interior of the state to allow for re-population of the shoreline. To do this, it is necessary to protect both the essential shoreline and interior habitats (Bowerman 1993).

Terns

Terns have also been reported as having noticeable negative side effects attributable to contaminants. Increased contaminant burdens in fish eating avian species of Lake Michigan have long been implicated in reproductive and developmental anomalies (Environment Canada 1991). Bioaccumulation factors for coplanar PCB congeners from fish consumed by terns have revealed ratios of up to 176-fold, when comparing PCB concentrations in spottail shiners and Forster's tern eggs in Green Bay (Hoffman and others 1993).

Suppression of natural reproductive productivity can have effects on population balances, as witnessed during the 1960's and 1970's for many avian species. Common tern numbers peaked in the early 1960s and have decreased since the late 1980's (Environment Canada 1991). Both the Caspian tern and the Forster's tern have been reported as having poor reproductive success in Lake Michigan (Kurita 1987). Impaired reproduction has been associated with contaminant exposure in several species. (Hoffman and others 1993). Hatching success of laboratory-incubated Forster's tern eggs from Green Bay, Wisconsin, was only one half that of eggs from an inland control colony (Hoffman and others 1987). In 1985, hatching success of laboratory-incubated common tern eggs from Green Bay and Saginaw Bay colonies was lower ($p<0.05$) than that of eggs from the Cut River (Lake Michigan) colony (Hoffman and others 1993).

Tern populations have been increasing in the Great Lakes basin as contaminant levels have declined and nesting areas have been protected, but reproduction and survival are still being impacted. In 1988, 42 percent of the Forster's tern nestlings in Green Bay died prior to fledging, and growth of surviving nestlings was much lower than normal (Harris and others 1992b). Nestlings were accumulating dioxins, furans, and PCBs from prey (Ankley and others 1993). Even higher exposures are predicted to occur in years following high river flows when contaminated sediments are moved into estuaries where colonies are nesting (Harris and others 1992a).

Other Wildlife

Very little information is available on reptile or amphibian populations and impacts of contaminant exposure in the Lake Michigan ecosystem or elsewhere in the Great Lakes basin. Amphibians may be particularly susceptible to waterborne pollutants because of their highly permeable skin and aquatic developmental stages (Wake and Morowitz, 1991). A study of leopard frog populations along Wisconsin's northern Lake Michigan in the mid-1970's found a large number of unoccupied, suitable habitats, high mortality rates at occupied sites, and acutely toxic concentrations of atrazine (Hine and others 1981). Preliminary results from a study of green frogs from wetlands along Green Bay and the Fox

River indicate that PCB and metal accumulation is occurring and that survival, development, and growth of tadpoles may be impaired by these exposures (Jung and Karasov 1995).

Snapping turtles have been used throughout the Great Lakes basin to monitor PCB accumulation because of their longevity and high fat content. A snapping turtle collected in Wisconsin's Menominee River in 1984 had 130 ppm PCBs in its abdominal fat (WDNR, 1993). A turtle collected in 1988 from Cedar Creek in the Milwaukee River basin had a PCB concentration in abdominal fat of 630 ppm, which was comparable to samples from Lake Ontario (Olafsson and others1983). Eggs from PCB-contaminated females had impaired development and a high rate of abnormalities (Bishop and others 1991). Thus, it is highly probable that snapping turtle reproduction is reduced at PCB-contaminated sites within the Lake Michigan basin.

Wildlife Assessment

This wildlife section of the LaMP has focused on two impaired beneficial uses:

- Degradation of wildlife populations
- Bird or animal deformities or reproductive problems

Deformities are documented for birds, but less so for mammals, reptiles and amphibians. Trace amounts of toxic chemicals are enough to affect reproduction and growth. The LaMP Subgoals 4, 7, and 8 are not supported for wildlife in the Lake Michigan basin, although progress is being made under Subgoal 10 to improve management activities.

4.2.4 Human Systems

While the preceding sections focused primarily on the ecological health of the Lake Michigan basin, humans are also a critical part of the ecosystem. This section addresses the role of humans in the ecosystem and trends in human populations, human interaction with the lake system, human health, and other economic activities that affect the lake ecosystem. Additional information on human health is presented in Appendix C.

Census data for 1990 indicate a basin population of 10,057,026, most of which is located in the densely populated southern portion of the basin, within the original boundary of the Lake Michigan basin. After the reversal of the Chicago River at the beginning of the twentieth century, which caused the Chicago River drainage to flow into the Illinois River system rather than Lake Michigan, the Lake Michigan watershed was reduced by 673 square miles (1.743 km^2). Because that area contains much of the current Chicago metropolitan region, the Chicago River diversion resulted in a reduction in the Lake Michigan basin population to 7,142,776.

Within the original basin boundary, Illinois contains 3,494,115 people, or 34.7 percent, of the basin's population--more than any other state. (The post-diversion figures, however, leave Illinois with the smallest portion of the Lake Michigan basin's land area (241 square km [93 square miles] or .03 percent) and contains 579,865 people, or 8.1 percent of the basin's population.) Though the water used within the diversion area is not discharged to the Lake Michigan basin, the water supply for that population comes directly from Lake Michigan.

Indiana has 1,564 square km (604 square miles), or 2.5 percent of the basin's land area and contains 10.8 percent (339,264) of the basin's population. Although only slightly more than 2.5 percent of the original Lake Michigan basin is located within Indiana and Illinois along a relatively narrow stretch of land in the southern basin, nearly one out of every two people (45.5 percent of the entire basin population) lives within this area.

Wisconsin has 2,467,463 people in its share of the basin, or 24.5 percent of the basin population. Approximately 70 percent of Wisconsin's coastal population resides in the four southwestern basin counties of Ozaukee, Milwaukee, Racine, and Kenosha in the southeastern part of the state. Over half of the state's coastal population resides in Milwaukee County alone. The population of the city of Milwaukee and neighboring Racine declined significantly from 1970 to 1980 (-11.3 percent and -9.9 percent respectively), although population decline slowed considerably between 1980 and 1990 (-1.3 percent and -1.7 percent, respectively). In contrast, the city of Green Bay had a stable population during the 1970s and experienced a significant 9.7 percent population increase from 1980 to 1990--a trend that continues into the 1990s. Lake Michigan coastal populations in Wisconsin counties outside Milwaukee increased by 4.2 percent between 1980 and 1990 and 5.3 percent between 1990 and 1995. However, trends indicate continued high rates of second-home development in the northeast portion of the basin. Seasonal populations in coastal counties peak during summer months, when there is almost one visitor for every two permanent residents.

Michigan has 3,007,954 people in its share of the basin, or 30 percent of the Lake Michigan basin population. Census population figures, based on the number of permanent residents in an area, do not reflect the seasonal aspects of a population. Seasonal populations (tourists and recreational visitors) can play an important role in characterizing certain areas in the Lake Michigan basin. A study of the 10 county area of the northeastern portion of the basin (northwest Michigan), for example, concluded that one person in six (about 16 percent) staying in the region in 1995 was not part of the permanent population. Forty percent of those were people staying in second homes. Data for the eastern basin indicate that second-home development is projected to slow somewhat between 1990 and 2010. However, counties with smaller permanent populations that have winter ski resorts experience a much higher percentage of winter seasonal populations.

Humans interact with the Lake Michigan ecosystem in many ways. The following sections discuss the manner in which humans affect and are affected by the Lake Michigan ecosystem.

4.2.4.1 Swimming

Lake Michigan has some of the finest beaches on the Great Lakes, particularly along its eastern shore. Of a total 3,100 coastal acres, 1,200 are publicly owned and available for use while an additional 1,200 privately owned acres have significant potential for public use. It is important to note that most shoreline areas along Lake Michigan fully support all forms of water-based recreation, including swimming, boating, and wading. However, some areas do experience closures due to contamination. Beach closings resulting from high pathogen loads have a tremendous negative effect on the tourist industry. In 1996, visitors to the Indiana counties bordering Lake Michigan spent over $523 million (MDNR 1998a) and beach closings can cost an area up to $5 million per day in lost revenue (Ting and others 1996).

Swimming: Status

Table 4-2 summarizes at what level states report that Lake Michigan is supporting the designated uses related to swimming.

Table 4-2. Swimming, Secondary Contact and Aesthetics/Industry Designated Use Impairments on Lake Michigan (miles)

Use	Supported	Threatened	Partially Supported	Not Supported
Primary Contact (e.g., swimming)	1,546	53	40	20
*Secondary Contact (e.g., bathing and wading)	1,488	5	60	
*Aesthetics/Industry	1,363		190	

References: Michigan, Indiana, Illinois, and Wisconsin 305(b) reports, 1996.
*Miles not reported by Indiana and Illinois.

More specific information on the current condition of beaches and potential population affected is available through the EPA's BEACH Program. For the 1998 Survey, 1997 beach data was received for approximately 148 miles of beaches on Lake Michigan, including Green Bay and Grand Traverse Bay. This represents 9 percent of the lake's shoreline (These data has been compiled from individual local beach survey responses to the EPA 1998 Beach Health Survey. Individual beach survey responses collected in 1999 for the 1998 swimming season are now online and can be found on the internet at http://yosemite.epa.gov/water/beach1999).

Table 4-3 lists the bacteriological water quality standards for the Lake Michigan States in 1997 and summarizes the number of exceedances reported in the EPA BEACH Program's 1997 Survey (EPA 1998) and the Natural Resources Defense Council's Testing the Waters - 1999: A Guide to Water Quality at Vacation Beaches. When reviewing these data, it is important to note that, despite the potential risks to the public from gastrointestinal illness and other infections, water quality monitoring programs vary widely at the state and local levels. Different states and jurisdictions monitor for different indicator organisms, and also have different criteria and standards for postings or advisories. In addition, frequency of monitoring bacterial contamination at public beaches is highly variable around the lake. Because of this variability, it is difficult, and potentially misleading, to compare water quality between jurisdictions or summarize data for all beaches. Even within a beach, variability in the data from year to year may result from the process of monitoring and variations in reporting, and may not be solely attributable to actual increases or decreases in levels of microbial contaminants. It is important to keep these limitations in mind when looking at Table 4-3 (EPA 1998i; NRDC 1999).

As an example, in looking at the 1997 data in Table 4-3, Illinois waters exceeded their guidance level standard more frequently than Indiana. However, Illinois' guidance level is lower than that for Indiana. Also, most Illinois beaches are monitored daily, or at least several times a week. The increased frequency of exceedances could simply be due to more frequent monitoring, or other factors, and the data above would need to be supplemented with other information if an attempt at comparisons between jurisdictions were to be made (Data summarized from EPA BEACH Program, 1999c; NRDC, 1999).

Table 4-3. Bacteriological Water Quality Standards and Total Advisories/Closures 1993-1998 for Lake Michigan States -- for the State of Michigan this chart includes beach advisories and closures for Lakes Huron, St. Claire and Erie (summarized from EPA 1998i and NRDC 1999)

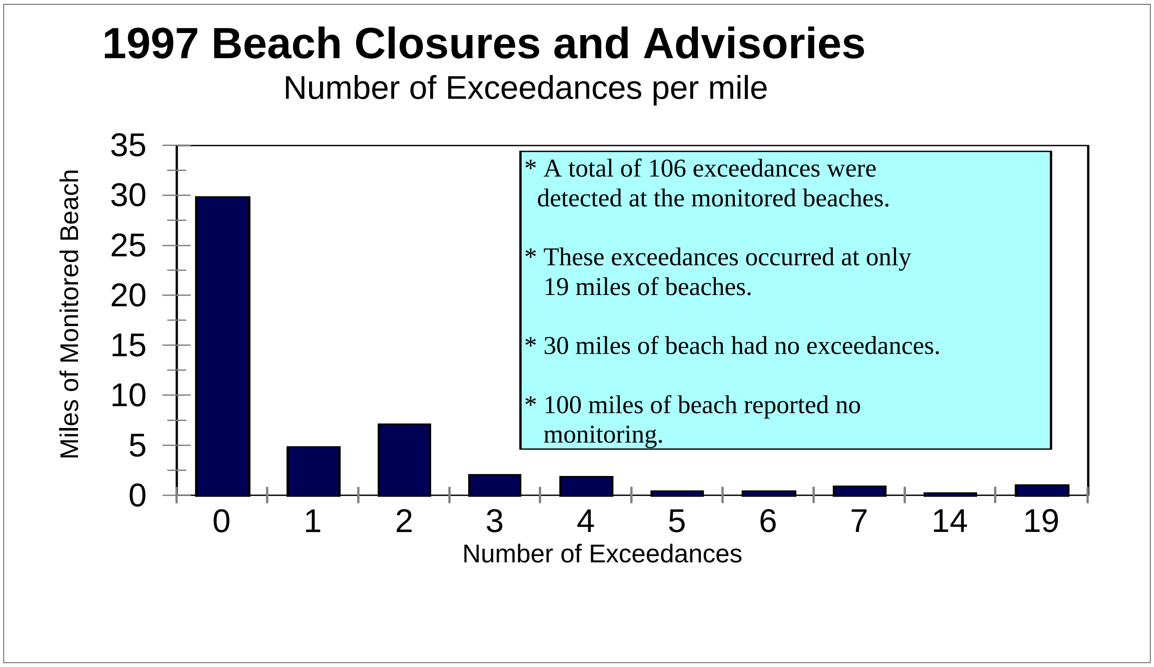
STATE BACTERIOLOGICAL WATER QUALITY STANDARDS								
State	General[1] Standard	Parameter	1993 adv./ clos.	1994 adv./ clos.	1995 adv./ clos.	1996 adv./ clos.	1997 adv./ clos.	1998 adv./ clos.
IL[2]	200 20 LM	fecal coliform	73	36	55	66	90	38
IN[3]	125 235 os	*E. coli*	30	36	14	34	30	154 +1p
MI[3,4]	130 300 os	*E. coli*	-	26 +3e	96 +1e	18 +1e	236	227 +1p
WI	200	fecal coliform	94	148	114 +1e	120	137	139 +2p

[1] All standards indicate the number of microorganisms per 100 ml of water not to be exceeded based on the geometric mean of not less than 5 samples taken over a 30-day period, unless otherwise noted.
[2] Seasonal standard
[3] Illinois monitors for both fecal coliform and *E. coli*
[4] May be exceeded if due to uncontrollable nonpoint sources. Primary standard can be temporarily suspended due to flood, accident, or emergencies that affect a sewer or wastewater treatment system.
p = permanent beach closure
e=extended closure 6-12 weeks
gm= geometric mean
os= one sample
LM= Lake Michigan Std.

The limitations in the ability to compare frequency of exceedances of microbiological guidelines has posed a challenge for the development of a lakewide indicator to evaluate trends in recreational water quality. Despite these limitations, frequency of beach postings to indicate elevated pathogen levels has traditionally been used as an indicator of recreational water quality. Microbial standard exceedances may be a better measure of actual health risk related to recreational water quality, and recent discussions are leaning toward developing an indicator that uses microbial monitoring data, supplemented by beach postings data. This combination will give a much more informative picture about microbial quality of recreational use waters (IJC, IITF Swimmability Workshop, October, 1999).

To put the number of closures in a geographic perspective, Figure 4-4 shows numbers of exceedances per mile of monitored beaches on the Lake Michigan shoreline, compiled from the EPA Beach Health Survey responses from the 1997 swimming season. In virtually every case, these measured exceedances resulted in the issuance of postings or advisories (this data has been compiled from individual 1997 beach survey responses to the EPA 1998 Beach Health Survey. Individual beach survey responses for the 1998 swimming season are now online in the EPA 1999 Beach Health Survey and can be found on the internet at http://yosemite.epa.gov/water/beach1999).

Figure 4-4. 1997 Beach Closures and Advisories



Adapted from EPA 1998 Beach Health Survey

Swimming: Human Health Issues

The Great Lakes are an important resource for recreation, including activities such as swimming and sailboarding which involve body contact with the water. Apart from the risks of accidental injuries, the major human health concern for recreational waters is microbial contamination by bacteria, viruses, and protozoa (Health Canada, 1998; WHO, 1998). Chemical pollutants may also pose health risks, but exposure to disease-causing microorganisms from sources such as untreated or poorly treated sewage is a greater risk (Health Canada, 1999).

Microbial Contaminants

Human exposure to micro-organisms occurs primarily through ingestion of water, and can also occur via the entry of water through the ears, eyes, nose, broken skin, and through contact with the skin. Gastro-intestinal disorders, respiratory illness and minor skin, eye, ear, nose and throat infections have been associated with microbial contamination of recreational waters (Health Canada, 1998, WHO, 1998). Consequently, one of the Specific Objectives of the Great Lakes Water Quality Agreement is that "recreational waters should be substantially free from bacteria, fungi, and viruses that may produce enteric disorders or eye, ear, nose, throat and skin infections or other human diseases and infections" (IJC 1987). Table 4-4 lists waterborne pathogens which could be present in contaminated water.

Table 4-4. Pathogens and Swimming-Associated Illnesses

Pathogenic Agent	Disease
Bacteria	
E. coli	Gastroenteritis
Salmonella typhi	Typhoid fever
Other salmonella species	Various enteric fevers (often called paratyphoid), gastroenteritis, septicemia (generalized infections in which organisms multiply in the bloodstream))
Shigella dysenteriae and other species	Bacterial dysentery
Vibrio cholera	Cholera
Viruses	
Rotavirus	Gastroenteritis
Norwalkvirus	Gastroenteritis
Poliovirus	Poliomyelitis
Coxsackievirus (some strains)	Various, including severe respiratory diseases, fevers, rashes, paralysis, aseptic meningitis, myocarditis
Echovirus	Various, similar to coxsackievirus (evidence is not definite except in experimental animals)
Adenovirus	Respiratory and gastrointestinal infections
Hepatitis	Infectious hepatitis (liver malfunction), also may affect kidneys and spleen
Protozoa	
Cryptosporidium	Gastroenteritis
Giardia lambia	Diarrhea (intestinal parasite)
Entamoeba histolytica	Amoebic dysentery, infections of other organisms
Isopora belli and *Isopora hominus*	Intestinal parasites, gastrointestinal infection
Balantidium coli	Dysentery, intestinal ulcers

Source: NRDC 1999.

Studies have shown that swimmers and people engaging in other recreational water sports have a higher incidence of symptomatic illnesses such as gastroenteritis, otitis, skin infection, and conjunctivitis, and acute febrile respiratory illness (AFRI) following activities in recreational waters (Dewailly 1986; WHO 1998). Although current studies are not sufficiently validated to allow calculation of risk levels (Health Canada 1992), there is some evidence that swimmers/bathers tend to be at a significantly elevated risk of contracting certain illnesses (most frequently upper respiratory or gastro-intestinal illness) compared with people who do not enter the water (Dufour 1984; Seyfried 1985a,b; EPA 1986; WHO 1998). In addition, children, the elderly, and people with weakened immune systems are those most likely to develop illnesses or infections after swimming in polluted water (Health Canada, 1998).

Despite these studies, there are challenges in establishing a clear relationship between recreational water exposure and disease outcomes. Less severe symptoms resulting from exposure to microorganisms are not usually reported, which makes statistics on cases related to recreational water exposure difficult to determine. In addition, the implicated body of water is not often tested for the responsible organism and when it is tested the organism is not usually recovered from the water. With the exception of gastro-intestinal illness, a direct relationship between bacteriological quality of the water and symptoms has not been shown -- a causal relationship exists between gastrointestinal symptoms and recreational water quality as measured by indicator-bacteria concentration (WHO 1998). Therefore, research efforts are focusing on conducting epidemiological studies to better establish the relationships between diseases and the presence of microorganisms in the water (Health Canada 1997; Health Canada 1998a; EPA 1999m).

Protecting Human Health

Annex 2 of the Great Lakes Water Quality Agreement lists "beach closings" as a beneficial use impairment related to recreational waters (IJC 1987). According to the International Joint Commission, a beach closing impairment occurs "when waters, which are commonly used for total body contact or partial body contact recreation, exceed standards, objectives or guidelines for such use" (IJC 1989).

Federal and State recreational water quality guidelines recommend bacterial levels below which the risk of human illness is considered to be minimal. For public beaches, the regional Health Departments generally monitor beach water quality (in Chicago, the Chicago Park District conducts beach water quality monitoring). When contaminant indicator levels in the bathing beach water reach levels that are considered to pose a risk to health, public beaches may be posted with a sign warning bathers of these potential health risks.

The primary tool used at present to evaluate beach water quality is the measurement of "indicator" organisms that estimate the level of fecal contamination of the water. The indicator organisms most commonly used are fecal coliforms, *Escherichia coli* (*E. coli*), and enterococci. These coliform bacteria are microorganisms that usually occur in the intestinal tract of animals, including humans. High levels of these organisms in recreational water are indicative of fecal contamination and the possible presence of intestinal-disease-causing organisms (Health Canada 1998; WHO 1998).

The EPA uses either *E. coli* or enteroccocci as indicators of recreational water quality. There is an increasing move by states toward their use, especially *E. coli*, since it is better correlated with gastrointestinal illness than fecal coliforms, and elevated fecal coliform counts do not always indicate a human health hazard (fecal coliforms include many species which are not exclusively found in human and animal wastes). See Table 4-3 for the indicators used by each of the Lake Michigan States. EPA will be developing policies to ensure that states and tribes adopt the currently recommended *Ambient Water Quality Criteria for Bacteria - 1986* and make the transition to monitoring for *E. coli* and enterococci indicators rather than total coliforms or fecal coliforms (EPA 1998j; Bartram and Rees 2000).

A number of initiatives have recently been developed to specifically address recreational water quality. EPA established the Beaches, Environmental Assessment, Closure, and Health (BEACH) Program in 1997 "to significantly reduce the risk of waterborne illness at the nation's beaches and recreational waters through improvements in recreational water protection programs, risk communication, and scientific advances" (EPA 1999n). Under the BEACH Program, the first National Health Protection Survey of Beaches, conducted in 1997, focused on the collection of beach-specific information from coastal and Great Lakes states. Data from the second annual survey, conducted in the spring of 1999, can now be accessed on the BEACH Program website at http://www.epa.gov/OST/beaches/ (EPA 1999j). EPA will also develop a national inventory of digitized beach maps which will be linked with locations of pollution sources through a Geographic Information System (EPA 1998j).

In addition, the U.S. federal Clean Water Action Plan, developed by EPA, Department of Interior, and other federal agencies, was announced in 1998, and describes a series of actions designed to strengthen core clean water programs carried out by a number of U.S. governmental agencies. As part of this plan, EPA has developed the *Action Plan for Beaches and Recreational Waters* ("BEACH Action Plan", EPA/600/R-98/079), a multi-year strategy for reducing the risks of waterborne illness to recreational water users (EPA 1999j). The BEACH Action Plan describes EPA's actions (including the Beach Program) to improve and assist in state, tribal, and local implementation of recreational water monitoring and public notification programs (EPA 1998j).

4.2.4.2 Fishing

Billions of fish inhabit the shallows and depths of Lake Michigan. About 40 species of fish are commonly found in Lake Michigan (see Table 4-5). Most species are native to the lake. A few have been added by design and others have made use of human alterations of the connecting waters and channels to gain access. Listed below are some fish species found in Lake Michigan.

Table 4-5. Fish Species Found in Lake Michigan

Common Name	Genus and Species	Common Name	Genus and Species
Sea lamprey	*Petromyzon marinus*	Northern pike	*Esox lucius*
Lake sturgeon	*Acipenser fulvescens*	Carp	*Cyprinus carpio*
Alewife	*Alosa pseudoharengus*	Emerald shiner	*Notropis atherinoides*
Lake whitefish	*Coregonus clupeaformis*	Spottail shiner	*Notropis hudsonius*
Bloater	*Coregonus hoyi*	Longnose sucker	*Catostomus catostomus*
Blackjaw cisco	*Coregonius nigripinnis*	White sucker	*Catostomus commersoni*
Longjaw sisco	*Coregonius alpenae*	Cannel catfish	*Ictalurus punctatus*
Shortjaw cisco	*Coregonus zenithicus*	Bullheads	*Ictalurus spp.*
Deepwater cisco	*Coregonus johannae*	Trout-perch	*Percopis omiscomaycus*
Kiyi	*Coregonus kiyi*	Burbot	*Lota lota*
Shortnose cisco	*Coregonus reighardi*	Ninespine stickleback	*Pingitius pingitius*
Lake herring	*Coregonus artedii*	Smallmouth bass	*Micropterus doldmieui*
Round whitefish	*Prosopium cylindraceum*	Yellow perch	*Perca flavescens*
Lake trout	*Salvelinus namaycush*	Walleye	*Stizostedion vitreum vitreum*
Brook trout	*Salvelinus frontinalis*	Freshwater drum	*Aplodinotus grunniens*
Rainbow trout	*Oncorhynchus mykiss*	Slimy sculpin	*Cottus corgatus*
Brown trout	*Salmo trutta*	Spoonhead sculpin	*Cottus ricei*
Coho salmon	*Oncorhynchus kisutch*	Fourhorn sculpin	*Myoxocephalus quadricornis*

Common Name	Genus and Species	Common Name	Genus and Species
Chinook salmon	*Oncorhynchus tshawytscha*	Rainbow smelt	*Osmerus mordax*
Gizzard shad	*Dorosoma cepedianum*	White perch	*Morone americana*

Source: Sommers, L. and others, Fish in Lake Michigan, Distribution of Selected Species, Michigan Sea Grant Program, 1981.

Over 43 percent of all Great Lakes fishing is done in Lake Michigan. Both commercial and sport fishing are significant contributors to the overall economies of the states in the Lake Michigan watershed.

Commercial fish production (non-tribal and tribal) in Lake Michigan consists of over 14.6 million pounds of fish with an estimated value of almost $11 million annually. Lake Michigan commercial fishing production resulted in the catch of the following species, with the percentage of the catch indicated:

Table 4-6. Commercial Fish Catch for Lake Michigan (Percentage by Weight) (1996)

Species	Percentages of Commercial Catch	Species	Percentages of Commercial Catch
Alewife	<0.4	Lake Whitefish	50.3
Gizzard shad	0.2	Whitefish round	0.7
Rainbow smelt	9.7	Chubs	25.1
Brown bullhead	<0.1	Chinook salmon	0.4
Channel catfish	<0.1	Lake trout	3.0
Burbot	0.3	Suckers	4.2
White perch	<0.4	Carp	<0.1
White bass	<0.1	Yellow perch	6.0
Freshwater drum	<0.1	Walleye	<0.1

Source: National Biological Service, Commercial Fish Production- pounds and value, Lake Michigan, U.S. Waters, 1996

Fish sold commercially is produced as food for humans (95 percent) and for animals (5 percent) with the remainder not sold commercially.

Harvests of sport-caught fish are difficult estimate due to incomplete data regarding all species. The harvest of Salmonines from Lake Michigan are estimated as shown in Table 4-7 below. Overall, the total value of sport fishing in all the Great Lakes is estimated at over $4 billion (FWS).

Table 4-7. Recreational Harvest of Salmonines from Lake Michigan, 1986 - 1996 (Michigan State University, Department of Fisheries and Wildlife, 1997)

Species							
Year	Chinook	Coho	Lake	Rainbow	Brown	Brook	Total
1986	934,012	358,274	215,178	88,995	147,065	4,525	1,748,049
1987	711,295	284,304	239,399	117,926	117,851	1,287	1,472,062
1988	375,729	277,396	242,561	123,069	81,693	5,145	1,105,593
1989	361,204	393,992	257,361	140,768	84,172	2,196	1,239,693
1990	228,676	230,256	181,429	111,414	71,905	5,929	829,609
1991	282,862	150,771	241,542	166,153	93,933	1,660	936,921
1992	170,458	249,256	142,014	158,130	70,501	4,431	794,790
1993	143,539	256,919	163,245	169,735	118,664	1,967	854,069
1994	149,413	271,474	156,860	186,562	115,898	7,483	887,690
1995	242,777	180,230	189,679	166,281	89,939	1,914	870,820
1996	304,191	239,937	104,739	145,069	68,189	443	862,565

Note: Estimates of other species of sport-caught fish are not available.

Fish Consumption (includes commercial, recreational, and subsistence)

Fish species residing in waters contaminated with lipophilic pollutants (i.e., fat-soluble pollutants as PCBs) bioaccumulate these contaminants and become a further source of contamination for larger, predator fish (e.g., sport caught trout and salmon) (Humphrey 1988). This process results in a biomagnification or increase in the levels of contaminants in the predator fish which may subsequently be consumed by humans. Fish consumption has been shown to be a major pathway of human exposure to persistent toxic substances such as PCBs (Birmingham et al. 1989; Fitzgerald et al. 1996; Humphrey 1983; Newhook 1988), exceeding exposures from land, air, or water sources (Humphrey 1988). Humphrey (1988) reported that PCBs were the dominant contaminants detected in Lake Michigan trout (3,012 parts per billion or ppb) and chinook and coho salmon (2,285 ppb), surpassing other contaminants such as DDT (1,505 ppb, 1,208 ppb), hexachlorobenzene (5 ppb, 5 ppb), oxychlordane (25 ppb, none shown), trans-nonachlor (195 ppb, 162 ppb), and dieldrin (75 ppb, 53 ppb), respectively in trout and salmon. Fish specimens collected from the dinner plate of study participants were used to determine these median PCB concentrations. Recently, total PCB levels have decreased in most Lake Michigan fish species and appear to remain below the FDA action level of 2 mg/kg (parts per million or ppm) but the concentrations in chinook and coho salmon have risen slightly since the late 1980s (Stow and others 1995).

There is sufficient evidence that consumption of contaminated sport fish and wildlife can significantly increase human exposure to Great Lakes contaminants. A spectrum of major contaminants have been identified in cooked Great Lakes fish, and methods have been recommended for reducing the amount of contaminants by judiciously preparing and cooking the fish.

All four Lake Michigan states have fish consumption advisories. These advisories are necessary due to potential human health effects from contaminants found in fish flesh. Fish consumption advisories allow the public to make informed decisions and minimize their health risks while continuing to enjoy the benefits of eating fish, a healthy source of protein low in saturated fats (IDNR 1999). Fish consumption advisories are often used by states as an indicator of whether their waters meet the designated use of fishability. The fish consumption advisories are updated annually and can be found at the following web sites:

- Illinois: www.idph.state.il.us/public/press99/fish_advs_99.htm
- Indiana: www.state.in.us/isdh/dataandstats/fish/fish_99
- Michigan: www.mdch.state.mi.us/pha/fish
- Wisconsin: www.dnr.state.wi.us/org/water/fhp/fish/advisories

Wisconsin has restricted fish/wildlife consumption in the Lower Green Bay/Fox River, Menominee River, Sheboygan River (bluegill, crappie, rock bass, carp, smallmouth bass, walleye pike, trout, catfish, and coho and chinook salmon), and Milwaukee estuary. Fish and wildlife tainting/flavor problems exist in the Lower Green Bay/Fox River (Wisconsin 305b report 1996).

Illinois has designated 63 Lake Michigan coastal miles as not meeting designated use due to fish consumption advisories (PCB's and chlordane). The Waukegan area has restriction on fish consumption. Also, the Lake Michigan area has species included in a moderate to high level of contamination (lake trout, coho and chinook salmon, and brown trout (Illinois 305b Report 1996).

In Indiana, all 43 miles meet fishable designation. However, the Indiana Lake Michigan fish consumption advisory extends for 241 square miles which encompasses all of the southern most waters of the lake. The current fish consumption advisory for Lake Michigan and tributaries includes the following species: brook, brown, rainbow and lake trout; carp; catfish; chinook, pink and coho salmon; longnose and white sucker; walleye; and whitefish. Specific size categories are identified in the advisory. All fish tissue samples collected from the Grand Calumet River show a continued high level of PCB contamination. All fish in the Grand Calumet River and Indiana Harbor Ship Canal are given a Level 5 - Do not eat advisory level by the Indiana fish Consumption Advisory (Indiana 305b Report 1996; IDNR 1999).

Michigan has designated all Lake Michigan coastal miles as not meeting designated use due to fish consumption advisories (PCBs, Chlordane and Mercury). The fish consumption advisory for all areas north of Frankfort include brown trout, carp, catfish, lake trout, sturgeon, and walleye. For the areas south of Frankfort, all of these species are included with whitefish being added. The Michigan portion of Green Bay has fish consumption advisories for brook trout, brown trout, carp, catfish, lake trout, northern pike, rainbow trout, splake, sturgeon, walleye, and white bass. Little Bay de Noc has a fish consumption advisory for longnose suckers. Many Michigan tributaries to Lake Michigan also have similar fish consumption advisories (Michigan 305b Reports 1996).

The following Lake Michigan Areas of Concern have identified fish consumption as an impaired use in their respective Remedial Action Plans: Lower Green Bay/Fox River, Grand Calumet River/Indiana Harbor, Kalamazoo River, Manistique River, Menominee River, Milwaukee Estuary, Muskegon River, Sheboygan River, Waukegan Harbor, and White Lake (State 305b Reports 1996).

Table 4-8. Fish Consumption Designated Use Impairments on Lake Michigan (miles)

Use	Supported	Threatened	Partially Supported	Not Supported
Fish Consumption			538	1,121

References: Michigan, Indiana, Illinois, and Wisconsin 305(b) reports, 1996.

Fishing: Human Health Issues

Early investigations of Lake Michigan fish consumption have broadened our knowledge about transmission of contaminants from fish to humans, including maternal exposure of the fetus and infant. Investigating a cohort of Lake Michigan fisheaters, Humphrey (1988) discovered that sport anglers who regularly consumed Great Lakes salmon and trout (consumption rate of greater than or equal to 24 pounds/year [or greater than or equal to 11 kg/year]) had median serum PCB levels approximately 4 times higher (56 ppb) than those who consumed no Lake Michigan fish (15 ppb) (consumption rate of 0 to 6 pounds/year [or 0 to 2.7 kg/year]). Halogenated contaminants (e.g., PCBs) have also been detected in adipose tissue, breast milk, and cord blood, associated with consumption of contaminated fish (ATSDR 1998). Other studies have also supported these findings. For example, Schwartz and others (1983) demonstrated that consumption of Lake Michigan fish was positively associated with the PCB concentration in maternal serum and breast milk. Maternal serum PCB concentrations were also positively associated with the PCB levels in the umbilical cord serum of the infant (Jacobson and others 1983).

Although the levels of PCBs have declined in most species of Lake Michigan fish, lipophilic pollutants, such as PCBs, have a tendency to bioaccumulate in the human body. Hovinga et al (1992) reported a mean serum PCB concentration of 20.5 ppb in 1982 for persons consuming more than 24 pounds of Lake Michigan sport fish per year, and 19 ppb in 1989 demonstrating little decline within the seven year interval. For those ingesting less than 6 pounds of Lake Michigan sport fish per year, the mean serum PCB concentrations were 6.6 ppb in 1982, and 6.8 ppb in 1989. The mean serum PCB concentrations for those consuming <6 pounds of Lake Michigan fish per year are comparable to the mean serum PCB levels of 4 to 8 ppb found in the general population who do not have occupational PCB exposure (Kreiss 1985).

Research has shown that vulnerable populations and high consumption communities at risk of exposure to contaminants from fish consumption include Native Americans, minorities, sport anglers, elderly, pregnant women, and fetuses and infants of mothers consuming contaminated Great Lakes fish (Dellinger and others 1996; Fitzgerald and others 1996; Lonky and others 1996; Schantz and others 1996). These communities may consume more fish than the general population or may have physiologic attributes, such as physical or genetic susceptibilities that may cause them to be at great risk. Higher body burdens of mean serum PCBs and DDE were found in an elderly cohort of Lake Michigan fisheaters (i.e., ≥50 years of age) who were compared to nonfisheaters (Schantz and others 1996). Fisheaters had mean serum PCB levels of 16 ppb while the nonfisheaters had mean levels of 6 ppb. For DDE, fisheaters had mean serum levels of 16 ppb and the nonfisheaters had a mean level of 7 ppb.

In addition, women have been shown to consume Great Lakes fish during their reproductive years (Courval and others 1996; Lonky and others 1996; Waller and others 1996). There are also gender differences in fish consumption patterns. A Lake Michigan sport anglers study, with subjects between the ages of 18 and 34 years, also demonstrated gender differences with males tending to consume more fish than female subjects (Courval and others 1996). Research has subsequently shown that consumption of contaminated fish by these at-risk populations is associated with adverse human health effects.

Developmental, reproductive, neurobehavioral or neurodevelopmental, and immunologic effects have been reported in studies conducted within the Great Lakes basin and outside the basin. Developmental effects in the form of a decrease in gestational age and low birth weight have been observed in a Lake Michigan Cohort exposed prenatally to PCBs (Fein and others 1984).

Reproductive effects have also been reported. Courval and others (1997) examined couples and found a modest association in males between sport-caught fish consumption and the risk of conception failure after trying for at least 12 months. Studies of New York state anglers have not shown a risk of spontaneous fetal death due to consumption of fish contaminated with PCBs (Mendola and others 1995), nor an effect on time-to-pregnancy among women in this cohort (Buck and others 1997).

Neurobehavioral or neurodevelopmental effects have been documented from exposure to persistent toxic substances in newborns, infants, and children of mothers consuming Great Lakes sport fish. Early investigations of the Lake Michigan Maternal Infant Cohort revealed that newborn infants of mothers consuming >6.5 kg/year of Lake Michigan fish had neurobehavioral deficits of depressed reflexes and responsiveness, when compared to non-exposed controls (Jacobson and others 1984). The fisheating mothers consumed an average of 6.7 kg of Lake Michigan contaminated fish per year, equal to 0.6 kg or 2 to 3 salmon or lake trout meals/month. Prior to study admission, exposed mothers were required to have fish consumption that totaled more than 11.8 kg over a 6-year period. Subsequent studies of the Michigan Cohort have revealed neurodevelopmental deficits in short-term memory at 7 months (Jacobson and others 1985) and after 4 years of age (Jacobson and others 1990b), and also growth deficits at 4 years associated with prenatal exposure to PCBs (Jacobson and others 1990a). A more recent investigation of Jacobson's Michigan Cohort has revealed that children most highly exposed prenatally to PCBs showed IQ deficits in late childhood at 11 years of age (Jacobson and Jacobson 1996). Highly exposed children received prenatal PCB exposure equal to at least 1.25 ug/gram (ppm) in maternal milk, 4.7 ng/milliliter (ppb) in cord serum, or 9.7 ng/milliliter (ppb) in maternal serum.

Initial testing for neurotoxic effects were not observed by Schantz and coworkers (1999) in an elderly adult population (i.e., ≥50 years) of Lake Michigan fisheaters with exposure to PCB and DDE. This study is ongoing.

Immunologic effects have also been reported. Smith's study (1984) demonstrated that maternal serum PCB levels during pregnancy were positively associated with the type of infectious diseases that infants developed during the four months after birth. In addition, incidence of infections has been shown to be associated with the highest fish consumption rate of mothers (i.e., at least three times per month for three years) (Swain 1991; Tryphonas 1995).

Other health effects have been documented with PCB exposure. Elevated serum PCB levels were associated with self-reported diabetes and liver disease in cohorts of Red Cliff and Ojibwa Native Americans (Dellinger and others 1997; Tarvis and others 1997). Fischbein and coworkers (1979) found that workers exposed to a variety of PCB Aroclors reported joint pain.

Health effects studies conducted outside the Great Lakes basin have supported the reports from the Great Lakes basin. A summary of these health effects studies can be found in the recent paper published by Johnson and others (1998).

Fishing: Protecting Public Health

The purpose of fish consumption advisories is to protect public health by alerting the residents of potential health risks from consuming contaminated fish (EPA 1995). Advisories can also include information to educate the public about the healthy benefits of fish consumption and to minimize exposure to contaminants in fish by proper preparation and cooking (Tilden and others 1997). Within the Great Lakes, PCB contamination of Great Lakes fish is generally responsible for health advisories, while mercury contamination is responsible for advisories covering inland bodies of water, such as rivers and lakes (Kamrin and Fischer 1999).

The Great Lakes Sport Fish Advisory Task Force, consisting of environmental and health professionals from the eight Great Lakes states, developed a Health Protective Value (HPV) as a guideline for determining risk from consuming contaminated Great Lakes fish (Anderson and others 1993; Kamrin and Fischer 1999). The HPV is the highest acceptable daily intake of a contaminant (e.g., PCBs) in fish that would not result in a health risk, particularly reproductive and developmental effects, and applies to both sensitive and less sensitive groups (Kamrin and Fischer 1999). For PCBs, the HPV is 0.05 ug PCBs/kg/day. Species of fish are assigned a consumption category that would result in a PCB intake level below the HPV. This value is derived from animal and human study findings, and is similar to the EPA's reference dose for computing non-cancer risk. There are five consumption categories including *unlimited consumption*, *one meal a week*, *one meal a month, one meal every two months,* and *do not eat*. Five of the Great Lakes states have adopted this guideline and two use a version of the HPV. The five include Illinois, Minnesota, Ohio, Pennsylvania, and Wisconsin. Michigan uses the HPV and the U.S. FDA standard of 2 ppm for fish. Illinois uses the HPV for Lake Michigan, but also uses the U.S. FDA standard for inland waters. Indiana also employs the HPV and includes a safety factor for sensitive populations.

Tilden and others (1997) conducted a population-based survey of fish consumption within the eight Great Lakes states. The study results demonstrated that almost 50 percent of the Great Lakes fish consumers had an awareness of the health advisories (of the 50 percent, approximately 60 percent of the males and less than 40 percent of the females were aware of the advisories). These findings emphasize the importance of targeting health advisories to sensitive groups such as women of reproductive age. The sensitive groups include women of childbearing age and their fetuses and infants, the elderly, sports anglers, and minorities. More information about sensitive groups may be found under the "Weight of Evidence" discussion (Appendix C).

Studies have shown that having an awareness of health advisories can be successful in changing fishing and fish consumption habits (Fiore and others 1989; Velicer and Knuth 1994). The communication programs in the Great Lakes generally target caucasian, licensed anglers (Tilden and others 1997). Written information (i.e., regulation booklets and advisory brochures) is circulated by the government and the fishing industry to licensed anglers, and these sources of information appear to be effective in reducing consumption of contaminated fish. For example, Fitzgerald and coworkers (1999) found that 97 percent of the men in their study were aware of fish advisories and two-thirds of these men had reduced their fish consumption. This reduction in fish consumption was due to public health intervention strategies such as risk communication along with the use of fish advisories. More recent efforts have been directed toward groups with less awareness of health advisories such as women of childbearing age, minorities, and other frequent fish consumers (Knuth 1995; Tilden and others 1997). One of these projects is the ATSDR-funded Consortium of Great Lakes States headed by Dr. Henry Anderson. Anderson and his group have developed outreach materials for women of childbearing age and minority groups which are being used in seven of the eight Great Lakes states (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Wisconsin). These outreach materials such as posters and recipe cards are being adapted by each of the states for their specific needs, and are being distributed at women and childrens' clinics, health fairs, state fairs, and fishing shows to increase health advisory awareness.

4.2.4.3 Hunting

There are many areas of the Lake Michigan watershed available for hunting. Many areas offer excellent hunting opportunities for waterfowl, deer, small game and other animals. State game areas are identified below.

Table 4-9. Wildlife Refuges and Game Areas in the Nearshore Areas of Lake Michigan. SOLEC 1996.

Areas	South Central	Southwest	Northeast	Northwest
State game areas			Betsie River Manistee River Muskegon Pentwater Petobego	Mudlake

Hunting also takes place on private lands throughout the Lake Michigan watershed.

In the Green Bay area, the small waterfowl marshes at river mouth-areas around the lake support nesting and loafing waterfowl. Significant waterfowl marshes also exist in the Fox and Wolf River drainages and at Seney, Michigan.

The open water of the Lake is important to many species of waterfowl. Migrating and wintering waterfowl use the open waters as resting areas. Large ‘rafts’ of ducks and geese have been observed many miles from land. Although many species of waterfowl use the open water, its overall value is low when compared to the shoal and marsh areas along the lakeshore. While the open water is used for resting, the shoals and marshes are used for resting, nesting, and feeding. These areas are some of the most important waterfowl hunting areas. Lake Michigan has a total of 175, 432 acres of shoal.

Table 4-10. Lake Michigan Shoal Acreages.

State	Acreage
Michigan	107,234
Wisconsin	63,388
Illinois	2,710
Indiana	2,100
Total	175,432

These shallow-water areas are one of the prime requirements for the production and maintenance of waterfowl populations and is used as spawning grounds by many Lake Michigan fishes.

Degraded habitat in the urbanized southern basin supports little wildlife. However, some paradoxes occur here. Large flocks of nesting waterfowl are to be found off the Gary Steel complex during the fall. City parklands and forest preserves support small populations of rabbits, squirrels, and furbearers.

Hunting: Human Health Issues

Schmitt and others (1993) made a determination regarding whether contaminant levels in waterfowl warrant a consumption advisory in Michigan. The Michigan Department of Community Health (MDCH) is responsible for establishing fish and wildlife consumption advisories for Michigan. The Food and Drug Administration (FDA) uses a “tolerance level” for PCBs in poultry of 3 ppm on a ‘fat basis.’ The MDCH consumption trigger level and the FDA ‘action level’ for PCBs in fish is 2 ppm on a ‘wet weight basis’ (ppm wet weight = ppm fat basis x percent fat/100 percent). The amount of duck meat consumed by people is small when compared to domestic poultry, but is close to the estimated U.S. per capita consumption of fish (6.5 g/day). A survey of Michigan waterfowl consumption shows the average number of duck meals eaten by duck hunters is 4.5 per year. Assuming an average meal size is 0.6 lb., this equates to a consumption rate of 4.4 g/day. The results of this survey are a major factor in a decision by MDCH to use the MDCH fish consumption advisory trigger levels instead of the FDA domestic poultry ‘action levels’ for contaminants when evaluating the need for consumption advisories for wild waterfowl (MDNR, 1992).

4.2.4.4 Boating

Sport fishing and recreational boating anchor an important marine-coastal recreation sector of the area economy. According to the 1991 national fishing and hunting survey, 34 percent of all Great Lakes anglers fished in Lake Michigan, a close second to Lake Erie (35 percent). These 868,000 anglers were estimated to have spent $454 million (U.S.) on their trips and equipment-related items. The stocking of huge numbers of trout and salmon has been a fundamental part of this fishing success story.

The number of recreational boats operated on Lake Michigan each year is estimated at 400,000, or nearly half of the number for all the Great Lakes. Although boating has a strong connection to fishing, which relies on clean water and productive fish stocks, much of the boating activity is tied to marina and new residential development, which alters nearshore habitat and degrades water quality in localized areas. Around the southern shore of Lake Michigan, about 1,000 new slips were added per year in the late 1980s and early 1990s. In Indiana, for example, Lake Michigan boat slips increased from 1,100 in 1985 to 2,700 in 1991, though many new marinas in Indiana are being built on previously developed sites.

4.2.4.5 Lake and Landscape Observation

There are many areas in the Lake Michigan coastal area to observe the natural beauty of the lake, the wildlife and the landscape. Table 4-11 provides a listing of most of the national lakeshores, parks, state and national forests, preserves, natural areas, environmental areas, wilderness areas, and research areas. Lake Michigan and its extensive drainage basin encompass a wide variation in vegetative and climatological situations. The basin’s northern extremities are forested with a spruce-fir biome on both sides of the Lake. As one moves south through the basin, the forest cover begins to change and gives way to agricultural lands at the Green Bay latitude in Wisconsin. In Michigan, the forest cover extends further south, to approximately Muskegon. Land around the southern tip of the Lake (excluding urbanized areas) is almost completely agricultural with little tree cover remaining in Indiana and Illinois.

Nearshore waters are used periodically by a variety of waterfowl species from late summer until migratory flights the following spring are complete. Groups of dabbling ducks begin to use areas adjacent to coastal wetlands as resting and refuge sites in August and September. Sites with open water in the winter can become important to wintering flocks of mallards as resting areas.

Protecting Natural Areas in Your Community

There is a growing movement to protect and restore natural areas, including wetlands and streams, prairies and savannas, and woodlands. Leading this movement in the northwest Indiana, Chicago, and southeast Wisconsin area, is a group called *Chicago Wilderness*, a coalition of over 100 organizations that recently completed a regional *Biodiversity Recovery Plan.* The plan imagines a region "*filled with life . . . where the evening air is rich with bird calls and the scent of flowers . . . where children splash and play in clean creeks, and peer below the surface of the water at fish and other aquatic creatures . . . where people learn to gently and respectfully enter back into a positive relationship with the nature that surrounds them . . . and where rare plants, animals, and natural communities are nurtured back to health and offered a permanent home next to our own – to the benefit of our health and our economy – in preserves large enough to sustain them forever.*"

Among other things, this plan identified a critical role for local governments, including park districts, cities and counties, and wastewater agencies, in achieving this vision. To assist, the Northeastern Illinois Planning Commission (NIPC) has developed a guidebook for *Protecting Nature in Your Community.* The objectives of the guidebook are to educate local government entities regarding the benefits of biodiversity in their communities and to provide them with the tools to enable protection and restoration within existing and new developing urban areas.

There are a host of reasons for protecting natural areas and biodiversity at the local level. They include quality of life, recreation, aesthetics. For example, it has been documented that natural areas, parks and open space create a high quality of life that attracts tax-paying businesses and residents to communities. There are also strong economic reasons for protecting natural areas. A pair of 1998 studies by The Trust for Public Land found that while land conservation projects caused a short-term rise in local property taxes, over the long term, communities that had protected the most land enjoyed the lowest property tax rates. Natural landscapes – including prairies, woodlands, and wetlands – also control erosion, help retain stormwater, help clean the air of pollutants, mitigate global warming by absorbing carbon dioxide and other greenhouse gases, and help shelter and cool our homes. It is estimated, for example, that the economic benefits generated by a single acre of wetland are $150,000 to $200,000.

The recommended roles of local governments range from developing environmentally sensitive land use planning and zoning and subdivision regulations, to improving their management of stormwater and wastewater. Local governments, particularly park districts, are encouraged to prioritize natural areas in their open space acquisition programs, and to actively manage and restore existing natural areas. Local governments also are encouraged to promote the use of native vegetation for landscaping and to require better protection of streams, lakes, and wetlands from the effects of new development.

Table 4-11. Lake and Landscape Observation Areas in the Nearshore Areas of Lake Michigan. SOLEC 1996.

Areas	South Central	Southwest	Northeast	Northwest
National lakeshores	Indiana Dunes		Sleeping Bear Dunes Nordhouse Dunes Michigan Islands	
State parks	Indiana Dunes Warren Dunes Van Buren Saugatuck Holland Grand Haven P.J. Hoffmaster Muskegon	Illinois Beach	Wilderness Kohler-Andrae Charles Mears Ludington Silver Lake Orchard Beach Fisherman Island Leelanau Young Old Mission Peninsula Traverse City Petoskey	Fayette Palms Book Wells Newport Peninsula Whitefish Dunes Rock Island Potawotami
Local parks	Whihala Beach Marquette Park	Chicago Park District Cary Avenue Beach Centennial Park Gilson Park Kenilworth Beach Lakefront Park Lloyd Park Beach Moraive Park Sunrise Park Fuss Park Waukegan Harbor Complex	Marion Island	
State forests			Mackinac Pere Marquette	Point Beach Lake Superior Escanaba river
National forests			Manistee	Hiawatha
Preserves/ natural/ environmental/ wilderness areas	Gibson Woods Oak Ridge Prairie Tolleston Ridges Clark and Pine Bongi Hoosier Prairie Moraine Ivanhoe Lake Powderhorn Sand Ridge	Forest Preserve district Chiwaukee Prairie Ripon Prairie Chiwaukee Prairie Audubon Goose Pond Renak-Polak Spruce Lake Bog Sander's Park Oakfield Ledge Mayville Woods Neda Mine Vanderbloemen Bog Cedarburg Woods Sapa Spruce Bog Kurtz Woods Riveredge Creek and Pond Zinn Spring Bluff	M. Shrotleff E. Johnson Sims-Moffat Betsie River Point Betsie Lucia K. Tower Green River Cedar River Palmer-Wilcox-Gates Skegemog Swamp Oyster Bay Leffingwell Forest	Cedarburg Bog Cedar Grove Hawk RS Wilderness Ridge Maribel Caves Two Creeks Buried Forest Fairy Chasm Kohler Park Dunes Point Beach Ridges Portage Point Rapid River St. Vital Island Fishdam River Ford River Round Island Ogontz River Spider Gravel Fish Islands Peninsula Park Ridges Sanctuary Sister Islands Two Creeks Seagull Bar Toft Point Newport

Areas	South Central	Southwest	Northeast	Northwest
Preserves/ natural/ environmental/ wilderness areas (continued)				Jackson Harbor Ridges Mud Lake Whitefish Dunes Marshall's Point Moonlight Bay Beach Coffee Swamp Mink River Estuary Two Wilderness Islands Garden peninsula Escanaba River Little St. Martin Island Voight Bay Goose island Point Aux Chenes Bay Naubinway Island North Shore
Research areas			Beaver Island High Island Central Michigan Bio. Station	Nahma Sturgeon River Summerby Swamp Point aux Chenes Marsh

Five species of diving ducks (lesser scaup, canvasback, redhead, ring-necked duck, and greater scaup, listed in order of importance) and six species of sea ducks (common goldeneye, bufflehead, oldsquaw, hooded merganser, red-breasted merganser, and common merganser) use the nearshore waters of the Great Lakes for feeding and resting. Seeds, tubors, rootstocks, and vegetative parts of submerged plants, benthic organisms, and fish are eaten in accordance with availability and with each duck species' food preferences. Diving ducks are most abundant group of waterfowl: flocks of hundreds and even thousands of birds are associated with the 15 major waterfowl habitat complexes in the Great Lakes that have been identified by Prince and others (1992).

Osprey and Bald Eagles are two aquatic raptors which historically nested along the shoreline of the Great Lakes and on offshore islands. Few species of mammals use the nearshore waters. River otter, mink, beaver, muskrat, and raccoon occur in sheltered parts of the system, including embayments and tributaries.

Islands, most of which occur in water less than 30 meters deep provide nesting habitat for many species of aquatic birds. These include species of colonial nesting gulls, terns, herons, cormorants, as well as species of reptiles and amphibians.

4.2.4.6 Water Consumption (including diversion)

Public Water Supply

The following public water supply uses of Lakes Michigan water are estimated by the Great Lakes states and compiled by the Great Lakes Commission in the 1992 Great Lakes Regional Water Use Data Base Repository:

Table 4-12. Public Water Supply Uses of Lakes Michigan Water

Water Use Category	Withdrawn	(million gallon per day)	
		Diverted	Consumed
Public (municipal supply)	1,644.49	1,151.23	73.12
Self Supply - Domestic	1,190.52	4.12	175.82

Public water supply category includes water withdrawn by public and private water suppliers and delivered to users that do not supply their own water. Self supply includes water withdrawn from wells, cisterns, or other residential sources.

Within the Lake Michigan watershed, the only approved surface drinking water supplies in Wisconsin are Lake Michigan and Green Bay, Lake Winnebago, the Fox River from Lake Winnebago downstream to the upper dam in the city of Appleton and Rainbow Lake at King in Waupaca County (State 305b Reports 1996).

In Illinois, Indiana and Michigan, no drinking water impairment exists currently (State 305b Reports 1996) (see Table 4-13).

The following Lake Michigan Areas of Concern have identified drinking water as an impaired use in their respective Remedial Action Plan: Lower Green Bay/Fox River and Grand Calumet River/Indiana Harbor.

Table 4-13. Drinking Water Supply Designated Use Impairments on Lake Michigan (miles)

Use	Supported	Threatened	Partially Supported	Not Supported
**Drinking Water Supply	1,513	20	20	–

References: Michigan, Indiana. Illinois, and Wisconsin 305(b) reports, 1996.
**Not reported by Indiana.

Water Consumption: Human Health Issues

Access to clean drinking water is essential to good health. The waters of Lake Michigan and surrounding areas are a primary source of drinking water for millions of people who live in the basin. Because the average adult in Canada and the U.S. consumes about 1.5 liters (1.6 quarts) of water a day, health effects can be serious if the drinking water supply has high levels of some contaminants (Health Canada 1993, 1997). Consequently, the Great Lakes Water Quality Agreement designates “restrictions on drinking water consumption, or taste and odor problems” as an impaired beneficial use -- note that “taste and odor” is an aesthetic impairment as opposed to a health-related impairment (IJC, Annex 2.1.c. 1987).

Residents of the Lake Michigan basin use water for drinking, cooking, bathing, and other household uses. This water is obtained from a variety of suppliers, both public and private.

A variety of contaminants can adversely impact drinking water, including microorganisms (e.g. bacteria, viruses, and protozoa such as cryptosporidium), chemical contaminants (including naturally occurring chemicals and anthropogenic or synthetic chemicals), and radiological contaminants (including naturally-occurring inorganic and radioactive materials) (IJC 1996; Health Canada 1997; OME 1997). Some contaminants of raw water supplies, such as aluminum, arsenic, copper, and lead, can be both naturally occurring and/or result from human activities. Other contaminants, such as household chemicals, industrial products, urban stormwater runoff, fertilizers, human and animal waste, nitrate (from fertilizers and sewage), and pesticides may also end up in raw water supplies (EPA 1999o; Health Canada 1998c).

Microbial contamination of drinking water can pose a potential public health risk in terms of acute outbreaks of disease. The illnesses associated with contaminated drinking water are mainly of a gastro-intestinal nature, although some pathogens are capable of causing severe and life-threatening illness (Health Canada 1995). In most communities, drinking water is treated to remove contaminants before being piped to consumers, and bacterial contamination of municipal water supplies has been largely eliminated by adding chlorine or other disinfectants to drinking water to prevent waterborne disease. By treating drinking water, we have virtually eliminated diseases such as typhoid and cholera. Although other disinfectants are available, chlorination still tends to be the treatment of choice. When used with multiple barrier systems (i.e. coagulation, flocculation, sedimentation, filtration), chlorine is effective against virtually all infective agents (EPA/Government of Canada 1995; Health Canada 1993, 1997, 1998e).

Localized outbreaks of water-borne disease have been linked to contamination by bacteria or viruses, probably from human or animal waste (EPA 1999o). Recently, there has been increasing concern over the presence in drinking water of parasites such as Giardia and Cryptosporidium (the most common source of which is animal feces), which are resistant to common disinfection practices, and may pass through water treatment filtration and disinfection processes in sufficient numbers to cause health problems (Health Canada 1998[b]). For example, in 1993, the city of Milwaukee, Wisconsin, experienced an outbreak of cryptosporidiosis that affected over 400,000 residents, causing severe diarrhoea, nausea, stomach cramps, and other symptoms. The outbreak was caused by Cryptosporidium oocysts that passed through the filtration system of one of the city's two water-treatment plants (WDNR 1998; Health Canada 1997).

Cryptosporidium

Cryptosporidium is a one-celled parasite that is spread through human or animal fecal contamination. When the organisms are ingested, they cause an infection and irritation of the digestive track that leads to acute diarrhea. For healthy people, this is generally a short term condition. However, it can be an extremely dangerous for small children and adults with AIDs, cancer, or other health problems. There is no effective drug for the treatment of cryptosporidiosis and currently it is not known whether any concentration of the organisms is safe for human consumption (U.S. CDC 1994).

Cryptosporidium poses a greater hazard than other potential pathogens in drinking water supplies because of its ability to withstand traditional drinking water treatment. Individual organisms form small hard shelled oocysts when in hostile environments such as surface water. These oocysts are resistant to chlorine and small enough to evade most filter technologies. However, since the Milwaukee outbreak, EPA has strengthened turbidity requirements for finished tap water, to ensure better filtration methods. However, even in water meeting the new standards, small numbers of oocysts may still breach filters (U.S. CDC 1994).

Certain chemical contaminants are of concern in drinking water because of possible health consequences associated with these substances. These contaminants may be in the raw (untreated) water as a result of industrial and agricultural activities, or in treated wastewater discharges. Some may also be present in the treated water as a result of chemicals used in the drinking water treatment process (Health Canada 1998). A snapshot of some chemical contaminants of concern (including chlorination disinfection by-products, and PBT chemicals) is presented below.

Chlorination Disinfection By-products

Other processes commonly used by water treatment plants include the addition of disinfectants such as chlorine to inactivate or kill micro-organisms. Chlorine and other disinfectants can combine with naturally occurring organic matter in the raw water to produce chlorination disinfection by-products. Of the chlorination disinfection by-products, trihalomethanes (THMs) are present in the highest quantities. Evidence from toxicologic and epidemiologic studies suggests a link between by-products of the chlorination process and increased risk of some cancers (e.g., bladder and colon) and adverse pregnancy outcomes (e.g., miscarriage, birth defects and low birth weight). The amount of chlorination required and resulting levels of chlorination disinfection by-products are dependent upon the quality of the raw water, including microbiological quality and organic content (Health Canada 1995b, 1997). In the U.S., EPA is developing standards to address the issue of disinfectants and disinfection-by-products.

PBT Chemicals:

Food, including fish consumption, is the primary route of exposure to persistent, bioaccumulative and toxic chemicals, including PCBs and mercury. For the U.S. Great Lakes basin, measured levels of these persistent toxic chemicals in drinking water are below the Maximum Contaminant Levels (MCLs) and therefore they are not considered to be a human health concern for drinking water. (Personal communication, Doug Mandy, Minnesota Department of Health, 2000).

Protecting Public Health

Although there have been sporadic outbreaks of illness related to the use of drinking water, the drinking water in the Lake Michigan basin is of good quality. However, continuing efforts must be made to inform health professionals and the public of the results of analyses of drinking water. Information on local water quality is available from several sources, including the state public health department and local water supplier. The EPA requires public water supplies to be monitored for bacteriological, inorganic, organic and radiological contaminants. The chemical analyses of drinking water include physical and chemical characteristics of the water, as well as contaminants resulting from natural sources or human activities. In addition, the EPA's Office of Groundwater and Drinking Water's (OGWDW) web site at http://www.epa.gov/OGWDW/ provides detailed information on the nation's drinking water, including drinking water and health, drinking water standards and local drinking water information. Community water suppliers deliver high quality drinking water to millions of people every day, and a network of government agencies are in place to ensure the safety of public drinking water supplies. Our drinking water is safer today than ever but problems can, and do occur, although they are relatively rare.

The EPA has established legally enforceable standards for public water supply systems called National Primary Drinking Water Regulations. These standards are used to protect the quality of drinking water by limiting levels of contaminants in public water systems that can adversely affect public health. Public water supplies are required to monitor drinking water for a host of contaminants to ensure consumer safety. Frequency of monitoring depends on the type of system, whether the source water is surface or groundwater, the type of contaminant, whether or not a contaminant has been previously detected or has exceeded the standard, and the number of people served by the public water system.

Information on local water quality is available from several sources, including the state public health department and local water supplier. To inform the public of the results of the chemical analyses of drinking water and to demonstrate a commitment to protect human health, each community public water supply is required to generate an annual Consumer Confidence Report that is made available to all residents receiving water from that water system. Consumer Confidence Reports provide information about the source(s) of water used, its susceptibility to contaminants, the levels of contaminants detected in the water, the likely source(s) of contaminants, and potential health effects of any contaminant detected above that specific Maximum Contaminant Level. Consumer Confidence Reports can be reviewed to give an indication of overall quality of treated surface water and groundwater, and the condition of the drinking water service.

Each State also has a department that regulates drinking water systems, and these agencies can also provide information about the local water supply and its quality. In addition, the EPA maintains a data base which contains information on individual ownership, locations, violations, and enforcement actions (EPA, 1999a).

4.2.4.7 Summary of Human Health Issues: LaMP Goals and Pathways of Exposure Relevant to Human Health

The first three endpoint goals of the Lake Michigan LaMP are: (1) we can all eat any fish; (2) we can all drink the water; (3) and we can all swim in the water. The major pollutant pathways of exposure to humans is directly related to these three goals. From a public health perspective, the potential environmental pathways of human exposure to Lake Michigan pollutants include inhalation of air, ingestion of water, foodstuffs or contaminated soil, and dermal contact with water or airborne pollutants. Multimedia analyses indicate that the majority (80 to 90 percent) of human exposure to chlorinated organic compounds comes from the food pathway, a lesser amount (5 to 10 percent) from air, and minute amounts (less than 1 percent) from water (Birmingham and others 1989; Newhook 1988).

Table 4-14. LaMP Goals and Pathways of Exposure

Goal	Public Health Pathway of Exposure
We can all eat any fish	Ingestion of food (fish)
We can all drink the water	Ingestion of water
We can all swim in the water	Dermal contact

Most of the data available on human exposure to toxic substances in the Lake Michigan basin comes from the analyses of contaminant levels in drinking water and sport fish. The consumption of contaminated sport fish and wildlife can significantly increase human exposure to the Lake Michigan critical pollutants and pollutants of concern. A spectrum of these major contaminants has been identified in cooked Lake Michigan fish. Investigators have demonstrated that blood serum levels of these contaminants are significantly increased in consumers of contaminated Lake Michigan sport fish as compared to nonfisheaters (Humphrey 1983a,b; Jacobson and others 1989; Waller and others 1998).

Even though residents of the Lake Michigan basin are exposed to toxic substances from many sources originating within and outside the basin, the main routes of human exposure to contaminants from the waters of Lake Michigan are ingestion of fish and to a lesser extent ingestion of drinking water (National Health and Welfare Canada 1991). Several investigators have shown that exposure from fish far outweighs atmospheric, terrestrial, or water column sources (Swain 1983; Humphrey 1983b).

Weight of Evidence

The Agency for Toxic Substances and Disease Registry (ATSDR)reported on the most recent findings for human health in the Great Lakes used a weight of evidence approach to substantiate the public health threat from exposure to persistent toxic substances (Johnson and others 1998). ATSDR concluded that even with the limitations of individual research efforts the "collective weight of evidence" from wildlife, laboratory and human population studies shows that persistent toxic substances can cause negative human health outcomes such as cancer and neurobehavioral problems (Johnson and others 1998).

During the 1970s, the use of Lake Michigan as a disposal site for agricultural, industrial and domestic wastes became an increasingly widespread concern due to detrimental effects on fish and wildlife, and the potentially adverse effects on human health. Summary information about human health issues related to swimming, fishing, hunting, and drinking water is included in the Human Systems sections above (Swimming, 4.2.4.1; Fishing, 4.2.4.2; Hunting, 4.2.4.3; Water Consumption, 4.2.4.7). Detailed discussion of the weight of evidence and health studies related to human health issues in the Lake Michigan Basin are presented in the Human Health Appendix, Appendix C, attached at the end of the LaMP.

4.2.5 Economic Vitality

The Lake Michigan system supports a major economic base. The following section discusses the roles of the lake in the regional and world economy.

4.2.5.1 Water Used for Industrial and Agricultural Purposes

Waterborne navigation has played an important role in the history of human development around Lake Michigan. The development of the Great Lakes region proceeded along several lines that took advantage of the many resources within the basin. The waterways became major highways of trade and were exploited for their fish. The fertile land that had provided the original wealth of furs and food yielded lumber, then wheat, then other agricultural products. Bulk goods such as iron ore and coal were shipped through Great Lakes ports, and manufacturing grew.

The promise of agricultural land was the greatest attraction to the immigrants to the Great Lakes region in the 19th century. By the mid-1800s, most of the Great Lakes region was settled, where farming was possible. The population swelled tremendously, with about 400,000 people in Michigan and 300,000 in Wisconsin.

Wheat and corn were the first commodities to be packed in barrels and shipped abroad. Grist mills, one of the region's first industries, were built on the tributaries flowing into the lake to process the grains for overseas markets. As populations grew, dairying and meat production for local consumption began to dominate agriculture in the Great Lakes basin. Specialty crops, such as fruit, vegetables and tobacco, grown for burgeoning urban populations, claimed an increasingly important share of the lands suitable for them.

The rapid, large-scale clearing of land for agriculture brought rapid changes in the ecosystem. Soils stripped of vegetation washed away to the lakes. Tributaries and silty deltas clogged and altered the flow of the rivers. Fish habitats and spawning areas were destroyed. Greater surface runoff led to increased seasonal fluctuation in water levels and the creation of more flood-prone lands along the waterway. Agricultural development has also contributed to Great Lakes pollution, chiefly in the form of eutrophication. Fertilizers that reach waterways in soils and runoff stimulate growth of algae and other water plants. The plants die and decay, depleting the oxygen in the water. Lack of oxygen leads to fish kills, and the character of the ecosystem changes as the original plants and animals give way to more pollution-tolerant species.

Modern row crop monoculture relies heavily on chemicals to control pests such as insects, fungi and weeds. These chemicals are usually synthetic organic substances and they find their way to rivers and lakes to affect plant and animal life, and threaten human health. The problem was first recognized with DDT, a very persistent chemical, which tended to remain in the environment for a long time and to bioaccumulate through the food chain. It caused reproductive failures in some species of birds. Since the use of DDT was banned, some bird populations are now recovering. Other, less persistent, chemicals have replaced DDT and other problem pesticides, but toxic contamination from agricultural practices continues to be a concern. DDT levels in fish are declining but, in spite of being banned, some other pesticides, such as dieldrin, continue to persist in fish at relatively high levels.

The original logging operations in the Lake Michigan basin involved clearing the land for agriculture and building houses and barns for the settlers. Cutting was generally done in the winter months by men from the farms. They traveled up the rivers felling trees that were floated down to the lakes during the spring thaw. The logs were formed into huge rafts or loosely gathered in booms to be towed by steam tugs. This latter practice had to be stopped because logs often escaped the boom and seriously interfered with shipping. In time, timber was carried in ships specially designed for log transport.

The earliest loggers mainly harvested white pine. In virgin stands these trees reached 60 meters (200 feet) in height, and a single tree could contain 10 cubic meters (6,000 board feet) of lumber. The wood was light and strong and much in demand for shipbuilding and construction. Each year, loggers had to move farther west and north in search of white pine. The trees were hundreds of years old and so were not soon replaced. When the resource was exhausted, lumbermen had to utilize other species. The hardwoods such as maple, walnut and oak were cut to make furniture, barrels and specialty products.

Paper-making from pulpwood developed slowly. Paper production developed at Green Bay and elsewhere in the Lake Michigan basin. Eventually, Canada and the U.S. became the world's leading producers of pulp and paper products. Today much of this production still occurs in the Great Lakes area.

During its early stages, clear-cutting was the usual timber industry practice and, without proper rehabilitation of the forest, soils were readily eroded from barren landscapes and lost to local streams, rivers and lakes. In addition, much of the cleared land was permanently converted to agriculture land uses.

Since early in the industrial age, the waterways, shorelines and woodlands of the Great Lakes region have been attractions for leisure time activities. Many of the utilitarian activities that were so important in the early settlement and industrial development became recreational activities in later years. For example, boating, fishing and canoeing were once commercial activities, but are now primarily leisure pursuits.

Recreation in the area became an important economic and social activity with the age of travel in the 19th century. The recreation industry includes production and sale of sports equipment and boats, marinas, resorts, restaurants and related service industries that cater to a wide range of recreational activities. In some areas of the basin, recreation and tourism are becoming an increasingly important component of the economy, replacing manufacturing. The Lake Michigan basin provides a wide range of recreational opportunities, ranging from pristine wilderness activities in national parks such as Sleeping Bear National Lakeshore to urban waterfront beaches in major urban areas.

The increasingly intensive recreational development of Lake Michigan has had mixed impacts. Some recreational activities cause environmental damage. Extensive development of cottage areas, summer home sites, beaches and marinas has resulted in loss of wetland, dune and forest areas. Shoreline alteration by developers and individual property owners has caused changes in the shoreline erosion and deposition process, often to the detriment of important beach and wetland systems that depend upon these processes. The development of areas susceptible to flooding and erosion has caused considerable public reaction. There is pressure to manage lake levels to prevent changes that are part of natural weather patterns and processes. Pollution from recreational sites and boats has also caused water-quality degradation.

Recreational uses are a threat to the quality of the Great Lakes ecosystem, but they also provide a basis for protecting water quality by attracting and involving people who recognize that protecting of the ecosystem is essential to sustain the recreation that they value. Today more people than ever use and value the lakes for recreational purposes.

The following industrial and agricultural Lake Michigan water uses, Table 4-15 (not drawn through municipal systems) were estimated by the Great Lakes states and compiled by the Great Lakes Commission in the 1992 Great Lakes Regional Water Use Data Base Repository:

Table 4-15. Industrial and Agricultural Uses of Lake Michigan Water (1992)

Water Use Category	(million gallon per day)		
	Withdrawn	Diverted	Consumed
Industrial	1,988.50	3.66	147.50
Thermoelectric Power - Fossil Fuel	3,697.70	0.00	40.65
Thermoelectric Power - Nuclear	5,347.12	0.00	42.70
Hydroelectric Power	5,751.96	0.00	0.00
Irrigation	31.35	0.00	24.56
Livestock	545.59	0.00	436.47

Note: Industrial category includes water used in the manufacturing of metals, chemicals, paper, and allied products.

Comprehensive water use data for Wisconsin, Illinois, and Indiana in 1992 (Michigan data are not available) indicate that about 90 percent (18,455 of 20,500 million gallons per day [Mgal/day]) of the total water used in those parts of the Lake Michigan basin came from surface water, both from Lake Michigan directly and its tributaries. The remaining water comes from groundwater sources. The largest single use of surface water for all Lake Michigan basin states is for cooling at thermoelectric power plants (more than 48 percent for Indiana, Illinois, and Wisconsin).

The second largest water-use category in the Indiana, Illinois, and Wisconsin portion of the basin is hydroelectric power, which accounts for about 31 percent of total surface water use for the non-Michigan portion of the basin. Approximately 10 percent of the surface water in the Illinois, Indiana, and Wisconsin portion of the basin is used for industrial purposes. In fact, Indiana's concentration of heavy industry, particularly in its Lake Michigan counties, has made it the nation's largest industrial water-using state. Only about 7 percent of surface water (1.369 Mgal/day) in the Indiana, Illinois, and Wisconsin portion of the basin is used for public water supply. Since 1994, about 2,573 Mgal/day have been diverted from Lake Michigan to serve the Chicago metropolitan area, about half of which is for public water supply, and about half for navigation, sanitation, and water-quality purposes. Agricultural water use for irrigation and livestock represents about 4.5 percent of total water use from all sources.

Table 4-16. Agriculture/Industry and Aesthetics Designated Use Impairments on Lake Michigan (miles)

Use	Supported	Threatened	Partially Supported	Not Supported
*Agriculture	1,513		40	
*Aesthetics	1,363		190	

References: Michigan, Indiana. Illinois, and Wisconsin 305(b) reports.
*Not reported by Indiana and Illinois.

4.2.5.2 Commercial Navigation

Lake Michigan remains an important resource for waterborne navigation in and around every lakefront community and through many of its tributaries. The U.S. Congress has authorized a total of 51 Federal navigation projects in Lake Michigan and its tributaries. Information on commerce at these harbors and channels is provided in Table 4-17. The vast majority of commerce at Lake Michigan ports is internal to the Great Lakes (materials are transported from one Great Lakes port to another). Raw materials associated with steel making (i.e., iron ore, limestone, coal) dominate the overall tonnages of commercial cargoes transported to and from Lake Michigan ports. Coal remains a common cargo at many of the smaller commercial harbors, largely for coal-fired power plants.

Many of the Lake Michigan harbors were constructed in the 19th century as deep-draft commercial harbors with depths of 18 feet and greater. While many of these harbors still receive commercial cargoes, recreational use has replaced commercial navigation at a number of Lake Michigan ports. In several cases, commercial traffic has dwindled or completely stopped.

Deposition of sediments in artificially-deepened channels necessitates periodic dredging to maintain safe depths for navigation. A summary of dredging activities at federal harbors around Lake Michigan is shown on Table 4-18. Because recreational boats do not require the draft that most commercial vessels do, the navigation channels in some harbors are not maintained at authorized depths. In some harbors, commercial vessels only access the lower portions of the channel, and the upper portions are not maintained at authorized depths.

In addition to the federal navigation projects, there are numerous facilities for commercial and recreational navigation that are managed by public or private interests. Commercial facilities include a few harbors constructed by individual industries and numerous docks, slips and berthing areas of industries and utilities located adjacent to federal navigation channels.

Table 4-17. Summary of Commerce at Federal Harbors on Lake Michigan[1]

Federal Harbor	State	Total Tonnage, 1994 (thousands)	Major Cargoes	Tons In/Outbound (thousands)
Michigan City	IN		None reported	
Burns Waterway	IN	9,344	Iron ore Iron and Steel primary forms Limestone	4,757/Zero 661/Zero 524/15
Indiana Harbor	IN	15,739	Iron ore Asphalt, tar and pitch Limestone	10,708/Zero 2/1,167 1,247/33
Calumet River and Harbor	IL & IN	18,554	Coal lignite Limestone Iron ore	Zero/843 1,117/Zero 1,007/Zero
Chicago Harbor	IL	29,422	Coal lignite Sand and gravel Cement and concrete	2,013/854 1,757/558 1,243/32
North Branch, Chicago River	IL	1,944	Sand and gravel Non-metal. min. nec. Iron and steel scrap	648/Zero 208/Zero Zero/118
Waukegan Harbor	IL	604	Cement and concrete Gypsum Sand and gravel	271/Zero 248/Zero Zero/77
Kenosha Harbor	WI		Machinery (not elec.) Textile products	Zero/Zero Zero/Zero
Racine Harbor	WI		None reported	
Milwaukee Harbor	WI	2,641	Coal lignite Cement and concrete Asphalt, tar and pitch	563/Zero 382/8 208/Zero
Port Washington Harbor	WI	335	Coal lignite	335/Zero
Sheboygan Harbor	WI	12	Nitrogenous fertilizers	12
Manitowoc Harbor	WI	330	Cement and concrete Coal lignite Waterway improvement materials	172/Zero 126/Zero Zero/19
Two Rivers Harbor	WI		None reported	
Kewaunee Harbor	WI		None reported	
Sturgeon Bay and Lake Michigan Ship Canal	WI	88	Asphalt, tar and pitch	88
Algoma Harbor	WI		None reported	
Green Bay Harbor	WI	2,288	Coal lignite Limestone Cement and concrete	897/Zero 414/Zero 235/Zero
Pensaukee Harbor	WI		None reported	
Oconto Harbor	WI		None reported	
Menominee Harbor and River	MI and WI	217	Coal lignite Non-metal. min. nec. Pig iron	89/Zero 68/Zero 44/Zero
Cedar River Harbor	MI		None reported	
Gladstone Harbor	MI	265	Coal lignite Limestone Asphalt, tar and pitch	126/Zero 44/Zero 32/Zero
Manistique Harbor	MI	1	Distillate fuel oil Gasoline	1 0
Grays Reef Passage	MI	9,763	Coal lignite Limestone Cement and concrete	234/3,079 1,010/1,722 345/1,192

Federal Harbor	State	Total Tonnage, 1994 (thousands)	Major Cargoes	Tons In/Outbound (thousands)
Mackinaw City Harbor	MI		None reported	
St. James (Beaver Island)	MI	5	Unknown or nec. Distillate fuel oil	4 1
Charlevoix Harbor	MI	1,549	Cement and concrete Coal lignite Limestone	8/1,148 300/Zero 10/Zero
Traverse City Harbor	MI	282	Gasoline Distillate fuel oil	161/Zero 121/Zero
Leland Harbor	MI		None reported	
Frankfort Harbor	MI	81	Asphalt, tar and pitch Limestone Wood in the rough	70 10 2
Manistee Harbor	MI	483	Coal lignite Limestone Coal coke	326/Zero 89/Zero 12/Zero
Ludington Harbor	MI	1,093	Limestone Metallic salts Sand and gravel	595/Zero 133/113 11/158
Pentwater Harbor	MI		None reported	
White Lake Harbor	MI		None reported	
Muskegon Harbor	MI	2,004	Coal lignite Limestone Slag	1,199/Zero 243/2 221/Zero
Grand Haven and Grand River	MI	878	Sand and gravel Limestone Coal lignite	Zero/263 183/Zero 167/Zero
Holland Harbor	MI	391	Limestone Coal lignite Slag	160/Zero 154/Zero 58/Zero
Saugatuck Harbor and Kalamazoo River	MI		None reported	
South Haven Harbor	MI	7	Limestone	7
St. Joseph Harbor	MI	631	Limestone Cement and concrete	383/Zero 248/Zero
New Buffalo Harbor	MI		None reported	

[1] Data from *Waterborne Commerce Statistics*, USACE 1996. Tonnages shown are for 1994. Cargoes reflect top three (where available).

Dredging and Dredged Material Management

Bottom sediments are dredged from Lake Michigan and its tributaries for a variety of purposes in addition to navigation maintenance, including water supply intake maintenance, waterfront development, infrastructure construction and repair, and environmental remediation. The USACE annually expends approximately $20 million for maintenance dredging at Great Lakes harbors and channels. On average, about 4 million cubic yards of sediments are dredged from 35 federal navigation projects on the Great Lakes each year.

The options for managing dredged material might be divided into the following categories:

- Open water placement
- Beach/littoral nourishment
- Beneficial use (upland)
- Confined disposal
- Treatment

Table 4-18. Summary of Dredging Activities at Federal Navigation Projects on Lake Michigan

Federal Harbor	State	Channel Depth[1] (Auth/ Maint)	Dredging Cycle (years)	Ave. Dredged Quantity[2] (cu yd)	Dredged Material Management Method(s)[3]
Michigan City	IN				BN, BU, C
Burns Waterway	IN				BN
Indiana Harbor	IN				X
Calumet River and Harbor	IL/IN				C
Chicago Harbor	IL		20+		C
Chicago River	IL		20+		C, X
Waukegan	IL		1		BN, X
Kenosha	WI		7	25,000	C
Racine	WI				
Milwaukee	WI		4	50,000	C
Port Washington	WI				C
Sheboygan	WI	25 / 25	4	30,000	BN, X
Manitowoc	WI	25 / 21	5	40,000	C
Two Rivers	WI		15	50,000	BN
Kewaunee	WI	20 / 20	4	30,000	C
Sturgeon Bay	WI	23 / 23	5	30,000	BU
Algoma	WI	14 / 14	10	25,000	BU
Green Bay	WI	26 / 26	1	234,000	C, BU
Pensaukee	WI	6 / 6	20+	201,000	BN
Oconto	WI		10	50,000	BU
Menominee	WI/MI		5	30,000	O
Cedar River	MI				
Gladstone	MI				
Manistique	MI				X
Grays Reef	MI		20+		O
Straights of Mackinaw	MI				
Mackinaw City	MI				
St. James	MI				
Cross Village	MI				
Inland Route	MI	5 / 5	10	1,000	C, BU
Petoskey	MI				
Charlevoix	MI		20	15,000	BU
Grand Traverse Bay	MI		4	10,000	BN
Leland	MI	12 / 12	1	15,000	O, BN
Frankfort	MI		10	35,000	BN
Arcadia	MI	16 / 9	1	4,000	O, BN
Portage Lake	MI		5	30,000	BN
Manistee	MI		4	30,000	BN
Ludington	MI		3	60,000	BN
Pentwater	MI	16 / 12	1	20,000	O, BN
White Lake	MI		5	30,000	BN

Federal Harbor	State	Channel Depth[1] (Auth/ Maint)	Dredging Cycle (years)	Ave. Dredged Quantity[2] (cu yd)	Dredged Material Management Method(s)[3]
Muskegon	MI		3	70,000	BN
Grand Haven	MI		1	42,500	BN, BU
Holland	MI		5	200,000	BU, BN
Saugatuck	MI		4	20,000	C, BN
South Haven	MI		8	25,000	BN
St. Joseph	MI		1	42,000	BN, BU
New Buffalo	MI		4	10,000	BN

[1] Maximum authorized channel depth and maximum channel depth currently maintained. Channel depths shown are feet LWD.
[2] Average quantity dredged during last three cycles. If cycle is more than 20 years, quantity show is from last dredging.
[3] O = open water disposal; BN= beach/littoral nourishment; BU = upland beneficial use; C =- confined disposal; X = part or all of channel not maintained because of lack of CDF.

Open water placement involves the discharge of dredged material directly to the lake. Hydraulically dredged material may be discharged by pipeline a short distance offshore. Mechanically dredged material may be placed in bottom-dump barges or scows and towed to disposal sites several miles away. Discharged dredged material settles through the water column and deposits on the bottom at the disposal site. The dredged material may remain in a mound at the site or may disperse, depending on the materials physical properties and the hydrodynamics of the disposal site. Open water placement is used with approximately 32 percent of Great Lakes dredged material. Most open water disposal sites in the Great Lakes are dispersive in nature.

Beach/littoral nourishment involves the placement of dredged material directly onto a beach or into the shallow water. Beach nourishment is typically discharged by pipeline from a hydraulic dredge. Suitable dredged material is typically a fine sand and may only stay on the beach for a limited time before being eroded into the littoral drift. Littoral nourishment involves a discharge to near shore, shallow areas, and is typically done with bottom dump scows when a mechanical dredge is used. Beach and littoral nourishment are used with approximately 12 percent of Great Lakes dredged material.

Beneficial use of dredged material includes beach and littoral nourishment (as discussed above) and a variety of upland applications, described here. Upland beneficial uses for dredged material include construction fill, landscaping, agricultural applications and wetland and habitat enhancement. Dredged material from Great Lakes harbors has been used for these and other beneficial uses. For upland uses, dredged material is typically placed into a storage area or confined disposal facility (CDF) for dewatering and then transported by truck for use. The development of islands for wildlife habitat with dredged material is typically done by direct placement from a pipeline. The USACE has continuing authorities to provide federal funding (cost-shared) for the additional cost associated with beneficial use of dredged material for the protection, preservation and enhancement of wetlands and aquatic habitat. Port authorities in Duluth, Green Bay, Milwaukee and Toledo are actively pursuing the development of local markets or applications for dredged material.

Confined disposal is the placement of a dredged material into a secure area where the sediment is physically contained. CDFs are diked structures that have been built for the disposal of contaminated dredged material. Summary information on the 21 CDFs constructed by the USACE to serve federal navigation projects on Lake Michigan is provided in Table 4-19. The size, shape, design and level of complexity of these facilities has varied widely depending on dredging quantities, methods of disposal, sediment contamination levels, state and local requirements and site characteristics. Contaminated dredged material can also be placed in commercial landfills, although this has been done more frequently with environmental cleanup dredging than with navigation dredging.

Treatment technologies are available to destroy, extract, or immobilize sediment contaminants. These technologies are in varying stages of development, with relatively few full-scale technologies available off-the-shelf. Treatment technologies have been used at a limited number of sediment remediation projects around the Great Lakes. Most developed technologies require sediments to be dredged, placed into a holding/storage area, and dewatered prior to treatment. No single technology can address the entire suite of contaminants present in many sediments. A number of treatment technologies were evaluated by the USACE as part of a Great Lakes study conducted 30 years ago (Buffalo District 1969). In addition, the EPA Great Lakes National Program Office conducted a comprehensive analysis of sediment treatment technologies under the Assessment and Remediation of Contaminated Sediments (ARCS) Program (Averett and others1990; Allen 1994; EPA 1994c).

Table 4-19. Confined Disposal Facilities for Lake Michigan Harbors and Channels

Name/Location	State	Type[1]	Year Built	Size (acres)	Capacity (yd^3)	Percent Filled	Existing or Planned Uses after Filling	Construction Authority[2]	Construction Cost[3]
Michigan City	IN	U	1978	3	50,000	100	Recreation/Park	1	$300,000
Chicago Area	IL	L	1984	42	1,300,000	30	Park/Industry	1	$7,800,000
Grand Haven Harbor	MI	U	1974	36	310,000	100	Public Use	1	$433,000
Milwaukee Harbor	WI	L	1975	44	1,600,000	87	Expansion	1	$5,963,000
Dickinson Island	MI	I	1975	174	2,000,000	67	Wildlife Area	1	$5,072,000
Manitowoc Harbor	WI	L	1975	24	800,000	45	Land Use Dev.	1	$4,147,000
Kenosha Harbor	WI	L	1975	32	750,000	100	Public Use	1	$8,270,000
Bolles Harbor	MI	L	1978	25	335,000	44	Marina Expansion	1	$972,000
Holland Hbr-Riverview Site[4]	MI	L	1978	11	120,000	100	Recreation/Park	1	$1,583,000
Holland Hbr-Windmill Site[4]	MI	I	1978	17	160,000	100	Recreation/Park	1	$1,654,000
Sebewaing Harbor	MI	U	1979	9	84,000	100	Airport Extension	1	$1,300,000
Green Bay Harbor	WI	I	1979	60	1,200,000	99	Recreational	1	$5,565,000
Kewaunee Harbor	WI	L	1982	28	500,000	74	Recreational	1	$2,017,000
Frankfort Harbor	MI	U	1982	80	74,000	5		1	$800,000
Inland Route	MI	U	1982	9	19,500	38	Wildlife Area	1	$176,000
Bayport/Green Bay	WI	L	1965	400	650,000		City Landfill	2	City Owned
Kawkawlin River	MI	U	--	--	--	--		2	Private
Monroe Edison	MI	U	--	43	--	100	Detroit Edison	2	Private
Port Sanilac	MI	U	1979	13	143,300	100	Municipal Landfill	2	Used Once
Verplank/Grand Haven Harbor	MI	U	1974	19	134,000	100	Parking Lot	2	City Property
Whirlpool/St. Joseph Harbor	MI	U	1978	14	25,000	100	Transfer Site	2	$638,076
Malleable/St. Joseph Harbor	MI	U	1978	--	35,000	100		2	Unknown

[1] U - Upland, I - In water, Island, L - In water, Adjacent to land or breakwater

[2] 1 = Constructed under Section 123, PL 91-611, 2= Constructed under other authority

[3] Actual construction costs, not adjusted for inflation.

[4] Both facilities considered as one

4.3 Overview of Lake Michigan Status and Management Needs

This chapter documented the current status of the Lake Michigan ecosystem. Overall, the ecosystem has been impaired by habitat loss, toxic and conventional pollutants, aquatic nuisance species, resource harvesting, and climate change. The following discussion presents the status of the research and information gathering, international and U.S. protection efforts, and restoration activities that should be supported to better manage the ecosystem in the future, especially with regard to wetland resources. Many of these management activities are further addressed in Chapter 6.

4.3.1 Research and Information Gathering

Given the variety and extent of impacts on the Lake Michigan ecosystem, some effort to evaluate the relative degree of stress posed by each type of impact is needed. Busch and others (1993) set out a system for assessing the degradation of specific habitats based on measurable criteria. This system requires a detailed measuring regime, both of the habitat being studied and nearby non-degraded habitats. This system has not been implemented to date. In the absence of systematic basin-wide monitoring of relative impacts, the Nature Conservancy (1994) has used a simple ranking system based on professional judgement. Results of this evaluation showed greatest stress on biodiversity resulting from habitat destruction, alteration of lake levels and stream flows, and competition from non-native species. Unlike the addition of toxic chemicals and nutrients, whose effects were given a medium score, the physical alterations were seen to be generally irreversible. In establishing priorities to conserve and protect habitat, further analysis and consensus on the relative threat posed by different impacts seems desirable.

While systematic inventories and assessments of habitats on a basin-wide level are in their early stages. For example, the EPA Region 5 Critical Ecosystems Team is currently developing a data base and series of maps to characterize ecologically rich regions in the basin (www.epa.gov/ecopage/err).

To provide a consistent national database on wetlands, the Nationals Wetlands Inventory (NWI) is classifying and mapping all wetlands in the U.S. from aerial photographs. The information is also being entered into three database systems that will comprise the NWI Geographic Information System (GIS) and allow computer access to the data. The NWI also prepares wetland trend studies and special reports to Congress.

No comparable national program to map other habitat types has been conceived.

One obstacle to basin-wide inventories is the lack of consensus on an ecosystem-wide habitat classification system. In the U.S., the NWI is using the system developed by Cowardin and others (1979) for mapping wetlands. Busch and Sly (1992) and an international team that included many Canadian and U.S. participants reported on the Aquatic Habitat Classification (AHC) System to facilitate mapping of all types of aquatic habitat. The AHC uses the NWI system and expands it to provide more detailed application to open water and tributary habitats and should be amenable to incorporation in computer database systems (Busch and others 1993). It is not clear whether a consensus on the basin-wide use of the AHC has developed.

4.3.2 International Protection Initiatives

Numerous laws and initiatives in both Canada and the U.S. are designed to protect and restore Great Lakes habitat. The ongoing loss and impairment of habitat suggests they have not yet been successful in reversing the trend of the last two centuries. Whether or not they have slowed the rate of degradation cannot be ascertained as the data are not available or inadequate to accurately determine basin wide trends.

The North American Waterfowl Management Plan (Plan) is a joint Canadian - U.S. - Mexican effort that offers many opportunities for wetland protection and enhancement in the Great Lakes basin. The Plan has among its goals to protect approximately 407,000 acres of critical aquatic and associated upland habitat, enhance approximately 135,000 acres of wetlands, and create approximately 19,000 acres of wetlands. Ongoing losses and alteration of habitat were the reasons for setting these goals. Program implementation has evolved to restoring historical hydrology and vegetation as close as possible.

In 1986, the U.S became a signatory to the RAMSAR Convention on Wetlands of International Importance, especially as waterfowl habitat, and to date thirty wetlands, including one in the Lake Michigan basin, Horicon Marsh, Wisconsin, have been identified and protected under this treaty.

The International Tracking System standardizes reporting of wetland restoration, protection, and other data in the U.S. and Canada. Data are available for the fiscal years 1992 through 1996 (October 1, 1991 to September 30, 1996) although full accounting of acreage is sometimes not completely updated for the ensuing year (Joe Artman, pers. communication).

4.3.3 Protection Initiatives

Within the United States, wetlands are managed through a mixture of federal, state and local initiatives, with public input from citizens and interest groups. The federal government's primary tool for protecting wetlands is Section 404 of the Clean Water Act. In accordance with Section 404, the USACE and EPA regulate the discharge of dredged or fill materials in "all waters of the United States". Under Section 404 the USACE considers the advice of EPA, the U.S. Fish and Wildlife Service (Service), the National Marine Fisheries Service, other agencies and the public when deciding whether to issue or deny a permit.

One state in the Lake Michigan basin, Michigan, has assumed administration of the Section 404 program. Most, but not all, wetland permit actions are handled by the Department of Environmental Quality in Michigan. Other states in the basin also have wetland management laws that afford varying levels of protection to wetlands.

Federal agencies are obliged to comply with the Federal Wetlands Executive Order 11990, and Federal Floodplains Executive Order 11988, which direct that wetland and floodplain impacts should be avoided or minimized to the extent possible. The Order requires specific procedures for agency activities related to: 1) acquiring, managing and disposing of federal lands and facilities; 2) providing federally undertaken, financed or assisted construction and improvements; and, 3) conducting federal activities related to land use.

In 1990 the U.S. Environmental Protection Agency released National Guidance on Water Quality Standards for Wetlands (Environmental Protection Agency 1990a). In this document, EPA regional officials and State Water Quality Managers are required to (1) include wetlands in the definition of

"State waters," (2) establish beneficial uses for wetlands, (3) adopt existing narrative and numeric criteria for wetlands, and (4) adopt narrative biological criteria for wetlands, and (5) apply anti-degradation policies to wetlands.

The conservation provisions of the 1985 Food Security Act (Farm Bill) and the 1990 Food, Agriculture, Conservation and Trade Act (FACT Act) have continued to encourage the preservation of a vast acreage of agricultural wetlands and highly erodible croplands. The Swampbuster provision eliminates price supports for individuals who convert wetlands to produce agricultural commodities.

Programs and partnerships are underway by the United States Forest Service and several other U.S. Department of Agriculture Agencies. State and local governments are active in habitat initiatives. Within Lake Michigan basin states there are Natural Heritage programs, although they are focused on natural communities and species more than "habitat." Notable programs in some states include Michigan's Dune Protection Act and Wisconsin's shoreline zoning program, and local watershed councils. Private sector initiatives such as the Nature Conservancy's, Ducks Unlimited and Trout Unlimited are all vital to habitat in the basin.

The U.S. Environmental Protection Agency has included coastal wetlands as a resource class in its Environmental Monitoring and Assessment Program (EMAP) for the Great Lakes. The EPA has begun to plan pilot and demonstration studies to determine the best way to monitor the condition of wetlands on each of the Great Lakes.

4.3.4 Restoration

Wetlands and aquatic habitat restoration is still a rather young science, with long-term rewards unclear. A fair amount of restoration is being attempted around the Great Lakes system, and while its overall effectiveness in terms of quality is uncertain, it holds a clear potential in terms of offsetting historically lost or altered acreage.

Habitat loss, particularly in the case of wetlands, is in many cases a continuum - a matter of degrees of degradation and/or function loss, rather than an "all-or-nothing" proposition. This means that restoration of function is also not necessarily a simple "yes/no" question: restoration can be partial or incremental as resources or conflicting uses allow. Restoration and protection of partially degraded sites is therefore an important goal; complete restoration of all natural values is not the only worthwhile goal.

A search of the 1992 through 1996 data of the International Tracking System found that acres had been restored and acres protected in U.S. counties which are at least partly in the Lake Michigan Basin. The total combined acreage for fiscal years 1992 through 1996 was 12,033.1 acres, but some comparability is lost due to category changes, (more categories now available) through time. For the entire U.S. Great Lakes basin counties, the combined acreage was 10,858.87 acres for fiscal years 1992 and 1993 alone. Comparing this to the previously quoted estimate of 20,000 acres lost per year basin-wide, both countries still appear to be falling well short of just keeping the wetland habitat base they have.

4.3.5 Recommendations

As discussed in Chapter 6, many initiatives to protect and restore the Great Lakes ecosystem are planned and under way. Integrating habitat considerations into these initiatives will increase their effectiveness.

Some solutions to the various environmental stresses that cause losses and alteration of habitat, including wetlands, have to be implemented at the lowest levels of government. Advice, advocacy, data, education, funding and lobbying offered by any group to local clientele may facilitate a solution. Successful local management ordinances are often those with: 1) an underpinning of sound technical data, a comprehensive plan, and evenhanded administration; and 2) a partnership between the federal and state governments, the local community, and its citizens in developing and implementing the ordinance.

Conservation actions aimed at protecting diversity, productivity and function of the Great Lakes basin must strategically address the key sources of stress. First efforts should focus on protecting habitats that are most important to the basin's ecosystem. They must also concentrate on reducing key sources of stress, and do so sustainably in a variety of socioeconomic settings that represent the diversity of challenges present in the basin. Integral to all actions is the need to gain a better understanding of what key species and communities need to survive.

4.4 Overall Assessment

More than 200 years of settlement have reduced the size and extent of many Great Lakes habitats and impaired the functional integrity of many that remain. The Great Lakes contain a mosaic of types and quality of habitat: a healthy habitat type in a given lake can coexist with another that is not at all healthy, while the opposite situation may prevail in another lake. Thus, habitat area figures, even when available, do not allow accurate comparisons of areal extent of habitat types, especially across jurisdictions. Conveying habitat status remains largely descriptive and anecdotal.

At this time, the Lake Michigan ecosystem is an outstanding natural resource of global significance that is under stress and in need of special attention.

Although efforts have been made to remediate damage, particularly in the area of chemical pollution, human impacts to the ecosystem are continuing to impair its function. Toxic air deposition and nonpoint source pollution are problems. Fish advisories remain in effect. In some areas the water supply is susceptible to contamination. Some Lake Michigan beaches experience episodic closures due to high bacteria counts. Unique habitats are fragmented by poor land use practices including uncontrolled development. Contaminated sediments threaten nearshore waters and wildlife. Exotic species have not been prevented from entering the ecosystem nor have they been controlled once established.

Future progress will depend on the stewardship activities and partnerships underway throughout the basin. Public and private organizations and individuals in Lake Michigan basin communities recognize and are taking responsibility for environmental problems. From inter-agency task forces to watershed groups to industry, collaborative, place-based partnerships are finding ways to restore and protect the Lake Michigan ecosystem health. These activities are discussed further in Chapter 6.

Table 4-20. Lake Michigan LaMP Summary Table (Chapter 4)

CHAPTER 2	CHAPTER 3		CHAPTER 4				CHAPTER 6	
Lake Michigan LaMP: Vision, Goals and Ecosystem Objectives	**Indicators and Monitoring of the Health of the Lake Michigan Ecosystem**		**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	**Pressure**	**Human Activity**	**Impairment**	**Spatial**	**Temporal**		**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 Waters - Mercury - Dioxin	• Restrictions on fish and wildlife (F/W) consumption • Tainting of F/W flavor	Lakewide Regional	Ongoing Episodic			
2. We can all drink the water. 	• Raw water quality data • Source water assessments	• Water utility notifications • Source water protection	• Restrictions on drinking water consumption or taste and odor problems	Local	Episodic			
3. We can all swim in the water. 	• *E. Coli* levels in recreational water	• Beach closing advisories • State 305(b) WQ reports	• Beach closings	Local	Episodic			
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	• Degradation of F/W populations • Fish tumors, or other deformities • Degradation of Benthos • Eutrophication or undesirable algae • Degradation of phytoplankton and zooplankton • Loss of F/W habitat • Bird or animal deformities or reproduction problems	Regional Local Local Local Lakewide Lakewide Local	Evolving Episodic Ongoing Episodic Ongoing Ongoing Episodic			
5. Public access to open space, shoreline and natural areas is abundant and provides enhanced opportunities for human interaction with the Lake Michigan ecosystem. 	• Urban density • Coastal parks acreage • Conservation easements	• Open space funding and protection statutes • Coastal zone management	• Degradation of aesthetics	Local	Evolving			
6. Land use, recreation and economic activities are sustainable and support a healthy ecosystem. 	• Contaminants in recreational fish • Sustainable forests	• Superfund cleanups, dredging • CRP percent of eligible farm lands • Brownfields to greenfields redevelopment	• Restrictions on dredging • Added cost to agriculture or industry	Local Local	Evolving Evolving			