Chapter 5:
Lake Michigan Stressor Sources and Loads

Chapter 5 addresses stressors that limit the achievement of the stated vision, goals, and subgoals of the Lake Michigan Lakewide Management Plan (LaMP). There are three general categories of stressors: physical, biological, and chemical. The primary sources of these stressors are land use, point source discharges to surface water, air emissions leading to air deposition, and in-place contaminants or legacy sites. Appendices A, B, and C provide more detailed information regarding the regulations and management programs, physical and chemical properties, and human health effects of each of the stressors described throughout the chapter. Physical stressors include land use and water use and development, primarily for agriculture, mining, urban-suburban development, navigation, waste disposal, and construction of canals. Biological stressors include exotic species and human pathogens. Since the 1830s, eight fish species, seven invertebrate species, three disease pathogens, nine algae species, and two marsh plants are known to have invaded and become established in the Lake Michigan basin. Approximately 10 percent of all exotic species have a significant ecological or economic impact. In the Lake Michigan basin ecosystem, there are currently six viruses, nine bacteria, five protozoa, two algae, one worm, and one yeast/fungi causing or potentially causing serious human health problems. Twenty chemicals or classes of chemicals are identified as chemical stressors. They are divided into three groups: critical pollutants (polychlorinated biphenyls [PCB], dieldrin, chlordane, DDT and metabolites, mercury, and dioxins/furans); pollutants of concern (arsenic, cadmium, chromium, copper, cyanide, lead, zinc, hexachlorobenzene [HCB], toxaphene, and polynuclear aromatic hydrocarbons [PAH]); or emerging pollutants (atrazine, selenium, and PCB substitute compounds). This section also addresses nutrients and radionuclides as pollutants of interest. For each chemical or class of chemical, the uses, general sources, physical and chemical characteristics, contribution to use impairments, and gaps in data collection and existing knowledge are discussed.

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Chapter 5:
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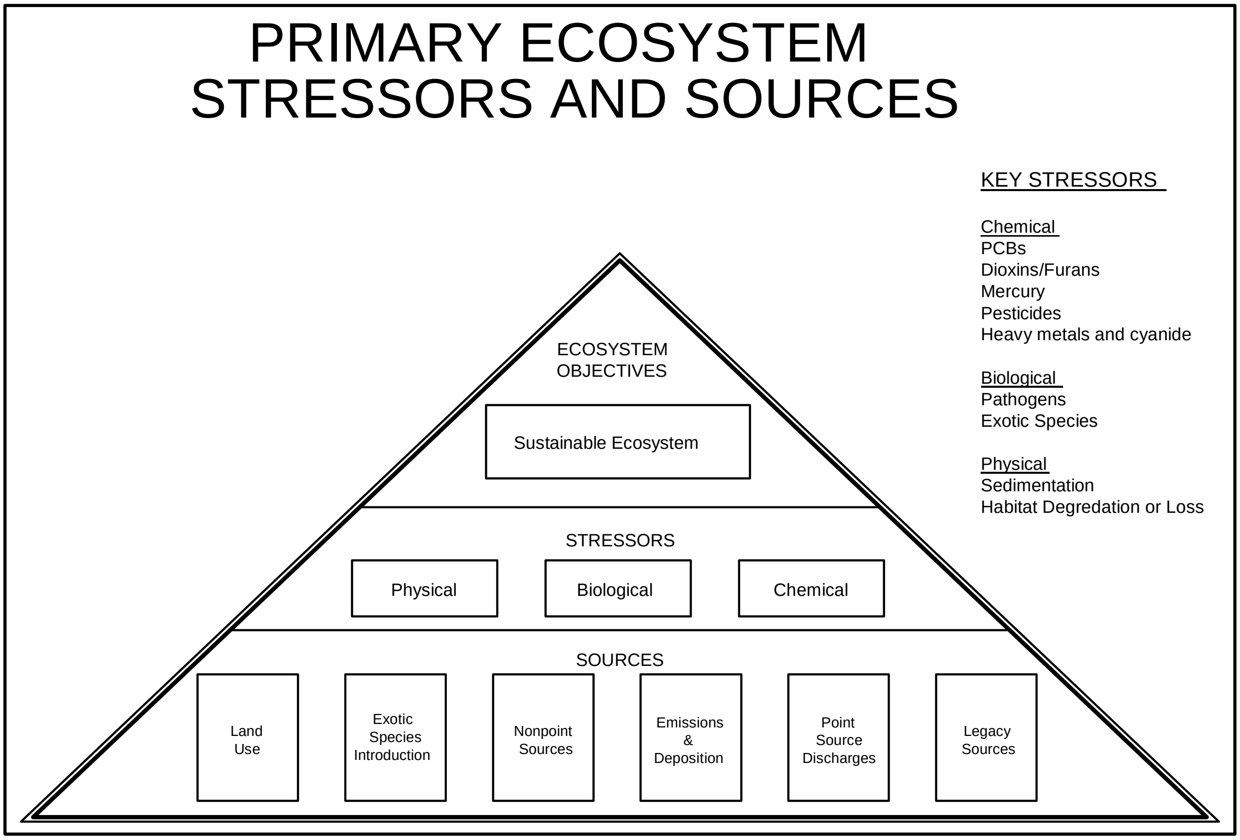
5.1 About this Chapter

In Chapter 2, the LaMP presents the vision for the Lake Michigan ecosystem. The chapter describes the three overarching principles (remediation, integrity and sustainability, and partnership frameworks) that provide a framework for developing subgoals. Chapter 2 also identifies two overall goals that must be achieved to realize this vision: (1) restoring and protecting the lake's ecosystem and (2) using a collaborative process of placed-based partnerships to accomplish the restoration and protection. Restoring and protecting the lake's ecosystem involves understanding the stressors that have damaged or threaten to damage the ecosystem. Figure 5-1 displays the primary ecosystem stressors and sources within the Lake Michigan basin.

Figure 5-1. Lake Michigan Primary Ecosystem Stressors and Sources



This chapter addresses the stressors that limit the achievement of the vision, goals, and subgoals for Lake Michigan outlined in Chapter 2 and presented in Figure 5-2. The icons included in Figure 5-2, and previously introduced in Chapter 2, will aid the reviewer in understanding which subgoals are affected by each stressor. There are three general categories of stressors:

- Physical
- Biological
- Chemical

This section presents an overview of the stressors on the Lake Michigan ecosystem and the sources of information used to understand and describe those stressors. Section 5.2 describes the following sources of the stressors and the information collected to characterize those stressors: (1) land uses, (2) point source discharges to surface water, (3) air emissions that may lead to air deposition of contaminants in the Lake Michigan basin, and (4) existing sources of in-place or legacy pollutants. Section 5.3 discusses the loadings and effects of the physical, biological, and chemical stressors. Chemical stressor-specific information on regulatory and management programs, physical and chemical properties, and human health effects, are included in Appendices A, B, and C, respectively. By characterizing key stressors affecting the lake, the specific management activities described in Chapter 6 can be tailored and focused to address the key problems in the Lake Michigan basin.

The reader will notice that data on concentrations and loadings of the chemical stressors discussed in this chapter may vary. These should not be construed as inconsistent or conflicting data. Numerous different studies were used to describe loadings of pollutants to the Lake Michigan ecosystem. These studies may have been performed at different times for different purposes, using different sampling and analytical techniques. The different data are presented to help the reader understand the extent to which the problems have been evaluated as well as the relative magnitude of the loading of certain chemicals to the ecosystem.

In addition, data are often reported by political jurisdiction, state, or county. Ecosystems do not observe political boundaries. Where possible, loading data were attributed to specific sources at specific locations. In other cases, county-wide data were used when any portion of the county resided within the Lake Michigan watershed.

Finally, names of individual sources are generally not provided unless they are specifically named in studies used to complete this chapter. This would include studies completed for National Priorities List sites and Areas of Concern.

Figure 5-2. Lake Michigan LaMP Subgoals

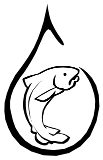
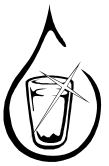
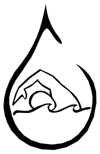
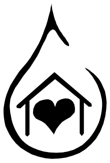
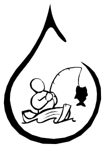
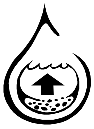
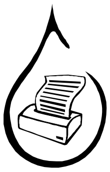
End Point Subgoals		
Subgoal 1	We can all eat any fish.	
Subgoal 2	We can all drink the water.	
Subgoal 3	We can all swim in the water.	
Subgoal 4	All habitats are healthy, naturally diverse, and sufficient to sustain viable biological communities.	
Subgoal 5	Public access to open space, shoreline, and natural areas is abundant and provides enhanced opportunities for human interaction with the Lake Michigan ecosystem.	
Subgoal 6	Land use, recreation, and economic activities are sustainable and support a healthy ecosystem.	

Figure 5-2. **Lake Michigan LaMP Subgoals** (continued)

Means (to End Point) Subgoals		
Subgoal 7	Sediments, air, land, and water are not sources or pathways of contamination that affect the integrity of the ecosystem.	
Subgoal 8	Exotic species are controlled and managed.	
Subgoal 9	Ecosystem stewardship activities are common and are undertaken by public and private organizations in communities around the basin.	
Subgoal 10	Collaborative ecosystem management is the basis for decision-making in the Lake Michigan basin.	
Subgoal 11	We have enough information/data/understanding/indicators to inform the decision-making process.	

5.1.1 Physical Stressors

Human activities have altered the Lake Michigan basin and created physical stressors that threaten the basin ecosystem. Most major human-related stressors are the result of post-settlement modifications to the terrestrial and aquatic elements of the basin ecosystem. This section will present an overview of physical stressors and discuss changes in land use, erosion, lake-level fluctuations, and stressor loadings and effects. A summary of the data sources used to prepare this section are presented below.

5.1.1.1 Overview of Physical Stressors

In the 1800s, forests and wetlands throughout the basin were converted to agriculture uses by early settlers. This change from natural vegetation to row crops accelerated erosion and increased turbidity in nearby waters. Mining for iron ore in the northern basin and for sand and gravel along the nearshore areas became common practice. Soon after, industrialization and rapid population growth led to the development of cities and suburban areas with high population density, especially in the southern basin. As a result, nearshore water began being used for process water, drinking water, and the disposal of pollutants. Nearshore water was also used extensively for navigation and the construction of canals, locks, dams and water-level control structures.

These stressors still play a major role in the Lake Michigan ecosystem today. Although mining and agricultural practices in the northern basin have decreased, they are still active in the Lake Michigan basin. Urban sprawl is also a prominent land use issue, primarily in the southern portion of the basin. Urban sprawl has resulted in new stresses to the ecosystem such as increased sanitary, stormwater, and combined sewage systems, decreased groundwater recharge, increased transportation infrastructure (such as, roads and highways) and reliance on vehicles, increased impervious surfaces associated nonpoint source runoff, and degradation of urban streams.

5.1.1.2 Land Use

This section describes physical changes within the Lake Michigan basin, the extent of those changes, and their impact on the sustainability of the Lake Michigan ecosystem. These physical changes or stressors involve land use and water use within the basin and present a significant challenge to achieving the Lake Michigan end point subgoals 4, 5, and 6. Land use near the Lake Michigan coastal environment degrades critical habitats, reduces the opportunity for the general public to access and enjoy the shoreline, and lessens the overall sustainability of the ecosystem. Certain land use also contributes to loading of chemical and biological stressors. Achieving sustainable land and water use within the basin also involves overcoming other challenges as described in the means to end point subgoals 9 and 10 (ecosystem stewardship and collaborative ecosystem management). Traditional federal, tribal, and state environmental regulatory programs are not well suited for addressing land and water use issues.

The following sections discuss stressors derived from agricultural, urban, and mineral extraction land uses.

AGRICULTURAL LAND USE

Land classified as farmland includes cropland, woodland, and permanent pastures. Within the Great Lakes basin, approximately 33 percent of the land is used for agriculture. Farmland in the Great Lakes basin declined by 9.6 percent between 1981 and 1992, as much of this land was converted to residential and commercial uses. These trends occurred primarily near major metropolitan areas, but many rural areas also contributed to the decline (SOLEC 1996).

These agricultural land use characteristics and trends are similar for the Lake Michigan basin. The predominant development trend in the Lake Michigan basin is low-density sprawl extending from the suburban and urban areas. The decline in farmland in the Great Lakes basin between 1981 and 1992 involved more than 1 million acres (7 to 15 percent) in Michigan and Wisconsin. In addition, the Illinois portion of the basin also experienced a 19.5 percent decline in farmland during this time period (Great Lakes Commission 1996a and SOLEC 1996).

Agricultural land use is found throughout the Lake Michigan basin, predominantly in the southern portion. Approximately 37 percent of the land in the western basin is used for agriculture, with more than 99 percent of that land in cropland and pasture. Small areas of orchards, grove, and vineyards are located on the Door County Peninsula. In the southern part of the basin, the second largest land use (after urban land use) is agriculture, which is found mostly in the St. Joseph River basin. The eastern basin is approximately 28.5 percent agricultural, including cropland, pasture land, and orchards. Parts of these areas are classified as 3 of the top 20 most threatened high quality lands (prime farm land or unique soils and climatic requirements) under development pressure by the American Farmland Trust. The three are Southern Wisconsin and Northern Illinois Drift Plain, Southwestern Michigan Fruit and Truck Belt, and Western Michigan Fruit and Truck Belt.

These areas are important to the overall balance and sustainability of the basin in order to achieve the LaMP vision and desired outcome of “A sustainable Lake Michigan ecosystem that ensures environmental integrity and that supports and is supported by economically viable, healthy human communities.” The current management of these lands stresses the Lake Michigan ecosystem by contributing sediment load to the basin water bodies that carries with it pesticides and nutrients. Urban runoff also contributes sediments contaminated with not only pesticides and nutrients but also chemicals, oils, and road salt. These substances accumulate or persist in the lake because, unlike rivers that are constantly flushed with water, the lake is a sink. A drop of water entering Lake Michigan will take an average of 100 years to either evaporate or be washed into Lake Huron. For a particle of soil, the retention time is even longer and its attached contamination can be taken up in the food web of the lake — a food web that includes the human population.

Sediments also affect the habitat systems of the lake. Lake Michigan contains 40 percent of the coastal wetlands in the entire Great Lakes system. These wetlands provide habitat for larval stages and an abundant food supply for predators. Sediment can bury submergent and emergent plants, while nutrients cause excessive growth.

A number of scientific investigations are underway to further investigate the processes governing sediment, nutrient, and contaminant cycling in the lake. For example, the Episodic Events: Great Lakes Experiment (EEGLE) led by the National Oceanic and Atmospheric Administration’s (NOAA) Great Lakes Environmental Research Laboratory began in 1996. That year a massive turbidity plume, 10 miles offshore, 200 miles long, and composed of as much as 1 million tons of material was observed by satellite. The plume can appear as early as February or as late as May, and for the last 5 years, it has been studied by more than 40 environmental scientists from federal and state agencies and universities. For more information, see Appendix A or the study web site at www.glerl.noaa.gov/eegle/

The Lake Michigan Mass Balance (LMMB) Project led by the EPA Great Lakes National Program Office collected data from air, water, sediment, the open lake, and selected tributaries in 1994 and 1995. The purpose of the study was to improve the understanding of key environmental processes governing contaminant cycling and availability within the relatively closed ecosystem of the lake. The data will be used to support modeling of lake processes, including a sediment transport model. The model will help predict how particles from near-shore locations such as tributary mouths are transported to depositional zones, usually in deep water. www.epa.gov/grlakes/lmmb/sedtrans.html

In the winter of 1999, the Lake Michigan Forum held a work shop on sediment issues in the basin followed by a summer 1999 workshop on stewardship projects. The forum has formed an Agriculture Pollution Prevention Task Force to address specific pollution prevention projects for sediments and pesticides in the Lake Michigan Basin. A report will be issued in summer of 2000. www.lkmichiganforum.org.com

Agricultural Land Use: Erosion and Sedimentation

Wind and water erode soil particles from plowed farmland and carry the particles to water bodies such as nearby streams and lakes. Once in the water body, the suspended particles are eventually deposited to the sediment. Eroded soil particles have the following effects on surface water (EPA 1997[l]):

- Cloudy water and a reduction sunlight reaching submerged aquatic vegetation
- Covered fish spawning areas and food sources
- Covered habitats for aquatic organisms
- Clogged fish gills
- Medium to retain pollutants

Traditional tilling practices expose large areas of soil to wind and water erosion. Traditional tilling has historically been heavily used in corn and soybean fields, which are the primary crops in much of the Lake Michigan basin. Conservation tillage practices, such as no-till farming, contour plowing, and maintaining vegetative cover in erosion-prone areas, expose less soil to erosion forces and reduce sedimentation in surface waters (SOLEC 1996).

Overgrazing of pastures by livestock also contributes to soil erosion and sedimentation. Overgrazing (1) exposes soil exposure to wind and water erosion and (2) reduces vegetative filtration of soil particles from runoff (EPA 1997[l]).

Agricultural Land Use: Nutrients

Nutrients, including nitrogen, phosphorus, and potassium, are applied to agricultural fields to enhance crop production. They are typically applied in commercial fertilizer, manure, sludge, or through chemigation systems. Legumes and other nutrient-rich crops can also contribute excess nutrients to surface water. When an excess of these nutrients is applied or produced, the excess is often transported to surface water bodies in runoff (EPA 1997[l]). Nutrients are necessary for a balanced, sustainable ecosystem, but increased nutrient levels in surface water beyond what is necessary can result in the following (EPA 1999e):

- Increased aquatic plant growth
- Increased algae production
- Depletion of the water's dissolved oxygen content due to plant decay and increased nighttime oxygen uptake during algal blooms
- Foul tastes and odors from aquatic plant decay and algal blooms
- Increased turbidity from algae, which reduces the amount of sunlight penetrating the water and reaching submerged aquatic vegetation

- Decreased growth of submerged aquatic vegetation, resulting in loss of habitat for fish and other aquatic organisms

Recent trends are toward fewer livestock farms with larger numbers of animals per farm (SOLEC 1996). This trend results in larger amounts of manure at each farm location. Confined animal feeding operations (CAFO) enable farmers and ranchers to efficiently feed and maintain large numbers of livestock; however, they also produce large quantities of animal waste. Large amounts of livestock manure from farms and CAFOs contribute high concentrations of nutrients to surface water (EPA 1997[l]).

Agricultural Land Use: Pathogens

Manure from farms and CAFOs also contribute pathogens to surface water. Bacteria contained in animal waste affect surface water in the following ways (EPA 1999e):

- Fish and mass deaths of other aquatic organisms
- Food source poisoning
- High fecal coliform counts that affect humans via direct contact

The method, timing, and rate of manure application are key factors in the potential impact of the manure on surface water. For example, incorporating the manure into the soil, composting the manure, and refraining from manure application when the ground is frozen or snow-covered will reduce the potential for pathogens in the manure to reach surface water (EPA 1999e).

Agricultural Land Use: Pesticides

Pesticides include herbicides, insecticides, fungicides, and rodenticides. These compounds can be transported to surface water through direct runoff, surface water runoff, wind transport, and atmospheric deposition. The effects of pesticides on surface water include the following (EPA 1997[l]):

- Fish kills and mass deaths of other aquatic organisms
- Aquatic vegetation reduction and habitat loss
- Food source poisoning

In the Great Lakes basin, herbicides comprise approximately two-thirds of the pesticides applied to crops, with corn and soybeans requiring a large portion of the herbicides. Specialty crops such as tree fruit, which are typically grown in coastal counties, require use of insecticides and fungicides. Overall the use of pesticides is decreasing in the Great Lakes basin, due in part to the reduction in farmland, and also to reduced application rates. Greater specificity of pesticides enables farmers to reduce application rates, thereby reducing the amount of pesticides entering surface water (SOLEC 1996).

Urban Land Use

The stresses of urban sprawl are numerous. The virtually uncontrolled sprawl of low-density residential areas and other development leads to population-related generation of pollution, habitat loss, higher transportation and residential energy use, increasing encroachment on agricultural lands and natural areas, and burdensome physical infrastructure requirements. Nonpoint source pollution, including bacteria, metals, oils, biochemical oxygen demand (BOD), and nutrients, has a greater impact as population sprawl brings increased areas with impervious surfaces, increased nonpoint sources, and land modification that results in hydrologic changes. In northeastern Illinois, the overall population of the six-county Chicago metropolitan area increased only 4.1 percent from 1970 to 1990 but residential land consumption increased by an estimated 46 percent. Much of this land consumption is at the expense of agricultural land (SOLEC 1996).

As urban sprawl and residential development has encroached along the Lake Michigan shore, impervious or “hardened” surfaces such as roads, parking lots, sidewalks, and rooftops have had a significant impact on surface water runoff patterns. These surfaces cause spikes of increased runoff that damage the morphology of urban streams. They also reduce the ability of natural systems to cleanse runoff. With more pollutants and sediments remaining in the surface water runoff, the potential for environmental degradation and erosion into the receiving water body increases (SOLEC 1996).

Transportation continues to become more oriented towards private automobiles and trucking, as opposed to more efficient public transit and good rail systems. Continued urban sprawl increases reliance on cars and motor carriers and will necessitate controlling urban air pollution. Transportation congestion and commuting delays will further promote work-at-home practices (SOLEC 1996).

From 1992 to 1995, the U.S. Geological Survey (USGS) studied the Western Lake Michigan drainage area as part of the National Water-Quality Assessment Program and found that concentrations of cadmium, copper, mercury, nickel, lead, zinc, and of many toxic synthetic organic compounds were highest in fine river sediments in streams that drained urban areas compared to other land uses. Aquatic life and habitat is most degraded in urban areas with trace elements and synthetic organic compound concentrations in sediment and fish tissue exceeding aquatic-life criteria at some sites in the study (Peters 1998, USGS 1998).

Urban Land Use: Urban Industry

As the Lake Michigan basin moves from a heavy industry to an increasingly service-oriented economy, many abandoned industrial sites need to be addressed. These abandoned sites, commonly called “brownfields”, are found throughout the basin. The southern portion of the basin contains hundreds of these former industrial sites that are now areas of neglect and often sources of continuing pollution. Many of these industrial sites were constructed on fill sites, where foundry slag from processing was deposited. The slag, in the presence of sand, is highly permeable and is conducive to the leaching of contaminants. About 18 percent of land in Chicago is vacant or inactive former industrial sites. These sites present unique challenges to developing and revitalizing urban areas such as cleanup costs and liability issues. As a result, developers are often reluctant to redevelop these abandoned sites and instead migrate to undeveloped areas (SOLEC 1996).

The prominent steel industry in the Lake Michigan basin has had major impacts on land use and the nearshore environment. As an industry, its facilities occupy immense tracts of nearshore land in the southern tip of the Lake Michigan basin. Past steel-making practices have generated tons of pollutants and have resulted in significant air emissions and sediment, soil, and groundwater contamination that remain a concern. Current practices have significantly improved air emissions and water discharges from the steel mills including reduced water usage, recycling, and closed-loop systems. Steel mills are also making site cleanup progress under RCRA corrective action.

Urban Land Use: Urban Erosion and Sedimentation

Soil erosion in the Lake Michigan basin can be attributed to human activities and natural forces. The natural activity of waves is the primary erosion force along Lake Michigan shores and most of the erosion occurs as a result of storms. During periods of higher than average water levels, the wave attack is much higher along the shoreline profile and bluff recession can accelerate rapidly. During periods of lower than average water levels, wave attack is less noticeable, but is occurring further offshore. Other factors, such as groundwater flow, surface runoff, agricultural practices, and human building practice can still cause coastal bluffs to recede, even when lake levels do not trigger collapses (www.lre.usace.army.mil).

The USGS conducted a coastal study of southern Lake Michigan after flooding problems in Chicago in the late 1980s and developed a model to predict the future of the coastline (USGS 1994). During the study, USGS found that the ice ridges that form along the lakeshore do not protect the shoreline from winter erosion and that the repeated formation and breakup of nearshore ice ridges results in significant transport and removal of beach sand trapped in floating ice. This sediment transfer occurs both along the shore and into the deep lake. This is one mechanism by which sand is lost from the nearshore system. USGS also measured bluff retreat along the Illinois shore and found that it averaged 20 to 25 centimeters per year (cm/yr) between Wilmette and Waukegan, Illinois; however, north of Waukegan it is close to 300 cm/yr. Sediments from the eroding bluffs provide most of the sand to the nearshore zone. As more structures are erected to protect the bluffs, less sand is available to the natural system. As the sand supply decreases, the finer-textured lakebed sediments are exposed to wave attack, accelerating coastal retreat (USGS 1994).

Not all of the damage caused by coastal erosion occurs in the lake. Erosion and flooding of Lake Michigan's coastline result in extensive damage to domestic, recreational, and industrial facilities that were built too close to the high water mark. When the lake level is high, bluff erosion increases, and beachfront property and structures are lost (USGS 1994). During times of low water levels, navigation channels and harbors in the lake have to be dredged of sediments that are often polluted and create disposal problems. Also, when the lake is low, hydroelectric output decreases, increasing the load on freshwater pumping facilities and complicating sewage disposal (USGS 1994).

Dredging marinas and bulldozing dunes for development projects remove the natural shoreline protection against wind and waves. As more homes and development projects are built along the lakeshore, the associated pedestrian and vehicle traffic destroys vegetation, degrades dunes, and weakens bluffs and banks. Inappropriate building practices in high bluff areas can cause runoff infiltration directly into a bluff, weakening and eroding the bluff. These processes are especially evident along the western Michigan shoreline where weakened shorelines have caused homes to fall into the lake (USAC 1999). In addition, as shorelines weaken, contaminated sediments around the lake are being washed into the lake, thereby contributing additional contaminant loads to the lake (EPA 1999d).

Urban Land Use: Tributary Dams

Tributaries are important sources of cool, high quality water, and they serve as spawning and nursery habitats for many species. In the 1800s, mill dams and later hydroelectric facilities were constructed and altered the habitat. Many dams remain in the Lake Michigan basin but their effects are different in warmwater and coldwater stream environments. In warmwater streams, lake fish populations are excluded from many tributaries, and habitat has been degraded badly in upstream areas through urbanization, poor agricultural practices, and physical alteration of stream channels. The dams have resulted in sediment (and associated pollutants) from warmwater tributaries burying historically important spawning reefs. Reduction in water clarity has also reduced submerged vegetation. Dam removal and better land use practices would likely improve fish community habitats. However, sea lampreys and exotic salmonids use coldwater streams as habitats. Dam removal could enhance sea lamprey populations by opening up previously unavailable spawning habitat. In addition to dams, many of the floodplain areas within the basin have been developed, and as a result, habitats such as important spawning and nursery areas have been degraded or destroyed (MDEQ 1999a).

Resource agencies are also concerned about the positive and negative effects of dams, hydroelectric facilities, culverts, diversions, or other structures that act as barriers to the movement of fish. Objectives of resource agencies include minimization and mitigation for the negative impacts of hydroelectric facilities on fish movements using adequately designed fish passage. This passage moves both potadromous and resident fish around hydroelectric facilities as determined necessary by the resource agencies (1) for the appropriate management of the river system and (2) to ensure that options for future aquatic management are protected in river systems where fish passage is not presently deemed necessary. Riverine or lake dwelling fish, like lake sturgeon, coaster brook trout, walleye, and many others, migrate within a river at different life stages. They must move between areas for food, spawning, overwintering, and population dispersion. The overall health of the ecosystem may be adversely affected in cases where passage introduces contaminated species to an upriver area where fish, wildlife, and humans consume the new food supply. To protect such species as bald eagle, mink, otter, and other fish-eating species, each passage prescription is carefully considered on a case-by-case basis by the regulatory and resource management agencies with jurisdiction in that area.

In Michigan, 113 hydropower plants are currently in operation, and in Wisconsin, there are currently 120 non-federally owned hydropower projects. Fish losses are common at thermal-electric and hydroelectric plants. Losses of young fish in Lake Michigan are significant; 3 to 10 percent of total annuals production. Plants around the basin are mitigating settlements for this damage. Although some new projects are proposed from time to time, the trend is to develop the hydro-generation potential of existing dams (SOLEC 1996).

Mineral Extraction

Mining for copper and iron ore has been significant in the northern portion of the Lake Michigan basin. As the steel industry prospered, the need for iron ore continued to grow. However, surface mining in the northern basin has altered the landscape and contributes to soil erosion and sedimentation in nearby waterways. The environmental impacts of mining include the presence of mill tailings. The tailings can be toxic to plant and animal life and can leach or erode toxic minerals into surface and groundwater.

Oil drilling also has great potential to damage Lake Michigan habitats along the eastern shore. Directional (or slant) drilling became common in Michigan in the 1970s and allowed companies to drill for oil and natural gas under the lake from shore locations up to 4,000 feet away. Ten permitted wells with bottom-hole locations are actively drilling under Lake Michigan. Thirty potential sites for drilling are located in Muskegon, Oceana, Mason, and Manistee Counties, all of them along critical dune areas (Lake Michigan Federation No date[c]).

Mineral Extraction: Sand Dune Mining

Lake Michigan has the largest concentration of freshwater sand dunes in the world. They have been in existence for 2,500 to 10,000 years. The dunes support plant and animal species that are not found anywhere else, but the dunes are threatened by human activities, especially sand mining. The Michigan Sand Dune Protection and Management Act was passed in 1976, but since then, the area permitted for mining has grown almost 50 percent. More than half of the Lake Michigan sand is exported to provide jobs in other states, and the dunes continue to disappear at a rapid rate, with about 46.5 million tons of sand extracted since the law was passed (Lake Michigan Federation 1999). Although the law was strengthened in 1986, it still does not adequately protect this unique habitat. For example, sand from three actively mined sites is used for fill and mined to clear space for residential development.

The major use of dune sand is by foundries that use sand to produce metal castings for molding parts. it. Since the passage of the Sand Dune Protection and Management Act, the demand for dune sand declined by about 30 percent. The Michigan Department of Environmental Quality attributes this to restrictions on the disposal of used foundry sand, but the USGS attributes it to a decline in the demand for foundry sand and glass. Manufacturing smaller parts requires finer sand grains, such as those left by inland glaciers, not the larger sand grains from the shore dunes. Many foundries are now reusing their sand due to the higher costs of disposal. Studies conducted by Michigan Technological University in 1978 indicated that inland glacial sand is a suitable replacement for dune sand (Lake Michigan Federation 1999). The Ford Motor Company has been using inland sand for many years.

Sand dune mining can have a negative impact on the unique species that inhabit the dunes. One species that is threatened is the piping plover, a bird on the federal endangered species list that relies on the shoreline for nesting. Threatened plant species include Houghton’s goldenrod, pitcher’s thistle, and dwarf lake iris, which is Michigan’s state wildflower. Other rare dune species include the ram’s head ladyslipper, white trillium, jack-in-the-pulpit, green-headed cone flower, and several orchids (Lake Michigan Federation 1999).

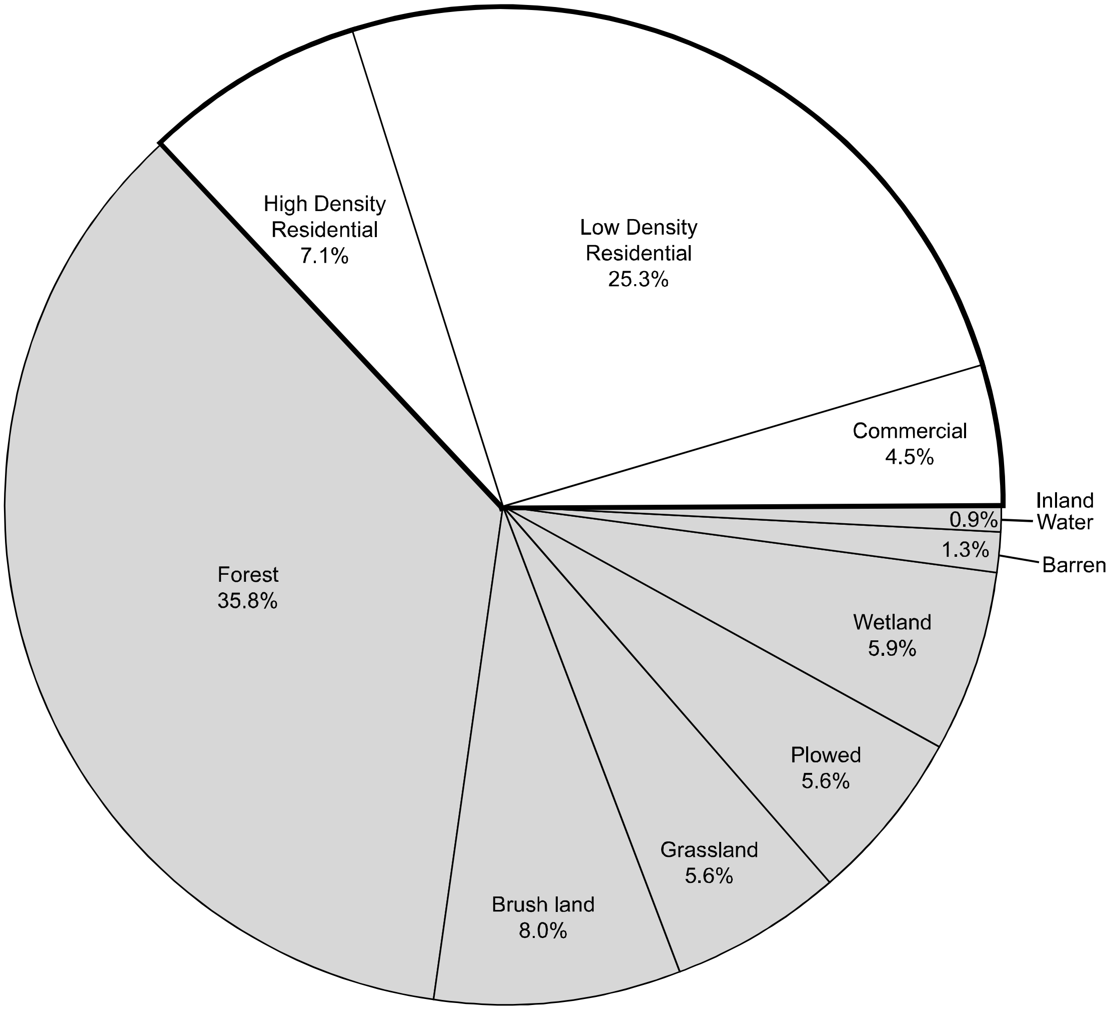
In addition to the negative impact dune mining has on species survival, it also has the potential to negatively affect the tourist industry. Sleeping Bear Dunes National Lakeshore in Michigan draws more than 1 million visitors each year. The National Park Service calculated in 1991 that the economic benefits of Sleeping Bear Dunes exceeded $39 million since the park’s creation, and it has provided more than 1,000 jobs (Lake Michigan Federation 1999).

The dunes provide coastal marshes and support the species that inhabit them, they contribute to a high quality of life for shoreline communities, and they moderate winds and weather blowing in from Lake Michigan. Sand dunes are irreplaceable and could not be recreated if they are destroyed by mining activities (Lake Michigan Federation).

5.1.1.3 Other Physical Stressors

Land use and its associated impacts are significant issues in the Lake Michigan basin. As urban areas grow and agricultural and open space decrease, land use has a significant impact on the quality and sustainability of Lake Michigan. This section addresses two other sources of physical stress to the Lake Michigan ecosystem not directly related to basin land use: natural erosion and climate change. The Lake Michigan shoreline is about 1,400 miles in length and includes approximately 67,600 square miles of land. Figure 5-3 presents the land use of the Lake Michigan shoreline.

Figure 5-3. Land Use of the Lake Michigan Shoreline (1978)



Source: **Living with the Lakes: Challenges and Opportunities. A Progress Report to the International Joint Commission. 1989.**

Natural Erosion

Storms and seiches produce wave, longshore current, wind, and ice action, eroding exposed rock from bluffs or sand from beaches. Wind and tidal effects of the sun and moon generate waves. When conditions are stormy, waves often strike the shore head-on. Usually, they strike obliquely, leaving a cuspate or nonuniform beach pattern.

Longshore currents are generated by obliquely striking waves. They move at an angle to the shore, carrying sediment eroded from bluffs and beaches and from the banks of streams and tributaries to distant shores. But as well as eroding sand from beaches and dunes, waves and longshore currents are also constructive forces, depositing sand to form dunes, beaches, sandbars, shoals, or spits.

Wind also erodes sand dunes and beaches. High velocity winds cause grains of sand to bounce along and collide with other sand grains by a process known as “saltation.” Eventually, a ridge of sand is formed parallel to the shore. Strong winds and human disturbances cause blowouts, or saucer-shaped gaps in dunes.

Ice erodes sand and rocky bluffs. At the shoreline, freezing waves churn with sand and build up, becoming ice shelves in the lake. During spring thaw, ice and sand break off and float free of the shore. Over time, water freezing and thawing in the fissures of rocky bluffs cracks off chunks of rock.

Groundwater and surface water runoff erode the nearshore. Groundwater seeps through the permeable layers of a bluff causing it to slump. Surface runoff, propelled by rain, snowmelt, and irrigation, removes soil from upland to nearshore areas.

The rate of change caused by these processes at any shoreline site is influenced by a host of factors, such as shoreline substrate, degree of exposure to wave action, natural or artificial barriers to alongshore sand movement, water level changes, the degree of winter ice cover, shoreline armoring, and natural and artificial disturbances. On the rockier shores of northern Lake Michigan, erosion is slow. On the sandier shores of the southern part of the lake, the effects of erosion can often be seen after a single storm event.

Another naturally-occurring source of stress is a recurrent plume of resuspended silt- and clay-like particles occurs annually during the spring isothermal period within southern Lake Michigan. Although light availability has been hypothesized to regulate, in part, Lake Michigan phytoplankton, linkages between the plume and the spring diatom bloom are unknown. Researchers are evaluating the impacts of the plume on the lake’s phytoplankton and in situ water-column optics to assess the influence of light availability on phytoplankton biomass and associated rate processes. The plume appeared to alter the intensity and composition of the spring bloom; generally, values of total chlorophyll biomass values at stations severely affected by the plume were slightly greater than values at less-affected stations. Centric diatoms, particularly species of *Cyclostephanos* and *Aulacoseira*, constituted the greatest proportion of the assemblages and appeared to have greater light-harvesting ability (as determined by microphotometric techniques) than other common phytoplankton, possibly explaining their dominance during this episodic event. Although no great differences in bulk P-1 parameters were observed, phytoplankton production appeared to be suppressed to a greater degree at nearshore stations severely affected by the plume than at the less-affected offshore stations (Millie and others 1999).

Climate Warming, Water Levels and Impacts on Lake Michigan

Based on projections using several state-of-the-art models (Mortsch and Quinn 1996, Croley 1991), experts from 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 (International Joint Commission [IJC] 2000).

Scientists have known for more than a century that gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide produce a *greenhouse effect* by allowing short wave solar radiation to enter the atmosphere, while at the same time preventing long wave terrestrial radiation to pass back out. This is a natural and beneficial process, without which Earth would be a frozen and lifeless planet. However, scientists are concerned that human activities, such as the burning of fossil fuels and the destruction of tropical rain forests, are elevating the concentrations of greenhouse gases to the point where they could have a dangerously disruptive effect on the atmosphere by producing an artificially *enhanced greenhouse effect*.

The anthropogenic factors that produced climate warming cannot easily be controlled or reversed. It is important therefore, to encourage the use of sustainable energy alternatives, reforestation, and other practices that will reduce the emissions of greenhouse gases, as well as to formulate adaptation strategies for societal adjustment to potential climate change and variability. These strategies should be based on realistic assessments of future greenhouse emissions and predictions, or scenarios, of the future climate that would result from them. As part of its Great Lakes St. Lawrence Basin (GLSLB) Project, Environment Canada has developed such scenarios for the Great Lakes region. A report that examines in detail these scenarios and the potential impact they would have on the communities and ecosystems in and around Lakes Erie and Ontario is in preparation (Jessup in prep.).

The results of models run on the scenarios created for the GLSLB project, predict the same general results, but to varying degrees. Air temperature, precipitation, evapotranspiration, runoff, and lake surface water temperatures will increase. Total basin moisture, snow, soil moisture, groundwater levels, lake levels, and percent ice cover are predicted to decrease.

In addition to changes in the type of precipitation, there will also be an increase in precipitation variability and intensity caused by the greater frequency of intense cyclones, and the reduction of mild ones. The effect of this, coupled with increased evapotranspiration, may be a corresponding increase in both the frequency and severity of floods (IPCC 1996) and droughts.

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.

The Chicago Tribune (Kendall and Ahmed-Ullah 2000) recently reported that lower than usual snow and rainfall since 1997 adds another source of stress to Lake Michigan. The lake is at its lowest level in years, about 9 inches lower than 1999. Carriers shipping cargo on the Great Lakes will be unable to fill their holds to capacity for the second year in a row so that they will not run aground, reducing the total tonnage shipped on the lake and decreasing the raw materials and finished products available to industries that depend on them. In 1999, 1,000-ft oceangoing ships had to reduce their loads by up to 3,500 tons to make it through the locks that lead out of the lakes. The lower lake levels allow the water temperature to increase resulting in increased proliferation of the bacteria that cause beach closures. Beach closures rise as lake levels drop.

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.

It should not be assumed that climate change impacts on the Great Lakes basin ecosystem will take place only gradually over the next several decades. Human-induced climate change will be superimposed on normal climate variability and natural events, intensifying storm events or climate conditions. Due to the predicted impacts of climate changes on lake levels, it is suggested that considerable caution be exercised with respect to any factors potentially reducing water levels and outflows (IJC 2000).

The Lake Michigan Technical Coordinating Committee decided early in the development process that addressing the issue of water levels in Lake Michigan was beyond the scope of the LaMP and was being addressed under other venues. However, with the potential impacts that climate change could have on the entire lake ecosystem, the Lake Michigan LaMP may need to further discuss this issue.

Falling lake levels are part of the reason the U.S. Fish and Wildlife Service(FWS) is drafting plans to manage Lake Michigan islands for the next 15 years and address issues such as hunting, boater access, protection of nesting birds, and creation of a biological inventory of plants and animals. The U.S. Army Corps of Engineers report “Living with the Lakes: Understanding and Adapting to Great Lakes Water Level Changes” can be found at www.glc.org/docs/lakelevels/lakelevels.html.

5.1.1.4 Sources of Data and Information

The following databases and documents were the primary sources of data and information used in discussing physical stressors.

1996 State of the Lakes Ecosystem Conference (SOLEC) Website
http://www.epa.gov/grtlakes/solec

This website was compiled after the 1996 SOLEC. The conference proceedings as well as papers pertaining to various land uses, land use change, and land use stresses in the Great Lakes region are presented on this website. The website is maintained by U.S. Environmental Protection Agency (EPA) Great Lakes National Program Office with input from Environment Canada (SOLEC 1996).

Great Lakes Environmental Assessment

This document was prepared by Limno-Tech, Inc. (LTI) in 1993 for the National Council of the Paper Industry for Air and Stream Improvement in an effort to characterize the state of the Great Lakes environment. Information is presented on the current status of, trends in, and likely causes for the conditions in the following areas: water and sediment quality, habitat, exotic species, human uses, and health effects on aquatic life, wildlife, and humans.

5.1.2 Biological Stressors - Aquatic Nuisance Species and Pathogens

Biological stressors cause a decline in the health of any ecosystem and negatively affect fish, plant, and wildlife populations. Biological stressors contribute to the following impairments (IEPA 1996b).

- Degraded fish and wildlife populations
- Benthos degradation
- Restrictions on drinking water consumption, odor or taste problems with drinking water
- Beach closings
- Added costs to agriculture or industry
- Degradation of phytoplankton and zooplankton populations
- Loss of fish and wildlife habitat

Introduction of aquatic nuisance species (ANS) and loss of normal habitat have been sources of biological stress in Lake Michigan for more than 150 years. The stresses caused by habitat loss and competitive pressures from ANS have a great impact on biological diversity of the lake because they affect multiple systems and tend to be less reversible than stressors in other categories (Nature Conservancy 1994). Invasion of nuisance species and loss of habitat are the two most significant, ongoing, and long-lived threats to the integrity of the lake ecosystem (LTI 1993). Consequences of such stress include loss of biodiversity in the lake, change in the make-up of the biota of the lake, losses to commercial and sport fishing industries, and threats to species that depend on the lake and surrounding areas for breeding grounds and habitat.

Aquatic Nuisance Species

Aquatic nuisance species are also called nonnative species, nonindiginous invasive species, and ANS. They are plants, animals, and microorganisms that are accidentally or deliberately introduced into an environment that is not their regular habitat. They survive at the expense of species that are already established. Aquatic nuisance species introduced anywhere in the lower Great Lakes often end up in Lake Michigan. The aquatic nuisances include fish, invertebrates, disease pathogens, algae, and marsh plants. When these species are free from the competitors, predators, parasites, and pathogens that control their populations in their native habitat, they thrive and are a major cause of continuing loss of desirable plant and animal species (MDEQ 1999b). Native Lake Michigan fish including lake trout, walleye, yellow perch, and whitefish are threatened by increasing populations of ANS, such as zebra mussels, sea lampreys, ruffe, and round goby (Anonymous 1997).

Since the mid-1800s, at least 136 ANS have become established in the Great Lakes basin. Ship ballast water is one of the most common vehicles for introducing ANS into the lake, as illustrated in Table 5-1. The invaders include 61 plant species, 24 fish species, 24 algal species, 24 mollusk species, and 7 oligochaete species. Most of them arrived from Europe (47 percent), the Atlantic Coast (18 percent)

Table 5-1. Aquatic Nuisance Species Found in Lake Michigan

Common Name	Species	Origin	Date of Discovery	Place of Discovery	Mechanism of Introduction
Fish					
Sea lamprey	*Petromyzon marinus*	Atlantic Coast	1830s	Lake Ontario	Canals, ship fouling
Alewife	*Alosa pseudoharengus*	Atlantic Coast	1873	Lake Ontario	Canals, accidental introduction with stocked fish
Common carp	*Cyprinus carpio*	Asia	1879	widespread	Deliberate release
rainbow smelt	*Osmerus mordax*	Atlantic Coast	1912	Crystal Lake, MI	Deliberate release
three-spined stickleback	*Gasteroosteus aculeatus*	unknown	unknown	unknown	unknown
white perch	*Morone americana*	Atlantic Coast	1950	Cross Lake, OH	Canals
round goby	*Neogobius melanostomus*	Eurasia	1990	St. Clair River	Shipping ballast water
tubenose goby	*Proterorhinus marmoratus*	Eurasia	1990	St. Clair River	Shipping ballast water
Invertebrates					
faucet snail	*Bithynia tentaculata*	Eurasia	1871	Lake Michigan	Shipping solid ballast, deliberate release
European ear snail	*Radix auricularia*	Eurasia	1901	Chicago	Aquarium release, accidental release
Zebra mussel	*Dreissena polymorpha*	Eurasia	1988	Lake St. Clair	Shipping ballast water
Oligochaete	*Branchuria sowerbyi*	Asia	1951	Kalamazoo River, MI	Accidental release
Spiny water flea	*Bythotrephes cederstromi*	Eurasia	1984	Lake Huron	Shipping ballast water

Table 5-1. Aquatic Nuisance Species Found in Lake Michigan (continued)

Common Name	Species	Origin	Date of Discovery	Place of Discovery	Mechanism of Introduction
Water flea	*Eubosima coregoni*	Eurasia	1966	Lake Michigan	Shipping ballast water
Parasitic copepod	*Argulus japonicus*	Asia	<1988	Lake Michigan	Accidental release, aquarium release
Disease Pathogens					
furunculosis	*Aeromonoas salmonicida*	unknown	<1902	Unknown	Release with stocked fish
microsporidian parasite	*Glugea hertwigi*	Eurasia	1960	Lake Erie	Release with stocked fish
whirling disease	*Myxobolus cerebralis*	unknown	1968	Ohio	Release with stocked fish
Algae					
diatom	*Biddulphia laevis*	widespread	1978	Lake Michigan	Shipping water ballast
diatom	*Cyclotella atomus*	widespread	1964	Lake Michigan	Shipping water ballast
Diatom	*Stephanodiscus binderanus*	Eurasia	1938	Lake Michigan	Shipping water ballast
Diatom	*Stephanodiscus subtilis*	Eurasia	1946	Lake Michigan	Shipping water ballast
Diatom	*Diatoma ehrenbergii*	widespread	1930s	Lake Michigan	Shipping ballast water
Diatom	*Cyclotella cryptica*	widespread	1964	Lake Michigan	Shipping ballast water
Diatom	*Cyclotella pseudostelligera*	widespread	1946	Lake Michigan	Shipping ballast water
Diatom	*Cyclotella waltereki*	widespread	1964	Lake Michigan	Shipping ballast water
Brown alga	*Sphacelaria lacustris*	unknown	1975	Lake Michigan	Shipping water ballast

Table 5-1. Aquatic Nuisance Species Found in Lake Michigan (continued)

Common Name	Species	Origin	Date of Discovery	Place of Discovery	Mechanism of Introduction
Marsh Plants					
Purple loosestrife	*Lythrum salicaria*	Eurasia	1869	Ithaca, NY	Canals, shipping ballast water
Seaside goldenrod	*Solidago sempervirens*	Atlantic Coast	1969	Chicago, IL	Accidental release

and Eurasia (14 percent). About 10 percent of these ANS have a significant ecological or economic impact (Great Lakes Commission 1999c). Table 5-1 shows the ANS that now inhabit Lake Michigan, their probable origin, when and where they were first discovered, and how they were introduced into the Great Lakes system. Species that are not native to Lake Michigan have been introduced in several ways over the past 150 years. Atlantic coast species such as the sea lamprey and the alewife arrived through the canals connecting the Great Lakes with the Atlantic Ocean, by ship fouling, and by accidental introduction with stocked fish. Some of the aquatic nuisance snails were deliberately released from aquariums, and some were unknowingly released with shipping ballast water. Almost all of the nonnative algae were released within the last 50 years in shipping ballast water. Marsh plants, such as purple loosestrife and seaside goldenrod, were introduced in shipping ballast and as an accidental release, respectively.

Table 5-2 shows the prevalence of the most common nuisance species in Lake Michigan.

Table 5-2. Exotic Species in Lake Michigan

Species	**Prevalence**
Zebra mussel	Widespread, hard to control
Sea lampreys	Widespread, under control
Alewives	Widespread, under control
Round goby	Widespread, hard to control
Ruffe	Not yet in Lake Michigan
Purple loosestrife	Widespread, hard to control
Spiny water flea	Widespread, hard to control
Eurasian water milfoil	Widespread, hard to control
Cercopagis pengoi	Widespread

This section discusses the following ANS whose effects on the Lake Michigan habitat are best documented: zebra mussels, sea lampreys, alewives, round goby, ruffe, purple loosestrife, spiny water flea, and *Cercopagis pengoi*. It also covers introductions of beneficial nonnative species used to control ANS.

Zebra Mussels

Zebra mussels were accidentally introduced into the Great Lakes from Eurasia around 1988 in shipping ballast water. They spread quickly to at least 20 states and two Canadian provinces bordering the Great Lakes and to the Mississippi River (FWS and others 1999). Zebra mussels can grow up to 2 inches (in), but they are usually less than 0.5 in long. They have a life span of about 5 years, and an adult female can produce more than 30,000 eggs per season (Great Lakes Commission 1999c). The larval mussels are scattered by currents over a wide area, and the adults attach in clusters to any hard, nontoxic surface.

Zebra mussels filter microscopic algae from the water column, diverting nutrients from open water to the lake bottom; this favors bottom-dwelling species and their predators over those that feed in open water, and it also gives rooted aquatic plants and associated species such as large mouth bass a chance to thrive at the expense of walleye and other species adapted to turbid water (Anonymous 1997). Zebra mussels have also had a negative impact on the population of the amphipod *Diporeia* species (spp.) in southern Lake Michigan. Nalepa's group (Nalepa 1987) at NOAA studied the densities of macroinvertebrate populations from 1980 through 1999. They found that the densities of *Diporeia* started to decline in 1992 in the southeastern part of the lake. By 1999, the area of reduced *Diporeia* populations expanded to include the southern part of the lake from Chicago on the western shore to Grand Haven on the eastern shore. Densities have declined to zero at depths of 45 meters. *Diporeia spp*. are important in the Lake Michigan food web because they feed on material that settles to the bottom and are a food source for most species of fish. Nalepa's group suspects the decline of *Diporeia* is due to the introduction and rapid growth of zebra mussel populations that filter out food material before it settles on the lake bottom, leaving little food for *Diporeia* (Nalepa 1987).

In addition to their negative impact on native species, zebra mussels damage boats left in the water, foul beaches, and clog water intake pipes (Minnesota Sea Grant Program No date), causing millions of dollars of damage to municipal power plants and water pumping stations (FWS and others 1999).

Sea Lampreys

Sea lampreys arrived in the Great Lakes in the 1830s by way of the Welland and Erie Canals, spread as far as Lake Michigan by 1936, and decimated the native lake trout population by the mid-1950s (Peeters 1998). They are primitive eel-like predators that attach to the body of a fish and suck blood and tissue from the prey's wound. Lampreys prey on all large Great Lakes fish such as lake trout, salmon, rainbow trout, whitefish, chubs, burbot, walleye, and catfish. Each lamprey can kill more than 40 pounds of other fish. Although the exact number of lampreys present in Lake Michigan before control efforts took effect is unknown, their effect on the lake's fishery is a good indicator. The catch of lake trout in Lake Michigan dropped from 5.5 million pounds in 1946 to 402 pounds in 1953 (Glassner-Shwayder 1999). Effective lamprey control programs were implemented by the mid-1960s, allowing reintroduction of some native species back into the lakes.

Alewives

Alewives were first seen in the Great Lakes in 1873. They came through the Welland and Erie Canals. Their impact on native fish populations evolved in conjunction with the decimation of the trout population by sea lampreys. Without the trout as predators, alewives flourished and became the dominant fish species in Lake Michigan, making up 85 to 90 percent of the lake's fish biomass by the mid-1960s (Grand Valley State University 1999). The alewife explosion caused the reduction or elimination of many native species. Six of seven chub species were eliminated, causing closure of the commercial chub season. Lake herring, yellow perch, and emerald shiner populations were also negatively affected, along with the commercial and sport fisheries on the lake (Grand Valley State University 1999). In the mid-1960s, before stocked predator species expanded enough to keep them under control, the alewife population explosion altered food webs, thereby increasing water turbidity. In addition, alewife corpses washed up on Lake Michigan beaches each spring causing a negative impact on the tourist industry and beach-related recreational activities (Great Lakes Commission 1999c).

Round Goby

The round goby was introduced into Lake St. Clair from shipping ballast water in 1990. In less than 10 years it spread to all five of the Great Lakes, including southern Lake Michigan, where it is now established in the Illinois Waterway System. The Illinois Waterway System provides a direct connection between the Great Lakes and the Mississippi River. Round goby are bottom-dwelling fish that could cause great negative impact on Great Lakes fisheries. They are aggressive, voracious feeders that can forage in total darkness. They take over prime spawning sites traditionally used by native species, and they compete with native fish populations for food and habitat, thus changing the balance of the ecosystem. Goby can survive in degraded water conditions, and they spawn more often and over a longer period than native fish. Bottom-dwelling species that are threatened by the round goby include sculpin, logperch, and darters (Glassner-Shwayder 1999).

Ruffe

Ruffe is a Eurasian percid fish not yet found in Lake Michigan, but it is likely that they will arrive soon. They were introduced into Duluth-Superior Harbor in the western part of Lake Superior in ship ballast in 1986. By 1991, ruffe was the most abundant species in the harbor. A 1992 report by the Great Lakes Fisheries Commission called ruffe a threat to North American fisheries, and a control program was established. By 1995, ruffe spread to northern Lake Huron. The impact of ruffe on other fish species is not proven, but research indicates that they cause profound changes in ecosystem energy flow, and simulation modeling indicates they will have a devastating effect on yellow perch (Glassner-Shwayder 1999). Even though ruffe are not yet established in Lake Michigan, plans are in place to control their spread to the Mississippi watershed through the Chicago, Des Plaines, and Illinois Rivers, indicating that they are expected to make their way into Lake Michigan in the future.

Purple Loosestrife

Purple loosestrife was brought to North America from Europe in the early 1800s, both in ship ballast water directly by settlers for their flower gardens. It has spread through much of the United States and Canada, including the area forming the Lake Michigan basin. About 190,000 hectares of wetland, marshes, pastures, and riparian meadows are affected by purple loosestrife each year. Purple loosestrife plants can produce nearly half a million seeds per square meter in wetland soil. This productivity has several devastating ecological effects. The plant thrives in moist soils, forming dense stands that rapidly degrade wetland areas and choke out native vegetation. The purple loosestrife stands are unsuitable as habitat for many wetlands animals, including ducks, geese, muskrats, frogs, and turtles. It threatens areas where fish spawn and where rice grows. The habitat destruction caused by purple loosestrife amounts to millions of dollars lost each year, and there is concern that the plant could spread further inland, encroaching on pastureland and cropland posing a threat to the economic health of the agriculture industry (Glassner-Shwayder 1999).

Spiny Water Flea

The spiny water flea (*Bythotrephes cederstroemi*), also called “B.C.,” is a 0.5-in crustacean introduced from Eurasia in shipping water ballast in the early 1980s. Since they were first identified in Lake Huron in 1984, they have spread to all the Great Lakes and to some inland lakes. Spiny water fleas are large zooplankton that compete with small fish, such as young perch, for food. They reproduce rapidly. During warm weather each female can produce up to 10 offspring every 2 weeks, and they can produce eggs that stay dormant during cold weather (Great Lakes Information Network No date[b]). Spiny water fleas are not heavily consumed by predators because their long barbed tail makes it difficult for small fish to eat them; as a result, only some large fish feed on them. Because it has relatively few predators, spiny water flea populations remain high, and the populations of plankton they eat have declined (Great Lakes Information Network No date [b]). They can foul fishing equipment when present in large numbers (Minnesota Sea Grant College Program No date).

Eurasian Water Milfoil

Eurasian water milfoil was accidentally introduced from Europe and reached the midwestern states between the 1950 and 1980. It is a floating plant that grows and spreads rapidly, choking out native plants, harming fish habitat, and interfering with boating, fishing, and swimming (Minnesota Sea Grant College Program No date; Great Lakes Information Network No date[a]). A key factor in this plant's success is its ability to reproduce from stem fragmentation and underground runners. A single segment of stem and leaves can take root and form a new colony. Boaters can easily spread the plant from lake to lake, and the mechanical removal of weed beds for commercial and recreational use creates thousands of new stem fragments. Removing native vegetation creates a perfect habitat for Eurasian water milfoil, but it has difficulty becoming established in lakes that have healthy native plant populations. It has little direct impact on fish and other aquatic animals (Great Lakes Information Network No date[a]).

Cercopagis pengoi

In September 1999, *Cercopagis pengoi*, a crustacean smaller than the spiny water flea, was first seen in Lake Michigan in Grand Traverse Bay (Great Lakes Information Network 1999). It was probably introduced into Lake Ontario in shipping ballast water from Eurasia in 1998. This species can reproduce both sexually and pathenogenically, produce up to 13 offspring at a time, have numerous broods per season, and produce eggs that can remain dormant over the winter, making it possible to establish a new population quickly from a relatively small seed population (Glassner-Shwayder 1999). *Cercopagis* usually resides in the warmer, upper ranges of the lake where it is very vulnerable to predation by larger planktivorous fishes. To avoid predation, they migrate to lower depths during the daylight hours. *Cercopagis* fouls fishing gear for both recreational and charter boat operations, sometimes making it impossible to reel in a line. Potential ecological disruptions resulting from *Cercopagis* include decline of native zooplankton populations, disruption of established food webs in the lake, and disruption of the established fishery.

Controlling Aquatic Nuisance Species

Because the impacts of ANS are unpredictable and most likely irreversible (LTI 1993), controlling the spread of existing invaders and preventing the introduction of new ones is imperative. The zebra mussel problem played a key role in prompting passage of the federal Nonindiginous Aquatic Nuisance Species Prevention and Control Act of 1990 (P.L. 101-646) (Great Lakes Commission 1999c). In drafting this legislation, Congress recognized the need for a well coordinated research, monitoring, and prevention program at the Great Lakes and national levels. As a result of this Act, the Aquatic Nuisance Species Task Force was established to coordinate government and private efforts relating to ANS. Also as a result of this Act, the Great Lakes Panel on Aquatic Nuisance Species was convened to address problems specific to the Great Lakes basin (Great Lakes Commission 1999c). Amendments to the 1990 Act form the National Invasive Species Act of 1996 (NISA), which provides for nationwide voluntary guidelines that may be followed later by mandatory controls (Anonymous 1997).

In recent years, progress has been made to decrease the number of new ANS introduced from ships. Ships now voluntarily exchange their ballast water at sea, flushing out organisms and raising the salinity of the ballast water to kill any freshwater organisms remaining in the ballast hold. Other methods include heating the water or passing the water through ultraviolet light (MDEQ 1998b).

The Michigan Department of Natural Resources and the Michigan Sea Grant College Program distribute a pamphlet for boaters and sport fishermen identifying zebra mussels, ruffe, spiny water fleas, and Eurasian water milfoil, describing the problems they cause and the danger of unknowingly transporting them to new locations on boats and fishing gear. It describes steps to prevent further infestations (Minnesota Sea Grant College Program No date).

Zebra mussels cause millions of dollars of damage to municipal and industrial water intakes. So far there is no viable way to manage or eliminate zebra mussels, but several mechanisms have been used to control infestations including a traveling screen mesh, micro-straining fabrics, physical scraping, electrical currents, electrostatic filters, and replacement of blocked intake pipes (Great Lakes Commission 1999c).

Trapping, release of sterile males, and application of lampricide to spawning areas resulted in a significant level of cost-effective, environmentally sensitive control for the last remaining unchecked population of sea lampreys in northern Lake Michigan and Lake Huron. The control program should decrease the sea lamprey populations in this area by at least 85 percent and allow restocking of lake trout and other fishery rehabilitation programs (Anonymous 1997).

The round goby is the newest fish to invade the Great Lakes. It was first seen in the St. Clair River near Detroit in 1990 and within 10 years had spread to Lake Michigan. So far, the goby is confined to the Great Lakes basin, and efforts are underway to prevent their spread to the Mississippi River through the I&M Ship Canal in Illinois. Congress appropriated $250,000 to construct an electronic barrier to prevent their passage through the canal (Anonymous 1997).

Obvious impacts caused by ANS have been described in the literature, but little is known about subtle or chronic effects that are not highly visible, are masked in their perception by other factors, or have not affected major parts of the ecosystem (LTI 1993).

Based on the information currently available, the rate of invasion by ANS appears to be accelerating, and the geographical regions from which these species originate is expanding.

Beneficial Aquatic Nuisance Species

Much attention is focused on undesirable ANS in Lake Michigan, but the deliberate introduction of some nonnative species has had beneficial effects. Once an effective sea lamprey control program was established in Lake Michigan, native lake trout could be re-introduced into the lake in the mid-1960s (Peeters 1998). Coho and chinook salmon, both nonnative species, were also introduced at the same time as the trout because they are more efficient predators of alewives. The trout and salmon stocking program resulted in a significant reduction in the alewife population, and this has allowed an increase in native species such as whitefish, bloater chubs, lake herring, burbot, and yellow perch. Alewives are now an important source of food for the introduced predator species (Peeters 1998). The Lake Michigan fishery has evolved from a simple fishery dominated by alewives in the early 1960s to a diverse fishery with complex species interactions today (Grand Valley State University 1999).

Reef Building

Although artificial reefs do not cause habitat loss, they do modify the existing lake habitat. Three artificial reefs were constructed in Lake Michigan to create habitat for fishery management, and their effectiveness is still being evaluated (Anonymous 1997). The Great Lakes Fishery Commission set up a task force in 1987 to look at the use and value of artificial reefs in the Great Lakes, and it advised that all reefs should be carefully planned to maximize benefits and avoid negative impacts. If the reefs are placed on soft sediments, they will sink, and their value in providing favorable habitat is wasted. So far the value of artificial reefs has been to attract fish, but any broader ecological benefits, such as productivity enhancement, have not been demonstrated (Anonymous 1997). The Great Lakes Fishery Commission's 1990 report (Gannon 1990) concludes that artificial reefs should be considered experimental and that they require comprehensive monitoring and long-term evaluation of ecological and socioeconomic perspectives.

In rare cases artificial reefs are used as a replacement to mitigate unavoidable destruction of natural reef habitat, but usually this is not an acceptable use because artificial reefs cannot replace the productivity of the natural ecosystem (Gannon 1990). Reefs should not be used to mitigate dissimilar habitat types, such as compensating for the destruction of a wetland by constructing a reef.

5.1.3 Pathogens

This section discusses pathogens as biological stressors on the Lake Michigan ecosystem, including the species that pose a threat to human health, the effects these pathogens have on physical health and the economy, sources and loadings in the Lake Michigan basin, and existing management programs.

5.1.3.1 Introduction

Pathogen loadings to Lake Michigan present a challenge to achieving two end point sub goals: *No. 2 — We can all drink the water* and *No. 3 — We can all swim in the water*. The following subsections provide an overview of pathogens in the Lake Michigan basin, including general sources of pathogens, management programs to control pathogens in surface waters, economic and health effects of pathogens, and specific sources and loadings in the Lake Michigan basin.

5.1.3.2 Overview

The following table, Table 5-3, lists the types of organisms that cause waterborne diseases (EPA 1996b).

Table 5-3. Causative Organisms of Waterborne Diseases

Viruses	**Bacteria**	**Protozoa**	**Algae**	**Worms**	**Yeasts, Fungi**
Hepatitis A	Coliforms	*Entamoeba*	Cyclospora	Schistosomes	Candida
Norwalk	Leptospira	*Cryptosporidium*	Microcystis		
Rota	Legionella	*Giardia*			
Adeno	Salmonella	*Naegleria*			
Entero	Aeromonas	Toxoplasma			
Reo	Pseudomonas				
	Shigella				
	Staphylococcus				
	Escherichia coli				

All of these pathogens are commonly found in North America, including the nearshore waters of Lake Michigan. The most prevalent human pathogens are *E. coli*, found in localized outbreaks; *Cryptosporidium*, found in rare, localized outbreaks; and *Giardia lamblia*, which is widespread in the lake. They are more common in areas polluted by agricultural runoff, sewage discharges, and wildlife excrements.

Some of the pathogens in the nearshore waters use humans as their host organisms. Many of these same organisms also thrive in wild and domestic animals, including amphibians, reptiles, aquatic birds, beaver, moose, and cattle that live, forage, or swim in lakes and tributary streams or otherwise frequently come into contact with the water (EPA 1996b). The pathogens or their cysts or eggs are discharged into nearshore waters in excreta or sewage.

In order to cause a disease, a pathogen must successfully invade some part of the body and either produce more of itself or secrete a toxin that interferes with normal body processes (USGS No date[a]). The *E. coli* bacteria found in human and animal digestive tracts is not considered a danger to healthy individuals, but its presence increases the possibility that other pathogens may be present that can cause amoebic dysentery, hepatitis, polio, and a number of digestive ailments (Ting 1996).

5.1.3.3 Effects

Recreational use of nearshore waters, including swimming, boating, windsurfing, and fishing, may result in exposure to microbial pathogens. Waterborne illnesses have become rare in the Great Lakes basin during the past 100 years thanks to vaccinations and effective hygiene measures, especially drinking water and sewage disinfection. Children, the elderly, and people with weakened immune systems are most susceptible to developing an illness or infection after swimming in polluted water. Diarrhea, sore throat, skin infections, and eye infections are common conditions caused by exposure to pathogenic bacteria, viruses, and protozoans.

E.coli is a coliform bacteria from human and animal wastes that is found on beaches and in nearshore water when sewage is discharged without proper treatment, and it can also be in drinking water that has not been adequately treated or disinfected. It is the most common pathogen found in the waters near public beaches (EPA 1996b). Ingesting *E. coli* results in diarrhea and flu-like symptoms.

Cryptosporidium is a protozoan that can pass through water treatment and disinfection processes in sufficient numbers to cause health problems. It causes a gastrointestinal disease called cryptosporidiosis. An outbreak of cryptosporidiosis in Milwaukee, Wisconsin in 1993 was the largest outbreak of waterborne disease ever in the United States (Water Reserves USA No date).

Giardia lamblia is a protozoan that is found in the gastrointestinal tract of some mammals that live in the Great Lakes basin, and it can enter the water through fecal matter from these animals. The organism causes severe diarrhea in humans. It is present even in pristine, clear, cold streams, so people who backpack or hike in the wilderness areas of the basin are advised to treat all water before drinking it (USGS No date[a]).

There are 581 beaches listed for the Great Lakes basin, and on any summer weekend, at least a million people visit them (EPA 1998h). Beach closures most often are caused by high levels of microorganisms coming from sewage overflows and polluted stormwater runoff from cities and farms. (EPA 1998h). Trends in beach closings and the economic impacts of the closings are discussed in Section 4.2.4.1 of Chapter 4.

There are viruses and bacteria present in the lake Michigan basin that are not a threat to humans but could have a negative impact on the health of some fish and wildlife species. *Renibacterium salmoninarum* is found in Lake Michigan. It can cause bacterial kidney disease in some salmonid species. Coho salmon, domestic Atlantic salmon, and chinook salmon are relatively susceptible to infection from this bacteria. Lake trout, rainbow trout, and brook trout are fairly resistant (Starlipper, Smith, and Shatzer 1997). A decline in these species would have a negative effect on the successful sport fishery that has been established in Lake Michigan since the mid-1960s. Newcastle disease virus (NDV) was found in juvenile double-crested cormorants nesting near Lake Michigan and other sites in the Midwest. Mortality is as high as 80 to 90 percent in some nesting colonies. Adult birds were not affected. NVD has the potential to infect domestic poultry, so early recognition and confirmation of the virus in wild birds is essential (Meteyer and others 1997).

The parasite *Myxobolus scleroperca* infected the sclerotic cartilage of 26 of 100 yellow perch studied in late summer 1991 from the Indiana waters of Lake Michigan. The parasite infected fish larger than 94 mm but not smaller ones, resulting in an uneven distribution on the host population. Either smaller fish are not susceptible or the susceptible individuals could die early. If this parasitic infection results in a decreased perch population, there could be a negative impact on the Lake Michigan fishery industry.

Blooms of blue-green algae (cyanobacteria) in areas of the lake used for drinking water sources can result in degraded water quality from toxins secreted by the algae (EPA 1996b). This can result in higher water treatment costs or higher expenditures for bottled water.

5.1.3.4 Sources and Loadings in the Basin

Since 1990 the rivers, creeks, and ditches of northern Indiana have exceeded the state criteria for swimmable water (less than 235 *E. coli* per 100 ml of water). High *E. coli* counts are sometimes associated with periods of heavy rainfall, but sometimes the cause cannot be identified (MDNR 1998a). *E. coli* levels are not uniform in the nearshore waters of Lake Michigan, and scientists still do not understand how extensively tributary streams transport the bacteria into the lake. Some beaches can be closed due to high *E. coli* levels at the same time that sampling at other beaches along the shoreline show no *E. coli* present (MDNR No date[b]).

Leading sources of pathogen pollution in Lake Michigan include unspecified point sources, agriculture, contaminated sediments, municipal and industrial discharges, combined sewers, and atmospheric deposition (EPA No date[q]).

5.1.3.5 Sources of Data and Information

The following sources provided material for this section.

Anonymous. 1997. *Artificial Reefs: Growing Interest, Growing Issues.* Great Lakes Commission Advisor. May/June. Page 10.

This report explored the pros and cons of building artificial reefs in the Great Lakes and the effect such reefs have on the lake fisheries.

Dewailly, E., Poirier, C., Meyer, F., 1996. "Health Hazards Associated with Windsurfing on Polluted Water ." American Journal of Public Health. 76(6): 690-691.

EPA. 1996. "Nearshore Waters Draft 2." State of the Lakes Ecosystem Conference (SOLEC '96). Accessed December 14, 1999. http://www.epa.gov.grtlakes/solec/water/index.html

This report is the proceedings of a conference designed to further the purpose of the Great Lakes Water Quality Agreement between the United States and Canada, which is to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem.

EPA Office of Water, 1999. BEACH Watch Program Homepage. EPA website at http://www.epa.gov/OST/beaches/. Revised April 13, 1999.

Great Lakes Commission. 1999. "Counterattack: Great Lakes Panel Targets Aquatic Nuisance Species." Accessed November 22, 1999. http://www.glc.org/ans/glpatack.html

This report addresses the economic and environmental impacts of exotic species in the Great Lakes, especially zebra mussels.

Health Canada, 1998a. *Health Related Indicators for the Great Lakes Basin Population.* Numbers 1 to 20.

Limno Tech. 1993. *Great Lakes Environmental Assessment.* National Council of the Paper Industry for Air and Stream Improvements. Ann Arbor, Michigan.

This report described the status of the Great Lakes in the early 1990s and addressed issues of special interest to the pulp and paper industry.

Michigan Department of Environmental Quality. 1999. *Environmental Quality Report 1999.* State of Michigan, Lansing, Michigan. 1999. www.deq.state.mi.us/osep/ftp/deqeq99.pdf

This is a status report on the progress made by Michigan and the Department of Environmental Quality toward cleaning up and protecting the state's groundwater, lakes, streams, rivers, land, and air. It will provide a baseline for measuring future progress in environmental protection.

Indiana DNR. 1998. "Healthy Beaches Initiative." Accessed December 15, 1999. http://www.ai.org/dnr.lakemich/beach/htm

This web site talks about the collaborative efforts among several agencies trying to protect the health of the Indiana shoreline of Lake Michigan and the impact of lakeshore activities on Indiana's economy.

Ting, Evert and others. 1996. "Sea Grant, Others Working to Reduce Lake Michigan Beach Closings." Purdue News. August 23. Accessed December 14, 1999. http://www.uns.purdue.edu/html4ever/960823.Pope.html

This web site addresses the problem of *E. coli* and other bacterial contamination along Lake Michigan beaches, describes testing programs to target areas of pollution, and describes the impact of beach closings on the local economy.

Whitman, R.L., Gochee, Angel V., Dustman, Wendy A., Kennedy, Kevin J., 1995. "Use of Coliform Bacteria in Assessing Human Sewage Contamination." Natural Areas Journal. 15:227-233.

Water Reserves USA. Undated. "Is Your Drinking Water Safe?" Accessed December 14, 1999. http://www.angelfire.com/ct/ThreeCs/

This web site describes the problems caused by microbial contamination in drinking water supplies.

Additional information on aquatic nuisance species can be found at
http://www.great.lakes.net/enut/exotic.html

5.1.4 Chemical Stressors

In addition to the physical and biological stressors described above, chemical loading to the lake is also a significant source of impairment. This chapter describes 20 chemicals or classes of chemicals that have been identified as critical pollutants, pollutants of concern, or emerging pollutants, and introduces other pollutants of interest. Loadings of the critical pollutants and pollutants of concern specifically limit the goals to be able to eat Lake Michigan fish, drink Lake Michigan water, and maintain a healthy ecological habitat. Emerging pollutants, on the other hand, are included as a precautionary measure, either because of their widespread use in the basin, the fact that these chemicals are beginning to show up in monitoring data, or both. In the following sections, the rationale for selecting the 20 chemicals is described. The sources, characteristics, and loadings for each of the chemicals are summarized in Sections 5.2 and 5.3.

5.1.4.1 Identifying Lake Michigan Critical Pollutants

This section discusses the classification and definition of the Lake Michigan LaMP Critical Pollutants, Pollutants of Concern, and Emerging Pollutants; describes the LaMP Pollutants; presents information on their uses, general sources, physical and chemical characteristics, and contribution to use impairments; and identifies gaps in data collection and existing knowledge.

The Great Lakes Water Quality Agreement (GLWQA) defines Critical Pollutants as substances that exist at levels that impair beneficial uses due to (1) their presence in open lake waters, (2) their ability to cause or contribute to a failure to meet Agreement objectives, or (3) their ability to bioaccumulate. The Agreement defines persistent toxic substances as any substance with a half-life[1] in water of greater than weeks (Annex 12 Subsection 1(a)).

Under the GLWQA, Canada and the United States agreed to develop, in consultation with state and provincial governments, LaMPs for open lake waters. In addition to addressing persistent toxic pollutants that contribute to ecological impairments, the LaMP process identifies those pollutants that have not yet been associated with an impairment, but whose characteristics suggest the ability to affect the system. These include pollutants that are present in the Lake Michigan watershed, have known toxic characteristics, persist in the environment, and bioaccumulate. State, tribal, and federal agencies have the responsibility to identify and reduce loadings of substances to Lake Michigan waters through the LaMP process before they reach levels sufficient to cause environmental degradation.

A Critical Pollutant Work Group, consisting of technical staff from EPA, FWS, USGS, and four Lake Michigan states, has developed a process for listing and delisting substances as LaMP Pollutants and has identified those chemicals that, based on existing information, are affecting Lake Michigan and its watershed to some degree.

LaMP Pollutants are substances that, despite past application of regulatory controls, persist at levels that, singly or in synergistic or additive combination are causing or are likely to cause impairment of beneficial uses due to the following:

- Presence in open lake waters
- Ability to cause or contribute to a failure to meet agreement objectives through their recognized threat to human health and aquatic life

- Ability to bioaccumulate

Process For Categorizing Lake Michigan LaMP Pollutants

The Critical Pollutant Work Group recommended that LaMP Pollutants be categorized based on degree of association with use impairments and spatial distribution or frequency of occurrence.

Keeping faith with the GLWQA, chemicals that violate the most stringent federal and state water quality standard or criteria, exceed a U.S. Food and Drug Administration (FDA) of the Great Lakes Governors' proposed action levels in Lake Michigan fish, or are associated with lakewide use impairments are classified as **LaMP Critical Pollutants**. These substances are the focus of the LaMP program. Prevention, reduction, and remediation activities to reduce loads and ambient levels of these chemicals in the environment will be pursued by the participating agencies. The following are Lake Michigan critical pollutants: polychlorinated biphenyls (PCB), dieldrin, chlordane, dichlorodiphenyltrichloroethane (DDT) and metabolites, mercury, and dioxins and furans.

LaMP Pollutants of Concern are those toxic substances that are associated with local or regional use impairments (including impairments in the Lake Michigan Areas of Concern [AOC]) or those for which there is evidence that loadings to or ambient concentrations in the Lake Michigan watershed are increasing. Management actions for these substances will emphasize pollution prevention efforts, available load reduction opportunities, and additional information collection. Pollutants of Concern include any chemicals associated with a use impairment in an AOC, if it is not already listed as a Critical Pollutant. Listing pollutants associated with impairments in only one or a few AOCs as LaMP Pollutants of Concern is merely a recognition that these substances are present in the Lake Michigan watershed, have been associated with an impairment (albeit on a local scale), and may be transported into the lake if control measures are not taken. The Lake Michigan Pollutants of Concern include the following: arsenic, cadmium, chromium, copper, cyanide, lead, zinc, hexachlorobenzene (HCB), toxaphene, and polynuclear aromatic hydrocarbons (PAH).

Emerging Pollutants include those toxic substances that, while not presently known to contribute to impairments or to show increasing loadings/concentrations, have characteristics that indicate a potential to affect the physical or biological integrity of Lake Michigan. These characteristics include presence in the watershed, ability to bioaccumulate, persistence (greater than 8 weeks), and toxicity. A brief summary of information concerning these characteristics will be developed for any pollutant listed as an Emerging Pollutant, as well as a description of information required to determine whether it should be moved up on or removed from the LaMP Pollutant list. Listing pollutants under "Emerging Pollutants" is another mechanism to help prevent substances from becoming lakewide problems. In terms of management action for Emerging Pollutants, the Critical Pollutant Work Group recommended data collection, research, and monitoring efforts. The LaMP recommends Emerging Pollutants as priorities for data gathering and research activities. The Lake Michigan Emerging Pollutants presently include the following: atrazine, selenium, and PCB substitute compounds.

Table 5-4 summarizes the pollutant categories for all of the pollutants, and lists the primary reasons for category designation.

5.1.4.2 Other Pollutants of Interest

In addition to the critical pollutants, pollutants of concern, and emerging pollutants identified in this LaMP, three other general classes of pollutants may also impairment the lake's resource: nutrients, radionuclides, and endocrine disruptors. This section summarizes the status of these stressors in the Lake Michigan basin.

Other Pollutants of Interest: Nutrients

Nutrients, primarily nitrogen and phosphorus compounds, are essential to the survival of all living organisms. When maintained at proper levels, nutrients are key components of healthy ecosystems.

Table 5-4. Lake Michigan LaMP Pollutants (EPA 1993)

Pollutant	Category Critical Pollutant	Category Pollutant of Concern	Category Emerging Pollutant	Reason
Total PCBs	#			Fish consumption advisories; strong association with fish and wildlife deformities and reproductive effects; evidence of reproductive and behavioral effects in human, fish-eating populations.
Dieldrin	#			Strong association with fish mortality and reproductive suppression in bald eagles; association with wildlife deformities and reproductive effects.
Chlordane	#			Fish consumption advisories; association with wildlife deformities and reproductive effects.
DDT and metabolites	#			Fish consumption advisories; strong association with eggshell thinning and reproductive suppression in bald eagles; association with wildlife deformities and reproductive effects.
Mercury	#			Fish consumption advisories; sediments classified as heavily polluted by mercury in 6 Lake Michigan tributaries in accordance with EPA sediment guidelines (1977(a)).
Dioxins/Furans	#			Fish consumption advisories; present in Lake Michigan fish and wildlife; fish consumption advisories for the Menominee River; additive effects of dioxin-like compounds associated with wildlife deformities and reproductive effects.
Lead, Cadmium, Copper, Zinc, Chromium, Arsenic, Cyanide		#		Sediments classified as heavily polluted by these inorganics in several Lake Michigan AOCs and tributaries in accordance with EPA sediment guidelines (1977(a)); association with degradation of benthic and planktonic communities; cause of restrictions on dredging
HCB		#		Low concentrations found in Lake Michigan fish tissues; causes porphyria (blocking of metabolic pathways) in animal and humans, possibly associated with porphyria in Lake Michigan herring gulls.

Table 5-4. Lake Michigan LaMP Pollutants (EPA 1993) (Continued)

Pollutant	Category			Reason
	Critical Pollutant	Pollutant of Concern	Emerging Pollutant	
Toxaphene		#		As a mixture of chlorinated camphenes (toxaphene mixtures consist of chlorinated camphenes), exceeds EPA water quality criteria in Lake Michigan; moderate association with fish abnormalities.
PAHs		#		Known carcinogens; widely found in nearshore waters of Lake Michigan; moderately associated with fish tumors, but no effects documented in Lake Michigan
Atrazine			#	Widely used as pesticide in Lake Michigan basin; breakdown rate is relatively slow; toxic to aquatic biota.
Selenium			#	Present throughout Lake Michigan basin with numerous sources; generally persistent and toxic.
PCB Substitute Compounds			#	Includes Isopropylbiphenyl, Santosol 100 and 150, Suresol 290, Diisopropylnaphthalene; Use in Lake Michigan basin as substitute for PCBs; detected in effluent, sediment, and fish in the basin; bioaccumulative and toxic.

However, when nutrient levels become elevated they can increase biological productivity in water bodies and ultimately degrade water quality.

Increased nutrients in waterbodies stimulate the growth of green plants, including algae. The amount of plant growth increases rapidly in the same way that applying lawn fertilizers (nitrogen, phosphorus and potassium) results in rapid, green grass growth. In the aquatic system the increased plant life eventually dies, settles to the bottom and decomposes. During decomposition, the organisms that break down the plants use up oxygen dissolved in the water near the bottom. With more growth there is more material to be decomposed, and more consumption of oxygen. Under normal conditions, when nutrient loadings are low, dissolved oxygen levels are maintained by the diffusion of oxygen into water, mixing by currents and wave action, and by the oxygen production of photosynthesizing plants.

Depletion of oxygen through decomposition of organic material is known as BOD, which is generated from two different sources. In tributaries and harbors it is often caused by materials contained in the discharges from treatment plants. The other principal source is decaying algae. As the BOD load increases and as oxygen levels drop, certain species of fish can be killed and pollution-tolerant species that require less oxygen, such as sludge worms and carp, replace the original species. Changes in species of algae, bottom-dwelling organisms (or benthos) and fish are therefore biological indicators of oxygen depletion.

By the late 1960s, the scientific consensus was that phosphorus was the key nutrient in the Great Lakes and that controlling the input of phosphorus could reduce eutrophication. In response to public concern, new pollution control laws were adopted to deal with water quality problems, including phosphorus loadings to the lakes. In 1972, Canada and the United States signed the Great Lakes Water Quality Agreement to begin a binational Great Lakes cleanup that emphasized the reduction of phosphorus entering all of the Great Lakes, including Lake Michigan.

Studies were conducted to determine the maximum concentrations of phosphorus that could be tolerated by the lakes without producing nuisance conditions or disturbing the integrity of the aquatic community. Mathematical models were then developed to predict the maximum annual loads of phosphorus that could be assimilated by the lakes without exceeding the desired phosphorus concentrations. These maximum amounts were then included in the GLWQA. Following a 1983 review of progress made through waste treatment and detergent phosphate controls, it was determined that control of phosphorus from land runoff was also necessary.

Phosphorus loads entering the lakes have been reduced to below the maximum amounts specified in the Agreement for Lake Michigan. Phosphorus concentrations in the lake are similarly below the maximum levels needed to prevent eutrophication. The return to lower amounts of phosphorus has resulted in reducing excess growth of algae lakewide, although certain embayments are still affected by eutrophication. The composition of the algal population including nuisance species has not given way to more desirable and historically prevalent species, such as diatoms. Elimination of some nuisance conditions appears to be improving the quality of the food web for some organisms. The trend appears to be toward an improved situation but one that may differ significantly from historic conditions. Certain embayments, such as the Fox-Wolf basin and Green Bay, are still experiencing impairments from excess nutrient loading (EPA 1998). Early results from the 1998 to 1999 open water monitoring also indicates the possibility that nutrient levels are rising in the open waters of the lake.

Figures 5-4 and 5-5 show the loads of sediments and phosphorous to Lake Michigan from tributaries whose drainage basins are greater than 325 square kilometers (Robertson 1996).

Other Pollutants of Interest: Radionuclides

Exposure to ionizing radiation can affect the various organs and tissues of the body, and may result from radiation originating in deep space, or emitted by the decay of radioactive elements found in the environment. These radioactive elements, or radionuclides, are unstable nuclides of a particular atomic species that return to stability by emitting ionizing radiation. Currently, there are 15 active nuclear power plant reactors in the Great Lakes basin; 8 are in the Lake Michigan basin. Specific radionuclides of interest in the Lake Michigan basin arising from natural and artificial sources include tritium (3H), carbon-14 (14C), strontium-90 (90Sr), radioiodine (129I, 131I), cesium-137 (137Cs), radon-222 (222Rn), radium-226 (226Ra), uranium isotopes (235U, 238U),and plutonium isotopes (239Pu, 240Pu, 241Pu).

By far, the greatest contribution to the average public radiation exposure is the natural background radiation that comes from radioactive elements in the earth's crust and from cosmic radiation originating in deep space. Natural sources contribute on average more than 98 percent of the human radiation dose, excluding medical exposures. The global average dose from natural sources as estimated by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993) is about 2.4 milliSieverts (mSv – a unit of effective dose) per year.

Figure 5-4. Sediment load via tributary discharge histogram

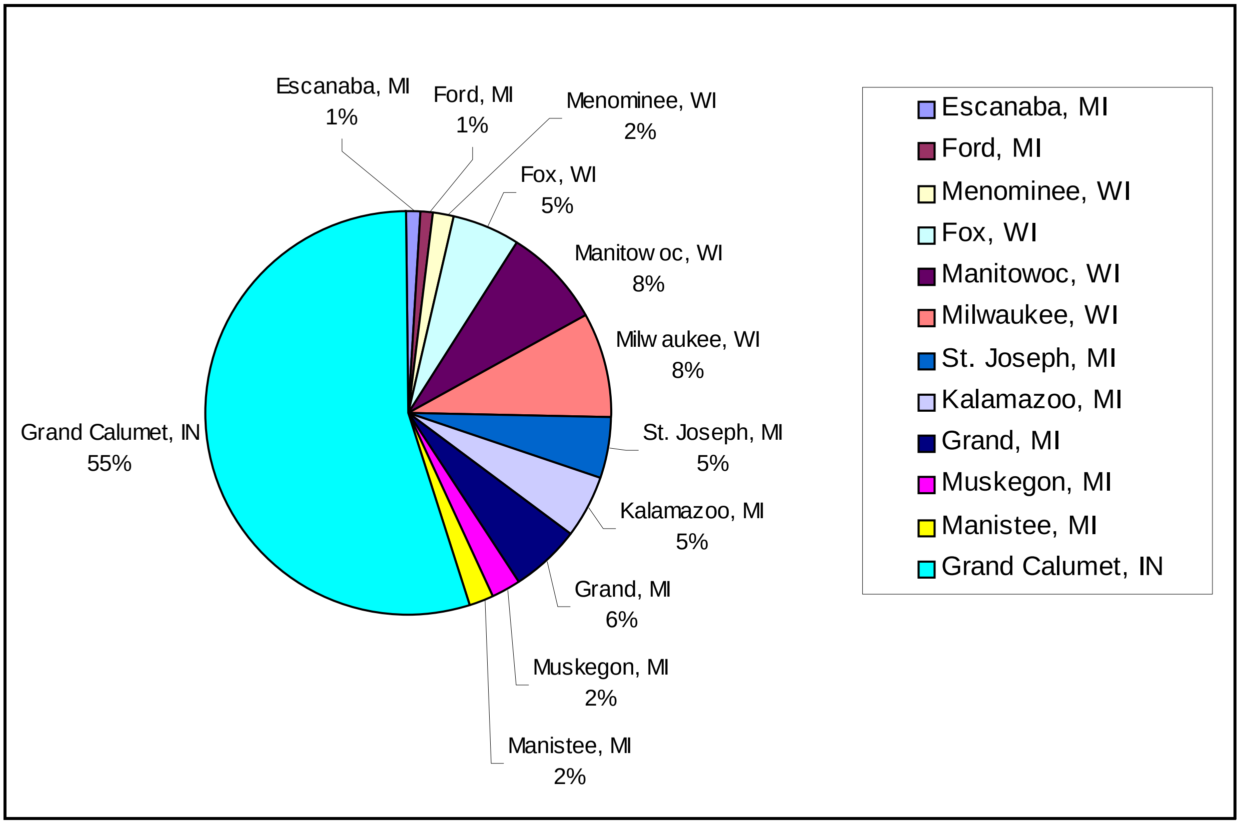
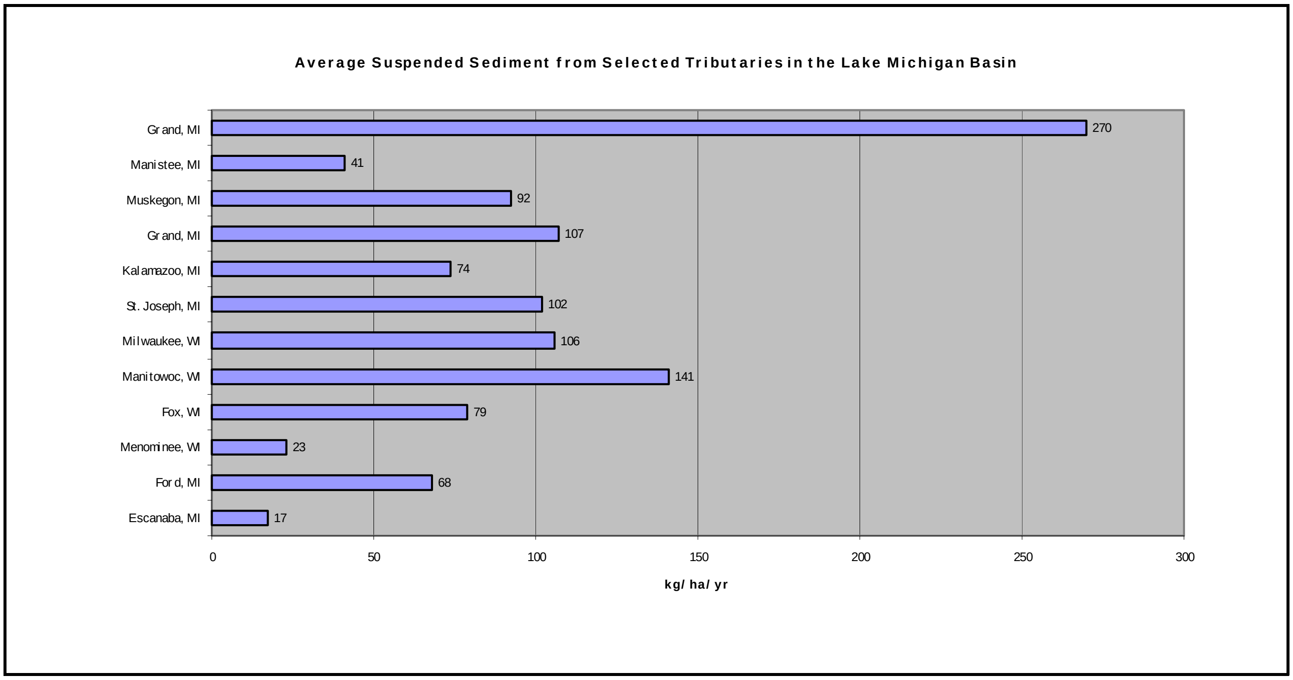


Figure 5-5. Phosphorous load via tributary discharge



Global fallout of radionuclides produced during atmospheric nuclear weapons tests has resulted in the largest total input of anthropogenic radioactivity into the lake, although the 1963 moratorium on atmospheric detonations of nuclear weapons has resulted in declining radiation levels since the mid-1960s. The total committed dose (the average total dose resulting from radionuclides accumulated in the body) to the year 2050 to each individual in the basin from weapons tests conducted between 1945 to 1980 has been estimated to be about 1.9 mSv (UNSCEAR 1993), most of which has already been received.

Increases in local exposure above background levels may result from radionuclides released during the various stages of the nuclear fuel cycle. Nearly all components of the nuclear fuel cycle are found within the basin, the main elements of which are uranium mining, fuel preparation, power generation, and waste management. Normal fuel cycle operations result in controlled and regulated release of radionuclides into the atmosphere and aquatic environments, adding to the radiation exposure from both natural sources and radioactive fallout from atmospheric nuclear weapons tests. The collective dose to the basin population from 50 years of exposure to natural background radiation is therefore of the order of 4.7×10^6 man-sievert (man-Sv). The collective dose from 50 years of fuel cycle operation in the basin based on actual radionuclide emissions from 1985 to 1989 (UNSCEAR 1993) has been estimated to be about 2.8×10^3 man-Sv, or about 3 orders of magnitude less than the exposure due to natural background radiation.

Other Pollutants of Interest: Endocrine Disruptors

The endocrine system is responsible for regulating and maintaining biological functions that are critical for normal growth, development and reproduction. It includes the brain, reproductive organs, and various endocrine glands. Endocrine glands monitor biological processes through chemicals called hormones (such as estrogen, testosterone, and adrenaline); this monitoring provide a means of communication between glands and tissues. These chemical messengers have unique locations in the body, called receptor sites, where they deliver their messages. The action of natural hormones binding to their specific receptor sites is a crucial step in the endocrine system's normal operations, and obstruction of this process can have profound effects on an organism's behavior and physiology. Moreover, the immune and nervous systems interact closely with the endocrine system, and any one of these systems can influence the others.

Recently, government, industry, and environmental groups are attempting to learn more about the environmental endocrine issue. Some man-made chemicals (such as certain pesticides, plastics, detergent ingredients, and food products) have the potential to interact with the endocrine system of humans and wildlife. Such chemicals are called ***endocrine modulators***, or as often described in the media, ***endocrine disruptors***.

Endocrine disruption by exogenic (originating externally) chemicals is not a new concept. Scientists generally agree that some chemicals could interfere with the endocrine system at high doses. For example, birth control pills, and some pesticides, such as DDT and toxaphene, now banned from use, are endocrine disruptors by design. The main question to be answered most recently is whether the health of humans and wildlife around the world is being adversely affected by the presence of *small amounts* of many different types of man-made chemicals in air, water, and food. With this and many other questions still unanswered, the potential risk associated with endocrine disruption by contaminants in the environment has become an intensely debated issue.

The Center for the Study of Environmental Endocrine Effects maintains a website with information on current developments as well as a bibliography of additional references. The Internet address is http://www.endocrine.org.

Endocrine disrupting chemicals work through several mechanisms, usually by either mimicking natural hormones, blocking receptor sites, or by delivering the inappropriate message. Reports describing endocrine-related ailments in both human and wildlife populations are emerging. Some of the more notable human physiological concerns are increases in reproductive tract cancers and abnormal sexual development. While several studies assert that there is a downward trend in male sperm counts, this is still an ongoing debate within the scientific community. Some of the more documented observations in wildlife populations are decreasing hatching success in birds, alligators, and turtles, the synthesis and secretion of a female hormone by male fish, changes in immune response, and behavioral modification. While there is disagreement among scientists on the cause and extent of the issue, there is a consensus that environmental endocrine disruption is a potential risk requiring immediate attention.

Some of the chemical classes that are receiving significant endocrine-related publicity are alkyphenols, carboxylate derivatives, and dioxins, which are found in many consumer products and industrial wastes. Also receiving attention are certain pesticides and medicinal products. Many of these chemicals are pervasive in our environment and human exposure occurs through several pathways, including inhalation, digestion, and dermal contact. Similar routes of exposure occur in wildlife. While many specific chemicals are labeled suspect, significant questions remain about their potency and efficacy to act as endocrine disruptors at environmental concentrations. Therefore, three major questions need to be answered: (1) what chemicals still need to be added to the list of those classified as endocrine disruptors, (2) how serious of a risk to humans and wildlife are endocrine disruptors at ambient environmental concentrations, and (3) how widespread in the environment are endocrine disrupting chemicals?

Evaluation of risk associated with hormonally active chemicals in the environment is based on the following: (1) *hazard*- the harmful effect that a chemical might have on the body even if it only happens at exposure levels that are unrealistic or never encountered in real life, (2) *potency*- how little of a substance is needed to cause a particular effect, and (3) *exposure*- the amount of chemical that comes into contact with the body.

There are currently efforts underway to address these issues and the above-mentioned questions by the National Academy of Sciences and the EPA Risk Assessment Forum. In addition, the Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC) is an advisory committee called together by EPA to provide guidelines for developing a screening and testing program for suspected endocrine disrupting chemicals. Under this strategy, further testing would be performed on those chemicals with significant endocrine disrupting potential.

To evaluate the potential for widespread endocrine disruptor effects in fish, EPA Region 5 initiated a program to assess whether endocrine disruptors may be adversely affecting fish populations in tributaries, harbors, and open waters of Lakes Superior, Michigan, and Erie. This effort is focused on chemicals that have only recently been shown to be endocrine disruptors to fish rather than evaluating endocrine disrupting chemicals such as PCBs and dioxins, which have already received considerable attention. Specifically, an effluent screening study funded by Region 5 and conducted by USGS at several large wastewater treatment plants in the Region was published in 1999. Survey results showed that degradation products of alkylphenol polyethxylate nonionic surfactants (APE) were present in the effluents at concentrations significantly higher than endocrine effect levels reported in the literature. This study is continuing and will analyze effluent, influent, and sludge samples at wastewater treatment plants in the following proposed locations: Duluth, Green Bay, Milwaukee, Akron (Cuyahoga River), and Detroit. Special emphasis is being placed on quantifying human hormone concentrations in these effluents, in addition to APEs. This study will also undertake a toxicity identification evaluation to determine the major chemicals and hormones responsible for fish endocrine disruption.

A second major study by the U.S. Department of Agriculture and funded by Great Lakes National Program Office can be characterized as a reconnaissance survey to assess whether there is potential for widespread endocrine disruption in Great Lakes tributaries and Lake Michigan, as typical of open Great Lakes water. This survey is evaluating known endocrine disruptor biomarkers to determine whether endocrine disruption may be occurring in fish populations in these locations. The study is also documenting concentrations of APE and a number of brominated flame retardants in fish tissue. (Chemical Manufacturers Association 1996; USGS 1999; and EPA/SOLEC 1998)

5.1.4.3 Sources of Data and Information

A variety of print and electronic information sources were reviewed to characterize chemical stressors. In general, data and information was collected through the following means:

- Electronic literature searches, using the DIALOG database of published documents
- Review of government, private organization, and university Internet sites
- Telephone calls to federal, state, and local government agencies; private organizations; and universities
- Electronic database searches

The sources used reported data in various units of measurement. Metric data reported in this document has been also converted to English units to make comparison between data more efficient. A conversion table is provided as part of Appendix B. The following databases and documents were the primary sources of data and information used in this report.

Atmospheric Exchange Over Lakes and Oceans Study

The Atmospheric Exchange Over Lakes and Oceans Study (AEOLOS), a 4-year study begun in 1993, was conducted in an effort to perform an integrated "Great Waters" deposition study to better understand the influence of toxic and nutrient air pollutants from major urban and industrial centers on the water-quality in the Chesapeake Bay and Lake Michigan. The AEOLOS strategy was to conduct a series of intensive field experiments in which pollutants were measured at fixed urban and ship-borne sites in both the Baltimore-Chesapeake Bay and the Chicago-Lake Michigan areas.

Integrated Atmospheric Deposition Network (IADN)

The Integrated Atmospheric Deposition Network (IADN) (www.epa.gov/grtlakes/monitoring/air/) is a joint U.S. and Canada monitoring and research program in operation since January 1990. The primary goal of IADN is to uncover seasonal and annual trends and then to identify sources. The first implementation plan for IADN stated that the objective of the study was the acquisition of "... sufficient, quality assured data to estimate with a specified degree of confidence the loading to the Great Lakes Basin of selected toxic substances." It uses a system of rural monitoring in the Great Lakes region for PCBs, PAHs, pesticides, and trace elements. Mercury is not yet included but will be in the future.

Lake Michigan Mass Balance Project

The LMMB Project (www.epa.gov/grtlakes/lmmb/) began in 1994 and will be concluded in 2001. The LMMB Project provides a coherent, ecosystem-based evaluation of toxics in Lake Michigan and will also study hazardous air pollutants for the Clean Air Act Amendments' Great Waters Program. The mass balance approach, demonstrated in the Green Bay Mass Balance Study (GBMBS), provides a consistent framework for integrating load estimates, ambient monitoring data, process research efforts, and modeling, leading to the development of scientifically credible, predictive cause-effect tools. More than

20 organizations are producing LMMB data through collection and analysis of samples. The primary goal of the mass balance study is to develop a sound, scientific base of information to guide future toxics load reduction efforts for Lake Michigan at the state and federal levels. From this goal, a number of specific objectives have been identified. Several of the plan's objectives call for identifying and quantifying the sources of toxics to Lake Michigan, as well as establishing cause-effect relationships and developing forecasting tools for the following:

- Determine loading rates for critical pollutants from major source categories (tributaries, atmospheric deposition, and contaminated sediments) to establish a baseline loading estimate to gauge future progress and to better target future load reduction efforts.

- Predict the environmental benefits (in terms of reducing concentrations) of specific load reduction alternatives for toxic substances, including the time required to realize the benefits.

- Evaluate the environmental benefits of load reductions for toxic substances expected under existing statutes and regulations and thereby determine if there is a need for more stringent, future regulations to realize further benefits.

- Improve our understanding of how key environmental processes govern the transport, fate, and bioavailability of toxic substances in the ecosystem.

The mass balance project will be based on the Enhanced Monitoring Program (EMP), a comprehensive, 1.6-year synoptic survey for selected toxic chemicals in the Lake Michigan ecosystem. In support of the mass balance study, the Environmental Research Laboratory-Duluth (ERL-D) Large Lakes Research Station in cooperation with the Atmospheric Research and Exposure Assessment Laboratory (AREAL), the NOAA Great Lakes Environmental Research Laboratory (GLERL), and other cooperators will develop a suite of integrated mass balance models to simulate the transport, fate, and bioaccumulation of toxic chemicals in Lake Michigan.

National Water-Quality Assessment (NAWQA) Program

The National Water-Quality Assessment (NAWQA) Program (www.water.usgs.gov/nawqa/nawqa_home.html) is designed to describe the status and trends in the quality of the nation's ground- and surface-water resources and to provide a sound understanding of the natural and human factors that affect the quality of these resources. The NAWQA Program is designed to assess historical, current, and future water-quality conditions in representative river basins and aquifers nationwide. As part of the program, investigations will be conducted in 59 areas called "study units," and these investigations throughout the United States are designed to provide a framework for national and regional water-quality assessment. Due to the similar design of each investigation and the use of standard methods comparison among study units can be made. NAWQA investigations measure water-discharge, sediment load, organic contaminants, aquatic biota, inorganic chemistry, sediment chemistry, trace metals, and habitat. In addition, the investigations measure marine- and coastal- salinity, freshwater flux, nutrients, and contaminants. NAWQA has national summaries for pesticides, nutrients, volatile organic chemicals, trace elements, surface water-quality modeling (SPARROW), and a compilation of findings on nutrients and pesticides.

Permit Compliance System

The Permit Compliance System (PCS) (www.epa.gov/oeca/datasys/possys.html) is a national management information system that tracks surface water discharges under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act. The NPDES permit program regulates direct discharges from municipal and industrial wastewater treatment facilities that discharge into navigable waters of the United States. PCS contains data and tracks permit issuance, permit limits, monitoring data, and other data pertaining to facilities regulated under NPDES. PCS records water-discharge permit data on more than 64,000 facilities nationwide. A separate program, called Effluent Data Statistics (EDS), is used to calculate loadings based on the PCS discharge data.

Because the PCS only requires facilities to report discharges of constituents on the facilities' permits, the data may be inconsistent between facilities. The Lake Michigan LaMP reports PCS data only for PCBs and mercury because studies were conducted to evaluate PCB and mercury PCS data. This data was published by the agencies that conducted the studies.

Regional Air Pollutant Inventory Development System

The Regional Air Pollutant Inventory Development System (RAPIDS) is the emissions inventory data management system used to compile the Great Lakes Regional Air Toxic Emissions Inventory Project. (www.glc.org/projects/air/rapids/rapids.html). The inventory contains statewide air emissions inventories of 49 pollutants to the Great Lakes and emissions estimates for point and area sources of toxic air pollutants. RAPIDS and the Great Lakes Emissions Inventory is a project of the eight Great Lakes states and the province of Ontario working under the Great Lakes Commission with funding from EPA. The first regional (eight states and one province) pilot inventory contains point and area source data from 1993. Inventory reports have been developed for 1993 and 1996 using emission estimates for point and area source data. The 1996 inventory includes emissions of 82 pollutants. An inventory report including estimates for emissions from mobile sources was released in March 2000. Emissions estimates reported in Section 5.3.3, for LaMP pollutants included in the inventories, include estimates for each of the counties within the Lake Michigan basin. Emission estimates for the entire county were used for counties with only a portion in the Lake Michigan basin.

Toxic Release Inventory (TRI) System

The Toxic Release Inventory (TRI) System (www.epa.gov/enviro/html/toxic_releases.html) contains information regarding more than 650 toxic chemicals and compounds that are used, manufactured, treated, transported, or released into the environment, as required under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA). Manufacturers of these chemicals are required to report the locations and quantities of chemicals stored on-site to state and local governments. TRI stores release-transfer data by facility, by year, by chemical, and by medium of release (air, water, underground injection, land disposal, and off-site transfer). TRI also stores treatment and source-reduction data. At the facility level, TRI stores facility name, address, latitude-longitude, and parent company. At the chemical level, TRI stores Standard Industrial Classification (SIC) codes, EPA identification numbers (EPA ID), and pollution prevention data (recycling, energy recovery, treatment, and disposal). At the medium level, TRI stores names and addresses of off-site transfer recipient facilities. TRI data collected for the Lake Michigan LaMP is based on data for each of the counties in the Lake Michigan basin. If only a portion of a county is within the Lake Michigan basin, TRI data for the whole county was included.

Other Sources of Data and Information

In addition to the above databases and documents, numerous sources were used in preparation of this report. For a complete listing of information sources see the bibliography at the end of this document.

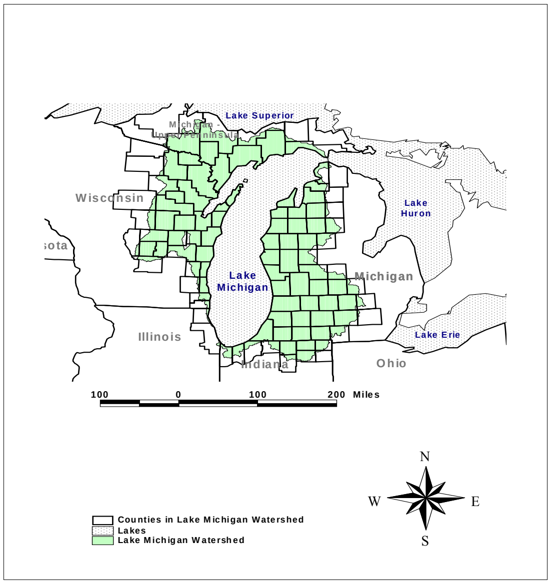
5.2 Overview of Stressor Sources

This section describes the various sources of stressors to the Lake Michigan basin other than nonpoint sources, which were discussed earlier under Physical Stressors: Land use and sources of aquatic nuisance species discussed and biological stressors. These are point source discharges, atmospheric emissions, and in-place pollution or legacy sources. Figure 5-6 shows the counties that are part of the Lake Michigan basin. These counties were the focus for research on stressor sources.

5.2.1 Point Source Discharges

Direct, point source discharges to Lake Michigan and its tributaries from industrial, municipal, and other sources are an ongoing source of pollutant loading to the lakes. Under Section 402 of the Clean Water Act, all point source discharges of pollutants to waters of the United States must be authorized under a NPDES permit. Certain point source discharges of storm water are not currently required to have NPDES permits, although pollution prevention activities are required for many types of storm water discharges associated with industrial and construction activities. NPDES permits require dischargers to meet minimum, technology-based treatment requirements for their wastewater. In addition, the discharges must also meet water quality-based standards developed by the states and tribes. Discharges must meet an acceptable level of pollution control for that type of discharge, regardless of whether or not that level of control is specifically needed to protect the water body to which the discharge is directed. In general, water quality-based standards are designed to protect specific water bodies, and technology-based standards are designed to assure a minimum level of control for a particular class of discharge, no matter where that discharge takes place.

Figure 5-6. Counties within the Lake Michigan Basin



Combined sewer overflows (CSO) are remnants of the country's early infrastructure. In the past, communities built sewer systems to collect both storm water runoff and sanitary sewage in the same pipe. During dry weather, these "combined sewer systems" transport wastewater directly to the sewage treatment plant. However, in periods of rainfall or snowmelt, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, lakes, or estuaries.

Indiana - 19 CSO permittees in the Lake Michigan Basin.

In April 1996, IDEM issued its final *Combined Sewer Overflow Strategy*. Indiana places a strong emphasis on universal nine minimum controls (NMC) implementation. The state reviews and approves/disapproves NMC documentation and does not consider NMC to be "implemented" unless it has approved documentation. Many communities implemented NMC voluntarily prior to permit reissuance requiring NMC. The ninth minimum control measure (monitoring) is implemented separately through a stream reach characterization and evaluation report (SRCER), a good bridge to long-term CSO control plan (LTCP) development. All communities in Indiana must develop LTCPs. When cities develop their Long-Term Control Plans, they estimate bacterial loads entering the receiving waters in order to better understand the relative contribution of CSOs to *E. coli* loadings in state waterbodies.

Michigan - 12 CSO permittees in the Lake Michigan Basin.

In Michigan, NPDES discharge permitting addresses CSOs. Permits include minimum technology-based requirements that align closely with EPA's nine minimum controls. Long-term planning is required for all CSO communities. Michigan places strong emphasis on retention or treatment under state definition of "adequate treatment," which is analogous to the CSO Policy approach.

Long-term planning in Michigan is designed to protect the designated uses of receiving streams and to ensure that discharges meet state water quality standards. The Michigan Department of Natural Resources works closely with communities to develop the long-term plans on a case-by-case basis. To help finance CSO projects, communities are eligible for low interest loans from the State Revolving Fund.

Wisconsin - 1 CSO permit in the Lake Michigan Basin.

Milwaukee recently completed a $2.2 billion effort to reduce the frequency of overflows from combined sewers and improve the quality of effluent from the Milwaukee Metropolitan Sewerage District’s (MMSD) two wastewater treatment plants. This effort involved significant improvement to existing sewers, the construction of tunnels to store wet-weather flows for subsequent treatment, and expansion of the MMSD’s two wastewater treatment plants.

There are currently more than 1,200 point source dischargers in the Lake Michigan basin. Loads from the various source categories are addressed in Section 5.3.

Illinois

The diversion of the Chicago River from the Lake Michigan basin to the Mississippi River System in theory removed all flows into the lake. In high storm flow events, the locks are opened and the Chicago River is allowed to flow into the lake. This occurs approximately once a year.

5.2.2 Atmospheric Emissions

Chemicals emitted to the atmosphere, whether from point sources (stacks), mobile sources, or area nonpoint source legacy sites, can ultimately find their way into the Lake Michigan basin. Pinpointing the source location is problematic due to the ability of airborne pollutants to travel great distances in some instances, before deposition on the earth’s surface, in this case, into Lake Michigan.

5.2.2.1 Air Deposition

There are three major processes of direct atmospheric deposition to Lake Michigan: wet deposition, dry deposition, and gas-exchange across the air-water interface (see Section 4.2.1). Wet deposition refers to the incorporation of particles and gases into precipitation, including rain, snow, and fog. Dry deposition is when pollutants reach the surface by turbulent movements of the air or, for large particles, through gravitational settling. Some pollutants may adhere to particles in the air and then fall out. The distance and the way the pollutant is transported depends on weather conditions, the type of pollutant, the form the pollutant is in, and particle size. Gas-exchange refers to the transfer of chemicals between the gas phase in the air and the dissolved phase in the water across the air-water interface of the lake surface. The direction and magnitude of gas exchange is a function of the chemical concentrations in the air and water, wind speed, temperature, waves, physical and chemical properties of the pollutants, and characteristics of the water (Delta Institute 1999 and EPA 1999d). Loadings from each of these processes are discussed in the following studies described earlier in Section 5.1.3.3: IADN, LMMB, AEOLOS, and others.

5.2.2.2 Long-Range Transport of Pollutants

Atmospheric transport and deposition have been well documented for certain toxic air pollutants and has been demonstrated on local, regional, continental and global scales. Monitors in the Great Lakes Basin have also shown the atmosphere to be a significant pathway for certain toxic pollutants to enter the lakes. Numerous studies have documented toxic pollutants affecting several of the lakes from both long-range sources and local sources. For example, air mass back trajectory analysis based on modeling suggests that inputs of toxaphene detected near Lake Huron have their origin in the historic use of the insecticide in the southern United States and Mexico. More recent ongoing studies (including AEOLOS) point to the impact of urban areas on Lake Michigan loadings of PCBs and PAHs downwind of Chicago over southern Lake Michigan.

The pathway for the transfer of these contaminants from their origin is often very complex. The nature of the pollutants and the meteorological conditions around the Great Lakes make the identification of the sources and geographic origins of the pollutants extremely difficult. Both pollutant-specific factors, as well as meteorological conditions, determine the distance a given pollutant will travel in the atmosphere. An example is the propensity of PAHs to volatilize from the water and be re-entrained in to the atmosphere where they can travel long distances before encountering conditions that favor their redeposition into water. Some factors that influence the extent and duration of the cycling include volatility and persistence of the pollutant; molecular weight; concentrations and temperatures in air, soil, and water; and atmospheric circulation, pressure, and meteorological conditions. Warmer conditions on seasonal and global scales generally favor greater net movement into the atmosphere. Redeposition often takes place in areas of colder atmospheric temperatures. The modeling of chemical fate and concentrations of semivolatile pollutants over very large areas is challenging, and lack of data on pollutant source and release makes the validation of existing models difficult.

5.2.2.3 Status and Current Efforts Underway

A number of recent research programs, assessments and reviews have considered atmospheric transport of pollutants to the Great Lakes. Key findings from these activities area summarized below.

As part of the Clean Air Act Amendments of 1990, Congress directed the EPA to identify and assess the extent of atmospheric deposition of air pollutants to the Great Lakes, the Chesapeake Bay, Lake Champlain, and coastal waters, collectively labeled the Great Waters. The EPA mandate was to compile periodic reports (known as The Great Waters Reports) to Congress on the progress of their assessment. The Great Waters Reports focus on 15 Pollutants of Concern (POC) that include mercury, chlordane, DDT, toxaphene, tetrachlorodibenzo-p-dioxin (dioxins), tetrachlorordibenzofuran (furans), and PCBs, all of which are pollutants affecting Lake Michigan. The initial report was submitted to Congress in 1994, and a second report in 1997, and a third anticipated for summer or fall of 2000. The following are some of the significant findings in the latest Great Waters Report:

- Air deposition represents a significant portion of pollutant loading to the Great Lakes; this portion is highly variable with respect to location and pollutant (air deposition varies between 5 to 100 percent for dioxin/furan, for example).
- General trends are steady or downward for all pollutants in the Great Lakes basin except cadmium; mercury accounts for the largest single input to the Great Waters, although U.S. emission rates have been declining since 1990.
- Determining the relative roles of specific sources contributing to specific water bodies is complex, requiring monitoring, modeling, and other analytical techniques.
- EPA is developing science and tools to assess the contribution of atmospheric sources to water pollution and to reduce total pollutant loadings to affected water bodies.
- The rate of decrease in deposition rates of banned pesticides and herbicides has slowed, which may reflect the persistence of the chemicals and their ability to cycle globally.

Another recent review of current understanding of pollutant transport to the Great Lakes and its implication on policy making was prepared by the Delta Institute in a draft report entitled, “Atmospheric Deposition of Toxics: Integrating Science and Policy.” Some highlights from this report and current programs discussed in it include the following,:

- PCBs and other semivolatile compounds can deposit to the earth’s surface and then revolatilize to the atmosphere over time. This process can continue over long distances, and is referred to as the “grasshopper effect.” This cycling is variable, with seasonal fluctuations depending on temperature, precipitation, and chemical properties.
- The IADN back trajectory analysis of toxaphene and DDT transport via air mass points to sources outside the Great Lakes basin for these substances. On the other hand, sources within the basin account for impacts caused by metals and PAHs. The IADN network provides useful trend information on pollutant concentrations and loadings over time. Results demonstrate that air concentrations of PCBs and other organochlorine compounds are declining significantly in the Great Lakes region.
- The AEOLOS targeted the southern end of Lake Michigan and the Chicago urban area. Significant findings include the following:
    - Dry deposition rates were greater than modeled predictions.
    - Ninety percent of the mass was due to particles more than 2.5 microns in diameter.
    - Mobile sources were the primary source of the coarse particulate material.
    - Urban site PCB precipitation concentrations were 2 to 3 orders of magnitude higher than in remote site locations.
    - An “urban plume” effect was confirmed in southern Lake Michigan for PCBs.
    - The trend for total PCB concentrations was downward (10 fold reduction in 14 years).

- Lake Michigan Urban Air Toxics Study (LMUATS) findings include the following:

  - Local sources are primarily responsible for higher vapor phase and particulate mercury levels in Chicago.
  - PAH results at rural air monitoring sites suggest some long-range transport is occurring; however, the median urban levels were 10 times higher than those at remote locations, reflecting local source impacts around urban locations.
  - PCB levels were 3 fold higher at the Chicago site and generally higher over the lake than at the downwind (western Michigan) or upwind sites.

- Preliminary results from the LMMB Project suggest that approximately 84 percent of the total mercury input to Lake Michigan is contributed by atmospheric deposition (wet and dry deposition and air-water exchange), whereas tributary inputs of mercury accounted for 16 percent of the total mercury input to the lake. Using a hybrid receptor model, localized urban sources in and around Chicago contributed approximately 19 percent of the total atmospheric loading to the lake (Landis 1998).

- The IJC, the binational body created by Canada and the United States to provide advice and help solve problems related to Great Lakes Basin waters, issued a modeling study in 1999. Some of the preliminary findings include the following:

  - Approximately 75 percent of dioxin deposition to the five Great Lakes originates from within the adjacent Great Lake states and provinces.
  - Sources up to 1,500 km distant were noted to have affected Lake Ontario, with about half of the dioxin deposition apportioned to sources near the lake.
  - The study results emphasize the need for continued systematic measurements of air, water, and precipitation and expanded emission inventory databases to provide additional data for modeling.

Additional studies linking emissions from air sources to water quality are discussed below.

- EPA's Mercury Report to Congress in 1997 noted that the 1994 to 1995 mercury contribution from U.S. anthropogenic sources to the atmosphere was 158 tons. Of the 158 tones, 87 percent was from combustion sources (waste incineration and utility fossil fuel plants). Estimated total annual input from all mercury sources was 5,500 tons world-wide, indicating that U.S. anthropogenic sources represent only 3 percent of global releases in 1995. Fifty-two tons (33 percent) of U.S. source emissions of mercury are deposited within the U.S. borders, while the remaining two-thirds (107 tons) are transported beyond U.S. borders, where they diffuse into the global reservoir. Depositional input to the U.S. from non-U.S. sources of mercury was estimated at 35 tons.

- In a study conducted by Pirrone and others (1998), air deposition was found to be the major contributor of mercury to the Great Lakes as indicated by sediment core analysis of mercury deposition rates over time. Atmospheric deposition fluxes in the Great Lakes were estimated to be almost an order of magnitude higher than the pre-industrial average to the whole of North America.

- Emissions and numbers of U.S. anthropogenic sources have declined for mercury, lead, dioxins and furans, and the banned and restricted use substances. For example, lead emissions in the Great Lakes region declined at a rate of 6.4 percent per year from 1982 to 1993 reflecting the national decline in lead emissions from the phase-out of leaded gasoline in automobiles.

- Emissions from U.S. anthropogenic sources have remained constant or are variable for cadmium and PAHs.

- Based on current atmospheric research by Cortes and others (1998) on atmospheric pollutant concentrations in the Great Lakes region, DDT, followed by dieldrin and chlordane, are estimated to fall below current detection limits in the atmosphere between 2010 and 2020. HCB is projected to be eliminated in the atmosphere by 2030 and 2060, respectively. These estimates assume current rates of long-range transport of these pollutants into the region. It should be noted that elimination of these pollutants in the atmosphere does not, because of their persistence, mean that concentrations would be eliminated in deposited media by these dates. However, these estimates indicate that reduction strategies in the Great Lakes, along with the original bans or restrictions on the use of these substances, are having the intended effect.

5.2.2.4 Data Gaps Identified

Even though considerable efforts and resources have been expended in characterizing and reducing the impact of several key pollutants of concern, the following data gaps still exist:

- Emission inventory databases need to be extended to include area and mobile sources and other minor sources that might provide a local or regional input to models that predict deposition rates.

- More accurate inventories of both natural and anthropogenic sources, and the chemical species emitted, are needed to better delineate long-range transport of pollutants like mercury.

- Locational information for mobile sources and area sources that may affect model predictions of deposition rate, seasonal variation, and other factors is needed.

- Spatial and temporal variability of ambient monitoring data are not adequately understood; comprehensive modeling of key pollutants along with validity testing of model predictions with observed concentration information is needed to determine representativeness of existing databases (over water measurements, simultaneous air-water measurements).

- The significance of watershed transport of pollutants deposited over land but transported into streams and channels whose inputs contribute indirectly to the riverine loading of the larger water body is uncertain.

5.2.3 Legacy Sources

The history of urban, industrial, and agricultural land uses in the Lake Michigan basin has left a legacy of contaminated sediments, land, and groundwater that is a continuing source of pollutant load to the lake. While state and federal remediation programs, such as those mandated under the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act (or Superfund) have begun to address this past contamination, many pollutants remain in the Lake Michigan system. This section briefly discusses these major, in-basin legacy sources and the pollutant stressors associated with these sources.

5.2.3.1 Contaminated Sediments

Contaminated sediments have been identified throughout Lake Michigan and its tributaries; however, the most serious levels of sediment contamination are found within the 10 AOCs in the basin: Manistique

River, Lower Menominee River, Lower Green Bay and Fox River, Sheboygan River, Milwaukee Estuary, Waukegan Harbor, Grand Calumet River-Indiana Harbor Ship Canal, Kalamazoo River, Muskegon Lake, and White Lake (see Appendix F). These sediments remain a source of pollutant load to the lake through resuspension and volatilization of certain pollutants, and by serving as a source of pollutants in the Lake Michigan food web. In particular, the LMMB Project has found that contaminated sediments are a significant source of continuing PCB and mercury load to the lake.

Examples of the sediment contamination problems found within the 10 Lake Michigan AOCs and successes and ongoing remediation efforts instituted in the AOC are discussed below.

Grand Calumet River- Indiana Harbor Ship Canal AOC

- The Grand Calumet River AOC contains 5 to 10 million cubic yards of contaminated sediment up to 20 feet deep. Contaminants include toxic compounds such as PAHs, PCBs, and heavy metals, and conventional pollutants such as phosphorus, nitrogen, iron, magnesium, volatile solids, oil, and grease. Ninety percent of the river’s flow originates as municipal and industrial effluent, cooling and process water, and stormwater overflows (EPA No date[n]).

  Concerns over managing these contaminated sediments have resulted in a suspension of dredging activities since 1972 and have reduced shipping capacity 15 percent over that time, resulting in increasing shipping costs. However, in 1991, under a Consent Decree, LTV Steel removed approximately 116,000 cubic yards of contaminated sediments. The project was completed in 1996 after a total of 120,000 cubic yards of contaminated sediment was dredged from a slip adjacent to Indiana Harbor. (Lake Michigan Forum No date).

Waukegan Harbor AOC

- Waukegan Harbor experienced extensive PCB and other toxic pollutant contamination of its sediments as a result of industrial releases and urban runoff. In 1992, a series of Superfund and privately-funded remediation activities were completed that resulted in the removal of approximately 453,600 kg (1 million pounds) of PCBs. After removal of the PCB-contaminated sediments, 3 years of fish sampling showed that PCB levels in alewife, coho salmon, chinook salmon, rainbow trout, and yellow perch in the Waukegan Harbor were below levels of concern. Alewife fish samples dropped from 10.0 to 0.5 parts per million (ppm). Signs warning anglers not to eat fish caught in Waukegan North Harbor were removed in February 1997, although fish consumption advisories remain in effect. Nonetheless, a 1996 sampling effort showed that the harbor sediments still do not support healthy benthic organism populations. Dredging activities to maintain navigation are also restricted (Lake Michigan Forum No date).

- Currently, two remedial investigations are underway on adjacent property of Waukegan Manufactured Gas and Coke and the Greiss-Pfleger Tannery.

White Lake AOC

- The White Lake AOC contains sediments contaminated with heavy metals, chlorides, and organic pollutants. Chromium and lead are found at the most elevated levels, and arsenic, cadmium, manganese, mercury, nickel, zinc, PCBs, and oil and grease have also been detected. Benthic communities in the sediment are impaired, but recent studies indicate that the biological community health may be improving (Lake Michigan Forum No date). Also, results of water samples collected in 1992 from the navigational channel between White Lake and Lake Michigan indicate that water quality has improved since the previous samples were taken in

1983. Heavy metal concentrations are lower than those observed in earlier sampling. Chloride concentrations are the lowest recorded since testing began in 1963, and phosphorous and nitrogen levels have remained stable since diversion of wastewater from White Lake in 1974.

Menominee River Bay AOC

- The Menominee River Bay has been contaminated by paint sludge from furniture manufacturing and other industrial operations for many years. Other pollutants include mercury, PCBs, and oil and grease. In 1995, more than 10 million pounds of hazardous waste were removed from the bay. An additional 20 million pounds of contaminated sediments were removed during this effort, which was part of an enforcement order issued to the Lloyd Flanders Furniture Company in Menominee. Degradation of the benthos in the bay has been documented primarily due to arsenic contamination in the sediments. The arsenic was released from the Ansul Fire Protection Company. (Menominee River AOC Fact Sheet). A RCRA Consent Agreement between Ansul Fire Protection Company, the EPA, and the State of Wisconsin was initiated in 1990. EPA ordered Ansul to remove 10,000 cubic yards of the arsenic contaminated sediment on July 1,1997. In 1993 and 1994, 11,500 cubic meters of sediment contaminated with paint sludge (RCRA hazardous for Pb) were removed from the Lower Menominee River by Ansul. In 1999, 12,329 cubic yards of arsenic-contaminated sediment were removed from the 8th Street slip.

Green Bay and Lower Fox River AOC

- Green Bay and the Lower Fox River contain high levels of PCB contamination from pulp and paper mill releases. EPA and the State of Wisconsin are currently developing remediation plans and beginning implementation activities for sediment clean-ups in the bay and river systems. In 1998, 4,600 cubic yards of PCB-contaminated sediment was removed from the Fox River. During the Deposit 56/57 dredging project, 30,000 cubic yards of PCB-contaminated sediment were removed in 1999.

Milwaukee Estuary AOC

- The Milwaukee Estuary sediment is contaminated with several heavy metals, oil and grease, and organic pollutants. The greatest concern in the AOC are PAHs and PCBs. In 1991, approximately 570,000 cubic meters (745,532 cubic yards) of contaminated sediment were isolated from the Milwaukee River by the removal of the North Avenue Dam (EPA No date[m]). In 1994, approximately 5,900 cubic meters of PCB-contaminated sediment were removed from behind Ruck Pond Dam. As a result, more than 95 percent of the mass of PCBs was removed from the area (EPA No date[m]).

Manistique River and Harbor AOC

- The Manistique River and Harbor contain large quantities of undecomposed sawdust from sawmills that have degraded sediments and aquatic life in the AOC. In the 1970s, PCBs, oils and heavy metals were identified as contaminants in the Manistique River and Harbor. Four studies by the EPA and MDEQ revealed that sediments near the Manistique Paper Company were polluted with elevated levels of PCBs, chromium, copper, and lead. The total amount of contaminated sediments in the AOC was estimated to be around 125,000 cubic yards.

  In 1995, EPA began annual dredging. From 1995 to 1998 approximately 92,000 cubic meters (120,232 cubic yards) of contaminated sediment and undecomposed sawdust were dredged from the river (EPA No date[m]). Dredging south of U.S. Route 2 bridge began June 1997. During

1998, about 31,200 cubic yards of wood chips, sawdust, and other solid material were dredged. About 1,525 cubic yards of sediment containing less than 1 ppm of PCBs was collected during the dredging process. (Lake Michigan Forum No date). EPA estimates that all dredging will be completed by winter 2000.

Sheboygan River and Harbor AOC

- The Sheboygan River and Harbor sediments contain PCBs, heavy metals, PAHs, and organic pollutants. Concerns over managing these contaminated sediments resulted in a suspension of dredging activities since 1968. The sources include several industries along the river and its tributaries, agricultural runoff, and urban runoff.

  From 1989 to 1991, a potentially responsible party (PRP) dredged approximately 5,300 cubic yards of PCB-contaminated sediments from the upper Sheboygan River. During 1989 and 1990, eight other sediment deposits were “Armored” in the upper Sheboygan River to prevent the PCB-contaminated sediment from moving downstream (EPA. No date[h]).

Kalamazoo River AOC

- The Kalamazoo River contains PCBs from de-inking operations at local paper mills. In 1997, the Kalamazoo Public Advisory Council, with support from MDEQ, appealed directly to the EPA and requested Emergency Action on the Bryant Millpond site. The result was an announcement by Allied Paper that it will commit up to $5.5 million to remove PCBs from Portage Creek (a tributary of Kalamazoo River) and contain them on site. Work done by EPA has begun. In April 1999, 165,000 cubic yards of PCB-contaminated sediment were removed.

  An emergency response team from EPA, along with MDEQ and the City of Kalamazoo, supervised the cleanup of Davis Creek (a tributary of Kalamazoo River). EPA removed about 270,000 gallons of oil, 3,200 tons of scrap metal, 1,400 cubic yards of asbestos, 33,000 gallons of flammable liquids, 15,000 gallons of caustic liquids, 25,000 tons of contaminated soil, and 18 tons of miscellaneous hazardous materials. (Lake Michigan Forum No date).

- In August 1990, the Allied Paper/Portage Creek/Kalamazoo River Superfund site was included on the National Priority List pursuant to CERCLA. Much of the field activities associated with the remedial investigations have been completed.

Muskegon AOC

- Waste lagoons, landfills, and industrial activity have contaminated the Muskegon AOC with heavy metals, volatile organic compounds, and PCBs. Concerns over managing these contaminated sediments resulted in a suspension of dredging activities. Remediation of contaminated sediment is ongoing at several locations on Muskegon Lake’s south side. Also, brownfield remediation is ongoing on Muskegon Lake’s south shore.

5.2.3.2 Contaminated Land and Groundwater

The Lake Michigan basin’s history of industrial and agricultural activity has also left the watershed with land and groundwater contamination. Industrial activities result in releases of heavy metals, PCBs, dioxins, and other synthetic organic chemicals to the land through disposal activities, spills, and unregulated releases. Agricultural land use results in land application and land disposal of pesticides, nutrients, and other agricultural chemicals. These applications can also result in groundwater contamination, which serves as a pathway for pollutant load to the lake. Approximately half of all surface water discharge in the Lake Michigan basin is derived from groundwater as baseflow (USGS 1999). As a result, pollutants released to the land can leach to the groundwater and ultimately reach the lake and its tributaries. For example, groundwater at the Grand Calumet and Indiana Harbor AOC is contaminated with organic compounds, heavy metals, and petroleum products and is discharging these pollutants to surface waters. EPA estimates that at least 16.8 million gallons of oil float on top of the groundwater at the AOC (Lake Michigan Forum No date).

Groundwater remediation efforts, as a result of Superfund-directed cleanups, are apparent in the AOC. For example, industrial facilities in the White Lake AOC such as DuPont, Koch Chemical, Occidental Chemical (formerly Hooker Chemical), and Howmet Corporation have installed groundwater pump and treat systems to stem the flow of polluted water to the AOC. As a result, there has been improvement in the water quality of White Lake. Analytical results for water samples collected in 1992 from the navigational channel between White Lake and Lake Michigan indicate that water quality has improved since the previous samples were collected in 1983. All parameters measured in 1992 in White Lake AOC met Michigan’s water quality standards.

The extent of land and groundwater contamination serving as a pollutant source in the Lake Michigan basin is not known. However, 155 Superfund sites are found within the basin and the history of industrial, agricultural, and urban land use, especially in the southern portion of the basin, has left a legacy of contamination that will need to be managed well into the future.

5.3 Stressor Loading and Effects

5.3.1 Trends in Habitat Loss

Habitat loss is a major limiting factor in the well-being of fisheries, wildlife, and avian populations in all of the Great Lakes, including Lake Michigan, and causes persistent and substantial negative impacts on lake biota (LTI 1993). Important habitat types in the Lake Michigan basin include dunes, wetlands, shoreline, reefs, nearshore water, offshore open water, and inshore terrestrial areas. Recovery or degradation of fisheries, birds, and mammal populations depends on the extent and condition of their habitat. Habitat loss and fragmentation is especially significant because it permanently alters the ecosystem. Land use stresses contributing to habitat loss in and around Lake Michigan include urban sprawl and nearshore development, industrial uses, hardening of landscape, soil erosion and sedimentation, transportation, oil drilling, mineral extraction, and agriculture (LTI 1993).

The Great Lakes wetlands are important plant and animal habitats. Draining and development have vastly reduced the areal extent of these wetlands and degraded their quality. About 70 percent of the original Great Lakes wetlands have been lost as a result of draining for agricultural use. Additional wetland acreage has been lost to urban and recreational development. Of the original Lake Michigan wetlands, less than 10 percent remain. Remaining wetlands are continually degraded by agricultural runoff, waste discharges, dam construction, filling, and dredging operations. These stressors result in high nutrient and sediment loadings (LTI 1993).

5.3.1.1 Trends in Agricultural Land Use

The predominant trend in U.S. land use is for increased development of farmland for residential and other urban uses. According to the Natural Resource Conservation Service (NRCS), between 1982 and 1992, developed land in the United States increased by 13.9 million acres, and between 1992 and 1997 it increased by 16 million acres. The majority of the newly developed acres were formerly farmland (NRCS 1997).

This trend is also occurring in the Great Lakes Basin. Between 1982 and 1992 there was a 1.8 million acre decline in farmland in the Great Lakes basin. These declines occurred primarily near metropolitan centers but also in rural areas to a lesser extent (SOLEC 1996). The predominant land use trend in the Lake Michigan basin is low-density sprawl extending into suburban and rural areas. This trend is occurring in each of the Lake Michigan states as described below.

- Between 1982 and 1992, Illinois lost 240,000 acres of farmland to urban uses; 29 percent of these acres were located in DuPage, Kane, Lake, McHenry, and Will counties, the 5 "collar" counties of Chicago, all within 50 miles of the Lake Michigan shoreline (ILUC 1999).

- Between 1992 and 1997, Indiana lost more than 500,000 acres of farmland, of which 74,623 acres were located in the northwest portion of Indiana nearest the Lake Michigan shoreline (Purdue University 1998)

- Between 1982 and 1992, Michigan lost more than 800,000 acres of farmland (MDA 1996), and between 1992 and 1998 it lost another 400,000 acres (MDA 1999)

- Between 1992 and 1997, Wisconsin lost 400,000 acres of farmland (USDA 1999).

Along with these changes in total farmland acreage are changes in individual farm characteristics and farming practices. The trend is toward fewer but larger farms. For example, the average farm size in Illinois increased by 6 percent between 1992 and 1997 (USDA 1997a) and in Michigan by 16 percent between 1982 and 1992 (MDA 1996). Other trends include fewer farms with livestock but larger numbers of livestock per farm and more intensive crop production practices (SOLEC 1996).

5.3.1.2 Trends in Urban Growth/Sprawl

The most significant population trend for the Lake Michigan basin is a shift away from central cities coupled with rapid growth in the surrounding metropolitan areas. In some places, this outlying growth reflects an increase only in the number of households (a shift in population density due to declining household size), not in population; however, in other places, it is a true increase in population in the outlying areas. In any case, this population shift to the urban periphery and suburbs together with the attendant trend towards smaller household sizes and demand for low-density development consumes vast amounts of agricultural lands and open space. It also alters the character of what once were small towns, distinct from urban areas, as these small towns are consumed by the ever-expanding metropolitan areas.

In metropolitan areas near the Lake Michigan shore, the implications for the nearshore area are even greater because, on the one hand, the lake geographically limits how far people can move lakeward away from the city and, on the other hand, the lake provides a natural attraction for new development. The result is that many of the people leaving the central cities are heading for the nearshore area. The city of Chicago, for example, lost population between 1980 and 1990, whereas the Chicago metropolitan area experienced continued growth in areas outside the central city to the south and away from the lake as well as to the northeast up along the Lake Michigan shoreline. The Milwaukee-Racine area in Wisconsin, discussed above, is another example where population decrease in the central city is countered by either lower rates of decrease or population increases at the county level.

Another trend is the remarkable population decrease in the highly urbanized areas in Northwest Indiana, which includes East Chicago, Hammond, and Gary. Between 1980 and 1990, the population in these cities declined by 14.8 percent, 10.1 percent, and 23.2 percent, respectively. This has been the trend since the 1970s and is expected to continue, though it has slowed somewhat in the 1990s. This population change has been influenced by the downsizing of steel mills and other manufacturing industries in the area. As the population declines in the tri-city area, more people move to the urban and suburban areas toward the southern watershed boundary as well as northward into Michigan along the Lake Michigan shoreline.

The automobile has facilitated the widespread emergence of urban sprawl over the last half century; resulting in the sparse settlement patterns and losses of agricultural land, open spaces, and natural areas. For example, in Michigan, the desire for large residential parcels of land has led to the loss of agricultural land at a rate of 10 acres/hour with a population that is expected to grow by 1.1 million between 1990 and 2020. Once land has been developed, it becomes nonrenewable and can never again be used for crop production. If current trends continue, the Michigan Society of Planning Officials predict that urbanized land in Michigan will increase by 63 to 87 percent between 1990 and 2020 (MDEQ 1998a).

Imperviousness, defined as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape, is a useful indicator to measure the impacts of land development on water quality. Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles or derived from other sources. During storms, accumulated pollutants are quickly washed off, and are rapidly delivered to aquatic systems.

Although urban sprawl, a principal outcome of the post-war economy, has been the dominant form of development, interest is growing in returning to higher-density, mixed-use community planning and redevelopment of underutilized or brownfields locations that would enhance the efficiency of municipal services such as transportation (SOLEC 1996).

The Lake Michigan basin, particularly the southern portion, has experienced significant transformation as the result of industrial land use. For example, steel is an important industry in the southern tip of the Lake Michigan basin where five large integrated mills with blast furnaces and three minimills produce about one-quarter of all U.S. steel. The lake has historically provided transportation, water for industrial processes, wastewater assimilation, and raw materials. However, as the regional economy shifts from a manufacturing-based to a service-based economy, the industrial activities in the Lake Michigan basin have declined or companies have relocated old operations inland rather than reinvest with modern technologies.

As industry has declined or retreated from the Lake Michigan shores, former industrial sites remain that can be used for public, commercial, or high-technology manufacturing uses. However, the costs associated with cleaning up some of these industrial sites is a difficult challenge to governments and communities.

5.3.1.3 Trends in Mineral Extraction Practices

The U.S. mining industry has experienced substantial layoffs and mine closings for decades and this trend continues. Some iron ore is still extracted in the northern basin to supply the steel industry, particularly steel production in the southern tip of Lake Michigan. Michigan and Wisconsin both have mining permitting programs that include reclamation plans.

5.3.1.4 Special Management Issues

Specific actions to address PHYSICAL STRESSORS are presented in Chapter 6, Table 6-1: RP1, RP5, RP6, RP8, SU2-5, IS4, IS13, RM 9 6

Programs that relate to the management of physical stressors are presented in Appendix A.

Special management issues include the following:

- Locally focused land use planning without considering lakewide impacts
- Managing nonpoint source pollution

5.3.2 Biological Stressors

Biological stressors in the Lake Michigan basin include ANS and human pathogens.

5.3.2.1 Trend in Aquatic Nuisance Species

Based on the information currently available, the rate of invasion by ANS appears to be accelerating, and the geographic regions from which these species come is expanding.

Special Management Issues

Programs that regulate and manage ANS are presented in Appendix A. Special management issues include the accelerating rate of invasion of ANS.

Specific actions to address BIOLOGICAL STRESSORS are presented in Chapter 6, Table 6-1: RP2, RP4, RP9, IS5 6

5.3.2.2 Trends in Human Pathogens

Table 5-5 shows the most common (prevalent) human pathogens found in Lake Michigan.

Table 5-5. Human Pathogens in Lake Michigan

Pathogen	Prevalence
E. coli	Localized outbreaks
Cryptosporidium	Rare, localized outbreaks
Giardia lamblia	Widespread

Beach closures serve as indirect indicator of excessive bacterial contamination of near shore waters near beaches (ET-1). The 36 Lake Michigan beaches in Cook County, Illinois, were often closed due to pollution prior to 1992. After a deep tunnel storage system was constructed to increase the holding capacity for stormwater, the frequency of beach closings decreased. There were no beach closing during 1993 and 1994, but isolated instances of pollution will probably continue to cause beach closings in the future (EPA 1998g).

There is currently no federal requirement that states monitor their beaches or notify the public when water quality standards are violated. Those states and counties that do choose to monitor their beaches may monitor different microorganism. EPA's Beach Environmental and Costal Health (BEACH) program recommends using standards developed for enterococcus or *E. coli* for microbial standards (EPA 1998[i]). Despite this recommendation, programs continue to monitor for other parameters, such as fecal coliform. The number of exceedances reported may be misleading because monitoring is not consistent at all beaches; some beaches do not conduct any monitoring. 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 Lake Michigan. Because of this variability, it is difficult, and potentially misleading, to compare water quality between jurisdictions or summarize data for all beaches.

There are 581 beaches listed for the Great Lakes Basin, and on any summer weekend, at least a million people visit them (EPA 1998[h]). The beaches that are closed most of the time are closed because of high levels of microorganisms coming from sewage overflows and polluted storm water runoff from cities and farms (EPA 1998h).

Special Management Issues

Specific actions to address BIOLOGICAL STRESSORS are presented in Chapter 6, Table 6-1: HH1-HH7, RP1

6

Programs that regulate and manage human pathogens are discussed below and presented in more detail in Appendix A.

Biological Pathogen Management Programs

National Pollutant Discharge Elimination System (NPDES). The CWA requires wastewater dischargers to have a permit establishing pollution limits and specifying monitoring and reporting requirements. NPDES permits regulate household and industrial wastes that are collected in sewers and treated ad municipal wastewater treatment plants. The permits also regulate industrial point sources and concentrated animal feeding operations that discharge directly into receiving waters (EPA No date[s]).

Beach Monitoring. EPA has a web site giving up-to-date information about water quality and beach closings at more than 1,000 beaches nationwide, including Chicago, Milwaukee, southwest Michigan, and Indiana Dunes. The information is available at http://www.epa.gov/ost/beaches (EPA 1998h). In 1995, 28 Lake Michigan beaches out of more than 200 being monitored were temporarily closed because of poor water quality (EPA No date[t]). Indiana tests waters near beaches on a weekly basis using an EPA-recommended standard for *E. coli* (MDNR 1998a).

Healthy Beaches Initiative. This is a collaborative effort among several agencies seeking to protect the health of the Indiana shoreline of Lake Michigan. This organization is especially concerned about sporadic, unpredictable high levels of bacteria in the nearshore waters in northern Indiana (MDNR 1998a).

E.coli Interagency Task Force. In response to bacterial contamination on Indiana beaches in 1996, 18 local, state, and federal agencies formed the E.coli Interagency Task Force to share information and address bacterial contamination along Lake Michigan. The Illinois-Indiana Sea Grant Program invested about $80,000 in research to differentiate human waste from animal waste by assessing the presence of a virus and bacteria in the waste. Being able to make that distinction will indicate the source of pollution. This group is also looking at bifidobacteria and poliovirus, both indicators of human fecal pollution. Poliovirus in associated with waste from newly immunized humans (Ting 1996).

Deep Tunnel Project. The 36 Lake Michigan beaches in Cook County, Illinois, were often closed due to pollution prior to 1992. The combined storm water and sanitary sewer system combined with a limited retention capacity for storm water prior to treatment contributed heavily to the problem. When the water storage capacity was exceeded, the locks separating the Chicago Sanitary Canal and lake Michigan were opened, and untreated effluent flowed into the lake. Most beaches would be closed for several bays because of actual or potential pollution. A deep tunnel storage system was constructed to increase the holding capacity for storm water. As sections of the tunnel system were put into use, the frequency of beach closings decreased. There were no beach closing during 1993 and 1994, but isolated instances of pollution will probably continue to cause beach closings in the future (EPA 1998g).

Special management issues include the following:

- Multiple sources contribute to microbial contamination.
- Lake Michigan beach monitoring programs are not consistent.
- Lack of network to share science, monitoring, and management data.

5.3.3 Chemical Stressors

The production and use of chemicals present a *potential* for the chemicals to enter the environment, whether by its intended use, as is the case with pesticides and fertilizers, or inadvertently through spills or leaks. The manufacturing of chemicals and the use of chemicals in manufacturing a wide variety of products, produce waste byproducts that must be managed. In the past many of these waste byproducts were placed in the environment without management controls resulting in a legacy of in-place chemical pollution found today in contaminated sediments in lake and river bottoms, in soils in industrial areas and slowly moving in the groundwater from sites where spills occurred. Today several environmental management programs are in place to control these waste byproducts. Chemicals in the waste byproducts still enter the environment but under the jurisdiction of these environmental management programs that control the rate and quantity (load) of the emissions or discharges through permits. These controlled emissions and discharges, and the legacy or in-place pollutants represent the **actual** presence of chemicals in the environment. The **potential and actual** presence of chemicals in the environment provide the potential load of chemicals to Lake Michigan.

This section presents information on the potential loading of chemicals or pollutants to Lake Michigan based on the potential and actual presence of each of the critical pollutants, pollutants of concern, and emerging pollutants, in the Lake Michigan basin counties. It also contains information about the current and past actual loading of each of these pollutant pathways to Lake Michigan and what impacts these pollutants have on achieving the subgoals, goals and vision for the Lake Michigan ecosystem. Finally, this section lists unique management challenges presented by these pollutants, which provides a framework for the management activities detailed in the strategic agendas presented in Chapter 6.

5.3.3.1 Polychlorinated Biphenyls

Critical Pollutant

PCBs are a group of synthetic organic chemicals with a variety of harmful effects on humans and the environment. These compounds are subdivided according to their chemical composition, with the differentiating factor being their respective degrees of chlorination. The physical and chemical properties of PCBs are described in Appendix B. PCBs were produced commercially and used extensively from 1929 to 1979 as coolants and lubricants in electrical equipment such as transformers, capacitors, and light ballasts, as well as in hydraulic fluids, plasticizers, carbonless copy paper, inks, and other items.

PCBs are highly stable under most environmental conditions and accumulate in animal and fat tissue, especially in fish and other aquatic life. PCBs are present in some types of Lake Michigan fish at concentrations exceeding FDA limits, resulting in fish consumption advisories (EPA1997k). The major source of PCB exposure for the general public is contaminated fish consumption.

Following is a discussion of the potential and actual releases of PCBs into the environment (the potential load to the lake), the current and past loading of PCBs to the lake, the impact of PCBs on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing PCBs.

POTENTIAL RELEASES OF PCBs TO THE ENVIRONMENT

PCBs have entered the environment from sites where they were used, through spills or leaks from accidents or gradual wear and weathering of PCB-containing products, during destruction of articles containing PCBs in municipal and industrial waste incinerators, through leaching from old landfill dumps, and through improper (or illegal) disposal of PCB materials. Today, PCB use is primarily restricted to pre-existing closed systems. However, PCBs can be released to the environment from several different sources, including the following:

- **Items containing PCBs intentionally for their useful chemical properties**. The majority of PCBs were used in transformers, capacitors, light ballasts, and other electrical components. Many of these items have long useful lives and remain in service today. Under TSCA, all uses of PCBs are banned unless they fall into specific use categories. The EPA has determined that certain PCB uses contain no unreasonable risk. However, PCBs can be released into the environment from leaks or spills from such equipment containing PCBs, from poorly maintained hazardous waste sites that contain PCBs or PCB-containing products, improper (or illegal) disposal, and fires. Equipment containing PCBs remains in the Lake Michigan basin. The EPA's PCB Transformer Database provides the most current information on the number of PCB transformers currently registered in use. There are 2,818 transformers containing about 5.5 tons (5,000 kilograms [kg])of PCBs that remain in use in the Lake Michigan states - Illinois, Indiana, Michigan, and Wisconsin (EPA 1999k).

- **Combustion or incineration of materials containing PCBs**. Sources of PCB air emissions from combustion include municipal waste combustion, medical waste incineration, hazardous waste incineration, sewage sludge incineration, and utilities. The Lake Michigan basin contains many of these combustion facilities.

- **Inadvertent generation during production processes**. Any chemical process that involves carbon, chlorine, and elevated temperatures (for example, the de-inking of newsprint and recycling of carbonless copy paper by paper mills) may inadvertently generate PCBs.

- **Storage and disposal facilities**. Releases of PCBs may occur from containers or items such as transformers if they are mishandled or broken during storage.

ACTUAL RELEASES OF PCBs TO THE ENVIRONMENT

- **Point source discharges**. PCBs are released to the environment through point source water discharges. The EPA PCS is a database that tracks permit compliance and enforcement status of facilities subject to NPDES permits under the Clean Water Act. The *reported* total values for PCB discharges from permitted point sources to tributaries in the Lake Michigan basin for 1990 to 1999 is 397.31 kg (875.92 lb). Annualized data does not provide information useful for establishing trends in reported discharges. Table 5-6 indicates the amounts discharged to individual water bodies (EPA 1999k):

The TRI database had no data on releases of PCBs to water.

- **Air emissions**. According to RAPIDS, 2.93 and 3.20 pounds of PCBs were emitted to the air in the Lake Michigan basin in 1993 and 1996, respectively (Great Lakes Commission 1999c and 1999d). The TRI database had no data on air emissions of PCBs.

Table 5-6. PCBs Discharged to Individual Water Bodies (1990 to 1999)

Water Body	Amount Discharge	
Wisconsin - Fox River/Wolf Creek	333.32 kg	(734.84 lb)
Wisconsin - Green Bay	1.87 kg	(4.12 lb)
Illinois - Western Shore	26.54 kg	(58.51 lb)
Michigan - Kalamazoo River	16.36 kg	(36.07 lb)
Michigan - Menominee River	4.12 kg	(9.08 lb)
Michigan - Grand River	15.1 kg	(33.29 lb)

- **Releases to land**. According to the National Response Center, there were 11 reported spills of PCBs, in the Lake Michigan states from 1993 to 1998 (EPA 1999k). The TRI database indicated that 1 pound (0.454 kg) of PCBs has been released to land in the past 10 years.

- **Legacy PCB contamination.** The major source of PCBs today is environmental cycling of PCBs previously introduced into the environment. PCB-contaminated sediments may re-suspend PCBs in the water, allowing for bioaccumulation in the food web. In addition, volatilization of PCBs from land and water surfaces into the atmosphere can result in subsequent wet or dry deposition and then re-volatilization. For this reason, and because of their persistence in the environment, PCBs that were released to the environment many years ago play an active role in the contamination of today's environment. An example of legacy sources is the PCB contamination in the Fox River. From 1957 to 1971, several pulp and paper mills released about 250,000 pounds of PCBs into the Fox River. PCBs were primarily released during the manufacture and recycling of carbonless copy paper (Lake Michigan Forum No date). The Kalamazoo River has also been contaminated with PCBs from these processes. Both of these rivers are now AOCs in which past depositions remain a problem.

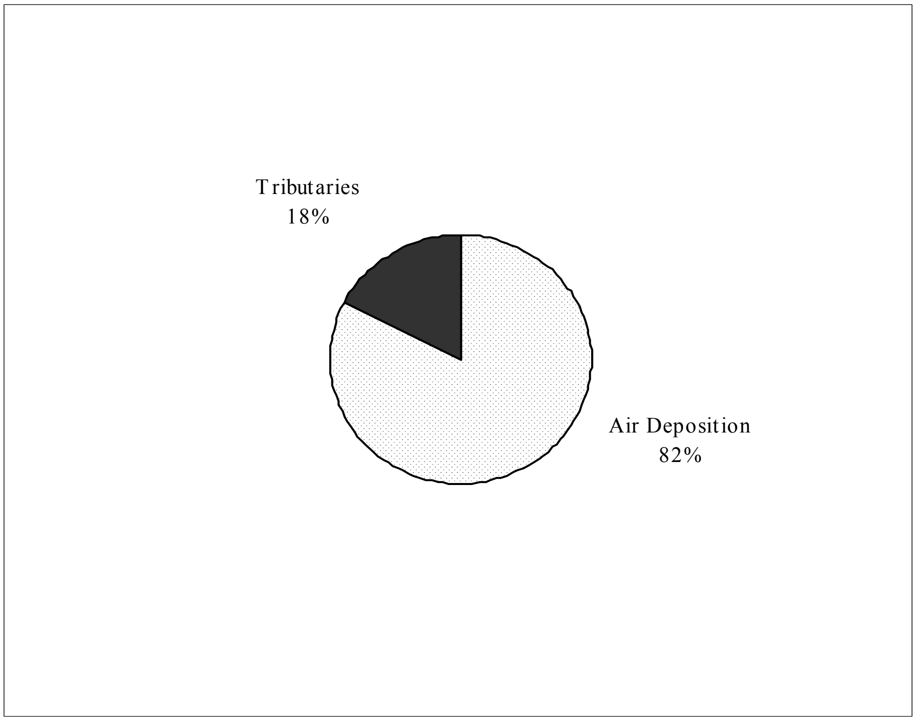
  There are 24 sites in the Lake Michigan basin listed on the National Priority List (NPL) that contain PCB contamination in soil, sediments, surface water, groundwater, or leachate. The PCBs at these sites have the potential to eventually be discharged to Lake Michigan. For example, the Allied Paper Inc./Portage Creek/Kalamazoo River Superfund site contains more than 350,000 lbs of PCBs in sediments and millions of tons of PCB-contaminated waste from the paper-making industry in five uncontained disposal areas on the river banks. PCBs continue to migrate into the environment from these areas due to river-induced erosion and surface water runoff (Lake Michigan Forum No date). Each of the 10 Lake Michigan AOCs have PCB-contaminated sediments and the Fox and Kalamazoo rivers have PCB-contaminated water. Many of these areas were heavily contaminated with PCBs in the past and now contribute significant PCB loads to Lake Michigan.

ACTUAL LOADINGS OF PCBs TO LAKE MICHIGAN

This section describes the specific sources and pathways of PCBs to Lake Michigan and the load of PCBs contributed via these pathways. Several studies have been performed to estimate loading of PCBs to Lake Michigan. This section reports recent estimates of PCB loads from air deposition, sediments, and tributaries and the AOCs. The total loading of PCBs to Lake Michigan is estimated to be 1,861 kg/yr

(4,103 lb/yr), according to the LMMB Project. Figure 5-7 shows the estimated percentage of PCBs contributed by various sources according to the LMMB Project (EPA No date[i]).

Figure 5-7. Loads of PCBs to Lake Michigan (EPA No date[i])



Atmospheric Deposition Pathway

Atmospheric deposition of PCBs plays a dominant role in PCB cycling in the Lake Michigan ecosystem. According to the LMMB, atmospheric transport and deposition of PCBs provide about 82 percent of the total PCB load to Lake Michigan. Because PCBs are no longer produced, the major source of PCBs to the atmosphere is volatilization from sites where they have been stored, disposed, or spilled; from incineration of PCB-containing products; and, to a lesser extent, PCB formation during production processes. In addition, as the following sections will describe, volatilization of PCBs from the water has been shown to be the dominant mechanism for exchange of PCBs between Lake Michigan and the atmosphere.

Concentrations of PCBs in air over Lake Michigan have been observed to range from 440 picograms per cubic meter (pg/m^3) (4.12 x 10^{-2} parts per trillion [ppt]) in the southern and mid region of the lake to 170 pg/m^3 (1.59 x 10^{-2} ppt) in the northern part of the lake (McConnell and others 1998). This section describes Lake Michigan studies that have estimated loads and sources of PCBs from atmospheric deposition.

Atmospheric Deposition Pathway: Load Estimates

There are three major processes of direct atmospheric deposition to Lake Michigan: wet deposition, dry deposition, and gas-exchange across the air-water interface. Loadings from each of these processes are discussed in the following studies: IADN, LMMB, AEOLOS, and others. Table 5-7 summarizes the findings of these studies.

Table 5-7. PCB Air Deposition Estimates

Study (year conducted)	Wet deposition kg/yr (lb/yr)	Dry deposition kg/yr (lb/yr)	Gas transfer kg/yr (lb/yr)
IADN (1993 to 1994)	110 ± 24 (243 ± 53)	32 ± 33 (71 ± 73)	-700 ± 720 (-1,543 ± 1,587)
LMMB/AELOS (1993 to 1995)	50 to 250 (110 to 551)	1,100 (2,425)	880 (1,940)
LMMB (1994 to 1995)	98 (216)	109 (240)	1,329 (2,930)

The IADN collects regional atmospheric data at the remote Sleeping Bear Dunes sampling site in Lake Michigan. The IADN estimates that wet and dry deposition of PCBs to Lake Michigan has decreased from 400 kg/yr (882 lb/yr) in 1988 to 42 kg/yr (93 lb/yr) in 1996 (EPA 1999f). In fact, some data show a net loss of PCBs to the atmosphere from Lake Michigan (Offenberg and Baker 1997).

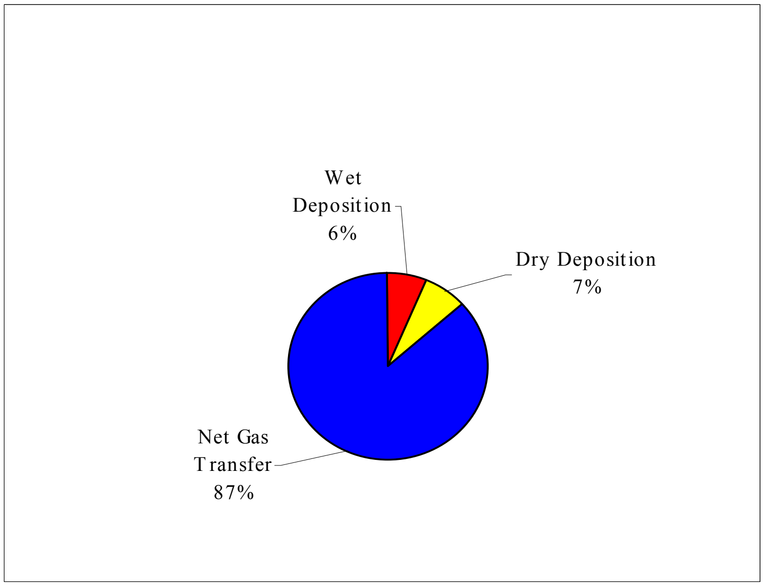
Although results from another recent IADN study indicated a substantial PCB load to Lake Michigan from wet deposition, the net deposition of PCBs to Lake Michigan was insignificant because gas transfer out of the lakes offset the flow of PCBs into the lake from wet and dry deposition, which was based on the 1993 to 1994 data from the Sleeping Bear Dunes sampling site (Hillery and others 1998). In addition, gas transfer of PCBs to the atmosphere from Lake Michigan seems to have steadily decreased. However, estimates of gas transfer and dry deposition had uncertainties, making it impossible to establish definitive trends (Hillery and others 1998). Despite these uncertainties, this study concluded that PCBs were approximately in equilibrium between the lake water and atmosphere. If PCBs are in fact at equilibrium, atmospheric PCB concentrations could be used to track changes in water PCB concentrations (Hillery and others 1998).

Franz and others (1998) conducted a study to estimate dry deposition of particulate PCBs to Lake Michigan as part of the LMMB. Samples were collected at multiple sites within the Lake Michigan basin from November 1993 to October 1995 and samples were also collected during the AEOLOS project in July 1994. This study estimated inputs of PCBs to be about 1,100 kg/yr (2,425 lb/yr) by particle dry deposition. Previous estimates for dry deposition ranged from 16 to 170 kg/yr (36 to 375 lb/yr). [The discrepancy is not clearly explained in Franz 1998.] In addition, LMMB projects have estimated PCB in puts from air-/water exchange to be about 880 kg/yr (1,940 lb/yr) and-about 50 to 250 kg/yr (110 to 551 lb/yr) by wet deposition (Franz and others 1998).

Hornbuckle and others (1995) conducted a study to determine the direction and magnitude of air-water PCB exchange on a seasonal and annual time scale. Air and water samples taken at sites throughout the northern two-thirds of Lake Michigan indicated net PCB volatilization of 71 kg/season (157 lb/season) in the spring to 190 kg/season (419 lb/season) in the fall. These results are reflective of seasonal variation in water temperature, which in turn affects volatilization rates. PCB removal from the lake via net volatilization was cited in this study to be approximately one-third the loss via sedimentation as reported in a study by Golden (1994). The Hornbuckle study and the results from the IADN suggest that the regional atmosphere and Lake Michigan are both sources and sinks for PCBs.

The LMMB Project has estimated the total Lake Michigan atmospheric loading of PCBs to be 1,536 kg/year (3,386 lb/yr). The LMMB Project estimates that 109 kg/yr (240 lb/yr) of PCBs enter Lake Michigan through dry deposition of dust, aerosols, and particulates. Lake Michigan receives about 98 kg/yr (216 lb/yr) PCBs from wet deposition of rain and snow. The LMMB Project estimates the net gas input of PCBs to be about 1,329 kg/yr (2,930 lb/yr) (EPA No date[i]). See Figure 5-8.

Figure 5-8. LMMB Estimates of PCB Air Deposition to Lake Michigan (EPA No date[i])



Based on these studies, wet deposition of PCBs to Lake Michigan ranges from 50 to 250 kg/yr (110 to 551 lb/yr) from wet deposition, 16 to 1,100 kg/yr (35 to 2,425 lb/yr) from dry deposition, and 880 to 1,329 kg/yr (1,940 to 2,930 lb/yr) for air-water exchange.

Atmospheric Deposition Pathway: Chicago as a Source

Chicago was identified as a significant source of PCBs loads within the 1-day airshed for Lake Michigan. The Chicago source includes PCB volatilization from the industrial footprint and PCB emissions from combustion and incineration facilities. The AEOLOS project was designed to estimate atmospheric deposition to the Great Waters as defined in Section 112 of the 1990 Clean Air Act. In 1994 and 1995, air concentrations of PCBs were measured in the industrial area of Chicago, IL; over southern Lake Michigan; and in a non-urban area as part of the AEOLOS project. Gas phase concentrations of total PCBs ranged from 0.14 to 1.1 nanograms per cubic meter (ng/m^3) (1.31 x 10^{-2} to 1.03 x 10^{-1} ppt) over the lake and from 0.27 to 14 ng/m^3 (2.53 x 10^{-2} to 1.31 ppt) in the urban area (Simcik and others 1997). In addition, the PCB concentrations over southern Lake Michigan were highest when the wind was from the direction of the industrial area (the lake shoreline from Evanston, IL to Gary, IN), and they were near regional background levels when the wind was from any other direction. PCB concentrations also increased with higher temperatures.

The Lake Michigan Urban Air Toxics Study (Keeler 1994) collected 12-hour atmospheric samples at three sites, by airplane, and research vessel for a full month in 1991. The study concluded that PCB levels were about 3 times higher at the Chicago sampling site than at the other sites and were generally found to be higher over the lake than at the downwind or upwind sites.

Fluxes of particulate PCBs were also higher in Chicago than less than 15 kilometers (9.3 miles) off shore and at rural sites. The geometric mean dry deposition flux is 0.2 micrograms per square meter per day (5.36 x 10^{-7} lb/acre-day) in Chicago and 0.06 µg/m^2-day (1.79 x 10^{-6} lb/acre-day) at the Sleeping Bear Dunes sampling site. However, dry deposition of PCBs in Chicago during the Franz study is about 3 times less than in 1979 and an order of magnitude less than previously reported levels using 1989 to 1990 data (Franz and others 1998). Modeling results show that more than 90 percent of PCB dry deposition is due to particles more than 2.5 microns in diameter and that duty vehicles using diesel or gasoline and soil dust are the major sources of these coarse particles (Delta Institute 1999).

Precipitation appears to be highly efficient at removing particulate matter, to which PCBs are bound, from the urban atmosphere. Under the AEOLOS project, the total concentrations of PCBs in Chicago precipitation ranged from 4.1 to 189 ng/L (4.1×10^{-3} to 1.89×10^{-1} ppt) (Offenburg and Baker 1997). Due to higher atmospheric PCB concentrations, the levels of PCBs in precipitation falling into southern Lake Michigan are from 2 to as much as 400 times greater than the measured background levels (Delta Institute 1999). Because 5 to 20 percent of the lake surface may be affected by precipitation originating from Chicago, PCBs in precipitation in and near Chicago increase the total PCB inputs to the lake by 50 to 400 percent over background loading levels (EPA 1999f). With wet deposition at background concentrations only, 50 kg (110 lb) of PCBs are input to Lake Michigan by wet deposition annually. Inclusion of the Chicago-influenced deposition over 5, 10, and 20 percent of Lake Michigan's surface area increases annual lakewide PCB wet deposition to 100, 150, and 200 kg/yr (220, 331, and 441 lb/yr), respectively (Offenburg and Baker 1997). These findings indicate that estimating atmospheric deposition based on one remote monitoring station, like the IADN, may underestimate deposition.

Finally, total PCB concentrations in southern Lake Michigan itself ranged from 80 to 350 picograms per liter (pg/L) (8.0×10^{-5} to 3.5×10^{-4} ppt) and were higher when the winds were blowing from Chicago (Delta Institute 1999). Offenburg and Baker (1997) also studied the enhancement of PCB loadings to Lake Michigan in the industrialized Chicago area. Total PCB concentrations in the lakeshore near Chicago were 2 to 3 times higher than values collected in more remote areas of the lake. However, total PCB concentrations in southern Lake Michigan have declined 10 fold over the past 14 years, resulting in a decline of 17 to 30 percent per year (Delta Institute 1999).

Sediments Pathway

Contaminated sediments are a source of PCB contamination in Lake Michigan because PCBs maybe released from sediments and resuspended in the water. PCBs are widespread at low levels throughout Lake Michigan sediment, but are concentrated at all of the AOCs. PCB loads from contaminated sediments in the Lake Michigan tributaries and AOCs are described in the following section.

Tributaries and Areas of Concern Pathway

Rivers and streams that flow into Lake Michigan are additional sources of PCB loads to the lake. The LMMB estimates that all of the tributaries combined contribute a load of about 325 kg/yr (716 lb/yr) to Lake Michigan (EPA No date[i]). Table 5-8 summarizes sediment and water PCB-loads.

PCBs continue to be a primary environmental contaminant in the 10 Lake Michigan AOCs. PCBs have been identified as contaminants in water and sediments in all of the Lake Michigan AOCs, including the Fox River and Lower Green Bay, Grand Calumet River/Indiana Harbor Ship Canal, Manistique River, Sheboygan River, Waukegan, Kalamazoo River, Lower Menominee River, Milwaukee Estuary, White Lake, and the Muskegon River. Illinois, Indiana, Michigan, and Wisconsin have all issued fish consumption advisories due to PCB concentrations.

The Lower Fox River is the source of 95 percent of the PCB load to Green Bay and is the source of the largest single load to Lake Michigan (WDNR 1997). Currents from the Fox River flush about 600 pounds of PCBs into Green Bay every year (Lower Fox River Intergovernmental Partnership 1998). As a result, an estimated 160,000 pounds of PCB have already migrated from the Fox River into Green Bay and Lake Michigan (Lake Michigan Forum No date). In addition, about 40 tons of PCBs remain in 11 million cubic yards of sediment in the river (Lower Fox River Intergovernmental Partnership 1998).

Brazner and DeVita (1998) measured PCB concentrations in young-of-the-year littoral fishes from Green Bay, Lake Michigan. Based on the PCB concentration gradient measured in fish samples, they determined that the Fox River was the primary source of PCBs. In addition, the percentage of the more-chlorinated PCB congeners observed in upper bay fish supports the hypothesis that less-chlorinated PCBs volatilize more quickly and therefore are less abundant farther from their source. Regarding Green Bay, PCB concentrations are highest in the lower bay and decrease with increasing distance from the mouth of the Fox River (Swackhamer and Armstrong 1987).

The Grand Calumet River drains about 500 million gallons of water into Lake Michigan per day. The Grand Calumet River and Indiana Harbor Ship Canal contain 5 to 10 million cubic yards, up to 20 feet deep, of sediments contaminated with PCBs and other toxic compounds (EPA No date[f]). An estimated 180 million pounds of sediments, containing 420 pounds of PCBs, are annually deposited in Lake Michigan from sediments out of the Grand Calumet River and Indiana Harbor (Chicago Cumulative Risk Initiative 1999). In addition, stormwater runoff and leachate, contaminated with PCBs, from 11 of 38 waste disposal and storage sites in the AOC are degrading water quality in the river (EPA No date [n]).

About 115,000 pounds of PCB-contaminated sediments once contaminated the Manistique River and Harbor. The total volume of PCB-contaminated sediments in the Manistique River and Harbor was estimated to be around 120,000 cubic yards.

Remediation of the Manistique AOC began in 1995 under a Superfund Emergency Removal Action because about 100 pounds of PCBs were being discharged into Lake Michigan due to natural erosion processes annually (EPA No date [f and m]). About 10,000 cubic yards of PCB-contaminated sediments were dredged in 1995. Remediation is scheduled to be completed in 2000.

The Sheboygan River and Harbor contribute about 30,000 cubic yards per year of PCB-contaminated sediments to the Sheboygan Harbor in Lake Michigan (Lake Michigan Forum No date). Total PCB concentrations in sediments from the Sheboygan River and Harbor range from 0.04 mg/kg (0.04 ppm) to more than 220 ppm. PCB concentrations decrease downstream towards Lake Michigan (David and others 1994). About 5,360 cubic yards of PCB-contaminated sediments were removed between 1989 and 1991 from the upper portion of the river.

Bioremediation was demonstrated on contaminated sediments in the Sheboygan AOC as part of the ARCS (alternative remediation of contaminated sediments) program. Under the ARCS program, a multi-organization endeavor of sediment assessment and remediation techniques were identified. EPA developed a plan with Tecumseh Products (Superfund site) to manipulate the contents of the confined treatment facility (CTF) to enhance naturally occurring biodegradation. Manipulation consisted of adding nutrients to sediments already containing indigenous populations of microorganisms (bacteria and fungi), and cycling the CTF between aerobic and anaerobic conditions (PCBs do not completely degrade either aerobically or anaerobically). The demonstration confirmed that the PCBs present in the Sheboygan River sediments had already undergone a great deal of anaerobic dechlorination (EPA 1994[e]).

Removal of 300,000 pounds of PCBs in 32,000 cubic yards of sediment from Waukegan Harbor and 700,000 pounds of PCBs in 18,000 cubic yards of soil from the OMC site resulted in removing fish warning signs in the harbor, although fish consumption advisories remain in effect. An Illinois EPA sediment sampling program has shown that the harbor is no longer a significant source of PCBs in Lake Michigan fish (IEPA 1997b). In addition, progress has been made toward de-listing the Waukegan Harbor as an AOC (Lake Michigan Forum No date).

The Kalamazoo River discharges into Lake Michigan 31 km north of South Haven. The Allied Paper Inc./Portage Creek/Kalamazoo River Superfund site contains more than 350,000 lbs of PCBs in sediments and millions of tons of PCB-contaminated waste. PCBs continue to migrate into the Kalamazoo River, and eventually Lake Michigan, due to river-induced erosion and surface water runoff (Lake Michigan Forum No date). The highest PCB concentration in contaminated Kalamazoo River sediments is 300 mg/kg (300 ppm) (EPA No date[f]).

The LMMB Project estimated annual PCB loads from Lake Michigan tributaries based on 1994 and 1995 data (see Table 5-8). According to these data, the Fox River contributes the largest load of PCBs to Lake Michigan (186 kg/yr) (EPA No date[j]).

Table 5-8. Estimated PCB Load From Lake Michigan Tributaries (EPA No date[j])

Tributary	Estimated Load (kg/yr)	Estimated Load (lb/yr)
Fox River	186.0	410
Grand Calumet	37.2	82.0
Manistique River	1.3	2.9
Sheboygan River	8.3	18.3
Kalamazoo	36.8	81.1
Grand	11.7	24.5
Menominee River	3.8	8.4
Milwaukee Estuary	7.3	16
Pere Marquette	0.5	1.1
Muskegon River	2.2	4.9
St. Joseph	9.3	20.5

IMPACT ON LAKE MICHIGAN

Trends in the concentrations of PCBs in lake trout and coho salmon in Lake Michigan have declined significantly since the 1970s, but have leveled off, or even increased in recent years in the case of coho salmon. This has occurred despite continued declines in concentrations in the water column, suggesting changes in the dynamics of the Lake Michigan food web. PCBs are still present at concentrations exceeding the Great Lakes' Governors' proposed action levels, resulting in fish consumption advisories for some Lake Michigan fish. These trends in PCB concentrations show significant declines since the 1970s, leveling off, and increasing in the early 1990s have been followed in herring gull eggs, and other wildlife. Appendix C contains detailed information on potential ecological and human health effects.

SPECIAL MANAGEMENT ISSUES

Specific actions to address PCBs are presented in Chapter 6, Table 6-1: RPPI, RPP2, RPP6, RPP10,RPP11, HH9, HH10 6

Programs regulating and controlling the management of PCBs are presented in Appendix A.

Special management issues include the following:

- Environmental cycling of legacy PCB contamination is a major source of PCB loading to Lake Michigan.
- Long-range transport of pollutants
- Urban nonpoint sources

5.3.3.2 Dioxins/Furans

Critical Pollutant

The term "dioxin" represents a class of halogenated aromatic hydrocarbon compounds including polychlorinated dibenzodioxins and dibenzofurans. There are a total of 210 possible congeners of dioxin, depending on the location and substitution of chlorine in the molecule . Those congeners with chlorine substitution in the 2,3,7, and 8 positions on the molecule are generally thought to be responsible for the greatest degree of toxicity associated with dioxin (EPA 1998b). TCDD (2,3,7,8 tetrachlorodibenzo-p-dioxin) is the most toxic and best understood of all the types of dioxin. As a result, the concentrations of all dioxin and furan compounds are typically reported as Toxicity Equivalent Concentration (TEQ) normalized to 2,3,7,8-TCDD. Dioxins and furans can be released to aquatic systems in various wastewater streams and sludges. Furans are also unwanted trace impurities of PCBs, HCB, pentachlorophenol, and phenoxy herbicides such as 2,4,5-T. Information on the physical and chemical properties of dioxin and furans is presented in Appendix B.

Both dioxins and furans are only slightly soluble in water, strongly sorb to soils and sediments, persist in soil and aquatic systems, and have a high potential for bioaccumulation. EPA classifies TCDD as a probable human carcinogen. Like herbicides such as trichlorophenols, dioxin is classified by the EPA as a limited evidence human carcinogen. Toxicological studies of furans (PCDF) indicate that the effects of this group of compounds are very similar to those of the dioxins. See Appendix C for additional information on dioxin and furan health effects.

Following is a discussion of the potential and actual releases of dioxins and furans into the environment, the potential load to the lake, the current and past loading of dioxins and furans to the lake, the impact of dioxins and furans on achieving the vision for the Lake Michigan ecosystem, and unique issues related to managing dioxins and furans.

POTENTIAL RELEASES OF DIOXINS AND FURANS TO THE ENVIRONMENT

- **Intentional use.** Dioxin is not a product formulated for use. It occurs purely as a by-product in processes such as combustion and chlorination. In the context of the Lake Michigan management activities, load reductions typically target “dioxin” in the form of 2,3,7,8-tetrachloro-dibenzo-p-dioxin because of the high degree of toxicity associated with that specific compound. Furthermore, most research completed to date has focused primarily on identifying sources of the 2,3,7,8-TCDD congener, rather than other forms of dioxins and furans.
- **Inadvertant generation during production processes.** EPA’s 1998 National Dioxin Inventory indicates that one of the primary historical sources of dioxin releases to water has been pulp and paper production processes, although the inventory found that the pulp and paper industry accounted for less than 2 percent of all releases to air, land, and water, and in products. Important potential anthropogenic sources also include releases from processes such as cement kilns and

metal smelting and refining. Dioxins are also formed as unwanted impurities during the manufacturing of other organic compounds including herbicides containing 2,4,5 trichlorophenoxy acids (2,4,5 T), 2,4,5 trichlorophenol, hexachlorophene, pentachlorophenol and PCBs. The pyrolysis (heat decomposition) of technical grade PCB mixtures produces several polychlorinated dibenzofurans (CDF) (Rappe 1979; Schecter and Charles 1991). Like dioxins, a primary source of furans are emissions as by-products of the pulp and paper production processes and non-ferrous metal manufacturing.

- **Combustion or incineration**. Some of the primary historical sources of dioxins have been atmospheric deposition from municipal and medical waste incineration. The most important potential anthropogenic sources include releases from processes such as municipal, medical and hazardous waste incinerators, cement kilns, metal smelting and refining, wood combustion, and household waste burning. A primary source of furans is atmospheric deposition due to emissions from waste incineration and burning of fossil fuels.

- **Commercial Products**. Pentachlorophenol has been used to preserve a variety of commercial products, including textiles and leather goods in the United States and abroad. In the past, pentachlorophenol was widely used as a pesticide although most of those uses are now restricted. Dioxin contamination in pentachlorophenol could contribute as much as 10,500 g TEQ/yr (23.14 lb TEQ/yr) in the United States (Slants and Trends 1995). Based on the normalized population of the Lake Michigan basin, more than 200 g TEQ/yr (0.44 lb TEQ/yr) of dioxin are assumed to be found in the basin. However, dioxin levels in products are likely to decrease because of declining use of pentachlorophenol. The disposal and use of commercial products contaminated by PCDDs and PCDFs, such as certain pesticides and pentachlorophenol-treated wood, is also a potential source of dioxin. Pulp and paper mill discharges to publicly-owned treatment works (POTW) are a diminishing problem in the Lake Michigan basin.

- **Wastewater treatment plant sludge.** One POTW in the Lake Michigan basin receives indirect discharges from a bleached kraft mill. However, new cotton clothing and other household items have been found to contain dioxins; the dioxins come out in the wash and are discharged to the wastewater treatment facility (Horstmann and McLachlan 1994). In 1990, the Western Lake Superior Sanitary District treatment plant sludge contained 0.014 g (0.00049 ounce) TEQ. If similar waste streams are managed by Lake Michigan basin POTWs, sludge generated by these plants are likely to contain more than 1 g TEQ based on population.

- **Natural sources.** There are also significant natural sources of dioxins and furans, including forest fires and volcanic activity. However, in the United States, atmospheric releases of dioxins and furans from forest and agricultural fires are relatively small compared to releases from anthropogenic sources.

ACTUAL RELEASES OF DIOXINS AND FURANS TO THE ENVIRONMENT

Dioxins and furans are generated by a variety of sources in the Lake Michigan basin. The following sources are highlighted in this analysis.

Industrial

- **Forest products**. Dioxins have been generated in pulp and paper mills from the paper bleaching process, especially in plants using elemental chlorine as a bleaching agent. In recent years, pulp mills in the basin have modified their bleaching processes by substituting chlorine dioxide for elemental chlorine, thereby virtually eliminating dioxins from pulp and paper mill effluents

(Stromberg and others 1996). Monitoring data provided by NCASI indicate that reductions in TCDD and TCDF releases resulting from changes in the bleaching processes to effluent, mill sludges, and pulp products have been estimated at 92 percent, 89 percent, and 93 percent respectively (on a TEQ basis). For the remaining five bleached kraft mills in the Great Lakes Basin, TCDD/TCDF releases in 1996 were estimated at 0.42 g TEQ in effluent, 0.04 g TEQ in sludge, and 0.29 G TEQ in product (NCASI 1997).

- **Petroleum refining**. Dioxins can be formed when catalysts used in petroleum refining are reactivated by burning off coke deposits at 380 degrees C (716 °F) to 525 degrees C (977 °F) in the presence of chlorinated compounds (Bear and others 1993). Seven petroleum refiners are currently operating in the basin. Dioxins in waste effluents from these facilities are thought to be associated with the regeneration of the catalyst reformer. For example, prior to 1991, 1.5×10^{-5} g (5.29×10^{-7} ounce) TEQ/yr was measured in the effluent of the Murphy Oil facility in Superior, Wisconsin. The dioxin in the effluent was thought to be associated with the regeneration of the catalyst reformer. Wastes from this process are now typically disposed in a hazardous waste facility (LSBP 1996).

- **Wood preserving**. Past industrial use of pentachlorophenols (PCP) to treat timber, railroad ties, and utility poles are a potential source of dioxins in the basin (Tetra Tech 1996). For example, 0.29 g (0.01 ounce) TEQ was observed in the soils in the vicinity of the Koppers Inc. facility in Superior, Wisconsin. The facility used PCP to treat railroad ties until 1979. Two Superfund sites in the Lake Michigan watershed, Cordova Chemical and the Ninth Avenue Dump, report soil or sediment dioxin contamination.

- **Metal smelting and refining**. Nonferrous metal, especially copper, smelting and refining are a known source of dioxin and furan emissions accounting for approximately 1.36×10^{-2} lb/yr TEQ air emissions in the United States (EPA 1997d). In the Lake Michigan basin, smelting and refining operations are primarily limited to the southern end of the watershed. TRI reported dioxin air releases from this sector totaled more than 20 g (0.71 ounce) in 1996.

Fuel Combustion

The combustion of wood and coal as an energy source for industrial and residential use is a known source of dioxins (EPA 1997). Increased attention has been devoted over the past several years to estimate the dioxin emission factors associated with these processes. Table 5-9 provides estimates of the wood and coal combustion rates in the Lake Michigan Basin and the current emission factors used to estimate dioxin TEQ emissions from those sources.

Incineration

- Burn Barrels. In the past several years, research has found that household “burn barrels” may be a significant dioxin source. WLSSD (1992) estimated that burn barrels produce 20 times more 2,3,7,8-TCDD per unit of household garbage burned than a controlled incinerator (for example, a municipal waste combustor [MWC]). Lemieux (1998) estimated that 1.5 to 4 households that burn their waste in the open (for example, in burn barrels) equal the dioxin generating potential of a fully-operational MWC. Overall, household waste combustion in burn barrels appears to be an overlooked, but potentially significant source of dioxin and other toxic air emissions.

Table 5-9. Dioxin Emissions from Wood and Coal Combustion

Fuel and Combustion Type	Quantity of Fuel Burned in Lake Michigan Basin (kg)[a]	Emission Factor (ng TEQ/kg fuel combusted)	Dioxin Emissions (g TEQ/yr)[d]
Coal, coal fired utilities and industrial boilers	1.8×10^9 (1,984,140 tons)	0.087[b] (0.087 ppt)	0.16 (0.0056 ounce TEQ/yr)
Coal, commercial and residential boilers	1.7×10^7 (18,739 tons)	22[c] (22 ppt)	0.37 (0.013 ounce TEQ/yr)
Wood, industrial wood furnace	1.2×10^8 (132,276 tons)	0.82[b] (0.82 ppt)	0.10 (0.0035 ounce TEQ/yr)
Wood, commercial and residential	1.5×10^8 (165,345 tons)	2[b] (2 ppt)	0.30 (.011 ounce TEQ/yr)
TOTAL			0.93 (0.033 ounce TEQ/yr)

[a] Adapted from Tetra Tech (1996).
[b] EPA 1998b
[c] Tetra Tech 1996

The average person in the United States generates between 800 and 1,350 pounds of household waste in a year (MDEQ 1999). The EPA estimates that 40 percent of people living in non-metropolitan areas burn their waste and that 63 percent of their daily waste is burned in burn barrels. Nationally, this amounts to more than 90 billion pounds of household waste burned in burn barrels every year. Normalized for the Lake Michigan basin population, this amounts to more than 4.7 billion pounds of household waste openly burned in the basin each year.

While such household waste burning is suspected to be a significant source of dioxin and other toxic air emissions, research findings differ as to the rates of dioxin emission per unit of household waste burned (Cohen 1999). Table 5-10 summarizes dioxin generation emission factors for several recent studies. The table illustrates that emission rate estimates vary over several orders of magnitude. As a result, these emission factor estimates are provided to illustrate the potential significance of the source. Much additional work remains to be completed to properly estimate the dioxin emissions from household waste burning that is occurring in the basin.

To illustrate the potential magnitude of household hazardous waste burning in the U.S. portion of the basin, Table 5-11 applies the Cohen (1999) emission factor to potential household hazardous waste burn rates in the U.S. Lake Michigan basin counties to generate an annual TEQ dioxin emission estimate. Extrapolation of national estimates on burning rates to the Lake Michigan basin yields an estimate of about 170 g (0.0060 ounce) TEQ/yr.

Table 5-10. Emission Factors for Household Waste Combustion in Burn Barrels

Source	Emission Factor (g TCDD/lb household waste burned)	Emission Factor (ounce TCDD/lb household waste burned)
Cohen (1999)	3.6 x 10^{-8} [b]	1.27 x 10^{-9}
Lemieux (1998) (recycler)[a]	1.04 x 10^{-7}	3.67 x 10^{-9}
Lemieux (1998) (non-recycler)	7.4 x 10^{-6}	2.61 x 10^{-7}
Two Rivers Regional Council (1994)	6.2 x 10^{-10}	2.19 x 10^{-11}
WLSSD (1992)	1.8 x 10^{-9}	6.35 x 10^{-11}

[a] Recyclers were assumed to reduce the proportion of newspaper, plastic, and some metals in their household waste.

[b] Expressed as grams TEQ/yr.

Table 5-11. Dioxin Generated from Household Waste Combustion in Burn Barrels

Lake Michigan Basin County Population[a]	Estimated Annual Waste	Estimated Pounds Burned	Estimated g TEQ/yr Emissions
14,138,704	1.91 x 10^{10}	4,774,999,964	172

[a] includes population of Cook County, Illinois

- Medical and industrial. Medical and industrial incinerators have been recognized as a significant source of dioxin and furan air emissions. The number of incinerations in the basin is declining as medical and industrial waste combustion is phased out.

- Small incinerators. Small incinerators (such as those operated by schools, apartment buildings , and retailers) have contributed a large proportion of dioxin and furan air emissions. However, as of 1999, all small incinerators are assumed to be closed in the United States as a result of the MACT regulations (see Appendix B). As a result, no dioxin air emissions are estimated for this sector in 1999.

ACTUAL LOADING OF DIOXIN AND FURANS TO LAKE MICHIGAN

Cohen and others (1995), modeled air deposition estimates, average depositional flux, and water effluent inputs for dioxins in Lake Michigan to help explain and understand the variations in loadings and accumulations (Table 5-12). Results showed that flux trends followed the pattern of industrialization around the lake, and that waterborne inputs play a lesser role than air deposition of dioxins to Lake Michigan.

Table 5-12. Modeled Air Deposition and Waterborne Inputs of Dioxins and Furans to Lake Michigan

Total Air Deposition (g TEQ/yr)	(ounce TEQ/yr)	Waterborne Inputs (g TEQ/yr)	(ounce TEQ/yr)
5 - 43	0.18 - 1.52	1.9	0.067

Pearson and others (1998) assessed current and historical inputs of dioxins and furans to the Great Lakes, including Lake Michigan. Concentration and accumulations of dioxins and furans were determined in dated sediment cores from northern and southern Lake Michigan depositional zones. Results showed that both currently and historically there is significantly more accumulation of dioxin in the northern part than in the southern part of the lake. This finding is inconsistent with long-range atmospheric transport and deposition, because air concentrations of dioxins are known to decline in more remote areas, and in theory then the air masses over northern Lake Michigan should be less contaminated, on average, than those over southern Lake Michigan. Thus, non-atmospheric sources of dioxin to northern Lake Michigan are implicated by this study. Through analysis of dioxin homolog mixtures in the cores and the atmosphere, it was estimated that the atmosphere currently provides 100 percent of dioxin to southern Lake Michigan, 33 to 50 percent of dioxin to northern Lake Michigan, but only 5 to 35 percent of the total furan in Lake Michigan as a whole. In addition, by comparing the sediment homolog compositions to those of non-atmospheric sources, such as contaminated sediment sources and industrial waste dischargers, likely non-atmospheric sources were suggested. For southern Lake Michigan it was suggested that effluent from bleached kraft paper mills or contamination from PCB spills could produce the homolog compositions observed. In northern Lake Michigan it was suggested that by products related to PCP, effluent from paper mills using large amounts of recycled stock, or effluents from sewage treatment plants could account for the added accumulations of dioxin. Additional data is required to definitively implicate any of the possible sources.

Finally, the RAPIDS data analysis has estimated approximately 230 g (8.11 ounce) TEQ of dioxin and furan air emissions in 1996. The predominant sources of the emissions included residential wood combustion and pharmaceutical preparations.

IMPACT ON LAKE MICHIGAN

Currently, the major route of exposure of 2,3,7,8-TCDD to the general population is estimated to occur through the food web, in particular through the ingestion of fatty substances such as meat, dairy products, and fish. As they are soluble in fats, dioxins and furans will accumulate in the bodies of humans and animals. A fish consumption advisory for the Menominee River in Michigan has been established because of exceedances of the 10 μg/g TEQ level in fish tissues. No advisories are currently in effect for the open waters of the lake.

SPECIAL MANAGEMENT ISSUES

Specific actions to address DIOXINS AND FURANS are presented in Chapter 6, Table 6-1: HH9, HH10, SU6, RPP1, RM5 6

The significant, remaining sources of dioxin emissions in the Basin include small industrial and other waste incinerators and backyard burning of household waste in burn barrels. Because most large emission sources in the basin are understood, the focus must now be placed on characterizing small, disperse sources. As a result, the control strategies applicable to these sources should include public education and outreach coupled with aggressive identification of these sources. Other areas to be pursued on a long-term basis are clean up of contaminated sites and investigation of continuing pentachlorophenol use. Current regulatory and management programs for dioxin/furans are discussed in Appendix A.

5.3.3.3 Dieldrin/Aldrin

Critical Pollutant

Aldrin and dieldrin are the common names of two insecticides that are closely related chemically. They were both used primarily for crop protection from various soil-dwelling pests as well as protection against termite infestation. Dieldrin is also a primary degradation product of aldrin. The last uses of aldrin and dieldrin in the United States were canceled in 1991 and 1989, respectively. Both are persistent and toxic in the environment. See Appendix B for physical and chemical properties of dieldrin and aldrin.

Following is a discussion of the potential and actual releases of aldrin and dieldrin into the environment, the potential load to the lake, the current and past loading of dieldrin and aldrin to the lake, the impact of dieldrin and aldrin on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing dieldrin and aldrin.

POTENTIAL RELEASES OF DIELDRIN/ALDRIN TO THE ENVIRONMENT

- **Historical use, global use, and environmental cycling.** Aldrin was first synthesized in the United States as a pesticide in 1948. Aldrin and dieldrin are active against insects by contact or ingestion. The primary use of these products was for control of corn pests by application to the soil. Other past uses were in the citrus industry and in general crop protection. Non-agricultural pesticide use included application against termite infestation of structures and against soil-dwelling pests such as ants, wireworms, and white grubs.

  All pesticide uses of aldrin and dieldrin were canceled in 1974, except for subsurface ground insertion for termite control, dipping of non-food roots and tops and moth-proofing by manufacturing processes in closed systems. Twenty one product registrations that remained for non-food crop uses of aldrin were allowed to lapse or were voluntarily canceled by the registrants. Most remaining aldrin products were canceled by 1987, with the last product canceled in 1991. Thirty product registrations that remained for non-food crop uses of dieldrin were allowed to lapse or were voluntarily canceled by the registrants. Most remaining dieldrin products were canceled by 1987; the last product was canceled in 1989 (HHS 1993a).

- **Hazardous waste sites.** In addition to sources associated with direct releases and historical applications, dieldrin and aldrin have been identified as contaminants for at least 13 hazardous waste sites in the four Lake Michigan states.

- **Stockpiles.** Waste pesticide collections (Clean Sweeps) continue to recover significant quantities of dieldrin, aldrin, and other Level I pesticides from agricultural users indicating that additional stored quantities are likely to exist. Quantities of dieldrin and aldrin recovered in the Great Lakes drainage basin are presented in Table 5-13 and Table 5-14. Improper storage or illegal use of such large quantities of dieldrin and aldrin could be a significant source to Lake Michigan.

ACTUAL RELEASES OF DIELDRIN/ALDRIN TO THE ENVIRONMENT

- **Point source water discharges, air emissions, and releases to land.** There are currently no known direct releases of aldrin and dieldrin to the environment as the result of product manufacturing, and TRI records indicate no reportable releases to the environment.

- **Legacy dieldrin/aldrin contamination.** The primary source of aldrin and dieldrin to the environment has been past agricultural use and application for termite control. Although application of these compounds was canceled, historical applications resulted in persistent soil residues that continue to serve as sources into the atmosphere as well as runoff into surface water (HHS 1993a).

Table 5-13. Estimated Clean Sweeps Collections of Dieldrin in the Great Lakes Drainage Basin (EPA 1998f)

State	**Years of Collection**	**Dieldrin Collected (kg)**	**Dieldrin Collected (lb)**
Illinois	1994 to 1998	4	8.8
Indiana	1992 to 1997	2	4.4
Michigan	1992, 1994, 1995	913	2,012.8
Wisconsin	1993 to 1996	99	218.3
Total		1,018	2,244.3

Table 5-14. Estimated Clean Sweeps Collections of Aldrin in the Great Lakes Drainage Basin (EPA 1998f)

State	**Years of Collection**	**Aldrin Collected (kg)**	**Aldrin Collected (lb)**
Illinois	1994 to 1998	35	77.2
Indiana	1992 to 1997	68	149.9
Michigan	1992, 1994, 1995	1,913	4,217.4
Wisconsin	1993 to 1996	157	346.1
Total		2,173	4,790.6

In addition to residues from past applications, aldrin and dieldrin have been detected in soils, sediments, surface water and groundwater at hazardous waste sites in every state bordering the Great Lakes (HHS 1993a). Soil, sediment, and groundwater at the Muskegan Chemical NPL site in Michigan are contaminated with dieldrin and aldrin. Direct and indirect releases from these sites may continue to provide a source of aldrin and dieldrin to the environment.

ACTUAL LOADINGS OF DIELDRIN/ALDRIN TO LAKE MICHIGAN

Atmospheric Deposition Pathway

The largest use of aldrin in the United States during the 1970s was in states bordering the Great Lakes and to the south and west, the direction of most prevailing winds. Aldrin application was highest in many of the states adjacent to the southern edge of the Great Lakes. Conversely, dieldrin use was relatively low in the Great Lakes region. However, the detection frequency of dieldrin was twice as high as for aldrin, which is not surprising, given the fact that aldrin converts readily to dieldrin in the environment (Majewski and Capel, 1995). Estimated trajectories of air masses show that model predictions support the long-range atmospheric transport of aldrin and dieldrin from these regions to the Great Lakes.

Recent fluxes of dieldrin have been measured through the IADN program at 5 locations around the Great Lakes. Dieldrin associated with both wet and dry deposition and in the gas phase was measured at all locations. Average annual concentrations of dieldrin at the IADN Lake Michigan master station are presented in Table 5-15. The wet and dry deposition fluxes of dieldrin to Lake Michigan are presented in Table 5-16. (IADN 1998)

Table 5-15. Average Annual Concentrations of Dieldrin at the IADN Lake Michigan Master Station (IADN 1998)

Year	Precipitation (ng/l or ppt)	Particle (pg/m^3)	Gas (pg/m^3)
1992	0.99	1.90 (0.0015 ppt)	34.00 (2.18 x 10^{-3} ppt)
1993	0.65	2.25 (0.0018 ppt)	39.50 (2.53 x 10^{-3} ppt)
1994	0.66	1.90 (0.0015 ppt)	36.30 (2.33 x 10^{-3} ppt)

Table 5-16. Fluxes of Dieldrin to Lake Michigan (IADN 1998)

Year	Wet (ng m^{2}d^{-1})	Dry (ng m^{2}d^{-1})
1991 to1992	2.70	0.38
1993	2.00	0.34
1994	2.60	0.46

Overall flux for the Great Lakes (except Lake Michigan, where net gas flux was not calculated) appears to be dominated by gas phase transfer out of the lakes (IADN 1998). This is consistent with the conclusions of Hillery and others (1998) for other chlorinated organics measured in the atmosphere over the Great Lakes. This trend for dieldrin was evident for data collected since 1990, although no overall decrease in either atmospheric concentrations or net flux was evident based on the average annual fluxes reported by the IADN (IADN 1998). However, Cortes and others (1998) provided estimates of temporal trends based on these same measurements using partial pressures corrected for seasonal temperature. Using this approach, Cortes and others (1998) calculated regional half-lives of dieldrin and found that there was a significant decrease of dieldrin in the atmosphere at all sites but Lake Ontario. The atmospheric half-life calculated for the Lake Michigan station was 1.5 years, resulting in an estimated date of virtual elimination from the atmosphere of 2010.

Sediments Pathway

Aldrin and dieldrin were measured in sediment cores from 5 locations in Lake Michigan (Golden 1994). The range of concentrations for both aldrin and dieldrin was relatively small and concentrations low. Aldrin was generally found at concentrations less than 2 ng/g (ppb) with little variation with depth. Dieldrin was detected at higher concentrations showing onset of contamination in approximately the

1940s. Concentrations in cores from northern Lake Michigan generally exhibited a peak around the 1970s and then a decrease in values in recent years. Although cores from Southern Lake Michigan show similar onset as those in the north, concentrations through the 1970s to the present have remained relatively constant. This trend may be a result of greater sediment activity (such as resuspension and mixing) in the southern basin rather than an indication of current inputs (Golden 1994).

Tributaries and Areas of Concern Pathway

A MDNR caged channel catfish study in the Menominee River found detectable levels of dieldrin (EPA No date[m]). Organochlorine contaminants (such as dieldrin) and heavy metals found in the Milwaukee Estuary AOC are shown to impair the bird or animal reproductive systems at that AOC. At White Lake AOC, a 28-day caged fish study conducted in the navigational channel between White Lake and Lake Michigan in 1992 showed that chlordane, DDE, and dieldrin were present. (EPA No date[m]).

IMPACT ON LAKE MICHIGAN

In Lake Michigan average dieldrin concentrations in lake trout increased from 0.27 mg/kg (ppm) in 1970 to 0.58 mg/kg (ppm) in 1979 followed by a decrease through 1986 (0.17 mg/kg [ppm]) and 1990 (0.18 mg/kg [ppm]) (DeVault and others 1995 and 1996). A similar trend is observed in dieldrin levels in whole bloaters, with an increase in tissue levels from 1970 through 1978 followed by a steady decline (Chemical Manufacturers Association 1997). There are currently no restrictions on fish consumption due to aldrin/dieldrin concentrations in fish from Lake Michigan (EPA 1997).

Concentrations of dieldrin in eagle eggs were above 2 ppm for eggs from Lake Michigan in 1986. Herring gull eggs have also been monitored for dieldrin. Some studies indicate a 30 percent decrease in dieldrin concentrations (over all Great Lakes) from 1971 to 1988 (Chemical Manufacturers Association 1997). However, even these studies indicate a possible increase in egg concentrations in the early 1990s in all of the Great Lakes, including Lake Michigan. Appendix C provides human health and ecological effects information for dieldrin and aldrin.

SPECIAL MANAGEMENT ISSUES

Specific actions to address DIELDRIN/ALDRIN are presented in Chapter 6, Table 6-1: RPP1, RPP16, IS13, RAI5 6

Programs regulating and controlling the management of dieldrin and aldrin are presented in Appendix A. Special management issues for dieldrin and aldrin include the following:

- Environmental cycling of legacy dieldrin and aldrin contamination as a major source of dieldrin to Lake Michigan.

- Long-range transport of pollutants

5.3.3.4 Chlordane

Critical Pollutant

Chlordane is a man-made chemical pesticide that was canceled in April 1988 due to concern over human cancer risk, evidence of human exposure and accumulation in body fat, environmental persistence, and danger to nonpest wildlife. If burned, chlordane emits a poisonous gas. See Appendix C for human health effects information. Chlordane is very persistent in the environment. It is resistant to both chemical and biological degradation and is strongly bioaccumulated in humans and aquatic organisms. See Appendix B for information on the physical and chemical properties of chlordane.

Following is a discussion of the potential and actual releases of chlordane into the environment, the potential load to the lake, the current and past loading of chlordane to the lake, the impact of chlordane on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing chlordane.

POTENTIAL RELEASES OF CHLORDANE TO THE ENVIRONMENT

- **Historical use, global use, and environmental cycling.** Prior to cancellation, chlordane's primary use in the United States was as a pesticide on agricultural crops, lawns and gardens, and as a fumigating agent used to control termites in houses. All uses of chlordane have been prohibited in the United States, and there is no current production or manufacture of the product in the United States Current sources of chlordane to the Lake Michigan are generally from historical use or production of the compound. On the basis of historic production figures, an estimated 70,000 tons of chlordane were produced since 1946, of which 25 to 50 percent is estimated to still exist unaltered in the environment (Dearth and Hites 1991b). Although no estimates of the percentage of application relative to the Great Lakes region are available, the primary applications in the United States were generally south and west of the region, coinciding with termite infestation. In addition, as a result of long-range atmospheric transport, uses of chlordane in other parts of the world still act as a source to Lake Michigan.

- **Hazardous waste sites.** In addition to sources associated with direct releases and historical applications, chlordane has been identified in at least 176 of the 1,350 hazardous waste sites that have been proposed for inclusion on the EPA's National Priorities List. Chlordane contamination has been identified at two Superfund sites in the Lake Michigan basin.

- **Stockpiles.** Waste pesticide collections from agricultural users (Clean Sweeps) continue to recover significant quantities of chlordane and other Level I pesticides indicating that additional stored quantities are likely to exist. Quantities of chlordane recovered in the Great Lakes drainage are presented in Table 5-17. Improper storage or illegal use of such large quantities of chlordane could be a significant source to Lake Michigan.

Table 5-17. Estimated Clean Sweeps Collections of Chlordane in the Great Lakes Drainage Basin (EPA 1998f)

State	Years of Collection	Chlordane Collected (kg)	Chlordane Collected (lb)
Illinois	1994 to 1998	397	875.2
Indiana	1992 to 1997	104	229.3
Michigan	1992, 1994, 1995	2,743	6,047.3
Wisconsin	1993 to 1996	554	1,221.4
Total		3,798	8,373.1

ACTUAL RELEASES OF CHLORDANE TO THE ENVIRONMENT

- **Point source water discharges, air emissions, and releases to land.** There are no TRI reported releases of chlordane.

- **Legacy chlordane contamination.** McConnell and others (1998) found that chlordane concentrations in air samples taken from Green Bay were 35 pg/m^3 (2.09 x 10^{-3} ppt) on average, with the lowest concentrations observed on the coldest days. This trend is consistent with an increase in the concentration of semivolatile compounds in ambient air at higher temperatures. Area air samples were also measured over open Lake Michigan. The average chlordane concentration was 247 pg/m^3 (1.47 x 10^{-2} ppt). Because all uses of chlordane are canceled, current concentrations are the result of historical use or use in other countries.

  Surficial concentrations of chlordane measured in Lake Michigan's southern and northern basin ranged from approximately 0.5 to 4 ppb. Concentrations of four chlordane-related compounds were measured in sediment cores from five locations around Lake Michigan. These profiles identify the 1940s as the onset of contamination with maximum concentrations occurring between 1960 and 1980. Concentrations associated with more recent sediments are lower, reflecting the decreased domestic use as a result of increasing regulation (Golden 1994). Concentrations of a number of chlorinated pesticides, including the three chlordane-related compounds (α- and γ-chlordane and *trans*-nonachlor), were measured in the atmosphere seasonally from January 1992 - December 1994 at Sleeping Bear Dunes, Michigan. Half-lives and virtual elimination dates for γ-chlordane and *trans*-nonachlor are presented in Table 5-18. The parameters used to calculate the half-life for α-chlordane were not significant at the 95 percent confidence level and, therefore, a virtual elimination date was not calculated. (Cortes and others 1998).

Table 5-18. Atmospheric Half-Lives and Virtual Elimination Dates at Sleeping Bear Dunes (Cortes and others 1998)

Compound	Half-Life (yrs)	Virtual Elimination Date
γ-chlordane	3.2	2015
trans-nonachlor	3.5	2015

ACTUAL LOADINGS OF CHLORDANE TO LAKE MICHIGAN

Chlordane has been detected prior to 1990 in waters of the Great Lakes at concentrations ranging from not detected to 0.3 ng/L (ppt), measured as *cis* and *trans*-chlordane (Stevens and Nelson 1989). Sediment concentrations measured from Great Lakes harbors ranged from 1.5 to 310 ppb (Puri and others 1990).

Chlordane was among the most commonly detected chemicals in fish samples taken from water bodies in Cook Country, IL and Lake County, IN (including Lake Michigan). The highest concentration, 0.58 mg/kg (ppm), was detected in a sample from Lake Michigan taken in 1986.

Atmospheric Deposition Pathway

Eisenreich and Strachan (1992) reported atmospheric loading of chlordane at 10 kg/y (22.0 lb/yr). According to the LMMB Project, the net deposition of trans-nonachlor is -57.32 lb/yr (-26 kg/yr) out of Lake Michigan (EPA No date[j]). 4.41 lb/yr (2 kg/yr) of trans-nonachlor are deposited in Lake Michigan due to dry deposition; 4.41 lb/yr (2 kg/yr) due to wet deposition; and 66 lb/yr (30 kg/yr) of trans-nonachlor leave Lake Michigan due to net gas output (EPA No date[j]).

Sediments Pathway

Data on transnonachlor will be added to future drafts.

Tributaries and Areas of Concern Pathway

A MDNR caged channel catfish study in the Menominee River found detectable levels of chlordane (EPA No date[m]). At White Lake AOC, a Michigan Department of Public Health fish consumption advisory for carp was issued due to elevated concentrations of chlordane and PCBs in carp tissue samples. A 28-day caged fish study conducted in the navigational channel between White Lake and Lake Michigan in 1992 showed that chlordane, DDE, and dieldrin are present. (EPA No date[m]). Chlordane showed decreasing levels in the Indiana Harbor Canal, a Lake Michigan tributary, from 1979 to 1994 (Chicago Cumulative Risk Initiative 1999).

The LMMB Project estimated trans-nonachlor loads from Lake Michigan tributaries based on data from January 1, 1995, to December 31, 1995 (see Table 5-19). According to these data, the Grand River contributes the largest load of trans-nonachlor to Lake Michigan (0.46 kg/yr).

Table 5-19. Estimated Trans-nonachlor Loads From Lake Michigan Tributaries (EPA No date [j])

Tributary	Estimated Load (kg/yr)	Estimated Load (lb/yr)
Fox River	0.09	0.02
Grand Calumet	0.04	0.09
Sheboygan River	0.002	0.004
Kalamazoo	0.09	0.2
Grand	0.29	0.64
Menominee River	0.02	0.04
Milwaukee Estuary	0.03	0.07
Pere Marquette	0.003	0.007
Muskegon River	0.04	0.09
St. Joseph	0.36	0.8

IMPACT ON LAKE MICHIGAN

Oxychlordane, a metabolite of chlordane, has been monitored in fish in Lake Michigan since 1977. Although levels have declined by 80 percent in lake trout from Lake Michigan over the last 10 years, fish from the southeast portion of the lake still have the highest observed concentrations of any of the Great Lakes (0.45 ppm). Oxychlordane levels in coho salmon fillets from Lake Michigan have declined from 2 ppm in 1980 to 0.5 ppm in 1984, but then steadily increased to above 1 ppm in 1992 (DeVault 1996) Oxychlordane levels in herring gull eggs from several gull colonies were above 0.3 ppm in Lakes Ontario, Michigan, Erie, and Huron in the mid-1970s and have declined to or below 0.1 ppm in all of the lakes except Lake Michigan. Concentrations in herring gull eggs from Lake Michigan have declined from levels close to 1 ppm in 1982 to about 0.25 ppm in 1989 through 1992 (Chemical Manufacturers Association 1997).

Fish consumption advisories due to unacceptable chlordane levels have been issued by the states of Wisconsin and Michigan (EPA No date).

SPECIAL MANAGEMENT ISSUES

Specific actions to address CHLORDANE are presented in Chapter 6, Table 6-1: RPP1, RPP16, IS13, RAI5 6

Programs regulating and controlling the management of chlordane are presented in Appendix A. Special management issues with chlordane include the following:

- Environmental cycling of legacy chlordane contamination is a major source of chlordane to Lake Michigan.
- Long-range transport of pollutants

5.3.3.5 DDT and DDT Metabolites

Critical Pollutant

DDT [1,1,1-trichloro-2,2-bis-(*p*-chlorophenyl)ethane] is a broad spectrum insecticide, and its use is no longer allowed in the United States. used on crops, grazing land, forest, and urban areas to control insects that transmit diseases such as malaria and typhus. DDT does not occur naturally. Its presence in the environment is the result of contamination from past production, use, disposal, and transport by air and water. Although use of DDT is currently canceled in the United States, measurable amounts of DDT and its metabolites (DDE [1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene] and DDD [1,1-dichloro-2,2-bis(p-chlorophenyl)ethane]) are still found in the air, water, sediment, and soil in and around the Great Lakes. See Appendix B for physical and chemical properties of DDT.

Following is a discussion of the potential and actual releases of DDT into the environment, the potential load to the lake, the current and past loading of DDT to the lake, the impact of DDT on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing DDT.

POTENTIAL RELEASES OF DDT TO THE ENVIRONMENT

- **Historical use, global use, and environmental cycling.** DDT was last used in the United States in the 1970s; however, production of DDT for export continued in the United States long after domestic applications ceased. Product manufacture and use continues outside the United States. Ninety percent of U.S. production of DDT insecticide was exported for use outside the country (Spectrum, 1998 as cited in EPA 1998a). As recently as 1985, two production sites in the United States manufactured DDT for export (HHS 1993).

  DDT's only known use in the United States was as a contact pesticide. It was applied to crops and forests, and sprayed directly on animals (mostly cattle) and human beings. Major uses were to control cotton crop pests and mosquitoes. DDT was extensively used during the Second World War among Allied troops and certain civilian populations to control insect typhus and malaria vectors. After 1945, it was primarily used as an agricultural insecticide. Domestic use of DDT was canceled in 1972 for crop production and nonhealth purposes. The last public health use was in the late 1970s.

  The patterns of use in Canada and Mexico are similar to use in the United States Most uses of DDT in Canada were phased out in the mid-1970s. Registration for remaining uses was discontinued in 1985. The use of existing stocks was allowed through 1990. DDT is still currently produced in Mexico for use in government-sponsored public health campaigns to control malaria. One private company produces DDT in Mexico subject to government approval. Mexican production is about 600 tonnes per year. Product manufacture and use also continues in other countries.

- **Current use of dicofol.** DDT is also an intermediate/reactant for dicofol, a miticide registered for use in the United States, Canada, and Europe. The U.S. imports dicofol that must contain less than 0.1 percent DDT. The USGS Pesticide Monitoring Program estimated that approximately 1.1 million pounds of dicofol is applied in the United States annually. Based on this estimate, approximately 1,000 pounds of DDT are being applied to croplands in the United States annually.

- **Hazardous waste sites.** In addition to sources associated with direct releases and historical applications, DDT has been identified as a contaminant for at least 18 hazardous waste sites in the four Lake Michigan states.

- **Stockpiles.** Waste pesticide collections (Clean Sweeps) continue to recover significant quantities of DDT and other Level I pesticides indicating that additional stored quantities are likely to exist. Quantities of DDT recovered in the Great Lakes drainage are presented in Table 5-20. Improper storage or illegal use of such large quantities of DDT could be a significant source to Lake Michigan.

Table 5-20. Estimated Clean Sweeps Collections of DDT in the Great Lakes Drainage Basin (EPA 1998f)

State	Years of Collection	DDT Collected (kg)	DDT Collected (lb)
Illinois	1994 to 1998	85	187.4
Indiana	1992 to 1997	177	390.2
Michigan	1992, 1994, 1995	2,743	6,047.3
Wisconsin	1993 to 1996	1,910	4,210.8
Total		4,915	10,835.7

ACTUAL RELEASES OF DDT TO THE ENVIRONMENT

DDT, DDE, and DDD are not TRI reported compounds.

- **Point source water discharges.** There are no reported releases of DDT.

- **Air emissions and releases to land.** Air emissions and releases to land could also result from improper use or disposal of stockpiled DDT. The use of dicofol also results in releases to air and land. Currently, there are no known producers of DDT in the United States (HHS 1994). However, long-range transport of DDT from use in other countries still has the potential to act as a source of DDT to the Great Lakes. Although studies during the 1980s indicated that the atmosphere was a sink for DDT volatilizing from the Great Lakes (Hillery and others 1998), recent measurements show that decreasing water column concentrations appear to have reversed that trend and the net flow of DDT is, for the most part, into the Great Lakes. This pattern of flow into and out of the lakes is partially seasonal and with continued global use, the potential is for the atmosphere to remain a source of DDT to the Great Lakes.

- **Legacy DDT contamination.** A major source of DDT to the environment has been past agricultural use and application for termite control. Although application of these compounds was canceled, historical applications resulted in persisting soil residues that continue to serve as sources into the atmosphere as well as runoff into surface water. (HHS 1994).

  DDT contamination of soils and sediment has been identified at three NPL sites in the Lake Michigan basin. DDT has also contaminated three Lake Michigan AOCs. Releases from these sites may continue to provide a source of DDT to the environment.

ACTUAL LOADINGS OF DDT TO LAKE MICHIGAN

Atmospheric Deposition Pathway

Although overall atmospheric concentrations of DDT are decreasing (Cortes and others 1998), the relative importance of atmospheric flux as both a source and a sink of DDT to the Great Lakes is becoming more significant. Pre-1990 measurements showed a significant net loss from the lake to the atmosphere. However, more recent data, presented in Table 5-21, shows that the trend may have reversed and the atmosphere may now be a source of DDT for Lake Michigan. Data for Lakes Superior and Erie reveal significant deposition into the lakes for 1991 to 1992 and 1993 to 1994.

Table 5-21. Air-Water Exchange Rate for DDT in Lake Michigan (Hillery 1997)

Year	Air-Water Exchange Rate (kg/yr)	Air-Water Exchange Rate (lb/yr)
Pre-1990	-460	-1,014.1
1991 to 1992	99±140	218.3 ± 308.6
1993 to 1994	76±90	167.6 ± 198.4

Some elevated concentrations of DDT have been observed around Lake Michigan. Significantly elevated levels of total-DDTs have been measured in air near South Haven, Michigan relative to other locations in the Great Lakes Basin (proposal from MDEQ, 1998). Recent levels at South Haven are also substantially greater than ambient levels that were monitored during the early 1970s at the time of peak DDT use. The range of 24-hr maximum values measured in northern Michigan by the MDEQ from 1992 to 1994 ranged from 0.030 to 0.076 ng/m^3 (2.07 x 10^{-3} to 5.24 x 10^{-3} ppt) compared to 0.986 ng/m^3 (6.81 x 10^{-2} ppt) measured at a site near South Haven. Though the reason for these elevated levels has not been determined, it is hypothesized that either DDT is volatilizing from contaminated soils during certain tillage practices, is being transported from other locations, or may be a result of legal application of the pesticide dicofol, which contains trace levels of DDT as a contaminant.

Recent data show net deposition of total-DDT was substantially into Lakes Superior, and Erie and that wet and dry deposition, at least, accounted for a significant input to Lake Michigan. Total-DDT transport was slightly out of Lake Huron while the net flow between Lake Ontario and the overlying atmosphere was not significantly different from equilibrium. The subsequent change in net direction of flow of DDT reflects the decline in water concentrations with decreased domestic use. (Hillery, Hoff, and Hites 1997).

Cortes and others (1998) estimated a virtual elimination date (for example, when the contaminant levels are below the detection limits of measurement equipment) at the IADN Lake Michigan sampling station of approximately 2010 for DDT and DDD. DDE’s virtual elimination date is estimated slightly later because of its higher atmospheric concentrations and longer half-life.

Sediments Pathway

Golden and others (1993) measured DDT and its metabolites in sediment cores from Lake Michigan. As the most rapid increase in concentrations occurred from 1960 to 1970 in all the cores, these data indicate that the majority of the input was most likely atmospheric. Rapid decreases observed in concentrations correspond with the cancellation of DDT use in 1972. However, both sediment cores from the north basin of Lake Michigan show unexpectedly high historical concentrations of DDT when compared to southern basin cores, most likely a result of inputs from the Fox River basin.

The rate of decrease in DDT concentrations in sediments of southern Lake Michigan has slowed considerably over the last decade and the continued elevated levels are probably due to continued inputs to the basin and long term movement of contaminated sediments to the main depositional basin. Eadie and others (no date) documented a major resuspension event in the spring months in the southern basin of Lake Michigan. This coastal turbidity plume persisted for over a month, progressing northward along the eastern shore. This event illustrates the process by which the large inventory of constituents stored in temporary sediment deposits can be re-supplied to the water column and redeposited into more permanent depositional environments, such as those in the northern basin. This large resuspension and mixing event, if an annual occurrence, may also account for the slower decline in surficial sediment concentrations observed in the southern basin.

Tributaries and Areas of Concern Pathway

Brazner and DeVita (1998) measured DDE (a DDT metabolite) concentrations in young-of-the-year littoral fishes from Green Bay, Lake Michigan. Based on even distribution of DDE concentrations measured in fish from throughout the bay, this study suggested that DDE appears to originate mostly from nonpoint sources rather than point sources (such as the Fox River) in the bay.

Because organochlorine contaminants (such as DDT) and heavy metals found in the Milwaukee Estuary AOC are shown to impair reproduction and development in wildlife elsewhere, the bird or animal deformities or reproductive problems use at that AOC is considered impaired. At White Lake AOC a 28-day caged fish study conducted in the navigational channel between White Lake and Lake Michigan in 1992 showed that chlordane, DDE and dieldrin are present. MDNR conducted a caged channel catfish study in 1993. The study found detectable levels of DDT and DDT metabolites (Lake Michigan Forum No date). A fish advisory for pesticides has been issued for the Menominee River (EPA No date[m]).

IMPACT ON LAKE MICHIGAN

DDE concentrations in eagle eggs collected in 1986 from Lakes Huron and Michigan were both above 30 ppm. (EPA 1998a) DDT and its metabolites have been measured in mussels at a total of 21 U.S. locations around the Great Lakes (except Lake Superior) as part of the NOAA Mussel Watch Program since 1992 (Robertson and Lauenstein 1998). The highest concentrations were observed for total DDTs in the southern basin of Lake Michigan. Concentrations greater than 160 ng/g (ppb) (dry weight) were observed in all samples collected from Milwaukee, WI to Muskegon Harbor (with the exception of one station at the southernmost tip of Lake Michigan). These concentrations were an order of magnitude higher than those detected at any of the other locations in any of the Lakes. However, the predominant compounds detected were the metabolites 4,4'-DDE and 4,4'-DDD, indicating that the source was most likely historical and that significant breakdown has occurred. Appendix C contains detailed information on potential human health effects.

SPECIAL MANAGEMENT ISSUES

Programs regulating and controlling the management of DDT are presented in Appendix A. Special management issues for DDT include the following:

Specific actions to address DDT are presented in Chapter 6, Table 6-1: RPP1, RPP16, IS13, RM5 **6**

- Environmental cycling of legacy chlordane contamination as a major source of DDT to Lake Michigan
- Long-range transport of pollutants

5.3.3.6 Mercury

Critical Pollutant

Mercury is a naturally occurring metal that is ubiquitous in the environment. Mercury is released to environmental media by both natural processes and anthropogenic sources. However, with the exception of mercury ore deposits, locally elevated levels of mercury in the environment are primarily the result of human activity.

Natural mercury most commonly occurs in combination with sulfur to form more than 25 different minerals, which are found in all classes of rocks, including limestone, calcareous shales, sandstone, serpentine, chert, andesite, basalt, and rhyolite. It also occurs as a trace element in fossil fuels such as coal. Natural releases of mercury occur as a result of mercury being slowly emitted from these rocks, both in the earth and underwater. Physical and chemical properties of mercury are described in Appendix B.

Anthropogenic releases of mercury primarily occur as a result of industrial processes and the combustion of waste and fossil fuels, especially coal. Releases also occur from the use and disposal of a wide variety of consumer products. About 60 percent of mercury deposition in the United States is derived from anthropogenic sources, with some of the highest deposition rates occurring in the Great Lakes Basin (EPA 1999[l])

Mercury is toxic, persistent in the environment, bioaccumulative, and is implicated in the degradation of fish and wildlife populations, as well as phytoplankton and zooplankton communities in the Great Lakes. The organic form of mercury, methylmercury, builds up in the tissue of fish and can be a health threat for those who consume Great Lakes and inland lakes fish (Bredin 1998). Appendix C contains detailed information on potential health effects.

Following is a discussion of the potential and actual releases of mercury into the environment, the potential load to the lake, the current and past loading of mercury to the lake, the impact of mercury on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing mercury.

POTENTIAL RELEASES OF MERCURY TO THE ENVIRONMENT

Mercury has many applications in industry due to its unique properties, such as its fluidity, its uniform volume expansion over the entire liquid temperature range, its high surface tension, and its ability to alloy with other metals. See Appendix B for more information on the physical and chemical properties of mercury. Industries that utilize mercury include electrical, medical, chemical and mining. Mercury is used in a wide range of commercial products, such as batteries, barometers, thermometers, switches, fluorescent lamps, and mercury arc lamps producing ultraviolet light.

Historically, mercury compounds were used extensively as pharmaceuticals. Some organic mercury compounds were also used in fungicidal and bactericidal applications. Currently, more effective and less harmful alternatives have replaced most pharmaceutical uses of mercury. The use of organic phenylmercuric acetate as a fungicide in interior latex paints was canceled in 1990 based on evidence that mercury vapors are released as the paint degrades. Alkyl mercurial compounds were used until the mid-1970s as a treatment to disinfect grain seeds. Most other agricultural applications of mercury compounds in bactericides and fungicides have been canceled due to the toxicity of mercury. The use of mercury as a wood preservative has also ceased due to the substitution of polyurethane. Currently, most organic mercury compounds (such as methylmercury) are produced by microorganisms in the environment, rather than being formed through human activity (HHS 1993b). Research is currently underway to better understand the conditions and process by which mercury is converted to methyl mercury.

Mercury is currently released into the environment by a wide range of sources, including metals production and other industries, combustion sources, and municipal and commercial sources (including mercury-containing product use and disposal). Atmospheric deposition of mercury emitted by manufacturing, combustion, or incineration processes contributes a large portion of the mercury found in water and soils. The following categories summarize potential sources of mercury releases to the environment.

- **Metals industry.** Currently in the United States there are no mines producing mercury as their primary ore. However, mercury releases have been reported from other types of metal processing operations including lead and copper smelting, electroplating facilities, and iron and steel mills. There are 21 lead and copper smelting facilities, 128 electroplating facilities, and 74 iron and steel mills reporting TRI or PCS data in the Lake Michigan basin.

- **Use of mercury as part of a manufacturing process or within a product.** Many products contain mercury, including electrical applications, such as switches and fluorescent lamps; batteries; and various instrument devices, such as thermostats and thermometers. In addition, mercury-containing compounds are involved in several manufacturing processes. Petroleum refineries and chemical manufacturing have various processes that result in mercury emissions or mercury-containing products. The Lake Michigan basin contains several facilities that use mercury as part of a manufacturing process or within a product. There are 7 petroleum refineries and 184 chemical facilities reporting TRI or PCS data in the Lake Michigan basin.

- **Combustion or incineration of materials containing mercury.** Sources of air emissions resulting from combustion include municipal waste incinerators, medical waste incinerators, hazardous waste incinerators, sewage sludge incinerators, fuel combustion, utilities, cement kilns, coke production, and residential wood burning. The Lake Michigan basin contains many of these combustion facilities. There are 393 utilities and 2 cement kilns reporting TRI or PCS data in the Lake Michigan basin.

- **Mercury product use and disposal.** Mercury emissions can result from use and disposal of products currently in use, such as batteries and thermometers. Additional releases of mercury occur as a result of the disposal of industrial, medical and domestic solid waste products that contain mercury. Waste water treatment plants are sources of mercury releases to water and to land through land application of sludge. Many products contained mercury in the past, such as paint and fungicides. Such products may still be in use, storage, or disposal facilities. (EPA. 1997g.)

ACTUAL RELEASES OF MERCURY TO THE ENVIRONMENT

TRI data on releases of mercury within the Lake Michigan watershed is summarized in Table 5-22. All releases were reported by electronics and plating facilities in northern Indiana and southwest Michigan.

Table 5-22. TRI Mercury Releases Reported in the Lake Michigan Basin (Pounds)

Year	*Air Releases*	*Land Releases*	*Underground Releases*	*Water Releases*	*All Releases*
1987 Total	2	0	0	0	2
1989 Total	500	0	0	0	500
1990 Total	15	0	0	0	15
1991 Total	15	0	0	0	15
1992 Total	10	0	0	0	10
1993 Total	15	0	0	0	15
1994 Total	15	0	0	0	15
1995 Total	15	0	0	0	15
1996 Total	15	0	0	0	15
1997 Total	10	330	0	0	340
Grand Total	612	330	0	0	942

- **Point source water discharges.** Mercury is released to the environment through point source water discharges. PCS data on mercury discharges in the Great Lakes Basin is presented in Table 5-23. (Many POTWs have permit limits and report discharges for mercury at detection limits. It is possible that the PCS database numbers presented in Table 5-23 reflect "potential" discharges based on method detection limits, not actual discharges.)

  The majority of the mercury reported in the PCS data was released by sewerage systems that discharged 876.37 kg (1,932.06 lb). There are no reported water releases in the TRI data.

- **Air emissions** RAPIDS data for 1993 and 1996 reports mercury emissions of 6.5 tons (13, 691 pounds) and 11.9 tons (23,870 pounds), respectively. Data on U.S. mercury emissions in 1990 and 1995 is compiled in the Draft Mercury Sources and Regulations, 1999 Update (BNS). This data is presented in Table 5-24**.** The sources that emit the most mercury nationally are likely the most significant emissions sources in the Great Lakes region as well.

Table 5-23. Mercury Discharges in the Great Lakes Basin, July 1991-June 1993

SIC Code/SIC Name	Total Mercury Discharges (kg)	Total Mercury Discharges (lb)
10 Metal Mining	1.76	3.88
26 Paper & Allied Products	0.57	1.26
28 Chemicals and Allied Products	63.37	139.71
33 Primary Metal Industries	0.04	0.09
34 Fabricated Metal Products	0.08	0.18
37 Transportation Equipment	0.07	0.15
39 Miscellaneous Manufacturing Industries	14.97	33.00
49 Electric, Gas and Sanitary Services	876.61	1,932.59
Public Administration	0.01	0.02
Total	957.51	2,110.95

Table 5-24. Estimates of U.S. Mercury Emissions (Tons) (BNS 1999)

Source	1990	1995
Utility Boilers-Coal	51.0	51.6
Municipal Waste Combustors	41.7	29.6
Medical Waste Incinerators	50.2	16.0
Solid Waste Processing and Transport	32	16
Use of Steel Scrap	12	12
Chlorine Production	10.0	7.1
Hazardous Waste Incineration	5.7	7.1
Mobile Sources - Non-Road	6.8	6.8
Mobile Sources - On-Road	5.0	5.0
Portland Cement (Nonhazardous Waste Fired)	4.0	4.0
Industrial Boilers	2.1	2.1
Others	22.0	19.3
Total	242	176

Each year, approximately 10 to 15 pounds of mercury are released to the air by TRI reporting facilities. A significant exception is 1989 when 500 pounds of mercury were released to the air.

- **Releases to land.** There was only one release to land reported in the TRI data, a 330-pound release in 1997.

- **Legacy mercury contamination.** One of the major sources of mercury today is environmental cycling of mercury previously introduced into the environment. Mercury-contaminated sediments may resuspend mercury compounds in the water, allowing for bioaccumulation in the food web. In addition, volatilization of mercury from land and water surfaces into the atmosphere can result in subsequent air deposition and then revolatilization. For this reason, and because of its long retention time in the environment, mercury released to the environment many years ago plays an active role in the contamination of today's environment. The Lake Michigan AOCs are examples of this type of source. Seven of these AOCs were heavily contaminated with mercury in the past and now contribute mercury loads to Lake Michigan. The Fadrowski Drum Disposal NPL site in Wisconsin is also contaminated with mercury. Remediation is complete at the Fradrowski site and monitoring continues. Analytical results indicate mercury is no longer present in surface water or sediment but high levels of mercury are present in one groundwater monitoring well.

ACTUAL LOADINGS OF MERCURY TO LAKE MICHIGAN

Sources may provide loadings to the lake from one of three pathways: air deposition, direct discharges including sediments, and tributary loadings. Several studies estimating the mercury loadings to Lake Michigan from each of these pathways have been conducted. The results of these studies are presented below.

Atmospheric Deposition Pathway

Mason and Sullivan (1997) assessed total and particulate mercury in water column samples from offshore waters of Lake Michigan in 1994 and 1995. Their estimate of atmospheric deposition of mercury in Lake Michigan is presented in Table 5-25. Preliminary estimates of the principal sources and sinks for mercury in Lake Michigan were made. The data indicated that about 80 percent of total mercury input was due to atmospheric sources, 17 percent from riverine input, and less than 1 percent from groundwater. Localized urban sources, such as Chicago, contributed approximately 30 percent to the total regional atmospheric loading to Lake Michigan. Atmospheric volatilization via gas exchange and sedimentary burial were the major pathways for mercury loss from the lake. The preliminary mass balance assessed in this study demonstrates the dominating influence of air-water exchange processes on Lake Michigan mercury concentrations.

Mercury emissions from coal-fired power plants, a major source of mercury in the basin, are predominantly in the vapor phase. Waste incinerators, another important source in the basin, burn trash and release volatile gaseous mercury and mercury in the combined or particulate form (EPA 1997[g]). In addition to entering the lake via air-water exchange and wet/dry deposition, these emissions may be eventually deposited on the surrounding soil to subsequently reach Lake Michigan via erosion and tributary-associated loadings. These loadings are accounted for in the tributary load estimates.

Table 5-25. Estimates of Atmospheric Deposition of Mercury in Lake Michigan

Source	Estimate (kg/yr)	Estimate (lb/yr)
Mason and Sullivan 1997	965	2,127.5
LMMB 1994 and 1995	1,048	2,310.4
Eisenreich and Strachan 1992	1,600	3,527.4

Sediments Pathway

Contaminated sediments are a source of mercury contamination in Lake Michigan because mercury may be released from sediments and resuspended in the water. Mercury loads from contaminated sediments in the Lake Michigan AOCs are described in the following section.

Tributaries and Areas of Concern Pathway

Regardless of source, mercury inputs to Lake Michigan have the potential to accumulate in aquatic biota, including fish. Brazner and DeVita (1998) measured mercury concentrations in young-of-the-year littoral fishes from Green Bay, Lake Michigan. Based on a generally uniform distribution of mercury concentrations measured in fish from throughout the bay (relative to other contaminants such as PCBs), this study suggested that mercury appears to mostly originate from nonpoint sources rather than point sources in the bay. However, the study did also observe unusually high mercury levels in fish from certain sites, and a slight increase in mean mercury tissue concentrations in the upper and lower bay compared with the middle bay fish. The authors suggest that these trends may indicate possible point sources, such as tributaries or contaminated sediments, in these areas. LMMB data indicates that the combined tributary loadings in Lake Michigan total 186 kg (410.1 lb) per year.

Hurley and others (1998b) studied mercury levels in several tributaries to Lake Michigan. Total, dissolved, and particulate-associated mercury were measured in 11 selected tributaries: the Manistique, Lower Menominee, Fox, Sheboygan, Milwaukee, Pere Marquette, Muskegon, Grand, Kalamazoo, and St. Joseph Rivers, as well as the Grand Calumet River/Indiana Harbor Ship Canal. Results indicated that both the form and flux of riverine mercury input to Lake Michigan were strongly dependent on seasonal influences and land use patterns. Mercury loading generally increased during spring melt and summer/fall storm events, and was associated with particulate mercury loading during these times of increased flow.

The LMMB estimated mercury loads from Lake Michigan tributaries based on data from April 1, 1994, to March 31, 1994 (see Table 5-26). According to these data, the Fox River contributes the largest load of mercury to Lake Michigan (76 kg/yr).

Table 5-26. Estimated Mercury Loads From Lake Michigan Tributaries (EPA No date[i])

Tributary	Estimated Load (kg/yr)	Estimated Load (lb/yr)
Fox	76.2	168.0
Kalamazoo	15.7	34.6
Grand Calumet	6.7	14.7
Grand	31.9	70.3
St. Joseph	19.4	42.8
Sheboygan	0.7	1.5
Milwaukee	1.1	2.4
Menominee	8.7	19.2
Pere Marquette	1.9	4.2
Manistique	3.5	7.7
Muskegon	2.8	6.2

The highest mercury concentration (182 ng/L [ppt]) was observed in the industrialized Fox River and was primarily associated with the particulate phase. The Grand Calumet River/Indiana Harbor Ship Canal, Grand River, and Kalamazoo River, all of which are thought to be strongly affected by point sources (such as the steel industry in the Indiana Harbor) and regional atmospheric deposition, also showed high mercury concentrations (up to 45.1 ng/L [ppt]) that were associated with particulate matter. In contrast, the tributaries in northern forested sites (Muskegon, Manistique, and Pere Marquette rivers) showed relatively low mercury concentrations, and mercury was primarily found in the dissolved (that is, filterable) phase.

Results also indicate that despite the higher total mercury concentrations in the Fox River and Indiana Harbor, the St. Joseph and Kalamazoo Rivers appear to be dominant in terms of total mercury flux to the open waters of Lake Michigan. Although the Fox River was observed to discharge, by far, the highest loads of mercury, these loads are primarily deposited in the Green Bay estuary and not the lake proper. In addition, the impact of the high mercury concentrations in the Indiana Harbor Ship Canal is diminished due to its relatively small hydraulic loading rate. The authors conclude that in the open waters of Lake Michigan, the direct effect of riverine inputs of mercury is likely to be diminished due to near shore particle sinks (such as Green Bay) and the short residence time of water-column mercury. For example, the Grand Calumet River/Indiana Harbor Ship Canal AOC contains 5 to 10 million cubic yards, up to 20 feet deep, of contaminated sediments. Contaminants include mercury and other compounds (EPA No date[n]). However, mercury contamination of these near shore estuarine zones may have a greater impact in terms of biotic production, such as fish spawning.

The transport and partitioning of mercury and methyl mercury was also assessed from April 1994 to October 1995. Total mercury concentrations ranged from 1.8 to 182 ng/L (ppt), with the overwhelming majority of mercury existing as particulate-associated forms. (The median percent of mercury in particulate-associated forms was 93.6 percent across all samples collected.) With distance downstream, both water column and sediment concentrations of mercury increased. In addition, particle enrichment with mercury increased downstream (that is, particles at the river mouth were enriched with mercury relative to upstream), and particles were also enriched with mercury relative to that of the surrounding soils. These trends suggest that bottom sediment resuspension, rather than soil erosion, is likely to be the predominant source of mercury from the Fox River. Although the concentrations of total mercury in the Fox River were high, measured methyl mercury concentrations (organic fractions) were relatively low (<0.03-0.43 ng/L [ppt]). In addition, methyl mercury in sediment constituted only 0.7 percent of the total mercury measured. The authors suggest that although mercury in the Fox River is the highest of the Lake Michigan tributaries, data indicate it is in a less bioavailable form (that is, for methylation) than the other tributaries.

IMPACT ON LAKE MICHIGAN

Fish consumption advisories for at-risk subpopulations and the general population (meal size and frequency restrictions) have been issued due to excessive mercury concentrations in Lake Michigan fish. See Appendix C for detailed information on human health effects associated with mercury. In particular, fish tissue concentrations of mercury exceed FDA action levels in Little Bay de Noc and the Muskegon River (EPA 1997). In contrast, despite the presence of severely mercury-contaminated sediments in the Fox River and Lower Green Bay (Hurley and others 1996), widespread fish consumption advisories have not been issued in these areas. This suggests that the particular chemical species of mercury present in the Fox River and Green Bay areas may have limited bioavailability, and thus a limited potential to bioaccumulate in fish to levels that would warrant fish consumption advisories (Hurley and others 1998a).

The mercury contamination of sediments has been verified in many Lake Michigan tributaries and AOCs. Mercury has been identified as a contaminant in water or sediments from several of the Lake Michigan AOCs, including the Lower Menominee River, Lower Green Bay and the Fox River, Milwaukee Estuary, the Grand Calumet River/Indiana Harbor Ship Canal, the Muskegon River, the Manistique River, and White Lake (EPA No date[m]). Fish consumption advisories have been issued at four of the AOCs. Concentrations for total Hg in Lake Michigan averaged 1.60 ± 0.25pM 0.32 ± 0.05 ppt) and particulate averaged 0.60 ± 0.18 pM (0.12 ± 0.04 ppt). (Sullivan and Mason 1998).

SPECIAL MANAGEMENT ISSUES

Programs regulating and controlling the management of mercury are presented in Appendix A. Special management issues for mercury include the following:

Specific actions to address MERCURY are presented in Chapter 6, Table 6-1: HH8-HH10, RPP1, RPP3, RPP12-RPP15, RM1, RM2, RM5-RM8, RM12

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- The Great Lakes Binational Toxics Strategy is an effort to reduce mercury and other persistent toxic substances in the Great Lakes. The Strategy has set reduction goals for the United States and Canada of 50 percent over the next 6 years and 90 percent over the next year for the two countries, respectively. (EPA No date[o])
- Long-range transport of pollutants
- Unregulated air emission sources of mercury such as coal combustion
- Environmental cycling

5.3.3.7 Inorganics

Pollutant of Concern

The inorganics listed as pollutants of concern in the Lake Michigan basin are lead, cadmium, copper, zinc, chromium, arsenic, and cyanide. Two other inorganics are discussed in the LaMP, mercury and selenium. Because mercury is a critical pollutant and selenium is an emerging pollutant, they are not discussed in this section.

The inorganic pollutants of concern are naturally occurring and are ubiquitous in the environment. They are released to environmental media by both natural processes and anthropogenic sources. For physical and chemical properties of these inorganics, see Appendix B.

Sediments and tributaries in several Lake Michigan AOCs are heavily polluted by one or more of these compounds. Additionally, they are associated with degradation of benthic and planktonic communities and are the cause of restrictions on dredging.

Following is a discussion of the potential and actual releases of inorganics into the environment, (the potential load to the lake), the current and past loading to the lake, the impact on achieving the vision for the Lake Michigan ecosystem, and unique issues associated with management of inorganics.

POTENTIAL RELEASES OF INORGANICS TO THE ENVIRONMENT

- **Metals Industry**. Lead emissions are generated primarily as a by-product from the operation of smelters and nonferrous foundries. Cadmium emissions are generated primarily as a by-product from mining and smelting operations. Copper is extensively mined and processed in the United States using both underground mining and open pit mining. Zinc is also mined using both underground mining and open pit mining. However, none of the Lake Michigan states is a major zinc-producing state. Zinc is used in a variety of steel production activities. Chromium has many uses in industry and is used for a variety of processes including making steel and other alloys, and metal finishing, especially chrome plating. Approximately 20 percent of the U.S. iron and steel production is contained in the Chicago, Illinois, and Gary, Indiana, area. Arsenic is used in metal mining and in metallurgy for hardening copper, lead, and alloys. No arsenic producers currently operate in the United States, and all raw materials for production of arsenic-containing products must be imported (EDF No date). Cyanide has many uses in industry and is used for a variety of processes including metal mining processes, metallurgy, and metal cleaning.

- **Use of inorganics as part of a manufacturing process or within a product**. The most significant use of lead metal is for lead-acid storage batteries used in automotive and industrial applications. One of the strongest demands for cadmium is in the production of nickel-cadmium batteries. Alloys containing copper and zinc are used to make pennies. Copper compounds are most commonly used in agriculture to treat plant diseases, like mildew, or for water treatment and as preservatives for wood, leather, and fabrics (ATSDR 1990). Zinc is used most commonly as a protective coating of other metals. Chromium is used in brick lining in industrial furnaces, manufacture of dyes and pigments, leather tanning, and wood preserving. The major use of arsenic in the United States is as a wood preservative. (National Safety Council No date). The predominant users of cyanides are the steel, electroplating, mining, and chemical industries.

- **Product use and disposal**. Lead may be present in significant levels in drinking water due to the presence of lead pipes in older structures or lead solder in copper pipes. Another source of lead is in the chips and dust of lead-based paint. According to EPA, in 1995, approximately 14 million homes had more than 5 square feet of damaged lead-based paint and nearly 7 million homes had excessive dust levels. Leaded gasoline use of many decades has also resulted in widespread lead contamination of soils in areas of high traffic density. Lead-containing waste products include storage batteries, ordnance, solder, pipes, items with lead-based paint, and solid wastes created by ore processing, iron and steel production, and smelting (HHS 1999b).

  Cadmium can be released during fuel combustion, disposal of metal-containing products, and application of phosphate fertilizer or sewage sludge. As a result of cadmium's presence in pigments, it can also be released from burning inks and dyes. Cadmium in soil may be increasing due to the application of municipal sludge or phosphate fertilizers, which may result in accumulation in plants and animals and human exposure. Another potential source of cadmium releases to the soil is land disposal of cadmium-containing wastes, primarily batteries. Coal and oil used in some thermal power plants is responsible for 50 percent of the total cadmium released to the air.

  Copper and copper compounds not recycled are disposed of in landfills or released into wastewater. Methods of copper-containing sludge disposal from wastewater treatment facilities include landfilling, landspreading, incineration, or ocean disposal.

  Waste products containing zinc are commonly used as a source of zinc for electrogalvanizing. Zinc is not regulated by the federal government as a constituent in hazardous waste. Unsalvageable zinc waste may be buried in an approved landfill. (HHS 1994c).

  Waste streams from electroplating as well as leather tanning, textile industries, and dye/pigment manufacturers can often contain chromium in the discharge to surface waters. Chromium III and VI concentrations can increase in soil as a result of disposal of commercial products containing chromium, chromium industrial waste, and coal ash from electric utilities. Most chromium released to the environment by industries is released on land and most of this waste is disposed of in landfills.

  Arsenic is regulated by the federal government as a constituent in hazardous waste. The primary route of disposal of solid wastes containing arsenic is landfilling. Other disposal alternatives for arsenic-containing wastes include incineration and recycling. There is, however, essentially no recycling of arsenic from its principal uses in wood preservatives or agricultural chemicals

  Cyanide is also found in a variety of industries' waste streams. Thiocyanates are present in water primarily because of discharges from coal processing, extraction of gold and silver, and mining industries. Thiocyanates in soil result from direct application of weed killers and disposal of by-products from industrial processes. Additional sources of thiocyanate include damaged or decaying tissues of certain plants such as mustard, kale, and cabbage (HHS 1997a).

ACTUAL RELEASES TO THE ENVIRONMENT

Table 5-28 presents TRI reported air, land, underground, and water releases of inorganics.

- **Point source discharges.** Point source discharges of inorganics to Lake Michigan include industrial steel industries, electric services, mining and smelting operations, municipal effluents, plating and polishing facilities, leather tanning operations, and wood preservation facilities.

- **Air emissions.** Industries with significant air emissions of inorganics include blast furnaces and steel mills, secondary metals facilities, foundries, electrical generating facilities, storage battery facilities, paving mixtures and blocks operations, sewerage systems, refuse systems, plating and polishing facilities, and the motor vehicle parts and accessories industry Table 5-27 indicates the mass of each inorganic that was emitted to the air in the Lake Michigan basin according to the RAPIDs database.

- **Releases to land.** Mine tailings, use of ammunition, sludge application, fertilizer use, coal and bottom fly ash, and smelter slugs and waste, are sources of releases of inorganics to land.

- **Legacy inorganic contamination.** Inorganics are contaminants at 34 Superfund sites in the Lake Michigan basin. Nine of the 10 AOCs are also contaminated with inorganics.

Table 5-27. RAPIDS Data on Air Emissions in the Lake Michigan Basin

Inorganics	Pounds released in 1993	Pounds released in 1996
Lead	266,771	173,011
Cadmium	121,469	119,294
Copper	52,346	162,816
Zinc	Not available	Not available
Chromium	62,480	98,864
Arsenic	22,484	24,603
Cyanide	Not available	Not available

ACTUAL LOADINGS OF INORGANICS TO LAKE MICHIGAN

Following is a description of the inorganic loadings contributed via the air deposition pathway, sediments, and tributaries.

Atmospheric Deposition Pathway

Hillery and others (1998) presents atmospheric loading data collected at Sleeping Bear Dunes, Michigan, the IADN master station for Lake Michigan for lead. Dry deposition of lead is 16,000 ± 13,000 kg/yr (35,274 ± 28,660 lb/yr). Although there is no significant change over time in the lead deposition data presented in Table 5-29, data from 15-20 years before these estimates were made shows that deposition is about a factor of five lower. The authors attribute this to the elimination of leaded gasoline.

Table 5-28. TRI Data on Releases of Inorganics (Pounds) in Lake Michigan Basin

InorganicS	**Air Releases**		**Land Releases**		**Underground Releases**		**Water Releases**		**All Releases**
	Max annual	Total	Max annual	Total	Max annual	Total	Max annual	Total	
Lead	144,650	845,157	2,186,750	7,034,794	0	0	21,831	115,658	7,995,609
Cadmium	4,050	8,460	9,516	11,182	0	0	0	0	19,642
Copper	823,041	2,453,924	245,294	1,196,641	16,720	19,203	13,087	81,394	3,751,162
Zinc	752,074	5,317,697	12,454,162	41,595,605	0	0	99,296	454,240	48,471,949
Chromium	188,003	694,913	2,671,350	17,420,881	72,869	187,677	65,451	187,508	18,490,979
Arsenic	21,178	26,981	6,702	12,702	0	0	5	6	39,682
Cyanide	465,278	2,578,339	25,417	79,723	48,000	50,800	40,744	209,710	2,918,572

Table 5-29. Net Atmospheric Loading of Lead in Lake Michigan (Hillery and others 1998)

Year	**Loading (kg/yr)**	**Loading (lb/yr)**
Pre-1990	130,000	286,601
1991 to 1992	72,000 ± 37,000	158,733
1993 to 1994	150,000	330,693

Dry deposition fluxes of inorganics associated with fine (<2.5 μm) and PM_{10}-coarse (2.5 to 10 μm) particles are presented in Table 5-30.

Sediments Pathway

Scudder and others (1995) sampled Lake Michigan sediments in 1992, 1994, and 1995 to determine the occurrence of a broad suite of trace elements, including lead, cadmium, chromium, copper, arsenic and zinc, in biota and stream bed sediment in selected streams in the Western Lake Michigan Drainages, a study unit of the NAWQA Program of the USGS. Urban land use was found to be the dominant factor influencing sediment concentrations of lead, copper, and cadmium because the highest concentrations were found at urban and integrator sites. Table 5-31 presents the number of observations in the western Lake Michigan drainages that equaled or exceeded Ontario Ministry of Environment and Energy (OMEE) LELs.

Table 5-30. Dry deposition fluxes (mg/km^2-h) to Lake Michigan

Element	Pirrone and Keeler (1995)		Holsen and others. (1993)		Eisenreich and Strachan (1992)	Clark (1992)	
	Fine	**PM$_{10}$-Coarse**	**Fine**	**PM$_{10}$-Coarse**	**Total**	**Fine**	**PM$_{10}$-Coarse**
Lead	2.1	22	1.2	9.3	26	123	502
Cadmium	2.8	27	0.6	4.2	4.1	4.1	14.2
Copper	4	48	6	45			
Zinc	13	75	16	120			
Chromium	1.6	10	1.1	8.4		5.74	25.9
Arsenic	1.5	8			6.5	11.6	37.6

Table 5-30a. Dry deposition fluxes (lb/mi^2-h) to Lake Michigan

Element	Pirrone and Keeler (1995)		Holsen and others. (1993)		Eisenreich and Strachan (1992)	Clark (1992)	
	Fine	**PM$_{10}$-Coarse**	**Fine**	**PM$_{10}$-Coarse**	**Total**	**Fine**	**PM$_{10}$-Coarse**
Lead	1.20 x 10^{-5}	1.26 x 10^{-4}	6.85 x 10^{-6}	5.31 x 10^{-5}	1.48 x 10^{-4}	7.02 x 10^{-4}	2.87 x 10-3
Cadmium	1.60 x 10^{-5}	1.54 x 10^{-4}	3.43 x 10^{-6}	2.40 x 10^{-5}	2.34 x 10^{-5}	2.34 x 10^{-5}	8.11 x 10^{-5}
Copper	2.28 x 10^{-5}	2.74 x 10^{-4}	3.43 x 10^{-5}	2.57 x 10^{-4}			
Zinc	7.42 x 10^{-5}	4.28 x 10^{-4}	9.14 x 10^{-5}	6.85 x 10^{-4}			
Chromium	9.14 x 10^{-6}	5.71 x 10^{-5}	6.28 x 10^{-6}	4.80 x 10^{-5}		3.28 x 10^{-5}	1.48 x 10^{-5}
Arsenic	8.57 x 10^{-6}	4.57 x 10^{-5}			3.71 x 10^{-5}	6.62 x 10^{-5}	2.15 x 10^{-4}

Table 5-31. Number of Observations from the Western Lake Michigan Drainages that Equaled or Exceeded OMEE LEL Concentrations in Sediment (Scudder and others 1995)

Element	Number of Observations	Number of Observations Exceeding OMEE LEL
Arsenic	40	18
Cadmium	41	25
Chromium	42	42
Copper	42	30
Lead	42	12
Zinc	42	17

Tributaries and Areas of Concern Pathway

Table 5-32 presents information on the number of Superfund sites and AOCs in the Lake Michigan basin contaminated with inorganics. There are a total of 34 Superfund sites contaminated with the inorganics listed in the table. Nine of the 10 Lake Michigan AOCs are also contaminated with the inorganics.

All of the inorganics have been identified as contaminants at AOCs; however, arsenic has been specifically identified as a primary cause of the identified use impairments in the Menominee River. Arsenic contamination has been identified in the sediment, groundwater, and surface water of the turning basin The turning basin cannot be dredged or used for large vessel navigation due to arsenic contamination of river sediments. Much of the arsenic contaminated sediment in the turning basin would be classified as a hazardous waste if it were removed without treatment. Furthermore, there is a localized degradation of fish populations and benthos, primarily due to arsenic-contamination of sediments. (EPA 1997c). The Grand Calumet River/Indiana Harbor Ship Canal AOC contain 5 to 10 million cubic yards, up to 20 feet deep, of contaminated sediments. Contaminants include cadmium, chromium, lead, and other pollutants (EPA No date[n]).

Table 5-32. Contaminated Superfund Sites and AOCs in Lake Michigan Basin

	Number of Superfund sites in basin	Kalamazoo River	Muskegon Lake	Manistiqu e River	Menominee River	Green Bay and Lower Fox River	Sheboygan River	Milwaukee Estuary	White Lake	Grand Calumet River/ Indiana Harbor Ship Canal	Waukegan Harbor
Lead	25		S	S	S	S	S	S	S	S,W	S
Cadmium	11		S	S	S	S		S	S	S	S
Copper	5		S	S	S	S	S	S		S	S
Zinc	5		S	S	S	S	S	S	S	S	
Chromium	21		S	S	S	S	S	S	S	S	S
Arsenic	23		S		S		W	S	S	W	S
Cyanide	7				S		W			W	S,W

Sources: CERCLIS List and AOC fact sheets

Notes:
s = sediment contaminant
w = water contaminant

Table 5-33 displays the levels of contamination in Indiana Harbor and Lake Michigan sediment. Sediments in the Indiana Harbor have higher concentrations of contaminants than those in Lake Michigan. Concentrations of cadmium, lead, and zinc in Indiana Harbor are about 200, 80, and 80 times, respectively, higher than those in Lake Michigan sediments (EPA 1994d).

Table 5-33. Contaminant Concentrations in Indiana Harbor and Lake Michigan Sediments (µg/g or ppm)

Inorganic	Indiana Harbor	Lake Michigan
Lead	879.0	11.9
Cadmium	20.0	0.1
Copper	Not available	Not available
Zinc	4,125.0	54.1
Chromium	650.0	4.4
Arsenic	29.5	10.1
Cyanide	Not available	Not available

IMPACT ON LAKE MICHIGAN

Elevated concentrations of inorganics have resulted in dredging restrictions and reductions in benthic habitat quality and populations at AOCs in Lake Michigan. Appendix C contains information on potential human health effects of exposure to these inorganics.

SPECIAL MANAGEMENT ISSUES

Specific actions to address INORGANICS are presented in Chapter 6, Table 6-1: RPP1, RPP5, RPP7, RPP12, RPP17

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An overview of the regulations and programs targeted at inorganics in the Lake Michigan basin may be found in Appendix A.

Pollutant of Concern

5.3.3.8 Hexachlorobenzene

HCB was synthesized and used from the 1940s to the late 1970s as a fungicide on grain seeds such as wheat. HCB has been used as a solvent and as an intermediate and additive in various manufacturing processes, including the production of synthetic rubber, PVC, pyrotechnics and ammunition, dyes, and pentachlorophenol. Although HCB is no longer produced as an end product, it is formed as an inadvertent by-product at trace levels in a variety of combustion and incineration processes, and in the production of several currently used products, including pesticides.

HCB is a white, crystalline solid that is a highly persistent environmental toxin. It is not highly water soluble and will quickly adsorb to the sediments where it may persist for a very long time. HCB degrades slowly in air and remains in the atmosphere through long range transport. There is evidence of continuing long range transport across North America. See Appendix B for a discussion of the physical and chemical properties of HCB.

HCB bioaccumulates in fish, marine animals, birds, lichens, and animals that feed on fish or lichens. HCB can also accumulate in wheat, grasses, vegetables and other plants. Environmental levels appear to have peaked in the 1970s and declined since that time.

Following is a discussion of the potential and actual releases of HCB into the environment, the potential load to Lake Michigan, the current and past loading of HCB to the lake, the impact of HCB on achieving the vision for the Lake Michigan ecosystem, and unique management issues of HCB.

POTENTIAL RELEASES OF HCB TO THE ENVIRONMENT

HCB was manufactured as an end product from the 1940s to the late 1970s. Its use as a pesticide was voluntarily canceled in 1984 and it is no longer intentionally manufactured in the United States Currently, HCB releases to the environment are primarily due to industrial processes and agricultural activities.

- **HCB produced as a by-product of manufacturing processes.** HCB is produced as a by-product from the manufacture of chlorinated solvents (such as tetrachloroethylene, trichloroethylene, and carbon tetrachloride), tires and pesticides. Facilities that inadvertently manufacture HCB reportedly store an estimated total of 0.15 to 1.52 million pounds of HCB on-site per year (HHS 1998).

- **Volatilization during the application of pesticides.** HCB is known to be a minor contaminant in several currently used pesticides including dacthal, picloram, pentachlorophenol (PCP), and chlorothalonil. The use of contaminated pesticides may release HCB through volatilization during the application process. Emissions of HCB from dacthal, chlorothalonil, and PCNB account for 95 percent of the total emitted from pesticide application, due to a combination of HCB content and annual usage (BNS Sources and Regulations). HCB is also a contaminant in the wood preservative, PCP, which is used to protect utility poles, railroad ties, and roadway guardrail posts. This may also cause releases of HCB through volatilization (at a 12 to 36 percent rate) or may leach into the surrounding soil (BNS Sources and Regulations).

- **Combustion and incineration processes**. HCB is emitted to the atmosphere in flue gases and fly ash generated at waste incineration facilities. It may also be produced and released through utility coal combustion and incineration. EPA estimates that utility coal combustion accounts for 30 percent of total national air emissions of HCB annually. Hazardous waste, municipal refuse, and medical waste incinerators, as well as cement kilns co-fired with organic waste, have the potential to emit HCB. The open burning of household wastes in backyard burn barrels may contribute to area sources of HCB, although quantities are not known.

- **Wastewater from manufacturing facilities.** HCB has been detected in treated wastewater from nonferrous metal manufacturers**.** It may also be found in the waste streams of wood-preserving plants**.**

ACTUAL RELEASES OF HCB TO THE ENVIRONMENT

- **Point source water discharges.** In 1997, TRI data indicate total releases of 250 pounds of HCB from the alkalies and chlorine industrial sector and 26 pounds from the agricultural chemicals sector nationally (BNS Sources and Regulations). Industrial and municipal sewage treatment plants may release HCB directly to water. There were no releases of HCB in the Lake Michigan basin reported to the TRI.

- **Air emissions.** According to RAPIDS, 0.122 pound of HCB was released in the Lake Michigan basin in 1996 from agricultural applications in Wisconsin. According to the EPA Final Report of Emission Inventory Data for Clean Air Act Section 112(c)(6) Pollutants (1998), an estimated 2.3 tons of HCB are released to the air annually in the United States EPA estimates national annual emissions of HCB from tire production to be 870 pounds per year based on 1993 data (BNS Sources and Regulations). According to EPA, tire manufacturing may account for 19 percent of total annual air emissions (EPA 1998). The manufacture of chlorinated solvents may release 1,162 pounds per year (BNS Sources and Regulations), accounting for 25 percent of total annual air emissions of HCB (EPA 1998). Pesticides production may release 916 pounds per year (BNS Sources and Regulations), accounting for 20 percent of total annual air emissions of HCB nationally (EPA 1998). The application of pesticides is estimated to release 292 pounds per year nationally to the air, or 6 percent of total annual national air emissions of HCB (EPA 1998). There were no releases of HCB in the Lake Michigan basin reported to the TRI.

- **Releases to land.** The application of HCB-contaminated pesticides and the use of HCB-contaminated utility poles may result in the release of HCB to the land, where it will adsorb to the soil. In addition, landfills and land disposal of sewage sludge may release HCB to the land.

- **Legacy HCB contamination.** Eleven NPL sites within EPA Region 5 and two NPL sites in the Lake Michigan basin identify HCB as a contaminant of concern for all media. Two AOCs in the Lake Michigan basin have identified HCB as a contaminant.

ACTUAL LOADINGS OF HCB TO LAKE MICHIGAN

This section describes the specific sources of HCB and the loading contributed by each source to Lake Michigan.

Atmospheric Deposition Pathway

Many of the facilities that produce HCB as a by-product, such as chlorinated solvent production facilities, do not exist within the Great Lakes Basin. However, because HCB is a highly stable compound, it remains in the atmosphere through long range air transport and is a major source of HCB loading to Lake Michigan. Long range air transport and deposition is a far greater source of HCB loading to the Great Lakes than are direct discharges to the lakes (Delta Institute 1999).

The southern portion of the lake appears to be greatly affected by HCB loadings from pesticides use, most likely due to the heavy agricultural land use throughout that portion of the basin (BNS Sources and Regulations).

Total annual air deposition of HCB into Lake Michigan is estimated to be 15 kg, based on 1993 source and emissions data from the 1,329 identified sources in the United States and Canada (Delta Institute 1999). Should sources outside the United States and Canada be taken into account, air deposition estimates could increase by a factor of 10 (Delta Institute 1999, citing Cohen and others 1995).

Sediments Pathway

HCB has been identified as an organic chemical contaminant in sediments in the Lower Fox River and the Manistee River.

Tributaries and Areas of Concern Pathway

Direct discharges of HCB to water are a minor source of loading to Lake Michigan. Water discharges of HCB are estimated to be 0.8 kg per year for the lake (EPA 1999). HCB has been listed as a toxic pollutant contaminating the Manitowoc River (BNS Sources and Regulations).

IMPACT ON LAKE MICHIGAN

Measurements of gas phase absorption and volatilization indicate that HCB is in near equilibrium, but is slightly loading Lake Michigan (EPA 1999). Bioconcentration and biomagnification of HCB in aquatic species are expected to be important on the basis of a high octanol-water partition coefficient (K_{ow}) value. HCB has also been associated with embryo mortality and loss of eggs due to a lack of adult attentiveness in incubating eggs of herring gulls. See Appendix C for a detailed discussion of potential ecological and human effects of HCB.

SPECIAL MANAGEMENT ISSUES

Programs regulating and controlling the management of HCB are presented in Appendix A. Special management issues for HCB include the following:

Specific actions to address HEXACHLOROBENZENE are presented in Chapter 6, Table 6-1: RPP1, RPP16, IS13, RM5, RM6

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- Long-range air transport of HCB from across North America

5.3.3.9 Toxaphene

Pollutant of Concern

Toxaphene, also known as camphechlor, was one of the most heavily used insecticides in the United States. The primary application of toxaphene was for insect pest control on cotton in the southern United States, although it was also used on other agricultural crops, livestock, and in the northern United States and Canada to kill unwanted fish in lakes. Due to toxaphene's implication in various adverse health and environmental effects, all uses are currently canceled in the United States (most uses of toxaphene were canceled in 1982 [EPA No date (p)]). Despite the fact that toxaphene is no longer used, measurable amounts of toxaphene are still found in the air, water, sediment and soil in and around Lake Michigan. Long range atmospheric transport from the southern United States has been identified as the major pathway of toxaphene input to the Great Lakes Basin. Information on the physical and chemical properties of toxaphene is presented in Appendix B.

Following is a discussion of the potential and actual releases of toxaphene into the environment, the potential load to the lake, the current and past loading of toxaphene to the lake, the impact of toxaphene on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing toxaphene.

POTENTIAL RELEASES OF TOXAPHENE TO THE ENVIRONMENT

- **Historical use, global use, and environmental cycling.** Toxaphene is a man-made insecticide, first produced in 1946. As toxaphene was the primary replacement insecticide for DDT after its cancellation in the early 1970s, toxaphene became one of the most heavily manufactured and prevalent pesticides in the United States. The name "toxaphene" was originally a trade name; however, over the years, the name toxaphene has come to refer to the various camphechlor mixtures.

Toxaphene was used agriculturally in the United States to control insects living on cotton, peas, corn, fruit, vegetables, and small grains such as rice, in addition to other crops. It acts as a nonsystemic stomach and contact insecticide. Toxaphene has a relatively low toxicity to bees, and therefore was used to treat many flowering plants. In addition to its use as a crop insecticide, toxaphene was also used to control livestock parasites such as scabies, lice, flies, ticks, and mange. In the northern United States, including the Great Lakes Region, toxaphene was used for control of unwanted fish stocks in small inland lakes (Swackhamer, Pearson, and Schottler 1998).

- **Hazardous waste sites.** In addition to sources associated with direct releases and historical applications, toxaphene may be a contaminant at hazardous waste sites in the Lake Michigan basin.

- **Stockpiles.** Waste pesticide collections (Clean Sweeps) continue to recover significant quantities of dieldrin, aldrin, and other Level I pesticides indicating that additional stored quantities are likely to exist. Quantities of toxaphene recovered in the Great Lakes drainage are presented in Table 5-34. Improper storage or illegal use of large quantities of toxaphene could be a significant source to Lake Michigan.

Table 5-34. Estimated Clean Sweeps Collections of Toxaphene in the Great Lakes Basin (EPA 1998f)

State	Years of Collection	Toxaphene Collected (kg)	Toxaphene Collected (lb)
Illinois	1994 to 1998	0	0
Indiana	1992 to 1997	5	11
Michigan	1992, 1994, 1995	315	694
Wisconsin	1993 to 1996	271	597
Total		586	1,292

ACTUAL RELEASES OF TOXAPHENE TO THE ENVIRONMENT

- **Point source water discharges, air emissions, and releases to land.** Currently, there are no known producers of toxaphene or toxaphene-like pesticides in the United States or in any other countries. Data indicate that toxaphene was most recently produced in 1992 in Mexico, India and Russia (Ritter and others 1995). TRI records indicate no reportable releases to the environment. Hazardous waste sites containing toxaphene also have the potential to act as sources of toxaphene to the environment through run-off and volatilization. Recently, however, toxaphene was not detected in confined disposal facilities in the Great Lakes Region (HHS 1998d).

- **Legacy toxaphene contamination.** Toxaphene is still widely distributed in the atmosphere as a result of volatilization from soil and water reservoirs that contain toxaphene from past usage. Therefore, long-range atmospheric transport of toxaphene has the potential to be a major source of toxaphene to Lake Michigan. While historical inputs appear to have a non-atmospheric component, the primary nonpoint source of toxaphene to Lake Michigan is currently due to atmospheric cycling between the lake and toxaphene transported long distances in the atmosphere (EPA 1997f and Pearson and others 1997).

ACTUAL LOADINGS OF TOXAPHENE TO LAKE MICHIGAN

Atmospheric Deposition Pathway

Concentrations of toxaphene in the airshed of the Great Lakes are summarized in Hoff and others (1992a). Other unpublished data were presented and discussed at a workshop on toxaphene in the Great Lakes held in Windsor, Ontario in March 1996 (Eisenreich 1996). The data presented indicated that toxaphene concentrations in air were about 30-50 pg/m^3 (1.77 x 10^{-3} - 2.95 x 10^{-3} ppt) in samples collected from 1989 to 1990 and ranged from approximately 2-12 pg/m^3 (1.18 x 10^{-4} - 7.09 x10^{-4} ppt) in samples collected from 1992 to 1996 using a somewhat different quantification protocol. There was little geographic variation over the Great Lakes. McConnell and others (1998) measured the concentrations of toxaphene in air from Green Bay in 1989 and over Lake Michigan in 1990. Average concentrations of toxaphene in Green Bay were 59 pg/m^3 (3.48 x 10^{-3} ppt) , and analysis of back-trajectory data from Green Bay showed that the atmospheric concentrations were likely to originate from air masses originating in the southern United States Over Lake Michigan, however, the average concentration of toxaphene was 65 pg/m^3 (3.48 x 10^{-3} ppt) and back-trajectory analysis indicated that atmospheric sources of toxaphene (at the time of the sampling) were more likely to be from local or regional volatilization.

Sediments Pathway

Analysis of sediment cores in Lake Michigan indicate that, with the exception of northern Lake Michigan, atmospheric inputs via gas absorption are the dominant source of toxaphene to Lake Michigan (Pearson and others 1997). In the Pearson and others (1997) study, historical concentrations and loadings of toxaphene to sediments from Lake Michigan, based on depth and accumulation rate analysis of sediment cores, were determined. The total burden of toxaphene delivered to the sediments of Lake Michigan from onset of deposition (1940 to 1950) to present day was estimated to be 10,200 kg (22,487 lb).

The maximum concentrations occur in the early 1970s to early 1980s, and surficial concentrations (representing current deposition) in most cores throughout the lake were similar at 15 ± 4 ng/g (ppb). This even horizontal accumulation of toxaphene in the sediments is typical of a pollutant entering a lake via air-water exchange, and thus provides strong evidence that the primary source of toxaphene to Lake Michigan is atmospheric input. However, in northern Lake Michigan, surficial concentrations of toxaphene in sediments were 2 to 4 times greater than southern Lake Michigan sediments (33 ± 12 ng/g [ppb]). This localized increase, due to lack of mixing throughout the lake, is typical of a non-atmospheric source (such as a point source). Pearson and others. (1997) estimated that northern Lake Michigan may be receiving up to 30 to 50 percent of its current toxaphene inputs from non-atmospheric sources.

The loss (via degradation) of toxaphene from Lake Michigan sediments was also investigated by Pearson and others (1997) through analysis of the congener homolog composition. Patterns suggested degradation of toxaphene in the sediments, although the rates were determined to be very slow with half-lives ranging from 40 to >100 years (Pearson and others 1997).

Tributaries and Areas of Concern Pathway

The non-atmospheric source of toxaphene to northern Lake Michigan has not been identified, though Green Bay and the Fox River have been suggested as possible sources. Localized origins of toxaphene around upper Lake Michigan (especially Green Bay) may include previous local use of the pesticide (for example, agricultural or to kill fish in small lakes). However, in 1997 a number of tributaries were sampled at locations that were felt most promising based on past pesticide use and current industrial activity.

IMPACT ON LAKE MICHIGAN

Dissolved aqueous concentrations of toxaphene measured in Lake Michigan between 1991 and 1996 ranged from 0.13 (±0.05) - 0.38 (±0.12) ng/L (ppt) (Eisenreich 1996 and Swackhamer and others 1998).

Concentrations of toxaphene in fish and birds have not been monitored long enough to fully evaluate possible trends. One study (Glassmeyer and others 1997) reported a decrease in toxaphene levels in lake trout and smelt from Lake Michigan between 1982 and 1992. However, these observations are based on data collected only from 1982 and 1992. In 1990, toxaphene concentrations of 1.91 ppm in lake trout in Lake Michigan were observed (DeVault and others 1995). Evans and others (1991) traced the biomagnification of toxaphene in the Lake Michigan food web and found that toxaphene was strongly biomagnified, increasing on average by a factor of five from plankton to fish (as cited in Environment Canada 1997c). In a more recent study, toxaphene concentrations were measured in Lake Michigan phytoplankton and zooplankton, and ranged between 5 to 250 mg/g (parts per thousand) dry weight (Swackhamer and others 1998). Bioaccumulation factors (mean normalized log BAFs) calculated in this study were 5.82 and 6.53 for phytoplankton and net zooplankton, respectively. In addition, the homolog distributions for the different phytoplankton showed a greater predominance of the more highly chlorinated compounds with increasing trophic level. These data indicate that toxaphene significantly biomagnifies in the food web in Lake Michigan. Thus, despite the fact that measured fish tissue concentrations of toxaphene currently do not exceed the FDA Human Health Guidelines, continued atmospheric toxaphene loading and the potential for bioaccumulation suggest the future potential for toxaphene-based fish advisories, as well as ecological effects. Information on the human health effects of toxaphene is presented in Appendix C.

SPECIAL MANAGEMENT ISSUES

Specific actions to address TOXAPHENE are presented in Chapter 6, Table 6-1: RPP1, RPP16, IS13 6

Programs regulating and controlling the management of toxaphene are presented in Appendix A. Special management issues for toxaphene include the following:

- Environmental cycling of legacy toxaphene contamination as a major source of toxaphene to Lake Michigan
- Long-range transport of pollutants

5.3.3.10 PAHs

Pollutant of Concern

PAHs are a group of organic chemicals found ubiquitously in nature. PAHs exist in more than 100 forms, most as complex mixtures found in soot or other burning residue. See Physical and Chemical Properties of PAHs in Appendix B. Pure chemical PAHs are used in medicines and to make dyes, plastics, and pesticides. They are also found in asphalt used in road construction, crude oil, coal, coal tar pitch, creosote, and roofing tar (HHS 1995). However, the commercial production of PAHs contributes little to the overall environmental load as the majority of PAH contamination is formed through the incomplete combustion of organic materials and fossil fuels.

PAHs do not readily dissolve in water. They are generally present in the environment as air vapor, or bound to solid particles in the air, soil, or water. Human exposure occurs through breathing contaminated air (cigarette smoke, wood smoke, exhaust, etc.) or by ingesting contaminated foods or liquids. Some PAH forms have been determined to be probable human carcinogens (HHS 1995). PAHs may also cause other detrimental human health effects to the skin, body fluids, and the ability to fight disease (Chicago Cumulative Risk Initiative 1999). Other adverse human health effects from PAHs are detailed in Appendix C.

Following is a discussion of the potential and actual releases of PAHs into the environment, the potential load to the lake, the current and past loading of PAHs to the lake, the impact of PAHs on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing PAHs.

POTENTIAL RELEASES OF PAHs TO THE ENVIRONMENT

The primary source of PAHs in the environment is the incomplete combustion of organic materials and fossil fuels. The commercial production of PAHs contributes little to the overall environmental load. Few forms of PAH are produced commercially in the United States. The Agency for Toxic Substances and Disease Registry (ATSDR) under the U.S. Health and Human Services (HHS), lists five PAHs and their commercial or industrial use:

- **Anthracene** is used as an intermediate in dye production, in the manufacture of synthetic fibers, as a diluent for wood preservatives, in smoke screens, as scintillation counter crystals, in organic semiconductor research, and to synthesize a chemotherapeutic agent.

- **Acenaphthene** is also used as a dye intermediate as well as in the manufacture of pharmaceuticals and plastics, and as an insecticide and fungicide.

- **Fluorene** is used in the formation of polyradicals for resins and in the manufacture of dyestuffs.

- **Phenanthrene** is used in the manufacture of dyestuffs and explosives and in biological research.

- **Fluoranthene** is used as a lining material to protect the interior of steel and ductile-iron drinking water pipes and storage tanks. (HHS 1995)

PAHs enter the environment through various methods, including the following:

- **Combustion Activities**. Forest fires, residential wood burning, auto exhaust, burning of municipal waste, cigarette smoke, industrial smoke or soot, char-broiling foods, and residential oil and gas heating systems (HHS 1995, Simcik and others 1997, Delta Institute 1999) all produce PAHs through incomplete combustion. According to the Great Lakes Regional Air Toxics Emissions Inventory Report, residential wood combustion is the largest source of atmospheric beuzo-a-pyrene (B[a]P) concentration. The residential wood combustion category included wood burned in fireplaces, wood stoves, furnaces, and fireplace inserts. Wood stoves are the primary concern due to their higher frequency of use over fireplaces. Newer wood stoves (post-1990 production) are required to meet EPA standards for emissions. However, wood stoves typically have a long usable life, so the majority of wood stoves still in use are older, non-EPA certified devices (EPA No date[l]).

- **Inadvertent generation during production processes**. Petroleum refining is the second largest contributor to atmospheric B[a]P load identified by the Great Lakes Regional Air Toxics Emissions Inventory Report, contributing an estimated 41.5 percent of the total B[a]P emissions to the Great Lakes region. Specifically, the catalytic cracking units that break down heavy weight hydrocarbons into lighter weight hydrocarbons are responsible for the emission. Two types of fluidized-bed catalytic cracking unit (FCCU) regenerators are used for this process: complete and partial burn combustion regenerators. The partial burn units use an oxygen-poor environment that leads to incomplete combustion, and therefore the formation of PAHs. The majority of units currently in use are complete burn FCCU regenerators (EPA No date[l]). The production of coke in coke oven batteries at blast furnaces and steel mills accounts for just under 10 percent of the B[a]P emissions estimated for the entire Great Lakes Basin. Emission of B[a]P in the coking process is related to charging, pushing, and quenching operations. The B[a]P release is related to flaws in the process, and are dependent on the maintenance of the coke ovens and individual worker practice (EPA No date[l]).

- **Storage and Disposal Facilities**. Discharges from industrial plants, waste water treatment plants, and hazardous waste sites may contribute water or soil contamination if PAHs inadvertently contaminate site runoff or waste streams, or leak from storage containers (HHS 1995). Eighteen sites in EPA Region 5 are currently on the National Priorities List (NPL) with B[a]P listed as one contaminant of concern (EPA No date[l]).

- **Nonpoint Source Runoff from Urban Areas**. PAHs are commonly found in parking lot and street runoff associated with vehicle wear, oil, and gasoline.

- **Natural Sources.** Natural sources of PAHs include forest fires, volcanoes, crude oil and shale oil (HHS 1995).

Table 5-35 identifies the leading sources of PAHs nationally. Several of the leading sources of PAHs listed below are working to reduce PAH emissions under EPA’s MACT (maximum achievable control technology) standard, through the Binationl Toxics Strategy (BNTS) program.

Table 5-35. National PAH Emissions (EPA 1998b)

Source Category	Emissions (tpy)	Percent Contribution
Residential wood/ wood residue combustion	8855	32
Consumer products usage	5732.8	20.8
Aerospace industry (surface coating)	136	5.9
Open burning: forest and wildfires	1417	5.1
Open burning: prescribed burning	1123	4.1
Petroleum refining: all processes	783	2.8
Primary aluminum production	662	2.4
Pulp and paper: Kraft recovery furnaces	649	2.4
Coke ovens: charging, topside and door leaks	538.5	2
Coke ovens: pushing, quenching and battery stacks	517	1.8
Blast furnace and steel mills	500	1.8
MON - continuous processes	440	1.6
Gasoline distribution: Stage II	374	1.4
Gasoline distribution: Stage I	354.5	1.3
Petroleum refining: catalytic cracking units	313	1.1
Open burning: scrap tires	294.4	1.1
Others (>1 percent each)	2789.5	10.1
Total	26976	

ACTUAL RELEASES OF PAHs TO THE ENVIRONMENT

- **Point source water discharges**. A small amount of PAHs are released to the environment through water discharges every year. TRI data in Table 5-36 show PAH releases to the water in the Lake Michigan basin from facilities in northern Indiana for the years 1995 to 1997, with a total of 18 pounds for those 3 years.

- **Air emissions**. According to RAPIDS, 4,263,783 pounds of PAHs were emitted to the air in the Lake Michigan basin in 1996 (Great Lakes Commission 1999c and 1999d). TRI data in Table 5-36 present PAH releases in the Lake Michigan basin from facilities in northern Indiana, with a total of 7,670 pounds over a 3-year period.

- **Releases to land**. The TRI database indicated that 138 pounds of PAHs were released to land in the Lake Michigan basin in the years 1995 to 1997, as shown in Table 5-36 below.

- **Legacy PAH contamination.** Volatilization of PAHs from land and water surfaces into the atmosphere can result in subsequent wet or dry deposition and then re-volatilization. For this reason, and because of their persistence in the environment, PAHs that were released to the environment many years ago play an active role in the contamination of today’s environment.

The TRI database lists PAH releases to the Lake Michigan Basin environment. The data listed below represents emissions from blast furnace and petroleum refining facilities in northern Indiana.

Table 5-36. TRI Annual PAH Releases in the Northern Indiana Lake Michigan Basin

Year	Air Releases (lb)	Land Releases (lb)	Underground Releases (lb)	Water Releases (lb)	All Releases (lb)
1995	1750	0	0	7	1757
1996	3460	110	0	6	3576
1997	2460	28	0	5	2493
Grand Total	7670	138	0	18	7826

ACTUAL LOADINGS OF PAHs TO LAKE MICHIGAN

This section describes the specific sources of PAHs to Lake Michigan and the load of PAHs contributed by these sources.

Atmospheric Deposition Pathway

Current studies indicate that the majority of the contamination of surface waters, such as Lake Michigan, with PAHs occurs through deposition of contaminated airborne particles (Delta Institute 1999; Simcik and others 1997; Franz, Eisenreich, and Holsen 1998). PAHs began accumulating in Lake Michigan sediments between 1880 and 1900, when the Lake Michigan basin experienced a rise in industrialization that caused a subsequent increase in coal combustion (Delta Institute 1999). The maximum PAH accumulation in Lake Michigan occurred between 1950 to 1975. The maximum accumulation rates in the southern basin were 70 ng/cm^2/ yr (0.1 ounce/acre/yr) and 100 to 150 ng/cm^2/ yr (0.14 to 0.21 ounce/acre/yr) in the northern basin. The higher accumulation rate in the northern basin is due to the south to north transport of sediment-bound PAHs. A slight decrease was observed in recent years in some cases due to a switch from coal to oil and natural gas and because of industrial emissions controls (Simcik and others 1996).

The EPA's 1990 Emissions Inventory of Section 112(c)(6) Pollutants lists additional sources of B[a]P. Wildfires, primary aluminum production, prescription burning, burning of scrap tires, coal combustion, on-road vehicles, residential coal combustion, non-road vehicles and equipment are listed as sources of B[a]P, in addition to the sources listed above. Wildfires were estimated to account for approximately half of the national PAH emissions in 1990 (EPA. No date[l]).

Atmospheric Deposition Pathway: Load Estimates

Various estimates of the total load of PAHs to Lake Michigan exist. A conservative estimate of PAH loading to Lake Michigan through particle dry deposition was estimated to be 5,000 kg/yr (11,023 lb/yr), according to a study that measured dry deposition of 17 parent PAHs at multiple sites in the Lake Michigan basin (Franz, Eischreich, and Holsen, 1998). The EPA, in its 1993 Great Lakes Regional Air Toxics Emissions Report, estimated the total B[a]P load to the entire Great Lakes Basin to be 121,563 pounds (EPA No date [l]). A 1996 report cited PAH atmospheric deposition to Lake Michigan of 600-800 mg/m^2/yr (5.35 to 7.14 lb/acre/day) from coke and steel production emissions (Delta Institute 1999).

An analysis of data collected for IADN estimates that the following loadings of B[a]P (Table 5-37) have occurred in Lake Michigan during the years 1988 to 1996 (Delta Institute 1999).

Table 5-37. B[a]P Load to Lake Michigan, 1988 to 1996

Year	Lake Michigan B[a]P Load (kg/yr)	Lake Michigan B[a]P Load (lb/yr)
1988	180	397
1992	84	185
1994	250	551
1996	117	258

EPA broke down the total estimated load to the Great Lakes Basin of B[a]P into sources, as listed below in Table 5-38 (EPA No date[l]).

Table 5-38. B[a]P Load to the Great Lakes Basin

Source Category	Percent B[a]P Load to Great Lakes Basin
Residential Wood Combustion	45.8
Petroleum Refining	41.5
Blast Furnaces and Steel Mills	7.6
Other Sources	5.1

One study of atmospheric levels of PAHs in the Great Lakes regions found that the air deposition of phenanthrene (PAH compound) into Lake Michigan increased significantly from 1991 to 1992 and 1993 to 1994 (Hillery and others 1998).

Atmospheric Deposition Pathway: Chicago as a Source

While the majority of the PAH load to the environment likely originates from a variety of natural and human-induced sources, most studies corroborate the fact that anthropogenic sources contribute a significant load, as is determined by the high levels of atmospheric and sediment PAH concentrations in and around urban centers such as Chicago and Milwaukee (Scudder and others 1995; Delta Institute 1999; Keeler 1994; Simcik and others 1997; and Franz, Eisenreich, and Holsen 1998).

PAHs in Lake Michigan sediments originate from several sources, including vehicular emissions; wood, oil, and natural gas burning for home heating; coal-fired power plants; and coke and steel production. A study by Simcik and others (1996) that focused on an urban area concluded that the dominant source of PAHs to the entire lake from around 1900 to the present is coke and steel production in the urban complex of Chicago, Illinois, and Gary, Indiana. This conclusion differs from a study conducted by Karls and Christensen in 1998, which found a regional historical pattern for central Lake Michigan with a significant contribution from wood-burning and an increasing dominance of oil-burning sources (as opposed to coal-burning by coke and steel production), which is consistent with U.S. fuel consumption data. Karls and Christensen also found that PAH loadings at Green Bay, the Fox River, and the Kinnickinnic River were strongly influenced by local industrial activities, primarily coke production at the Milwaukee Solvay Coke Company that operated from 1900 to the 1970s (Simick and others 1996).

These differing findings support the notion that urban sources are different and often much larger than regional sources. For example, Simcik and others (1997) reported the results of two intense sampling events in the mid-1990s that found ambient PAH air concentrations over Chicago averaged 27 to 430 ng/m^3 (2.62 to 41.7 ppt) while gas phase PAH concentrations over the lake approximately 10 to 20 km (6.2 to 12.4 miles) offshore ranged from 0.8 to 70 ng/m^3 (0.078 to 6.79 ppt). Overall, Keeler (1994) reported that PAH concentrations are generally 10 times higher at urban air monitoring sites as compared to rural monitoring stations.

Sediments Pathway

Anthropogenic input of PAHs to aquatic sediments exceeds natural sources. Airborne particles, contaminated with PAHs from anthropogenic activities, are often deposited in surface waters and result in contaminated aquatic sediments (Christensen 1997). PAHs have been identified as a contaminant in sediments in several Lake Michigan AOCs. In the Menominee River AOC, high concentrations of PAHs have been detected in river sediments adjacent to the Marinette wastewater treatment plant. Also, in the Muskegon Lake AOC, a sediment characterization study in the vicinity of the Division Street storm sewer outfall and Hartshorn Marina indicated elevated levels of PAHs.

Tributaries and Areas of Concern Pathway

PAHs are considered a key contaminant in 5 of the 10 AOCs in the Lake Michigan basin. The Lake Michigan AOCs are examples of legacy PAH contamination. Seven of the AOCs have PAHs listed as one of the contaminants of concern: The Muskegon Lake, Lower Menominee River, Lower Green Bay and Fox River, Sheboygan River, Milwaukee Estuary, Waukegan Estuary, and the Grand Calumet River/Indiana Harbor Ship Canal (Lake Michigan Forum No date). The Grand Calumet River/Indiana Harbor Ship Canal AOC contains 5 to 10 million cubic yards, up to 20 feet deep, of contaminated sediments. The contaminants in the sediments include PAHs (EPA No date[n]).

IMPACT ON LAKE MICHIGAN

Elevated concentrations of PAHs have resulted in dredging restrictions at several AOCs in Lake Michigan. Appendix C contains information on potential human health effects of exposure to PAHs.

SPECIAL MANAGEMENT ISSUES

An overview of the regulations and programs targeted at PAHs in the Lake Michigan basin may be found in Appendix A.

Specific actions to address PAHs are presented in Chapter 6, Table 6-1: SU1, SU6, RM5, RM6, RM8, RM11, RPP5, RPP9

6

5.3.3.11 Atrazine

Emerging Pollutant

Atrazine is one of the chloro-triazines, which also include simazine and cyanazine. See Appendix B for information on the physical and chemical properties of atrazine. Atrazine is a widely used herbicide for control of broadleaf and grassy weeds in corn, sorghum, rangeland, sugarcane, macadamia orchards, pineapple, turf grass sod, forestry, grasslands, grass crops, and roses. Trade names for atrazine include Aatrex, Alazine, Crisazina, Malermais, Primatol, and Zeapos. Atrazine has been widely used in the agricultural regions of the Great Lakes basin since 1959 when it was registered for commercial use in the United States Atrazine was estimated to be the most heavily used herbicide in the United States in

1987 to 1989, with its most extensive use for corn and soybeans in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, Ohio, Texas, and Wisconsin.

Following is a discussion of the potential and actual releases of atrazine into the environment, the potential load to the lake, the current and past loading of atrazine to the lake, the impact of atrazine on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing atrazine.

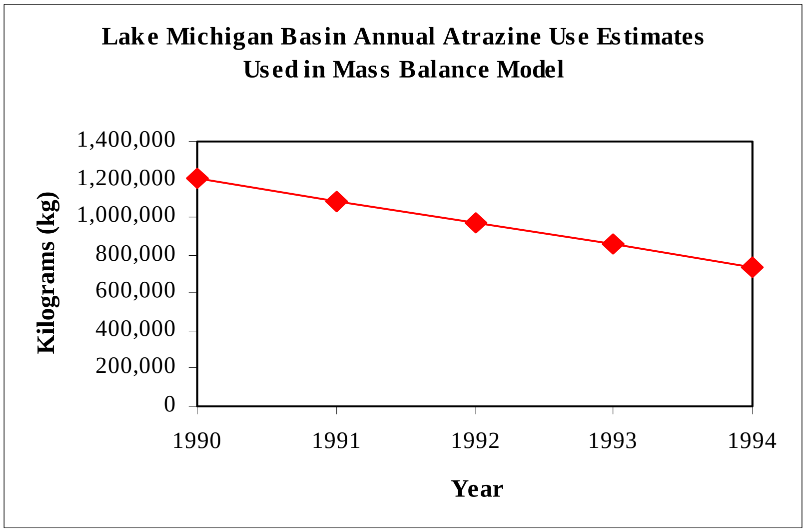
POTENTIAL RELEASES OF ATRAZINE TO THE ENVIRONMENT

- **Historic uses.** Atrazine is a herbicide used primarily to control broadleaf and grasses on corn crops and is one of the primary herbicides used in the Great Lakes. It is usually applied in the spring before or after emergence of the crop. Atrazine use is concentrated in the southern half of the Lake Michigan drainage basin. It also was used until 1993 for control of vegetation in fallow and in noncrop land. Effective in 1993, use for noncrop vegetation control was eliminated, and use was restricted by a requirement for a buffer zone between application sites and surface water. Atrazine is also used, to a much lesser extent, as a herbicide in industrial and commercial applications (for example, conifer reforestation) and for home and garden use. It is available in dry, liquid, granular, and powder formulations.

- **Production and distribution.** Atrazine may be released into the environment via effluents at manufacturing sites and from herbicide application on agricultural lands. There are no atrazine production facilities in the Lake Michigan basin. Atrazine's chemical properties make it susceptible to leaching and runoff, especially during heavy rains (Ribaudo and Bouzaher 1994).

Currently, there are four producers of technical grade atrazine in the United States and 36 registrants of atrazine-containing products available. Atrazine use has declined in recent years most likely because of label changes and increased environmental concerns; annual sales still range between 80 and 90 million pounds (Ribaudo and Bouzaher 1994). Estimated annual atrazine use during 1994 in the Lake Michigan basin is 740,000 kg (1,631,419 lb) (Schottler and Eisenreich 1997). Figure 5-9 shows the decrease in atrazine use from 1990 to 1994. Atrazine use estimates were obtained from "Mass Balance Model to Quantify Atrazine Sources, Transformation Rates, and Trends in the Great Lakes" (Schotter and Eisenreich 1997).

Figure 5-9. Lake Michigan Basin Annual Atrazine Use Estimates Used in Mass Balance Model



ACTUAL RELEASES OF ATRAZINE TO THE ENVIRONMENT

- **Point source water discharges, air emissions, releases to land**. According to RAPIDS, 1,420,276 pounds of atrazine were emitted to the air in the Lake Michigan basin in 1996. There are no TRI reported releases of atrazine.

- **Intended use.** In the 1950s through the 1970s, atrazine was used for only grass and broadleaf control. About 2 to 4 pounds of atrazine were used per acre. In the 1970s, atrazine was able to be applied in tank mixes that allowed for 1.5 to 2.5 pounds of atrazine per acre. For quackgrass control in Wisconsin and Michigan, 4 to 6 pounds were applied per acre. When a popular herbicide Roundup7 was introduced, the application rates for quackgrass control were able to be reduced to 1.5 to 2.5 pounds per acre. In the 1980s and 1990s, prepacks were used and resulted in a current average use rate of 1.1 pounds per acre (EPA 1998a). In 1995, atrazine accounted for 13.8 percent of the total pesticide use in the Lake Michigan Basin. 1.8 million pounds of atrazine were applied to agricultural fields in 1995 (Brody, Furio, and Macarus 1998).

ACTUAL LOADINGS OF ATRAZINE TO LAKE MICHIGAN

The major loading processes of atrazine in Lake Michigan include tributary, wet and dry deposition, and air-water exchange. Through a grant from the Great Lake National Program Office, Shawn Schottler and Steven Eisenreich developed a mass balance model to quantify atrazine sources, transformation rates, and trends in the Great Lakes. Sedimentation, air-water exchange, and dry deposition were estimated from chemical and physical properties of atrazine, lake hydrology and climatology, and published reports. Tributary and precipitation loadings were taken from existing data or estimated from physical properties in combination with herbicide use trends and watershed hydrology. Table 5-39 shows average values and standard deviation of measured concentrations in ng/L of atrazine in Lake Michigan from a Schottler and Eisenreich study (1997) and the LMMB Project (EPA No date[i]).

Table 5-39. Measured Concentrations (ng/L or ppt) of Atrazine in Lake Michigan

Year	Schottler and Eisenreich Study Concentrations	Standard Deviation of Measured Concentrations	LMMB Project Concentrations[a]
1991	35	2.0	34 (16)
1992	37	1.8	Not available
1993	37	Not available	37 (24)
1994	37	2.2	38 (38)
1995	39	Not available	40 (47)

Note: [a] Concentrations in parentheses include atrazine metabolites DEA and DIA.

The LMMB Project and Schottler and Eisenreich's mass balance model also calculated annual inputs and losses in kg/year of atrazine to Lake Michigan. Table 5-40 shows the average annual inputs and losses of atrazine to Lake Michigan as calculated in both studies. The Schottler and Eisenreich model found that the inputs are relatively constant for Lake Michigan so the inputs and thus outputs from 1991 to 1994 data were averaged. The data for the LMMB Project is presented for 1994 to 1995.

In 1990 and 1991, research for the EPA Great Lakes Program was conducted to quantify the concentrations, sources, and fate of atrazine and its transformation products, alachlor and metolachlor in

Lakes Michigan, Huron, Erie, and Ontario. Water column profiles of herbicide concentrations representing 4 to 10 depths per site were constructed for 10 sites in Lake Michigan. Atrazine and DEA were detected in 100 percent of the samples analyzed from Lake Michigan. No consistent vertical trends were able to be determined from the concentration profiles. In addition, the lack of vertical difference in atrazine concentration may show that the major inputs of atrazine occur before lake stratification or atrazine inputs are uniform to stratified waters. The data also showed little or no lateral variation in atrazine concentration. The study concluded that because lateral and vertical concentrations showed little to no variation, the measured concentrations probably reflected lake-wide averages. The vertically and laterally well mixed atrazine also suggests that the water column residence time has half-lives on the order of months to years (Schottler and Eisenreich 1997).

Table 5-40. Average Annual Inputs and Losses in kg/yr (lb/yr) of Atrazine for Lake Michigan (EPA No date[i])

Inputs and Losses	Schottler and Eisenreich Mass Balance Model Load	Percent of Total Load	LMMB Project Load[a]
Tributary	9,040 (19,930)	76	1,600 (3,527)
Wet Deposition	2,600 (5,732)	22	1,043 (2,299)
Dry Deposition	160 (353)	1	210 (463)
Air-water exchange	30 (66)	<1	*Need to obtain*
Net gas input	Not available	Not available	445 (981)
Net gas output	Not available	Not available	40 (88)
Outflow	2,900 (6,393)	24	*Need to obtain*
Transformation	8,890 (19,599)	76	*Need to obtain*
Sediment	25 (55)	<1	*Need to obtain*

a Load calculation includes transnonachlor

Average concentrations were also compared on a site-by-site basis. The results showed that 1992 concentrations were statistically greater than 1991 concentrations, which may suggest that atrazine is accumulating in the water column. Because the monitoring period was short, a longer period of data gathering is needed to confirm this hypothesis (Schottler and Eisenreich 1997).

Atmospheric Deposition Pathway

The Lake Michigan Urban Air Toxics Study conducted during the summer of 1991 in the lower Lake Michigan area consisted of integrated 12-hour atmospheric samples collected daily from July 8 through August 9 at three ground sites: Kankakee, Illinois; the Illinois Institute of Technology (IIT) in Chicago; and South Haven, Michigan. Micrometeorological parameters and pollutant concentrations were also measured at offshore locations near Chicago. Average concentrations for atrazine were 2 to 3 times higher at the background Kankakee site than the IIT site. These results are likely due to the higher pesticide usage in this rural agricultural area. The study also found significant concentrations for many pesticides at over-water sites in both the eastern portion of the lake and offshore of Chicago (Keeler 1994).

Of the 38,146 samples collected during the LMMB Project, 3,239 samples had detections of atrazine. Analytical data for atrazine were collected from a network of seven shoreline sites and one rural background site in the LMMB Project between April 1994 and October 1995 (Sweet, C.W. and K.S. Harlin 1997). Gas phase concentrations of atrazine were found only at the Illinois Water Survey's Bondville Environmental and Atmospheric Research Station near Champaign, Illinois. Atrazine was found in precipitation samples at all of the Lake Michigan sites. Concentrations of particulate atrazine were found in spring and summer samples of airborne particles at all sites, but the highest particulate concentration was found at Bondville.

A defined seasonal variation in monthly atrazine concentrations in rain were apparent at three sites from northern to southern Lake Michigan in the LMMB Project. Highest concentrations were seen in the spring (April to June), coinciding with application of atrazine to corn crops. In July, concentrations declined dramatically, and levels of atrazine were commonly not detected in rain samples between late fall and the following spring. High levels of atrazine in rain at all three sites from northern to southern Lake Michigan in April 1994, despite low levels of atrazine applied to crops, suggest that long-range transport from areas farther south contributed to the wet deposition of atrazine to Lake Michigan.

Sediments Pathway

The chemical properties of atrazine make it susceptible to leaching and runoff, especially during heavy rains. It has a large potential to leach or to move in surface solution, and a medium potential to adsorb to sediment particles (Ribaudo and Bouzaher 1994). Tributary inputs are the major source of atrazine to the lake. Minimal research has been conducted on atrazine in Lake Michigan sediments but it appears to have little effect on atrazine loading to Lake Michigan.

Tributaries and Areas of Concern Pathway

According to Schottler and Eisenreich's study and mass balance model, tributaries account for more than 75 percent of the total load of atrazine to Lake Michigan. Tributary loading was calculated based on the amount of atrazine used in the basin and the percentage of applied atrazine that is typically removed by runoff.

Between 1983 and 1985, 4,155 wells were sampled in the western Lake Michigan drainage basin as a part of the USGS NAWQA program. Atrazine and its degradation products exceeded the Wisconsin preventive action limit (PAL) of 0.3 mg/L (ppm) in about 10 percent of all wells sampled. Atrazine was detected in all 143 surface water samples collected including some at very low concentrations (0.005 mg/L [ppm]) from forested areas most likely due to wet deposition. Drinking water standards were exceeded in 6 percent of surface water samples for atrazine, and 1 percent of samples for simazine and alachlor (Peters 1998).

The LMMB Project estimated atrazine loads from Lake Michigan tributaries based on 1995 data (see Table 5-41) indicate that the St. Joseph River contributes the largest load of atrazine to Lake Michigan (605 kg/yr).

Table 5-41. Estimated Atrazine Loads From Lake Michigan Tributaries (EPA No date[j])

Tributary	Atrazine Estimated Load (kg/yr)	Atrazine Estimated Load (lb/yr)
Fox	255.3	562
Kalamazoo	83.5	184
Grand Calumet	25.4	56
Grand	362.3	797.1
St. Joseph	605	14.3
Sheboygan	3.2	7.04
Milwaukee	9.6	21.1
Menominee	11.5	25.3
Pere Marquette	19	41.8
Manistique	3.8	8.4
Muskegon	36.5	80.3

IMPACT ON LAKE MICHIGAN

Most of the atrazine use is concentrated in the southern portion of the basin, as the northern portion of the basin is highly forested. The intensive use of atrazine in Lake Michigan for about 25 years and its long half-life in these waters may make Lake Michigan act as end points in the environmental transport of atrazine. Tributary loading is the most important input to Lake Michigan. Information on the human health and ecological effects of atrazine is presented in Appendix C.

According to the Tierney, Nelson, Christensen, and Kloibery Watson model, available monitored atrazine concentrations in Lake Michigan are very similar to the most-likely loading rate and indicate a half-life of 2 years (Tierney, Nelson, Christensen, and Watson 1999). According to this study, historical and current atrazine concentrations are below the U.S. drinking water lifetime MCL of 3.0 μg/l (ppb). However, the Schottler and Eisenreich model predicts a half-life for atrazine exceeding 5 years in Lake Michigan. This long-half life has allowed atrazine to accumulate in Lake Michigan over the last decades. Schottler and Eisenreich's model shows that if atrazine use remains at current amounts and that the atrazine concentration remains at current amounts until the year 2010, the atrazine inventory will show minimal change.

SPECIAL MANAGEMENT ISSUES

Programs regulating and controlling the management of atrazine are presented in Appendix A. Special management issues for atrazine include the following:

Specific actions to address ATRAZINE are presented in Chapter 6, Table 6-1: RM11, IS1, IS9, IS13
6

- Internal transformation and outflow may produce a water column residence time of greater than 5 years in Lake Michigan.

- Although quantity of atrazine applied to crops has decreased, atrazine is still a widely used herbicide in the southern portion of the Lake Michigan basin.

- Atrazine is considered a key component to successful conservation tillage by the agricultural community.

5.3.3.12 Selenium

Emerging Pollutant

Selenium is a naturally occurring element widely distributed in the earth's crust and commonly found in sedimentary rock formations. Selenium is released to the environmental media by both natural processes and anthropogenic sources.

Naturally, selenium is not often found in its pure form but is usually combined with other substances. Selenium in rocks is combined with sulfide minerals or with silver, copper, lead and nickel minerals. Selenium and oxygen combine to form several compounds such as sodium selenite and sodium selenate. See Physical and Chemical Properties of selenium in Appendix B. Although it is an essential food element needed by humans in small amounts, too much selenium can be harmful to health.

Following is a discussion of the potential and actual releases of selenium into the environment, (the potential load to the lake), the current and past loading of selenium to the lake, the impact of selenium on achieving the vision for the Lake Michigan ecosystem, and unique issues with managing selenium.

POTENTIAL RELEASES OF SELENIUM TO THE ENVIRONMENT

Selenium enters the air, water, and soil as a result of both natural processes and human activities. Most selenium enters the environment as the result of human activities.

In the Lake Michigan basin, selenium compounds are released to the air during the combustion of coal and petroleum fuels, and during the smelting and refining of other metals. Other selenium emissions are released to the environment from glass manufacturing, electronics and electrical manufacturing, milling operations, duplicating equipment, pigments, fungicides, gaseous insulators, and solid waste (EPA No date[k]).

- **Metals industry**. Selenium has many uses in industry and is used for a variety of processes including making metal alloys. There are 271 metals industry-related facilities in the basin that may serve as sources of selenium.

- **Use of selenium as part of a manufacturing process or within a product.** The greatest use of selenium compounds is in electronic and photocopier components, but they are also widely used in glass, rubber, textiles, petroleum, medical therapeutic agents, and photographic emulsions.

- **Selenium product use and disposal.** Selenium is regulated by the federal government as a nonradioactive hazardous element. Disposal of selenium consists of treating an acidified solution of selenium with sodium sulfite to form the reducing agent, sulfur dioxide. The selenium solution is then heated to produce elemental selenium, which is less mobile in the environment and less bioavailable, and the solution is filtered and washed (HHS 1996b).

ACTUAL RELEASES OF SELENIUM TO THE ENVIRONMENT

From 1987 to 1993, according to the TRI database, selenium releases to land and water in the United States totaled more than 1 million pounds. These releases were primarily from copper smelting industries. The largest direct releases of selenium to water occurred in Indiana (about 5,300 pounds) (EPA No date[k]).

- **Point source discharges.** Point source discharges of selenium to Lake Michigan include industrial (primarily coal and petroleum manufacturers) and municipal sites (releases from disposal or run-off). According to the TRI database, there were no point source releases of selenium to the Lake Michigan Basin water from 1989 to 1997.

- **Air emissions.** The TRI database indicated that 171 pounds of selenium were emitted to the air in the Lake Michigan Basin. The largest selenium emissions occurred in 1990 from biological production facilities (according to the TRI SIC code). Selenium is not a listed chemical in the 1993 and 1996 RAPIDS database.

- **Releases to land.** The TRI database indicated that 580 pounds of selenium was released to land in 1997 in the Lake Michigan basin. Blast furnaces and steel mills were the primary sources of the selenium release.

- **Legacy selenium discharges.** Selenium is not a primary contaminant at any Superfund sites in the four Lake Michigan states or at any Lake Michigan AOC.

TRI data on releases of selenium within the Lake Michigan watershed is summarized in Table 5-42. All releases were reported by electronics and plating facilities in northern Indiana and southern Michigan.

Table 5-42. TRI Data on Releases of Selenium in Lake Michigan Basin

Year	Air Releases (lb)	Land Releases (lb)	Underground Releases (lb)	Water Releases (lb)	All Releases (lb)
1989	14	0	0	0	14
1990	79	0	0	0	79
1991	26	0	0	0	26
1992	13	0	0	0	13
1993	10	0	0	0	10
1994	11	0	0	0	11
1995	8	0	0	0	8
1996	10	0	0	0	10
1997	0	580	0	0	580
Grand Total	171	580	0	0	751

ACTUAL LOADINGS OF SELENIUM TO LAKE MICHIGAN

This section describes the specific sources and pathways of selenium to Lake Michigan and the load of selenium contributed via these pathways.

Atmospheric Deposition Pathway

The Lake Michigan Urban Air Toxics Study (1994) found a load of 0.93 ton of selenium from dry deposition due to sources from Chicago and Gary, Indiana. The dry deposition loads from Chicago and Gary to Lake Michigan are estimated to be 2 to 10 times greater than the loads from other regional sources of Lake Michigan (Keeler 1994).

Sediments Pathway

Contaminated sediments are a source of selenium contamination in Lake Michigan because selenium may be released from sediments and resuspended in the water. The average concentration of selenium in Lake Michigan sediment is 1.2 μg/g (ppm)(Chicago Cumulative Risk Initiative 1999).

Scudder and others (1995) sampled in 1992, 1994, and 1995 to determine the occurrence of a broad suite of trace elements, including selenium, in biota and stream bed sediment in selected streams in the Western Lake Michigan Drainages, a study unit of the NAWQA Program of the USGS. Sediment was sampled at 31 sites for trace elements and biota were collected at a subset of sites. They determined that forested land use was related to high concentrations of selenium in sediment; however, surficial deposits type was an additional factor for selenium. Selenium concentrations in caddishfly larvae were high in areas of shale or clayey deposits and areas with sulfide-bearing rocks. Sediment high in organic carbon contained high concentrations of selenium. They also determined that selenium concentrations in sediment were significantly higher at sandy sand and gravel sites. The highest sediment selenium concentration observed during this study was at one agricultural indicator site, Duck Creek in northeast Wisconsin, where rock bass collected in 1995 contained 17.5μg/g (ppm) selenium (Scudder and others 1995). In addition, Peters and others assessed the water quality of the Western Lake Michigan Drainages in 1995 and found slightly elevated selenium concentrations in fine sediments (Peters and others 1998).

Tributaries and AOC Pathway

Industrial discharge of selenium is prevalent in the Lake Michigan Basin.

IMPACT ON LAKE MICHIGAN

Selenium inputs to lake Michigan have the potential to accumulate in aquatic biota. In 1993, Custer and others collected 20 great blue heron eggs from a colony at the Indiana Dunes National Lakeshore. The eggs were artificially incubated until pipping and were then analyzed for organochlorines, mercury, and selenium. Selenium concentrations in eggs were above background levels, but below a concentration threshold associated with reproductive impairment (Custer and others 1998).

See Appendix C for a detailed discussion of potential ecological and human effects of selenium.

SPECIAL MANAGEMENT ISSUES

Specific actions to address SELENIUM are presented in Chapter 6, Table 6-1: RM11 **6**

Programs regulating and controlling the management of selenium are presented in Appendix A.

5.3.3.13 PCB Substitute Compounds

Emerging Pollutant

Following the 1979 U.S. restrictions on PCB use, other compounds began being used in dielectric fluids, in hydraulic system lubricants, and in solvents and carriers in carbonless copy paper manufacturing. Little was known about the potential impact of these substitutes on the basin; therefore, it was designated an emerging pollutant needing further evaluation. Compounds used in place of PCBs include the following:

- Mineral and silicone oils
- Bis(2-ethylhexyl)phthalate (DEHP)
- Isopropylbiphenyls
- Diphenylmethanes
- Butylbiphenyls
- Dichlorobenzyldichlorotoluene
- Diisopropylnaphthalene
- Phenylxylyl ethane

Information on most of these compounds is limited at this time. More extensive information is available for DEHP.

DEHP

DEHP is a semivolatile organic compound (SVOC) that belongs to a group of compounds called phthalates and phthalic acid esters (EPA 1999b). Appendix B contains detailed chemical and physical information for DEHP, and Appendix C contains human health effects information for DEHP. Although DEHP is used in place of PCB in dielectric fluids, it is most commonly used as a plasticizer for polyvinyl chloride (PVC) and other polymers such as rubber, cellulose, and styrene. DEHP is also used for the following purposes:

- In insect repellants, cosmetics, rubbing alcohol, liquid soap, detergents, decorative inks, lacquers, munitions, industrial and lubricating oils, defoaming agents used in paper and paperboard manufacturing, vacuum pump fluids, photographic film, wire and cable, and adhesives

- As a pesticide carrier

Presented below are discussions on the potential sources and pathways for PCB substitutes to enter the environment, actual known releases to the environment, known loading of these compounds to the lake, their impacts on the Lake Michigan ecosystem, and management issues that are unique for these compounds.

Potential Releases of PCB Substitutes to the Environment

DEHP

Primary sources of DEHP to the environment include releases from manufacturing facilities that make or use DEHP, releases from DEHP-containing products during use, leachate from landfills where DEHP-containing materials are disposed of, and incineration of materials containing DEHP.

- **Manufacturing losses**. DEHP is released to the environment during its production, transport, and use in manufacturing. Releases during DEHP production are primarily through waste water streams. Releases during DEHP transport are primarily through volatilization to air. Releases during the manufacture of DEHP-containing products are primarily through volatilization to air and in waste water streams (HHS 1987).

- **Product losses**. DEHP is released from manufactured products, such as rubber and PVC components, during their usable lifetime. Releases from these products are through volatilization to air and leaching to wastewater and storm water (HHS 1987).

- **Landfill leachate**. The most common disposal method for DEHP-containing products and wastes is landfilling (ATSDR 1987). DEHP may be released from landfills in leachate and through volatilization.

- **Incineration emissions**. Incineration is also used to dispose of DEHP-containing products and wastes. DEHP is released to air in the emissions from these incineration facilities (HHS 1987).

DEHP released to terrestrial systems will strongly adsorb to both the mineral and organic fractions of soil. It is degraded in soil under aerobic conditions but only very slowly in anaerobic environments (HHS 1987). DEHP adsorbed to soil can be transported to water bodies through surface runoff.

DEHP released to aquatic systems will either (1) adsorb to sediment or suspended matter, (2) be taken up by biota, or (3) biodegrade in approximately 2 to 3 weeks. DEHP does not readily evaporate or undergo hydrolysis in aquatic systems (HHS 1987, EPA 1999i). Because hydrolysis and biodegradation of DEHP is low, DEHP adsorbed to sediment provides a steady source of DEHP to overlying surface water and to downstream locations (HHS 1987).

DEHP released to the ambient air has a strong tendency to adhere to atmospheric particles that can be carried long distances until removed by rainfall (HHS 1987, EPA 1999i). DEHP removed from the ambient air by rainfall can be transported to water bodies by wet deposition or surface runoff.

DEHP is highly lipid soluble and, therefore, is readily absorbed by biota. It is degraded by microorganisms and metabolized by invertebrates, fish, and other mammals, thereby reducing its biomagnification potential (HHS1987). Thus, rapid bioconcentration factors are often seen in aquatic organisms, but biomagnification is less than for other compounds that resist degradation and metabolism.

Other PCB Substitutes

The other identified PCB substitutes are used in hydraulic systems, in the manufacture of carbonless copy paper, and in dielectric fluids. Releases of these compounds could occur from spills of the raw compound, volatilization, discharge in waste water effluent, and leaching from waste material containing the compounds.

Addison, Paterson, and Mackay (1983) modeled the predicted environmental distribution of several PCB substitute compounds in comparison to the PCB 2,4,5,4',5'-pentachlorobiphenyl. Their model predictions are presented below.

- More than 70 percent of diisopropylnaphthalenes and butylbiphenyls will be distributed to air compared to 5.7 percent of the PCB.

- More than 80 percent of phenylxylylethanes will be distributed to soil and sediment compared to more than 90 percent of the PCB.

- More than 70 percent of isopropylbiphenyls will be distributed to soil and sediment compared to more than 90 percent of the PCB.

ACTUAL RELEASES OF PCB SUBSTITUTES TO THE ENVIRONMENT

The available information on known releases of the identified PCB substitutes are limited. Information for DEHP is the most readily available and is presented below along with the results of one research study of several other PCB substitutes.

DEHP

The Agency for Toxic Substances and Disease Registry (HHS 1987) reported the following distribution of releases from the 1986 U.S. supply of DEHP:

- 0.4 percent was released to wastewater during DEHP production.
- 0.08 percent was released during transport of DEHP.
- One percent was released to air and 2 percent was released to water during manufacture of DEHP-containing products.
- One percent was released to air and 0.5 percent was released to water during use of DEHP-containing products.
- 92 percent was released in landfill leachate from disposal of DEHP-containing waste materials and products.
- 3 percent was lost through incineration emissions from disposal of DEHP-containing waste materials and products.

The TRI reports that in EPA Region 5 between 1987 and 1997, more than 89,000 pounds of DEHP were released to air, land, and water as discussed below.

- **Air emissions**. According to the TRI database, 52,707 pounds of DEHP were released to air.

- **Point Source Discharges.** According to the TRI database, 2,805 pounds of DEHP were released to water with more than 99 percent of the releases occurring in Indiana.

- **Releases to Land**. According to the TRI database, 30,501 pounds of DEHP were released to land with more than 95 percent of the releases occurring in Michigan.

- **Legacy DEHP Discharges.** DEHP is not a primary contaminant at any Lake Michigan AOC.

Other PCB Substitutes

The other identified PCB substitutes have not been extensively studied; therefore, information on releases to the environment is limited. Peterman and Delfina (1990) conducted sampling and analysis of several media from the Fox River in Wisconsin to determine if PCB substitutes were present. The study identified the PCB substitutes isopropylbiphenyls, diphenylmethanes, diisopropylnaphthalenes, and butylbiphenyls in the following matrices (Peterman and Delfino 1990):

- Effluent from a de-inking-recycling paper mill
- Effluent from a waste water treatment plant that received wastewater from a carbonless copy paper manufacturing plant
- Fish collected near both discharge points
- Sediment

ACTUAL LOADING OF PCB SUBSTITUTES TO LAKE MICHIGAN

Information is not available at this time regarding loading of PCB substitutes to Lake Michigan.

IMPACTS ON LAKE MICHIGAN

The impact of PCB substitutes on the Lake Michigan ecosystem is unknown at this time.

SPECIAL MANAGEMENT ISSUES

Specific actions to address
PCB SUBSTITUTES are
presented in Chapter 6, Table 6-1: RM11
6

Appendix A summarizes current regulations and non-regulatory programs pertinent to DEHP management in the Lake Michigan Basin. Special management issues with PCB substitutes involve a lack of information about their fate and transport in the environment from their use as a PCB substitute.

Table 5-43. Lake Michigan LaMP Summary Table (Chapter 5)

CHAPTER 2	CHAPTER 3		CHAPTER 4			CHAPTER 5		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**			**Lake Michigan Stressor Sources and Loads**		**Strategic Action Agenda: Next Steps**	
End Point Goal	**Indicating**	**Monitoring**	**Impairment**	**Spatial**	**Temporal**	**Stressors**	**Source**	**Means to an End Goal**	**Short-term Activities**
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 Local	Ongoing Episodic	• Chemical - PCBs - Mercury - Dioxin - DDT - Chlordane	• Air deposition • Legacy sites • Sediments • Incinerators • Burn barrels		
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	• Biological - Pathogens - ANS	• Land use • Point source • Nonpoint source		
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	• Biological - Pathogens • Physical • Chemical	• Land use • Point source • Storm water • CSO/SSO		
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 • FWS 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	• Physical - Sedimentation - Habitat destruction • Biological - ANS • Chemical - Nutrients - Toxics	• Land use/sprawl • Point source • Air deposition • Ballast water • Storm water • Agriculture runoff		
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	• Physical - Sprawl • Biological - ANS	• Land use		
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	• Physical • Biological • Chemical	• Land use • Point source • Legacy sites		